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A Bibliography of Sandia National Laboratories Solar Central Receiver Reports

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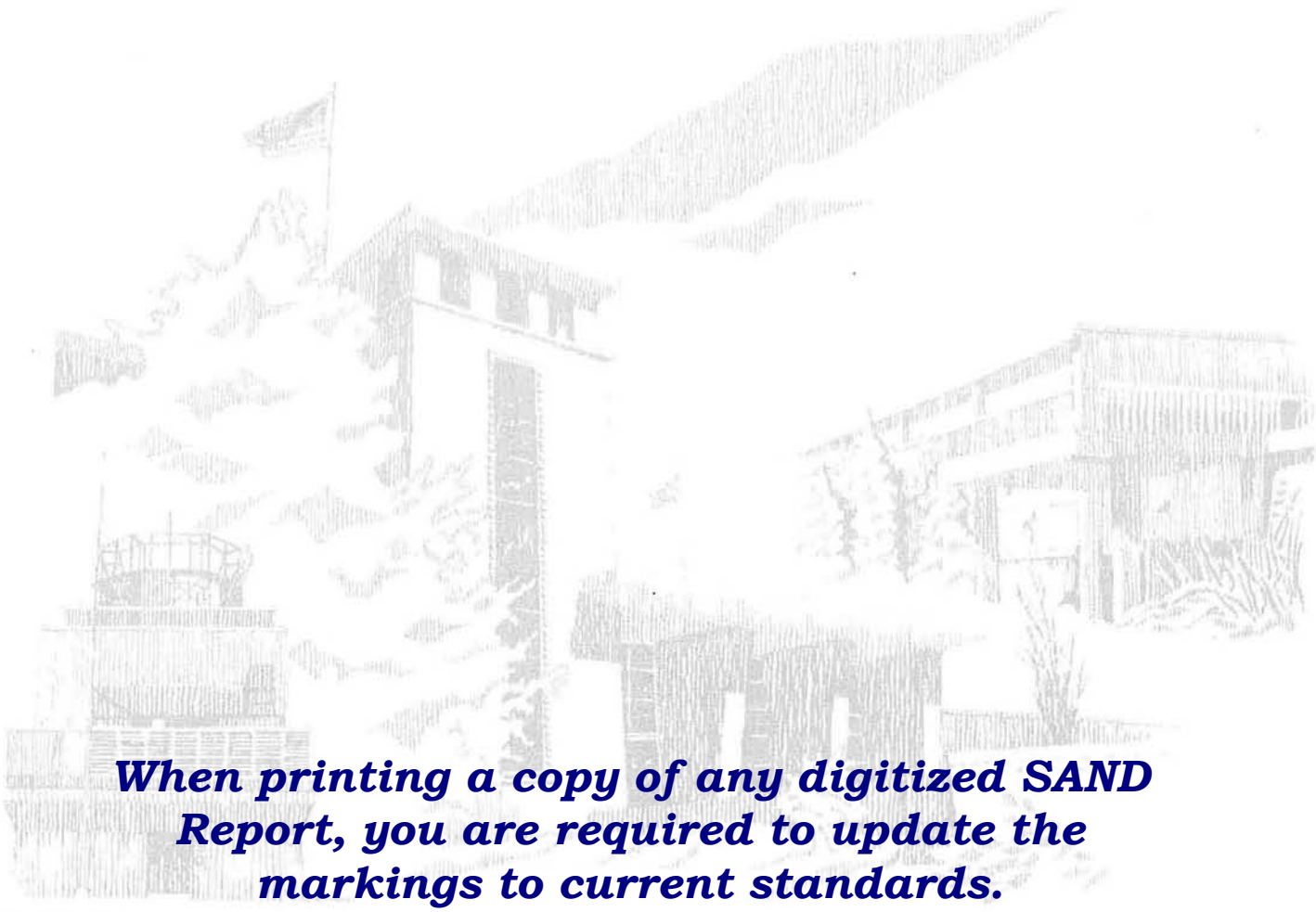

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ABSTRACT

The 1973-1983 published reports of the technical information developed by the Sandia National Laboratories Solar Central Receiver Program are compiled into this bibliography. An abstract of each report is included. Reports are listed in numerical order by report number and an author index is appended.

ANNOTATED BIBLIOGRAPHY

Listing by Document Number
in Numerical Order

SLL-73-0059: A HIGH TEMPERATURE SOLAR ENERGY SYSTEM; T. D. Brumleve; August 1973.

A method of collecting large quantities of solar energy at temperatures above 40^{o} C will be developed for applications such as chemical processing, electrical power generation, and other industrial uses where high temperatures are required or lead to greater efficiencies. The system consists of a large array of individually controlled, nearly flat mirrors that direct solar energy into a well insulated optical cavity located at the top of a tower. The highly concentrated solar flux enters the cavity from the bottom through a windowless aperture and is absorbed in a working fluid.

The following design features have the prospect of significantly reducing the capital and operating cost of collecting and utilizing solar energy:

1. Only the point focus type collector system is capable of collecting large amounts of solar energy at high temperatures.
2. Collector absorber system efficiency remains high at temperatures up to $1{,}000^{o}$ C or higher. This minimizes collector area, the largest single item of initial cost.
3. Thermodynamic efficiency of energy utilization is significantly increased since energy is supplied at high temperatures.
4. The optical cavity absorber has a number of innovations which significantly enhance system performance.
   a. No window is required thus avoiding associated energy losses and operational problems.
   b. Aperture size and thus radiation loss is reduced by use of a terminal concentrator.
   c. Cavity radiating temperature is minimized by direct absorption in a working fluid.

Each of the three types of solar-thermal conversion systems, point focus, linear focus, and flat plate have advantages and disadvantages depending on the application. Accurate economic comparisons between these systems as well as comparisons with nonsolar sources of energy must await further development and experimentation with all types. A central objective of this program is to answer the key economic questions for the point-focus method.

The program includes development of a working model of a complete laboratory scale system within two years and a pilot plant facility capable of delivering 10^9 Btu per day within 4-1/2 years. Additional programmatic details are documented separately.

SLL-73-0263: SENSIBLE HEAT STORAGE IN LIQUIDS; T. D. Brumleve; July 1974.

Initial investigations are presented covering several aspects of thermal energy storage as sensible heat in liquids. Heat loss to the environment from insulated tanks and underground mined cavities is characterized as a function of size, temperature difference, and time. Storage and interchange of hot and cool liquids within a single storage volume is discussed along with the advantages of preventing mixing. A technique for minimizing mixing through the use of a thermocline at the interface between hot and cool liquids is presented together with the mechanisms which degrade energy availability.

SAND-74-26: SOLAR INCIDENCE FACTOR AND OTHER GEOMETRIC CONSIDERATIONS OF SOLAR ENERGY COLLECTION; W. P. Schimmel, Jr.; July 1974.

A vector analysis was made of the 5-degree of freedom system occurring in a flat plate or focused collector system. The results of this analysis were extended to include the case of an intermediate flat plate reflector. Because the expressions obtained are very general in nature, it is possible to work from local weather bureau data (with an appropriate scale factor to take into account the ratio of specular to total insolation) for a comparison of various proposed collector systems. Armed with these results, systems analysts can begin to optimize candidate systems and evaluate the effect of system constraints. They will be freed from the tedious geometrical task of specifying incident radiation, so they can devote more time to the physics of solar absorption and other system considerations.

SAND-74-0099(REV): PROGRAM CYCLE: A RANKINE CYCLE ANALYSIS ROUTINE; J. P. Abbin and W. R. Leuenberger; October 1977.

This report describes the computer program CYCLE which models and analyzes various Rankine cycle systems including supercritical cycles with or without regeneration and supercritical cycles with and/or without superheat. The program will accommodate a variety of input constants. The program version presented is written in FORTRAN IV in a conversational mode suitable for timesharing. The subroutine is presently operating on Sandia's CDD 6600 computer as part of program SOLSYS and as a main program on the NOS timesharing computer system. The program is a part

of Sandia's Solar Community effort to analyze and evaluate systems for the conversion of solar energy to provide the community's total energy needs.

SAND-74-0241: EFFECT OF OUTDOOR AGING ON ACRYLIC SHEET; L. G. Rainhart and W. P. Schimmel, Jr.; September 1974.

One of the prime contenders for solar reflectors or concentrators is acrylic plastic. Other than the basic requirement of being a highly efficient reflector or transmitter of the solar spectrum, it must offer excellent long-term weatherability with minimum cost. The weatherability of acrylic polymers, although known to be good compared to other polymers, has been an unknown with regard to actual exposure data in the southwestern United States where the potential is high for solar energy installations. This report is a compilation of data obtained from an acrylic panel that has been exposed for over 17 years in the semi-arid desert terrain south of Albuquerque, New Mexico. A comparison is made with unexposed material having a very similar polymer structure. In general, chemical changes are not detectable while mechanical response shows some evidence of embrittlement. In spite of these, the decrease in optical transmission is surprisingly low. The as-recovered material (with dust eroded surface) had an integrated or total transmittance which was 10 percent less than the control material, based on a solar radiation spectrum. In order to isolate the degradation loss due to change in the basic polymer, a polished specimen of aged material was tested and showed only a 3 percent drop in transmission across the solar spectrum. It appears reasonable that this low loss could be duplicated in a solar reflector provided the mirror is coated with an abrasion-resistant glass resin system.

SLL-74-5209: THE TEMPERATURE OF CAVITY-TYPE SOLAR ABSORBERS WITH A CIRCULATING FLUID; M. Abrams; February 1974.

An analytical expression is obtained for the temperature of a cavity-type absorber of solar radiation which has a circulating heat transfer for fluid. This expression relates effective cavity temperature to the temperature of the incoming fluid, cavity geometry, emissivity, coolant flow rate, and the incident of radiated flux.

SLL-74-5222: COST OPTIMAL DEPLOYMENT OF MIRRORS ASSOCIATED WITH A HIGH TEMPERATURE SOLAR ENERGY SYSTEM; J. D. Hankins; December 1974.

An absorbing cavity or collector of solar energy is mounted on a tower which is assumed to be erected over horizontal terrain. Located about the base of the tower are many

mirrors which are small relative to the region over which they are deployed. The bases of the mirror mounts are rigidly attached to the ground. During daylight hours, each mirror is continuously positioned so that the specular component of incident sunlight is reflected into an aperture located in the base of the cavity.

A sharp upper bound is found on the maximum energy that can be redirected into the aperture by an array of mirrors belonging to a certain family G (the class of locally uniform rectangular arrays) whose total surface area is not more than some preassigned value. The upper bound is obtained by building up an optimal mirror array in local blocks. Although these blocks may not combine to generate a realizable deployment, their properties should be of assistance in finding superior members of G. These results are combined with a simple cost model to obtain a lower bound on the minimum cost per unit of redirected energy as a function of the unit mirror cost.

SAND-74-8008: A HIGH-TEMPERATURE SOLAR ENERGY SYSTEM; T. D. Brumleve; July 1974.

A system for collecting large amounts of solar energy at high temperature and high efficiency has been under investigation since late 1972 at Sandia Laboratories Livermore for applications which benefit from temperatures greater than 673 K (752^{o} F). The system consists of a large array of individually controlled, nearly flat mirrors which direct solar energy into a cavity-type absorber at the top of a centrally located tower. The concentrated solar flux enters the insulated cavity from the bottom through a windowless aperture and is absorbed directly in a film of molten eutectic salt flowing down the interior walls. It appears that over 95 percent of the solar energy entering the aperture can be absorbed and delivered to an electrical power plant at a temperature of about 768K (923^{o} F). Current economic studies indicate that in the southwestern U.S., at a mirror module cost of $20 to $40 per m^2, the system becomes competitive with new fossil power plants at a fuel cost of $1.50 to $2.50 per million Btu depending upon the mode of operation. For certain types of solar systems, busbar energy costs are only about 10 to 20 percent higher at $1.00 per million Btu. Continuing analytical, design, and experimental efforts are aimed at demonstrating component and system feasibility, optimizing system performance, and evaluating key economic questions. This paper briefly describes the system and summarizes the current status of these investigations.

SAND-74-8017: STATUS REPORT ON A HIGH-TEMPERATURE SOLAR ENERGY SYSTEM; A. C. Skinrood, T. D. Brumleve, C. T. Schafer, C. T. Yokomizo and C. M. Leonard, Jr.; September 1974.

This report summarizes the status of a Sandia Laboratories study of a solar energy collection method as an alternate source of the higher temperature energy for electrical power generation and industrial applications. Although in principal, solar energy could be utilized for almost any energy needs now being met by conventional fields, the diffuse nature of solar energy has made the cost of collection and utilization noncompetitive on an economic basis. We will explore several technical approaches to determine if this can be changed by technology and science.

The system consists of a large array of individually controlled, nearly flat mirrors which direct solar energy into a well insulated optical cavity absorber located at the top of a centrally located tower. Highly concentrated solar flux enters the cavity from the bottom through a windowless aperture and is absorbed in a working fluid. Results of studies by Sandia Laboratories, Livermore, California are summarized and future investigations are outlined. Emphasized is development of an efficient energy absorbing system for electrical power generation, and design consideration for a working system to verify performance calculations.

SAND-74-8031: PERFORMANCE CALCULATIONS FOR A HIGH-TEMPERATURE SOLAR ENERGY COLLECTION SYSTEM; C. M. Leonard, Jr.; January 1975.

A high-temperature, central receiver solar energy collection system is modeled with the DAZZLE computer program. Results for a large hypothetical system located near Albuquerque, New Mexico are given for clear weather on spring equinox, and summer and winter solstice days, and for a year of typical Albuquerque weather as described in the U. S. Climatic Atlas.

SAND-74-8604: PROSPECTS FOR SOLAR ENERGY UTILIZATION; T. D. Brumleve; June 1974.

Prepared for presentation at the Annual Conference of the California Society of Professional Engineers, June 13-15, 1974, Sahara Tahoe Hotel, Stateline, Nevada.

SAND-75-0132: SOLAR CENTRAL RECEIVER TESTING OPTIONS AT THE SANDIA RADIANT HEAT FACILITY; P. H. Adams and N. R. Keltner; April 1975.

This report describes the features of the Sandia Laboratories Radiant Heat Facility which are pertinent to central receiver heater/boiler testing, and suggests various options for design and fabrication of heater arrays for simulating the heating levels anticipated in absorbers which may be utilized in central receiver systems. In particular, options are discussed for testing the Martin Marietta Bench Model Cavity Receiver Steam Generator prior to planned experiments at CNRS, Odeillo, France.

SAND-75-5244: COATINGS FOR SOLAR ENERGY APPLICATIONS; D. M. Mattox; 1975.

The various applications of thin films and coatings for solar energy applications are reviewed. These include: reflecting surfaces, antireflection coatings, transparent conductors, selective solar absorbers, photovoltaics, and photo-electrolysis of water. It is shown that for vacuum deposition and electrodeposition, the technology exists for deposition of meaningful areas (>50 square miles/year) of coating for solar energy utilization.

SAND-75-5249: COATINGS FOR SOLAR ENERGY APPLICATIONS: D. M. Mattox; 1975.

The specular reflectance properties of several solar mirror materials have been measured as a function of wavelength, polarization and incident angle. Results for a 3-mm thick, silvered float glass mirror and an aluminized acrylic stretched film are presented. For the silvered-glass mirror, measured specular and hemispherical reflectance properties are in excellent agreement with reflectance values calculated from a multiple beam reflectance model. At 65^{o} from normal, the average solar reflectance is decreased only approximately 4% from the value at normal incidence. For the aluminized acrylic mirror, measured specular reflectance values at 15 mrad were in agreement with hemispherical reflectance values, while calculated reflectance values are as much as 2% high for one polarization. The average solar reflectance decreases only 2% at an incident angle of 65^{o} from normal, while the width of the specular beam increases slightly with incident angle.

SAND-75-5275: ESTIMATION OF DIRECT NORMAL RADIATION; E. C. Boes; 1975.

An attempt is made to derive a formula for direct insolation from total insolation.

SAND-75-8063: SURVEY OF HIGH-TEMPERATURE THERMAL ENERGY STORAGE; T. T. Bramlette, R. M. Green, J. J. Bartel, D. K. Ottesen and C. T. Schafer; March 1976.

This study represents a survey of current technology relating to high temperature thermal energy storage. The motivation for this study resulted from the need for energy storage in solar thermal applications; however, the results have much wider application. The generic classes of storage concepts considered are sensible heat, latent heat, and heat of reversible chemical reaction. The study includes a review of the basic thermodynamic aspects of thermal energy storage; a summary of storage concepts which have been conceptualized and/or built and tested, including comparisons of system characteristics within the generic classes; and, finally, specific technology surveys within the areas of materials problems, heat transfer and fluid mechanics problems and systems application. It is shown that the design and engineering of thermal storage systems have not progressed beyond the most simple concepts and that there has been only a limited effort in the design and construction of large scale systems. Current technology appears adequate to support the development of most sensible heat concepts and simple latent heat concepts while some degree of technology advancement will be required to develop advanced latent heat concepts and heat-of-reaction concepts. Specific recommendations for future research and development work are presented.

SAND-75-8266: TESTING A ONE MEGAWATT SOLAR RECEIVER IN AN ERDA RADIANT HEAT FACILITY; P. H. Adams, N. R. Keltner, C. T. Schafer, and A. C. Skinrood; July 1975.

This ERDA-funded study investigated the feasibility of testing a Martin-Marietta designed one megawatt solar receiver in an ERDA Radiant Heat Facility located at Sandia Laboratories. It was concluded that tests utilizing quartz lamp arrays inside of the receiver or graphite heater arrays at the aperture could provide valuable compatibility and qualification data as well as provide data which will aid in interpretation of results to be obtained from tests at the Centre National de la Recherche (CNRS) solar furnace at Odeillo, France. It is proposed that three series of Radiant Heat Facility tests be conducted: (1) simulator tests; (2) pre-CNRS; and (3) post-CNRS. ERDA authorization to Martin-Marietta and Sandia Laboratories by August 1, 1975

will allow tests to be conducted on a schedule compatible with currently planned tests at CNRS.

SAND-75-8305: SOME STRUCTURAL VIBRATION CONSIDERATIONS FOR THE PREVENTION OF MINERAL SCALE BUILD-UP ON FLUID-CARRYING DUCTS; L. M. Murphy; February 1976.

The question of removing solid salt build-up from heat exchanger surfaces where heat is being extracted from molten salts has been addressed. To assess the possibility of removing the solid salt with structural vibrations, a very idealized, but readily solvable and understood, model has been investigated. The model is that of an infinite length tube responding in a purely radial mode with a solid salt buildup on the surface. The tube is immersed in, and contains, a fluid and the solid salt is assumed to have strength only in its adherence to the tube. In this investigation it is shown that very large amplification of the salt/tube interface stress is possible at the appropriate forcing frequency. From this initial investigation it appears that the removal of the solid salt phase from heat exchanger surfaces by judicious use of forced structural vibration may indeed be feasible. Further analytical and experimenal work is warranted.

SAND-75-8610: NATURAL CONVECTION OF A HEAT GENERATING FLUID WITHIN CLOSED VERTICAL CYLINDERS AND SPHERES; R. J. Kee; April 1975.

Steady natural convective flow fields were numerically and experimentally characterized for the 0.7 PRANDTL number fluids having constant, uniformally distributed, internal heat sources. The bounding isothermal walls containing the fluids were considered to be either a sphere or a cylinder of finite height. An instrumented cylinder containing radioactive tritium gas was used to demonstrate experimental and analytical agreement for local temperatures over a range of Grashof numbers. For the spherical geometry, a generalized correlation was obtained for the surface-averaged Nusselt number as a function of a modified Grashof number.

SAND-76-0009: SOLAR RADIATION AVAILABILITY TO VARIOUS COLLECTOR GEOMETRIES: A PRELIMINARY STUDY; E. C. Boes; February 1976.

Solar energy collectors of various designs and installation orientations are being built or used. Because most existing solar energy data consists of measurements of total radiation incident upon a horizontal surface, and because geometric conversion to radiation incident upon another surface is difficult, the amounts of solar energy available to various locations are not well known. This paper reports

such solar energy availabilities to various collectors for both clear and average days in each of the four seasons at Albuquerque, Blue Hill, and Omaha. Unlike several similar previous studies, the amounts of solar energy given here are based directly on representative data samples consisting of simultaneous measurements of direct-normal and total-horizontal radiation at these three sites.

SAND-76-0346: HELIOS: A COMPUTER PROGRAM FOR MODELING THE SOLAR THERMAL TEST FACILITY, A USER'S GUIDE; C. N. Vittitoe, F. Biggs and R. E. Lighthill; March 1977.

HELIOS is a flexible computer code for evaluation of proposed designs of central tower solar energy collector systems, for safety calculations of the threat to personnel and to the facility itself, for determination of how various input parameters alter the power collected, and for design trade-offs. Input variables include atmospheric transmission effects, reflector shape and surface errors, sun tracking errors, focusing and alignment strategies, receiver design, placement positions of the tower and mirrors, time-of-day and day-of-year for the calculation. Plotting and editing computer codes are available. Complete input instructions, code-structure details, and output explanation are given. The code is then used on CDC 6600 and CDC 7600 computers.

SAND-76-0347: THE HELIOS MODEL FOR THE OPTICAL BEHAVIOR OF REFLECTING SOLAR CONCENTRATORS; F. Biggs and C. N. Vittitoe; March 1979.

The HELIOS model simulates the optical behavoir of reflecting concentrators. The model follows the incident solar radiation through the system (including the atmosphere) and includes all the factors that influence the optical performance of a collector. An important output is the flux-density pattern (W/cm^2) at a grid of points on a surface such as the absorbent surface of a receiver and is integral (power and loss) over the surface. The angular distribution of sun rays for the radiation incident on a concentrator is modified by convolution, using a fast fourier transform, to incorporate the effects of other nondeterministic factors such as sun-tracking errors, surface slope errors, and reflectance properties. The analytical methods used for the statistics, the off-axis reflecting optics, atmospheric effects, and the various coordinate sytems are described and illustrated. This model forms a basis for the simulation code HELIOS as well as for the other codes under development. Some of the HELIOS routines are described, a few of its capabilities are discussed and illustrated, and comparisons of data with calculations are presented. These capabilities have been

used for performance predictions, safety studies, design trade-offs, data analysis problems, the specification analysis of concentrator quality, and the general understanding of solar-concentrator technology.

SAND-76-0363: RANKINE CYCLE ENERGY CONVERSION SYSTEM DESIGN CONSIDERATIONS FOR LOW AND INTERMEDIATE TEMPERATURE SENSIBLE HEAT SOURCES; J. P. Abbin, Jr.; October 1976.

Design considerations are described for energy conversion systems for low and intermediate temperature sensible heat sources such as found in geothermal, waste heat, and solar-thermal applications. It is concluded that the most cost effective designs for the applications studied did not require the most efficient thermodynamic cycle, but that the efficiency of the energy conversion hardware can be a key factor.

SAND-76-0411: DISTRIBUTION OF DIRECT AND TOTAL SOLAR RADIATION AVAILABILITIES FOR THE USA; E. C. Boes, I. J. Hall, R. R. Prarie, R. P. Stromberg and H. E. Anderson; August 1976.

The only long-term US solar radiation data base with reasonable geographic coverage is the total-horizontal data recorded by the National Weather Service. Since most solar collectors will not be horizontal, designers will need to know the availabilities of solar radiation to different types of both flat-plate and concentrating collectors in various orientations. A project to determine the geographic distributions of these availabilities by month on a mean daily basis is in progress. The data base consists of hourly total-horizontal readings for 26 US locations for the years 1958 to 1962. This paper presents maps and tables showing the availability of direct-normal radiation by month for the US. The results indicate that there is more direct solar energy than has been generally believed; direct-normal radiation availability generally exceeds total-horizontal availability by about 60 percent in the winter. Availabilities to other surfaces will be described in the final report to be published at the conclusion of this project.

SAND-76-5141: OPTICAL MATERIALS FOR SOLAR ENERGY APPLICATIONS; D. M. Mattox; May 1976.

The application of optical materials to solar energy utilization is reviewed. It is shown that hundreds of square miles of optical materials will be required every year to have a significant input on the U. S. energy economy. Most of these materials will have to be fabricated at a very low areal cost. Various high-volume, low-cost

production processes applicable to solar-optical materials are presented. Major challenges to the optical technologist will be to control the optical properties of materials being fabricated at very high production rates and to develop new low-cost optical materials.

SAND-76-5155: PERSPECTIVE ON MATERIALS IN THE ENERGY PROGRAM; R. S. Claassen; January 1976.

This is an introductory paper for a series of presentations treating the general theme "Critical Materials Problems in Energy Production." Energy and materials are closely linked in many ways: e.g., production of materials, which requires their recovery and processing to manufacturing, consumes about 17 percent of all energy used in this country. To fully understand how materials affect our evolving energy program, one needs first to understand the interconnections with other aspects of the situation. Thus, in Section I, some historical perspective reveals what energy consumption has been thus far and what it is likely to be in the future. Section II provides the units and conversion factors most often used in energy discussions. The uses of energy and the forms that energy must take to be consumable are summarized in Section III. Financial aspects, particularly capitalization problems and fuel expenses, are covered in Section IV. The final section then provides a brief description of the materials problems to be discussed by the other authors in this series. 40 references.

SAND-76-5310: SPECULAR REFLECTANCE PROPERTIES OF MIRROR MATERIALS; R. B. Pettit; August 1976.

The absolute specular reflectance of flat mirrors at discrete wavelengths over the range 400 nm to 900 nm was obtained as a function of the reflected beam width from 1.0 mrad (0.057°) to 16.9 mrad (0.97°). The mirror materials were supplied by G. T. Sheldahl, 3M Company, Alcoa, and Carolina Mirror Company. For some of these materials, the reflected beam profile could be described by a normal distribution. In this case, the reflectance properties are completely characterized by a solar reflectance and a standard deviation. However, for other materials, the reflected beam profile was described by the sum of two normal distributions. Data for selected materials and examples of the curve fitting procedure are presented.

SAND-76-8022: EYE HAZARD AND GLINT EVALUATIONS FOR THE 5-MW SOLAR THERMAL TEST FACILITY; T. D. Brumleve; May 1977.

Potential eye hazards associated with concentrated reflected light are evaluated for the ERDA 5-MW Solar Thermal Test Facility to be constructed at Sandia Laboratories,

Albuquerque, New Mexico. Light intensities and hazardous ranges of single- and multiple-coincident heliostat beams are evaluated at ground level and the air space above the facility. Possible long-range and short-range effects of distractive glint effects of reflected beams are discussed. Also described are certain beam control modifications which were incorporated to minimize the altitudes at which overflying aircraft could encounter unsafe levels. Recommenations are made for further evaluation of intensity excursions during fail-safe shutdown situations, and for experiments to verify analytical models and to assess distractive glint effects.

SAND-76-8622: THE TEMPERATURE DISTRIBUTION ALONG AN ABSORBING-EMITTING FLUIDLAYER FLOWING OVER AN OPAQUE SUBSTRATE; M. Abrams; August 1976.

In order to determine the thermal behavior of the molten salt solar cavity, a theoretical model has been developed which predicts the temperature distributions along the molten layer and along the underlying substrate in the direction of flow. This model has been employed to assess the effects of altering the molten salt flow rate, optical thickness, reflectance of the substrate, and the film conductance between the substrate and molten layer. One of the findings of this study is that opacifying the molten layer (by the introduction of a suspension of radiation-absorbing particles, for example) significantly reduces the temperature level of the substrate while it simultaneously increases that of the fluid.

SAND-76-8677: DEVELOPMENT OF THE SOLAR POWER CENTRAL RECEIVER CONCEPT; L. M. Murphy and A. C. Skinrood; September 1976.

The main incentive for the development of the solar central receiver concept is to examine the collection and efficient use of solar energy to produce electricity. The particular concept being developed to accomplish this goal by various contractors are described and Sandia Livermores role as technical manager is discussed. In addition, the ERDA plan for eventual commercialization of this concept, as well as the role and use of the Sandia Solar Thermal Test Facility, is described. Furthermore, details of particular subsystem components as well as potentially fruitful research areas for Sandia and other development laboratories to pursue which can lead to performance improvements are discussed.

SAND-76-9104C: SOLAR ABSORPTION PROPERTIES OF A HIGH-TEMPERATURE DIRECT-ABSORBING HEAT TRANSFER FLUID; W. D. Drotning; May 1977.

The optical absorption properties of a high temperature molten salt heat transfer fluid, a eutectic mixture of KNO_3,

$NaNO_2$, and $NaNO_3$, known as Hitec (DuPont trade name), were measured from 0.35 mu m to 2.5 mu m using hemispherical transmission techniques. To enhance solar absorption, particulate metallic oxides of Co or Cu were introduced into the fluid. Absorption spectra of these oxide particle suspensions in the molten salt were determined as a function of dopant concentration ranging from 0 to 0.1 wt percent metal nitrate added to the Hitec. These measurements were carried out at 473 K under flow conditions to cause a homogeneous suspension of particles. Absorption coefficients at a single wavelength were measured up to dopant concentrations of 0.5 wt percent. The suspended particles cause an additional optical absorption throughout the visible spectrum, which is characteristic of the particular metallic oxide and closely follows a Beer-Lambert concentration dependence. The solar-averaged absorption in a fixed layer thickness was calculated for various concentrations of the fluid-oxide mixtures. The fluid without oxide particles absorbs approximately 8 percent of the solar spectrum per cm of path length, while addition of 0.1 wt percent of $Co(NO_3)_2 . 6H_2O$ increases this absorption to approximately 93 percent per cm. An equivalent wt percent of $Cu(NO_3)_2 . 3H_2O$ causes a solar-averaged absorption of 84.4 percent per cm. Effects of particulate scattering on the measurements are discussed.

SAND-77-0004: SOLAR RADIATION AVAILABILITY FOR NEW MEXICO; E. C. Boes; February 1977.

In order to design a solar system or to make a prediction regarding its performance, one needs to know the amount of solar energy which will be available to the system. An elementary description is given of the basic geometric considerations and background information on solar radiation availability. In addition, tables giving both average and clear day solar energy availabilities in the four seasons are presented. The solar energy available to a collector depends on the collector type and its orientation. The availabilities are presented for a wide variety of possible surface orientations, including orientations for focusing collectors, tracking collectors, and fixed collectors.

SAND-77-0034: SANDIA LABORATORIES ENERGY PROGRAMS; C. P. Lundergan, P. L. Mead and R. S. Gillespie; March 1977.

As one of the multiprogram Laboratories of the Energy Research and Development Administration, Sandia Laboratories applies its resources to a number of nationally important programs. About 75 percent of these resources are applied to research and development for national security programs having to do with nuclear weapons--the principal responsibility of the Laboratories. The remaining

25 percent are applied to energy programs and energy-related activities, particularly those requiring resources that are also used in nuclear weapon and other national security programs. Examples of such energy programs and activities are research into nuclear fusion. Protection of nuclear materials from theft or diversion, and the disposal of radio-active waste. A number of technologies and disciplines developed for the weapon program are immediately applicable for the development of various energy sources. Instruments developed to detect, measure, and record the detonation of nuclear devices underground, now being used to support the development of in-situ processing of coal and oil shale, are examples. The purpose of this report is to provide an overview of these and other energy programs being conducted by these laboratories in the development of economical and environmentally acceptable alternative energy sources. Energy programs are undertaken when they require capabilities used at the Laboratories for the weapon program, and when they have no adverse effect upon that primary mission. The parallel operation of weapon and energy activities allows optimum use of facilities and other resources.

SAND-77-0582: OPTICAL ANALYSIS OF SOLAR FACILITY HELIOSTATS; E. Igel and R. L. Hughes; May 1977.

An experimentally verified simple analytical model, based on classical optical aberrations, is derived and predicts the power reception of a central receiver solar facility. A laboratory simulation was made of a typical heliostat, and its images were photographed and measured at several angles of incidence. The analytically predicted image size is in agreement with the experiment to within less than 10 percent over an incident angle range of 60^{o}. Image size for several of the heliostats in the Sandia-ERDA Solar Thermal Test Facility array were calculated throughout a day and compared with ideal images and the size of the receiver. The optical parameters of the system and the motion of the sun were found to severely affect the design and optimization of any solar thermal facility. This analysis shows that it is the aberration astigmatism which governs the solar image size at the receiver. Image growth is minimal when heliostats are used at small angles of incidence, which usually corresponds to a limited operating time of two to three hours. However, image size is markedly increased at large angles of incidence. The principal result is that the predominant sources of image enlargement are identified and measures for minimizing these enlargements are presented. This analysis considers only the idealized optical problem and does not consider the pragmatic errors associated with implementation and operation of a heliostat array.

SAND-77-0642C: HELIOS: A COMPUTATIONAL MODEL FOR SOLAR CONCENTRATORS; F. Biggs and C. N. Vittitoe; 1977.

HELIOS is a computer code for mathematically simulating the behavior of the flux pattern from the concentrator field for a solar central receiver power station. Statistical methods are used to incorporate nondeterministic factors. The code is described, and some examples of its output are given.

SAND-77-0667C: PARAMETER STUDY FOR A CENTRAL-RECEIVER POWER STATION; F. Biggs and C. N. Vittitoe; 1977.

The interactions between alignment and focusing strategies and heliostat errors are described and illustrated. Some descriptions of astigmatic aberrations are developed and are used to suggest an evaluation criterion for concentrators. Finally, an analysis of measurements for evaluating heliostat reflectors is given.

SAND-77-0874: ESTIMATING MONTHLY MEANS OF DAILY TOTALS OF DIRECT NORMAL SOLAR RADIATION AND OF TOTAL SOLAR RADIATION ON A SOUTH-FACING, 45°, TILTED SURFACE; E. C. Boes and I. J. Hall; July 1977.

Direct Normal, DN, radiation data is presently available for only a few sites in the country while total horizontal, TH, radiation is available for many locations. If a mathematical function relating DN and TH were established, solar engineers could estimate DN for any site for which TH data is available. Total radiated energy on a tilted surface, TT, is also of interest to solar engineers. A recently completed report includes TT values for a surface tilted at 45° for 26 sites. A function relating TT and TH would permit one to estimate TT for sites where only TH data is available. Empirically derived functions relating DN and TH and TT and TH are presented.

SAND-77-0921: SANDIA SOLAR ENERGY TITLES; J. L. Gardner; June 1977.

This bibliography of reports, periodical articles, and conference papers represents research carried out by Sandia Laboratories in energy and conservation. Within each of approximately 300 entries, authors are listed alphabetically in each subject category. The following subjects are covered: conservation, drilling technology, environment and safety, fossil energy, goethermal energy, nuclear energy, and solar energy.

SAND-77-0938: OPTICAL PROPERTIES OF A SOLAR-ABSORBING MOLTEN SALT HEAT TRANSFER FLUID; W. D. Drotning; June 1977.

The optical absorption properties of a high temperature molten salt heat transfer fluid were measured from 0.35 micrometer to 2.5 micrometers using both hemispherical transmission and reflection techniques. This fluid has application as a direct-absorbing working fluid in a high temperature central receiver solar energy facility. The absorption spectrum of the pure molten fluid--a eutectic mixture of KNO_3, $NaNO_2$, and $NaNO_3$, known as Hitec (DuPont trade name)--displays a fundamental absorption edge near 410 nm, which was found to shift to longer wavelength linearly with temperature. Throughout the remainder of the visible spectrum, the fluid is transparent. To enhance its solar absorption, particulate metallic oxides of Co or Cu were introduced into the fluid. Absorption spectra of these oxide particle suspensions in the molten salt were determined as a function of dopant concentration ranging from 0 to 0.1 wt percent metal nitrate added to the Hitec. These measurements were carried out at 200° C under flow conditions to cause a homogeneous suspension of particles. Special transmission and reflection flow cells were designed and constructed to handle 200° C fluids. The suspended particles cause an additional optical absorption throughout the visible spectrum which is characteristic of the particular metallic oxide and closely follows a Beer-Lambert concentration dependence. The solar averaged absorption in a fixed layer thickness was calculated for various concentrations of the fluid-oxide mixtures. The fluid without oxide particles absorbs approximately 8 percent of the solar spectrum per cm of path length. Addition of 0.1 wt percent of $Co(NO_3)_2.6H_2O$ increases this absorption to approximately 90 percent per cm. Of the oxides studied, Co_3O_4 particle suspensions offer better solar absorption characteristics than CuO. Effects of particulate scattering on the measurements are discussed.

SAND-77-1173(REV): SOLAR THERMAL TEST FACILITY EXPERIMENT MANUAL; J. T. Holmes, L. K. Matthews, L. O. Seamons, D. B. Davis and D. L. King; August, 1978.

The Solar Thermal Test Facility is operated for the Department of Energy by Sandia Laboratories to advance the development of solar thermal electric power to a commercial scale. The STTF with a thermal collection capability of about 5 MW, is designed to perform a variety of functions. This document provides information on administrative procedures, the capabilities of the STTF, and the requirements of the experimentor. This document will be revised periodically to reflect the capabilities of the facilities and needs of experimentors.

SAND-77-1185C: HELIOS: A COMPUTATIONAL MODEL FOR SOLAR CONCENTRATORS; F. Biggs and C. N. Vittitoe; August 1977.

The HELIOS computer code calculates the power concentrated by a field of individually guided heliostats and the resulting flux density (watts/cm^2) falling upon an arbitrary target grid. The problem has individual subroutines for each task in order to incorporate options for a variety of facet shapes, heliostat designs, field layouts, and tower-receiver apertures, and to facilitate additions and code improvements.

HELIOS has been used extensively to analyze questions on safety, performance, design trade-offs, and tower protection engineering. Comparisons of HELIOS results with measurements have given good agreement. HELIOS calculates the "sun position" and uses it to establish alignment geometries. Atmospheric attenuation effects are included. Measured angular-distributions of incoming photons (sunshapes) and effects of aureole scattering are incorporated. Nondeterministic factors such as sun-tracking errors and facet-surface errors are described statistically and combined with the sunshape by numerical convolution. Shadowing and blocking are included. Several output choices are available, including graphical display of flux density distributions, of shadowing and blocking and of sunshape. Some of the modeling in HELIOS and samples of results are described.

SAND-77-1393: MODAL ANALYSIS OF THE FIRST PRODUCTION DESIGN HELIOSTAT USED AT THE SOLAR THERMAL TEST FACILITY (STTF); J. R. Janczy; September 1977.

The experimental study sought to characterize the dynamic modal characteristics of a heliostat to be used at the Sandia operated Solar Thermal Test Facility. Three modal studies were performed. Two studies were conducted of the yoke and one on the facet assembly. During the course of the test, Power Spectral Density studies were performed using wind-loading and transport environmental data. The modal (frequency, damping and stiffness) data is presented. The data obtained through the various studies compared favorably. The data indicates a possible structural modification, and this modification is discussed.

SAND-77-1412C: SOLAR ENERGY RESEARCH AT SANDIA LABORATORIES WITH UNIQUE HEALTH AND SAFETY PARAMETERS; L. L. Young; October 1977.

A general review of the major solar energy projects at Sandia Laboratories is given. The Solar Total Energy Test Facility, Solar-Powered Irrigation System, photovoltaics

research facilities, and the Solar Thermal Test Facility are described. The hazards associated with the reflection and reradiation of concentrated solar energy from solar collection systems are discussed. The radiation hazard to the retina of the eye is considered in particular.

SAND-77-1430: MARKOV CHAIN MODEL FOR CLOUD COVER SEQUENCES IN ALBUQUERQUE; F. G. Yost and E. A. Aronson; October 1977.

An estimate of the transition probability matrix for day-to-day cloud cover statistics is shown to have a limiting property characteristic of a Markov chain of ergodic states. It is suggested that this transition probability matrix can be used to estimate conditional probabilities of cloud free lines of sight.

SAND-77-1461C: SURVEY OF MIRROR DUST INTERACTIONS; R. S. Berg; September 1977.

Mirrors for concentrating solar energy collectors must maintain their specular reflectance properties in order to transfer energy to the receiver. When foreign particles fall on a mirror surface, they interfere with imaging properties of the mirror. There are numerous types of particulates, many of which tend to predominate in different geographical regions. The regions with highest solar inputs tend to be desert-like environments where silica dust dominates. Although silica dust is only one of a class of particulates, all dust materials have similar kinds of properties and effects. Dust interferes with the specular reflectances, both by absorbing and scattering incident light. In order to restore the reflectance, the dust must then be removed from the surface in a way that will not cause surface damage. The development of effective cleaning techniques could be aided by knowledge of the nature of the forces that attract and hold dust on the surface. These forces and ways they can be modified to affect cleaning are discussed.

SAND-77-1521C: AVERAGE SOLAR RADIATION AVAILABLE TO VARIOUS COLLECTOR TYPES; E. C. Boes, H. E. Anderson, I. J. Hall, R. R. Prarie and R. P. Stromberg; September 1977.

The results of a recently completed analysis of the seasonal and geographic distributions of solar radiation available to various types of solar collectors in the U.S.A. are given. The results are presented in the form of tables of seasonal mean daily amounts of solar radiation available to various configurations for tracking surfaces and to a comprehensive set of fixed surface orientations for 26 U.S. sites based on data for the years 1958-1962. All solar radiation availabilities described are separated into direct and

diffuse components so that they are applicable for both concentrating and flat-plate collectors. Also, some comparisons of the relative amounts of solar energy available to different solar collector schemes are presented. A primary conclusion of the study is that there is generally more direct solar radiation available to tracking, concentrating collectors than there is total radiation available to fixed, flat-plate collectors.

SAND-77-1750
V.3/3: SANDIA TECHNOLOGY; Sandia; September 1977.

This publication describes some of the Sandia Laboratories developments and accomplishments in unclassified programs. Subject 3 describes the history and some of the development leading up to the construction of 10-MW Central Solar Receiver Pilot Plant near Barstow, California.

SAND-77-1850: THERMOMECHANICAL BEHAVIOR OF POLYVINYL BUTYRAL FILM AND ITS EFFECT ON FOCAL STABILITY OF A SOLAR MIRROR-LAMINATE; A. M. Lindrose and T. R. Guess; May 1978.

The thermomechanical behavior of the polyvinyl butyral (PVB) films commonly used in automotive safety-glass is reported. The overall objective is to assess the effect of temperature on the focal stability of solar mirror-laminates that employ a PVB film interlayer between two sheets of glass. Experimental results presented include both tensile and stress relaxation data on the PVB film over the temperature range -30 to 60° C; also, three-point-blend flexural test data on laminate specimens are given. Each test set shows the PVB modulus to be highly dependent on temperature. For example, the apparent tensile modulus declines by almost a factor of a thousand, and the mirror-laminate flexural modulus of PVB film falls by a factor of four from -30° C to 60°C. In addition, the PVB stress relaxation data, shifted using time-temperature superposition concepts, provide an approximate master relaxation function for estimating arbitrary time and temperature behavior. When used with laminate data relating laminate modulus to interlayer modulus, the PVB master relaxation function gives a laminate-modulus master relaxation function. Analysis using the laminate-modulus relaxation function demonstrates that focus changes can be countered, regardless of time and the mirror's in-service temperature history, by increasing the stiffness of the frame that is used to support and focus the mirror-laminate.

SAND-77-8011: HIGHLIGHTS REPORT SOLAR THERMAL CONVERSION PROGRAM CENTRAL POWER PROJECTS; (1) R. W. Hughey, (2) C. Selvage, (3) W. I. Ratcheson and R. B. Gillette, (4) R. Hallett, (5) J. C. Powell, (6) F. A. Blake, (7) C. Gross Kreutz,

(8) A. Poirier, (9) W. B. Bienert, (10) A. Slemmons, (11) L. L. Vant-Hull and J. Raetz, and (12) T. R. Tracey; March 1977.

This report presents the highlights of the open session of the Energy Research Development Administration (ERDA), Solar Thermal Branch Semi-Annual Reviews held in Denver, Colorado, on December 7, 1976. The review covered status and plans for central receiver projects, the Solar Thermal Test Facility project, and the related research and development activities. Separate abstracts were prepared for 12 papers as follows:

(1) PENDING REQUESTS FOR PROPOSALS IN SOLAR CENTRAL RECEIVER PROGRAM:

The part of the ERDA program presently underway is mentioned. Future proposals will address the development of low-cost heliostats and an advanced central power system.

(2) 10-MW CENTRAL RECEIVER PILOT PLANT PROJECTS:

The concepts and schedules of parallel contracts awarded to four teams to study the central receiver concept are reviewed briefly.

(3) CENTRAL RECEIVER COLLECTOR SUBSYSTEM DESIGN:

Boeing is developing a preliminary design for the collector (heliostat) subsystem for a 10-MWe solar pilot plant. The collector subsystem concept, operating with a central receiver installation, is shown. Several heliostat field geometries have been investigated with the aid of a heliostat array simulation computer model. Three heliostats and a drive and control assembly are being tested at a Boeing desert test site in northeast Oregon to provide design data and verification of the preliminary design. An extensive evaluation program is being conducted on the key plastic materials used for the protective enclosure and reflector.

(4) CENTRAL RECEIVER PILOT PLANT DESIGN:

Progress is reported in a reevaluation of both the commercial and pilot plant system design as well as the receiver, thermal storage, and collector subsystem research experiment tests.

(5) CENTRAL RECEIVER PILOT PLANT DESIGN:

Progress on the pilot plant baseline design is described and illustrated. Heat storage was changed from latent to

sensible. Design and testing are described for collector, heat storage, and steam generator subsystems.

(6) CENTRAL RECEIVER PILOT PLANT DESIGN:

The following topics are discussed: system design and optimization and progress on collector, receiver, and thermal storage subsystems.

(7) 5-MW SOLAR THERMAL TEST FACILITY:

The ERDA 5-MW Solar Thermal Test Facility is described briefly. Progress to date on the major design/construction packages is shown. A condensed version of the overall design/construction schedule, an artist's rendering of the current facility design, an aerial photograph of the construction site, an artists'rendering of the test tower, and a cross section of the test tower are shown.

(8) SOLAR ENERGY RECEIVER:

A solar receiver/heat exchanger unit for advanced solar-powered electric generation plants is described. A reduced power model of this receiver was tested using a solar furnace. The test is described and some results are presented.

(9) HEAT PIPE CENTRAL SOLAR RECEIVER:

A solar-to-gas heat exchanger for a central receiver power plant is discussed. Three potential receiver configurations and typical wick structures for the heat pipes under development are shown. The performance of the tent wick heat pipe is presented. A conceptual design of a test module with a capacity of 1 MWt is sketched.

(10) CAVITY-TYPE LINE CENTRAL RECEIVER:

A cavity-type line central receiver and parabolic cylinder focusing collector array designed to generate steam for electric power are discussed. Progress to date is mentioned briefly. The system is described and illustrated including the line receiver, the heliostat, the heliostat focus system, the heliostat test, and the heliostat wash vehicle.

(11) LIQUID METAL COOLED SOLAR CENTRAL RECEIVER FEASIBILTY STUDY AND HELIOSTAT FIELD ANALYSIS:

A 100-MWe sodium-cooled, solar central receiver system is being analyzed to define the conceptual design and determine the technical feasibility of the system. Additional work on slope and latitude studies for a water/steam receiver, net energy balance, and insolation are described.

(12) 1-MWth SOLAR CAVITY STEAM GENERATOR:

Experience gained in infrared testing of a cavity-type central receiver is discussed briefly.

SAND-77-8017: THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT PROGRAM SEMIANNUAL REPORT (OCTOBER 1976 - MARCH 1977); R. W. Mar and T. T. Bramlette; August 1977.

This document summarizes the progress made by the Thermochemical Energy Storage and Transport (TEST) Program in the period October 1976 - March 1977.

SAND-77-8032: THERMOCLINE DEGRADATION IN A PACKED BED THERMAL STORAGE TANK; S. B. Margolis; May 1977.

The problem of thermocline degradation in a packed bed thermal storage tank arises in the analysis of a central receiver facility. This article discusses in detail the technical aspects of thermocline degradation.

SAND-77-8034: THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT; R. W. Mar and T. T. Bramlette; September 1977.

The objective of the Thermochemical Energy Storage and Transport Program is to develop, verify, and demonstrate the technology necessary to store and transport energy by reversible chemical reactions. Current emphasis is on such fundamental problems as chemical kinetics and heat transfer characterization.

SAND-77-8035: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT-EXECUTIVE SUMMARY; Sandia; October 1977.

As technical manager of the ERDA disivion of Solar Energy Central Receiver Program, Sandia Laboratories has recommended subsystem designs that should be incorporated into the 10-MW Pilot Plant to be built at Barstow, California. This document presents those recommendations along with a summary of technical information used in making these selections. These recommendationss are relative to

the design concept only; they are not intended to represent a rating of the contractors.

SAND-77-8051: THERMOCHEMICAL ENERGY STORAGE SYSTEMS: A REVIEW; R. W. Mar and T. T. Bramlette; February 1978.

This report reviews the characteristics of thermochemical storage systems, analyzes the present state-of-the-art of the relevant technical disciplines, and presents some potential solar storage applications. The material has been prepared as an invited contribution to the Solar Energy Handbook, W. C. Dickinson and P. N. Cheremisinoff, eds., to be published by Marcel-Decker.

SAND-77-8056: THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT PROGRAM SEMIANNUAL REPORT; T. T. Bramlette and R. W. Mar; March 1978.

This document summarizes the progress made by the Thermochemical Energy Storage and Transport (TEST) Program in the period April 1977 - September 1977.

SAND-77-8226: FISCAL YEAR 1977 ANNUAL OPERATING PLAN FOR THE THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT PROGRAM OF THE NATIONAL THERMAL ENERGY STORAGE PROGRAM; T. T. Bramlette and R. W. Mar; June 1977.

This Annual Operating Plan describes the Thermochemical Energy Storage and Transport (TEST) Program activities in fiscal year 1977. The long-range goals of the TEST Program are described, and the specific FY77 plans and required resources are detailed.

SAND-77-8243: TOWER DESIGN CONSIDERATIONS FOR THE SOLAR THERMAL CENTRAL RECEIVER SYSTEMS; L. M. Murphy; June 1977.

Some basic design considerations for concrete solar thermal power towers are described in this report. Seismic disturbances are of primary concern for the large towers being proposed for certain commercial systems. With larger receiver/tower systems, the tower top accelerations due to seismic disturbances are not significantly amplified. However, the attachment of the more massive receivers may become more difficult for the larger systems.

SAND-77-8264: ANALYSIS OF THERMALLY DEGRADED SENSIBLE HEAT STORAGE HYDROCARBONS; V. P. Burolla; December 1977.

Heat treated samples of three candidate fluids for sensible heat storage were analyzed using gel-permeation chromatography (GPC) and infrared spectrophotometry (IR).

Comparison of this data with previous work done at the Rocketdyne Division of Rockwell International reveals that:

a. The oil is undergoing large-scale thermal cracking that is probably catalyzed by the presence of degradation products.
b. The oil is possibly experiencing some amount of dehydrogenation.
c. There is a very small amount of bulk polymerization taking place.
d. There is little reason to suspect that the oils suffered any significant amount of oxidation.
e. The approximate molecular weight range of fresh Caloria HT 43 is from 170 to 550.

Sufficient information is now available to enable design of a processor (fractional distillation column) to ostensibly prolong the usable lifetime of the oil.

Based upon the results of a fairly simplistic test run at Sandia, mechanical shear degradation due to pumping and fluid flow in general should not contribute significantly to fluid decomposition.

SAND-77-8278: STEAEC-SOLAR THERMAL ELECTRIC ANNUAL ENERGY CALCULATOR DOCUMENTATION; J. B. Woodard; January 1978.

Solar Thermal Electric Annual Energy Calculator (STEAEC) is a computer model which estimates the annual performance of a solar thermal electric power plant. Written in Fortran IV for the CDC 6600, STEAEC is a quasi-steady state model with a constant (but user--variable) time step. Factors such as energy losses and delays incurred in start-up, effects of ambient weather conditions on plant operation and efficiency, effects of hold time and charge and discharge rates on deliverable energy and storage, subsystem maximum and minimum power limits, and auxiliary power requirements are taken into account in the computation of the annual electrical output of the plant. Default parameters may be easily modified through the use of NAMELIST inputs aimed at specific areas of concern.

SAND-77-8279: BUCKS-ECONOMIC ANALYSIS MODEL OF SOLAR ELECTRIC POWER PLANTS; J. M. Brune; January 1978.

BUCKS is a computer model designed for economic analysis of solar electric power plants. The model determines the levelized life-cycle revenue per unit output from the plant that will be sufficient to compensate for the fixed and variable costs, pay interest to bond holders, and provide return to stockholders. Cost scaling relationships for solar plant subsystems have been developed which allow BUCKS

in conjunction with a plant's performance model to perform a number of cost benefit calculations.

SAND-77-8280: A USER'S GUIDE TO MIRVAL - A COMPUTER CODE FOR COMPARING DESIGNS OF HELIOSTAT-RECEIVER OPTICS FOR CENTRAL RECEIVER SOLAR POWER PLANTS; P. L. Leary and J. D. Hankins; February 1979.

MIRVAL is a Monte Carlo Program which simulates the heliostats and a portion of the receiver for solar energy central receiver power plants. Models for three receiver types and four kinds of heliostats are included in the code. Three receiver types modeled are external cylinder, a cylinderical cavity with a downward-facing aperature, and a north-facing cavity. Three heliostats which track an elevation in Aximuth are modeled, one of which is enclosed in a plastic dome. The fourth type consists of a rack of louvered reflected panels with the rack rotatable about a fixed horizontal axis. Phenomena whose effects are simulated are shadowing, blocking, mirror tracking, random errors in tracking and in the confirmation of the reflective surface, optical figure of the reflective surface, insolation, angular distribution of incoming sun rays to account for limb darkening and scattering, attenuation of light between the mirrors and the receiver, reflectivity of the mirror surface, and mirror aiming strategy. Power runs (point in time) and energy runs (integration of power over time) execute in about the same length of time. Rays of light are selected from the vicinity of the sun and are traced until they either enter receiver or are lost in a prior absorption process or are deflected enough to miss the receiver. With a cylindrical receiver, rays which enter the receiver are tracked to the heat transfer surface; while, for the north-facing cavity, tracking stops at the plane of the aperature. For a power run, the output includes the power entering the receiver, the power density on the terminal surface, the power shadowed by each of processers (by mirrors, by tower, or by either), the power blocked by mirrors, the power incident on the ground, the power that is reflected by and clears the mirrors but misses the receiver, and the power that clears the mirrors for which it is absorbed or scattered between the mirrors and the receiver. For energy runs, the same set of alternatives are used, but the output refers to (time) average power. MIRVAL can be modififed for evaluation of other mirrors or receivers by changing a small number of subroutines.

SAND-77-8283: ANALYSIS OF THE THERMAL FATIGUE INDUCED BY DNB ISOLATIONS IN THE MDAC ROCKEYDYNE PILOT AND COMMERCIAL PLANT SOLAR RECEIVER DESIGN; J. S. Jones, Jr. and D. L. Siebers; December 1977.

This study is a theoretical investigation of the high cycle fatigue damage that may result from temperature isolations in the boiler tube wall around the location of the point of departure from the nucleate boiling (DNB) in the McDonnell Douglas/Rocketdyne receiver subsystem for the pilot and commercial solar power plants. The problem was analyzed using the SAHARA and HEATMESH heat transfer codes and the GNATS structural analysis code. For the lack of better information, several rather sweeping assumptions have been made concerning the nature of the flow near the DNB point to allow the thermal calculations to be made. Results of the structural analysis show that fatigue damage due to DNB isolations will not be a substantial problem in the pilot plant, but may cause a significant reduction in the life of the commercial receiver. It has been found, however, that the results are highly dependent upon the nature of the internal flow characteristics, pointing to the need for further investigation of DNB isolations so that the accuracy of the current assumptions may be verified.

SAND-77-8288: FISCAL YEAR 1978 ANNUAL OPERATING PLAN FOR THE THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT (TEST) PROGRAM OF THE NATIONAL THERMAL ENERGY STORAGE PROGRAM; T. T. Bramlette and R. W. Mar; May 1978.

The TEST program has been divided into four technological elements according to a Technology Breakdown Structure (TBS). The four TBS elements are: (1) thermal energy storage, (2) chemical heat pipe, (3) chemical heat pump storage, and (4) generic research. Each major element has been further divided into subelements which represent specific concepts or applications being pursued. The primary use of thermochemical storage technology is solar thermal electric systems, with particular emphasis given to long duration storage capabilities. Thermochemical technology in nonsolar utilities is also being considered. For example, chemical heat pipes for the transmission of thermal energy for industrial process heat and district heat applications appear to hold significant promise. The current TEST Program is investigating this end-use application coupled to three potential energy sources: (1) a coal gasification plant (open-loop heat pipe), (2) a very high-temperature nuclear reactor (high-temperature pipe), and (3) moderate-temperature sources available in the United States including nuclear, solar, and fossil (low-temperature heat pipe). In addition, the use of chemical heat pipes for transmission in distributed solar systems is also being

addressed. The only current application for chemical heat pump storage technology is solar heating and cooling.

SAND-77-8300: THE EFFECTIVENESS OF SPECTRALLY SELECTIVE SURFACES FOR EXPOSED, HIGH TEMPERATURE SOLAR ABSORBERS; M. Abrams; January 1978.

A theoretical heat transfer analysis of spectrally selective absorbers showed that spectral selectivity offers the greatest benefits for conditions of high absorber temperature and/or low values of solar irradiation. By using a two-band model of the selective absorber, it was found that the cutoff wave length which maximizes absorber efficiency depends on just two parameters: the absorber temperature, and the level of solar irradiation. The emittance of the infrared band was found to have a greater effect upon efficiency than the absorbance of the solar band when a critical dimensionless parameter exceeds unity.

SAND-77-8510: SOLAR CENTRAL RECEIVER POWER PLANTS; A. C. Skinrood; September 1977.

The first Solar Central Receiver Pilot Plant will be built in Barstow, California, starting in 1978. Experimental versions of subsystem designs have been constructed and tested. Sandia Laboratory is evaluating the technology that resulted from these experiments in order to develop a recommendation for the conceptual design of this pilot plant.

SAND-77-8512: AN ANALYTICAL SOLUTION FOR THE MULTI-DIMENSIONAL DEGRADATION OF A PACKED BED THERMOCLINE; S. B. Margolis; January 1979.

A multidimensional, time-dependent model of the thermocline degradation in a packed bed thermal storage tank is presented. The formulation includes the effects of finite tank lengths, multidimensional thermal conduction, heat transfer between the fluid and solid portions of the bed, and heat losses across all tank surfaces. The technique used to solve a coupled pair of parabolic partial differential equations describing the degradation of the thermocline is based on a vectorized separation of variables approach. Assuming cylindrical geometry, the analysis leads to separate eigenvalue problems for the radial, angular, and axial spacial dependencies of the fluid and solid temperatures in the bed. The eigenvalues are readily calculated and the corresponding eigenfunctions are shown to form a complete set of spacial basis functions for the solution base. The method results are illustrated by several examples.

SAND-77-8513: HIGHLIGHTS REPORT SOLAR THERMAL CONVERSION PROGRAM CENTRAL POWER PROJECTS; Sandia; November 1977.

This report presents the highlights of Energy Research and Development Administration (ERDA) Solar Thermal Branch Semi-Annual Review held in Seattle, Washington, on August 23-24, 1977. The review covered status and plans for central receiver projects, the Solar Thermal Test Facility project, and the related research and development activities.

SAND-77-8665: DIRECT CONTACT HEAT EXCHANGE FOR LATENT HEAT-OF-FUSION ENERGY STORAGE SYSTEMS; M. C. Nichols and R. M. Green; December 1977.

Rudimentary computational and experimental results are presented for a thermal energy storage process based on a novel counter-current, direct-contact heat exchange concept, the "shot tower." The process uses a phase change material and a mutually immiscible heat transfer fluid. A two-tank storage system is used, one each for "cool" and "hot" phase change material, respectively. In use, the phase change material is introduced from one of the storage tanks into a unique, direct-contact heat exchanger where it is frozen/melted while it passes through the countercurrently flowing heat transfer fluid which receives/supplies heat from/to the phase change material. Since these external heat exchangers need only be sized to meet the charge/discharge power demand, they can be quite small relative to the size of the storage tanks. The extensive and expensive heat exchanger surfaces required in conventional phase change systems can be totally eliminated. This uniquely simple external heat exchanger serves to make the system considerably less complex and potentially less expensive than any other phase change thermal energy storage system described to date. Preliminary calculations predict that a "shot tower" type heat exchanger using water/paraffin, having a length approximately 2 meters (approximately 6 feet) and a diameter of approximately 25 centimeters (approximately 10 inches), could extract heat from a tank of molten paraffin at a rate sufficient to supply domestic hot water to approximately 10 families.

SAND-77-8686: ANHARMONIC ANALYSIS OF A TIME-DEPENDENT PACKED BED THERMOCLINE; S. B. Margolis; July 1978.

A vectorized separation of variables approach is applied to a coupled pair of parabolic partial differential equations describing the degradation of a thermocline in a packed bed thermal storage tank. The time-dependent quasi-dimensional model includes the effects of a finite tank length, thermal conduction in the direction parallel to the tank walls, and

heat transfer between the fluid and solid components of the bed. For certain classes of boundary conditions, the analysis leads to an eigenvalue problem for the spacial dependence of the fluid and solid temperatures of the bed. The eigenvalues and corresponding eigenfunctions are readily calculated, and completeness of the eigenfunctions follows from a transformation to an integral equation by the construction of a Gren's tensor function. The method is illustrated by an example which arises in the analysis of the thermal storage subsystem of a central solar receiver power plant.

SAND-77-8763: ISSUES AND METHODOLOGY FOR THE SELECTION OF A CONCEPTUAL DESIGN FOR A SOLAR CENTRAL RECEIVER PILOT PLANT; A. C. Skinrood; 1978.

This paper describes the selection process used by Sandia Laboratories to recommend a conceptual design for the Solar Central Receiver Pilot Plant to be built at Barstow, California, by the U.S. Department of Energy. Included are key selection issues and their significance.

SAND-78-0117C: CONCENTRATOR-QUALITY EVALUATION: F. Biggs and C. N. Vittitoe; 1978.

The performance of a reflecting solar concentrator depends, of course, on its surface reflectance, but there are other important factors. Among these are sun-tracking errors, surface-slope errors, and surface irregularities. It is appropriate to use statistics to describe and analyze these nondeterministic factors. A scheme for specifying the quality of a solar concentrator that includes all these effects is described and illustrated. It is believed that this procedure is optimum in the sense that it requires a minimum of measurements to obtain a complete enough description of a concentrator to determine its optical performance under any operating geometry. The specification scheme is, therefore, suitable for use in general systems analysis studies involving solar concentrators.

SAND-78-0204C: REAL TIME COMPUTER CONTROL OF 5 MEGAWATTS OF SOLAR THERMAL ENERGY; E. D. Thalhammer; May 1978.

The Solar Thermal Test Facility (STTF) operates under the control of a nine machine distributed minicomputer network. The prime functions of this network are heliostat controls, heat rejection system controls, and data acquisition. The Control Computer is described here. This computers main tasks are: (1) the sun position calculation, (2) automatic heliostat command execution, (3) graphic display of heliostat status and selected items of tower and boiler control data, (4) operator control of the heliostat command

cycle, (5) heliostat alarm handling, and (6) the permanent recording of all test parameters necessary to fully describe the experiment performed. The control system is capable of directing 5 megawatts of thermal energy at any point within 327 meters of the solar receiver tower. Also described are the procedures and checking performed by the computers to ensure personnel and facility safety.

SAND-78-0205C: MASTER CONTROL AND DATA SYSTEM FOR THE 5 MW SOLAR THERMAL TEST FACILITY; D. M. Darsey; May 1978.

The world's largest solar-powered research facility, approaching construction completion near Albuquerque, New Mexico, is controlled by a distributed network of minicomputers. The philosophy of the system design and details of the system control components, operation and data capabilities are described.

SAND-78-0354C: MATERIALS PROBLEMS IN SOLAR, NUCLEAR, AND STORAGE OF ENERGY; R. S. Claassen; February 1978.

Developing energy technologies place increasing demand on material performance and in some cases exceed known material capabilities. Material choices in solar systems are dominated by cost. Distributed collectors and the central receiver illustrate practical problems. The demand for absolute safety in nuclear power requires a depth of understanding and level of knowledge about materials unachieved in previous engineering systems. Problems in water-cooled and breeder reactors emphasize the point. Fusion reactors will push far beyond our present knowledge of material response and behavior. Within limits, energy storage is practical today but present technologies such as batteries are being pushed hard and new schemes such as superconducting solenoids and thermochemical storage are under intense study.

SAND-78-0342C: SYSTEM ANALYSIS OF STORAGE IN SPECIFIC SOLAR ENERGY SYSTEMS;

SAND-78-0432C: HELIOSTAT DUST BUILDUP AND CLEANING STUDIES; R. S. Berg; March 1978.

The range of techniques that can be used to reduce dirt accumulation are described and some of the corresponding experiments being performed at Sandia are discussed. The mechanisms of dirt impingement and adhesion and the time development of adhesion forces are studied. The behavior of adhesion forces leads to restrictions on the periods when dirt is most susceptible to removal and on the potential removal techniques that can be used. The following experimental investigations are discussed: reducing dust

deposition, cleaning solution investigations, high pressure spray washing, and dirt characterization.

SAND-78-0510: HELIOSTAT DUST BUILDUP AND CLEANING STUDIES; R. S. Berg; March 1978.

Dirt accumulation on solar energy optical surfaces such as heliostats can cause losses of over 25 percent after relatively short outdoor exposure. Cleaning effectiveness depends on the technique used, the environmental conditions, and the amount of time the mirror has been exposed. Several continuous and periodic cleaning techniques have shown promise. Continuous cleaning using electrostatic repulsion has been tested in laboratory experiments and was shown to reduce dust accumulation. These experiments were performed in a low velocity (0 to 25 m/s) atmospheric wind tunnel fitted with a dust injector capable of injecting 10^4 times as many optically important particles as are present in the normal aerosol. Periodic cleaning using high-pressure sprays of up to 10,000 psi have been used to clean dirt from outdoor test samples. Tap water sprays at pressures above 500 psi seem to be equally effective and recover about 95 percent of the reflectance loss from dirt buildup. Several common detergents have been examined. Detergents with low-pressure sprays generally must be used on short intervals, less than two weeks, or they lose their effectiveness. Measurements on accumulated dirt show that a limited number of measurements are required to characterize the optical loss of a dirty mirror. Weighted reflectivity measurements at 500 nm can be used. The dirt buildup is a very complex function of time and environmental conditions.

SAND-78-0529C: 1-MW CALORIMETRIC RECEIVER FOR SOLAR THERMAL TEST FACILITY; L. O. Seamons, E. E. Rush and C. E. Moeller; December 1978.

A calorimetric solar receiver is described for measuring incident and absorbed solar radiation reflected from the heliostat field at the Department of Energy's 5-MW Solar Thermal Test Facility, Sandia Laboratories, Albuquerque, New Mexico. The receiver consists of nine 1-meter (3.28-ft) square panels in a 3-meter (9.84-ft) square array. Each panel is capable of absorbing 0.5-MW of power, but the total array is limited to 1 MW. Each panel is cooled by an ethylene glycol/water solution entering at 61° C (142° F) in a flow circuit parallel to the other panels. Each panel is instrumented with a turbine flowmeter, inlet and outlet coolant thermocouples, and nine heat flux gages with integral thermocouples on one third-meter grid spacings. Details of mechanical, electrical power, instrumentation, data acquisition, and structural designs are presented. Results from initial tests of concentrating up to 1 MW of thermal power on the receiver are presented.

SAND-78-1016C: MASTER CONTROL SYSTEM FOR THE CENTRAL RECEIVER SOLAR POWER PLANT; D. M. Darsey, R. C. Roundtree, R. R. Sheahan, M. A. Soderstrand and C. P. Winarski; October 1978.

A Master Control System (MCS) is described in terms of its operation and evaluation role for the nation's first major solar thermal electric power venture. The specific application referred to is the 10-MWe Solar Thermal Central Receiver Pilot Plant being built at Barstow, California. Five subsystems have been defined for the Pilot Plant version of this concept. They are designated as the Collector Subsystem (CS: i.e., heliostats), the Receiver Subsystem (RS: i.e., absorber and tower), the Thermal Storage Subsystem (TSS: i.e., tank and fluid), the Electrical Power Generation Subsystem (EPGS: i.e., turbine generator, and associated balance of plant), and the MCS. First, a brief history is provided of the Pilot Plant development which led to the adoption of the MCS configuration. Then, an overview of this configuration is presented, followed by a general discussion of subsystem control considerations. Next, functions of three primary MCS elements are described, followed by general definitions of associated software and steady-state operation modes. Finally, a summary and conclusions are presented pertaining to the overall MCS configuration and present/planned developments.

SAND-78-1052C: 5-MW SOLAR THERMAL TEST FACILITY; J. T. Holmes; April 1978.

The world's largest high intensity solar experimental facility will be fully operational in 1978. The Solar Thermal Test Facility is capable of delivering 5 million watts of thermal power to experimental equipment. The primary STTF testing programs will involve prototype components for central receiver solar electric power plants. The STTF also provides unique capabilities for other high solar flux and high temperature research and development work. Two hundred twenty-two mirror assemblies (called heliostats) are used to concentrate the sun's energy to an experiment located on the 61 meter tall concrete tower. Operation at partial power of about 1.8-MW(t) was achieved in May of 1977.

SAND-78-1141C: COST/PERFORMANCE COMPARISON OF LINE AND POINT FOCUS COLLECTORS IN PROCESS HEAT APPLICATIONS; J. K. Linn and H. M. Dodd; June 1978.

The performance and economic tradeoffs among the various line and point focusing concepts are considered. Point focusing collectors may hold a long-term advantage for certain applications or geographic locations. Energy

requirements for collector production, obtained from current manufacturing technologies, indicate that line focusing collectors may be the most desirable choice from a net energy standpoint.

SAND-78-1169C: SPECULAR REFLECTANCE LOSS OF SOLAR MIRRORS DUE TO DUST ACCUMULATION; R. B. Pettit, J. M. Freese, and D. E. Arvizu; May 1978.

The specular reflectance properties of silvered glass mirrors have been studied after the mirrors experienced five weeks of outdoor exposure in Albuquerque, NM. The reflected beam profile from angular aperatures of 3 to 15 mrad was determined from 400 to 900 nm using a bidirectional reflectometer. It was found that the main effect of the accumulated dust particles is to decrease the intensity of the specular beam while maintaining the same beam profile. At 500 nm, measured specular reflectance losses ranged from 6.5 to 24%. The diffuse reflectance outside an approximately 170-mrad cone around the specular direction was also measured from 320 to 2500 nm using an integrating sphere reflectometer. As expected, the reflectance losses determined from the two measurements were not in agreement. However, when properly normalized, the wavelength dependences of the reflectance loss determined by both measurements were identical for all areas measured. Thus, it is possible to calculate the solar-averaged specular reflectance loss from a single measurement at 500 nm. For the silvered glass mirrors studied, the solar-averaged specular reflectance loss is equal to 0.78 $\pm$0.04 times the specular reflectance loss measured at 500 nm.

SAND-78-1177C: SOLAR CENTRAL POWER TEST FACILITY HELIOSTAT DEVELOPMENT; D. E. Arvizu; June 1978.

The SCPTF, Solar Central Power Test Facility, capable of supplying 5-MW(e) energy onto a target on the tower, uses an array of 222 heliostats in a north field configuration. The SCPTF heliostat is described and the performance data gathered to date is discussed. This data led to certain corrections in the computer code HELIOS.

SAND-78-1190C: INSOLATION MODEL OVERVIEW; E. C. Boes; June 1978.

A brief summary of a variety of recent and current solar radiation resource assessment activities is presented. Detailed descriptions of several major solar data projects are included which are particularly important for SHAC system simulations. Recommendations are made regarding appropriate solar radiation resource information sources for various SHAC system design and analysis activities.

SAND-78-1303: QUALITY ASSURANCE PROGRAM FOR SOLAR THERMAL TEST FACILITY (STTF) HELIOSTAT PRODUCTION; F. P. Freeman and J. T. Hillman; August 1978.

The Quality Assurance (QA) Program followed during heliostat production for the Solar Thermal Test Facility is described. Problems encountered as well as the corrective action taken are discussed. Brief descriptions of the validation of processes, the Martin-Marietta Quality Control Inspections, and the data package and computer storage of Record of Assembly data are included. The experience gained is typical of a QA program which may be applied to other projects under the new requirements imposed by DOE AL Manual, Chapter 08XA ALO Quality Program.

SAND-78-1315(REV): USERS' MANUAL FOR COMPUTER CODE SOLTES-1 (SIMULATOR OF LARGE THERMAL ENERGY SYSTEMS); M. E. Fewell and N. R. Grandjean; June 1979.

SOLTES simulates the steady-state response of thermal energy systems to time-varying data such as weather and loads. Thermal energy system models of both simple and complex systems can easily be modularly constructed from a library of routines. These routines mathematically model solar collectors, pumps, switches, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine/generators, condensers, regenerative heaters, air conditioners, heating and cooling of buildings, process vapor, etc.; SOLTES also allows user-supplied routines. The analyist need only specify fluid names to obtain readout of property data for heat-transfer fluids and constants that characterize power-cycle working fluids from a fluid property data bank. A load management capability allows SOLTES to simulate total energy systems that simultaneously follow heat and power loads and demands. Generalized energy accounting is available and values for system performance parameters may be automatically determined by SOLTES. Because of this modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal energy systems such as a 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.

SAND-78-1600C: HELIOS AND RECONCENTRATORS; C. N. Vittitoe, F. Biggs, L. K. Matthews, and L. O. Seamons; May 1979.

The HELIOS computer code for modeling solar energy collection by reflecting systems has been evolving over the last two years. Recent extensions include application to reconcentrators and to the evaluation of heliostats at the Central Receiver Test Facility (CRTF) at Albuquerque, New

Mexico. Data are now becoming available for detailed comparisons between HELIOS predictions and experimental data. Such comparisons are now used as an aid to heliostat evaluation. Here HELIOS predictions are compared with image data produced by 23 heliostats at the CRTF and with data from a single facet chosen partially because of exceptionally large distortion. Two dimensional surface slope errors and reflectance properties are necessary to explain the single facet results. The method of treating reconcentrators is presented. Comparisons with reconcentrator data are planned. More detailed facet-normal measurements are needed. Considerable two-dimensional error data are needed to explain fine structure in present data.

SAND-78-1649: EFFECTS OF OUTDOOR EXPOSURE ON THE SOLAR REFLECTANCE PROPERTIES OF SILVERED GLASS MIRRORS; J. M. Freese; September 1978.

The specular reflectance loss of silvered glass heliostat mirrors has been studied over a nine-month period during which the mirrors were exposed to outdoor weather conditions. A bidirectional reflectometer was used to measure the reflected beam profile of approximately 9 cm square samples exposed to the environment on outdoor racks.

The reflectometer's incident beam had a 1 mrad divergence and the reflected beam intensity was determined at 3- and 15-mrad angular apertures and at wavelengths of 500, 700, and 900 nm, with an incident angle of 20°. Data were obtained by measuring exposed samples at two-day intervals.

It was determined from these experiments that elevation differences and variations in sample mounting angles up to 60° had little influence on dust accumulation rates. Weather conditions such as wind and rain can decrease as well as increase the reflectance of a mirror. The largest decrease in reflectance for a two-day period was 0.06 reflectance units, while the largest increase for a two-day period was 0.083 reflectance units. A snow weather condition can restore an exposed mirror's specular reflectance to within 0.01 reflectance units of the initial value obtained after the laboratory ultrasonic cleaning. Because of varying weather conditions, it is very difficult to take a short-term cleaning cycle result and predict the reflectance loss for a longer period of time.

Long-term exposure tests, where the mirrors were never cleaned, showed a gradually decreasing specular reflectance trend together with occasional sudden increases which corresponded to snow or rain weather conditions.

Because New Mexico has very localized weather conditions, compared to many other parts of the country, reflectance loss due to these weather conditions is dependent on mirror sample location.

SAND-78-1918: DEVELOPMENT OF A PORTABLE SPECULAR REFLECTOMETER FOR FIELD MEASUREMENT OF SOLAR MIRROR MATERIALS; J. M. Freese; October 1978.

A portable reflectometer designed for in-the-field measurements of solar mirror materials has been developed. This instrument is of a convenient size for use by one operator in an outdoor environment. Instrument design, operation, and calibration are discussed. It is shown that the instrument responds linearly; >-0.006 transmission units: to variations of intensity of incident and reflected beams and that the readings are not affected by the presence of stray light. The mirror materials measured with the portable instrument include samples of polished aluminum, metallized plastic film and silvered glass. The reflectance values of these materials were within >-0.005 reflectance units of the values obtained from appropriately averaging reflectance versus wavelength data taken with a laboratory bidirectional reflectometer. This instrument should prove useful in monitoring the effects of dirt and weathering on mirror specular reflectance in the field.

SAND-78-2047C: SPECULAR REFLECTANCE PROPERTIES OF SOLAR MIRRORS AS A FUNCTION OF INCIDENT ANGLE; D. N. Glidden and R. B. Pettit; May 1979.

The specular reflectance properties of several solar mirror materials have been measured as a function of wavelength, polarization and incident angle. Results for a 3-mm thick, silvered float glass mirror and an aluminized acrylic stretched film are presented. For the silvered glass mirror, measured specular and hemispherical reflectance properties are in excellent agreement with reflectance values calculated from a multiple beam reflectance model. at 65° from normal, the average solar reflectance is decreased only approximately 4% from the value at normal incidence. For the aluminized acrylic mirror, measured specular reflectance values at 15 mrad were in agreement with hemispherical reflectance values, while calculated reflectance values are as much as 2% high for one polarization. The average solar reflectance decreases only 2% at an incident angle of 65° from normal, while the width of the specular beam increases slightly with incident angle.

SAND-78-2065C: DEVELOPMENT OF A PORTABLE REFLECTOMETER FOR FIELD MEASUREMENTS OF THE SPECULAR REFLECTANCE OF SOLAR MIRRORS; J. M. Freese; May 1979.

Specular reflectance measurements of mirror surfaces used in solar concentrators are needed to determine the effect of accumulated dust on reflectance as well as to detect any permanent degradation of the mirror reflectance. Because it is impractical to remove a mirror from a collector for measurements in the laboratory, a portable reflectometer designed for in-the-field measurements of solar mirror materials has been developed. Unlike the standard laboratory bidirectional reflectometer, the portable instrument uses broad band spectral filters, circular apertures rather than silts and accepts a greater beam divergence. However, results obtained with the portable instrument correlated quite well with those of the laboratory reflectometer. The reflectance values of silvered glass, metallized plastic film and polished aluminum were within ± 0.005 reflectance units of the values obtained from appropriately averaging reflectance versus wavelength data taken with a laboratory bidirectional reflectometer. The portable instrument has proven useful in monitoring the effects of dirt and weathering on mirror specular reflectance in the field.

SAND-78-2072C: EFFECTS OF OUTDOOR EXPOSURE ON THE THE SOLAR REFLECTANCE PROPERTIES OF SILVERED GLASS MIRRORS; J. M. Freese; May 1979.

The specular reflectance properties of silvered glass heliostat mirrors have been studied during a 15 month period of exposure to outdoor weather conditions. A bidirectional reflectometer was used to measure the reflected beam profile at wavelengths of 500, 700, and 900 nm, with an incident angle of 20°. Data were obtained by measuring exposed samples at two-day intervals. It was found that weather conditions such as wind and rain could decrease or increase the reflectance of a mirror. The largest decrease in reflectance for a two-day period was 0.06 reflectance units. While the largest increase for a two-day period was 0.083 reflectance units. A snow storm restored an exposed mirror's specular reflectance to within 0.01 reflectance units of the initial value obtained after the laboratory ultrasonic cleaning. Because of varying weather conditions, it is very difficult to take a short-term cleaning cycle result and predict the reflectance loss for a longer period of time. In long-term exposure tests, where the mirrors were never cleaned, the specular reflectance gradually decreased while being modulated by occasional sudden changes which corresponded to snow or rain weather conditions.

SAND-78-2109C: ENVIRONMENTAL TESTING OF SOLAR REFLECTOR STRUCTURES; R. E. Allred, D. W. Miller and B. L. Butler; May 1979.

The reflector support structure of a concentrating solar collector provides and maintains the required shape for the reflective surface; it must perform its functions to the required accuracy over a 20 to 30 year life cycle with a minimum of maintenance. A program to determine the aging behavior of candidate reflector support materials and processes has been conducted at Sandia Laboratories, Albuquerque, since 1975. Materials evaluated include laminates, sandwiches and molded structures constructed of metals, ceramics, forest products and fiber-reinforced composites. Accelerated temperature-humidity cycling data and real time exposures indicate that a variety of material constructions may eventually meet the operational and lifetime requirements. Constructions which performed well in this study included plywood, fiberglass skin and core sandwiches, melamine skin/paper core sandwiches, aluminum skin/aluminum core sandwiches, and molded structures of sheet molding compound with integral ribs. The data also indicates that designers should be particularly concerned about maintaining thermal compatibility throughout the reflector structure, producing high integrity adhesive bonds, protecting the reflective surface from corrosion and using moisture insensitive materials.

SAND-78-2305C: WEIGHT MINIMIZATION OF SANDWICH TYPE SOLAR COLLECTOR PANELS; R. C. Reuter, Jr.; August 1979.

Solar collector modules of various types (e.g., line-focusing, heliostats) require stiff, lightweight structural panels to support and protect their reflective surfaces. Symmetric, sandwich type panel construction fulfills these requirements. Analytical methods are utilized in the present work to study the existence, utilization and practicality of a minimum weight, adequately stiff design for sandwich panel construction in the solar collector application.

SAND-78-2419C: OVERVIEW OF SOLAR SYSTEM DESIGN AND APPLICATION PRINCIPLES; V. L. Dugan; February 1979.

Solar thermal energy conversion systems represent a method of reducing dependency on stored energy reserves; this is done at the expense of an increased dependency on materials and land resources. The various technologies being investigated to convert solar radiation into thermal energy are reviewed, and general guidelines which should be followed in designing and applying cost-effective solar conversion systems are presented. This information is expanded upon and illustrated by a comparison of performance

results for a range of solar thermal technologies and by one solar irrigation application in the United States.

SAND-78-6013: AIR NAVIGATION HAZARDS ASSOCIATED WITH A CENTRAL SOLAR TOWER; F. Sicart and B. Gentili; April 1978.

The risks of interception by an aircraft flying over a central solar electric plant have been examined from two points of view: (a) dazzlement of the pilot and passengers; and (b) damage to the retina. The conditions foreseen for the Saint Chamas site for the various types of equipment can be summarized as follows: (a) overflight by commercial navigation 470 m above the field; (b) floor of military navigation fixed at 1,000 m above the field, and (c) occasional overflight by general navigation 300 m above the field. The latter type of aircraft thus appears to have the greatest risks, but the presence of the Marignane approach corridor severely limits traffic of this nature. The most important perturbation that a solar central station at Saint Chamas could create for aerial navigation is the risk of dazzlement to a commercial aircraft caused by accidental misalignment of a heliostat. This could be the result when a beam is intercepted by an aircraft; the probability of such an interception has been evaluated at 10^{-6}, under the following very pessimistic hypotheses: (a) establishment of the dazzlement threshold at 1 sun; (b) permanent loss of control of one heliostat on an average over the entire lifetime of the station; and (c) the screening effect produced by the nose of the aircraft is not taken into account; considering this effect should in fact reduce the risk very significantly. this probability would then predict one such occurrence in 14 years under the traffic conditions foreseen for 1985. Occasional overflight at 300 m could lead to a higher risk of dazzlement. But in any case this dazzle will not inflict any damage on the pilot's retina. Finally, the experimental programs planned in Albuquerque by ERDA and in Odeillo should allow evaluation of the effects on a pilot of a considerable reflected solar flux (surprise, dazzle) and the probability of unfavorable consequences, until now considered equal to unity.

SAND-78-7001: DEFINITION OF TWO SMALL CENTRAL RECEIVER SYSTEMS; R. J. Holl; January 1978.

The performance and costs of two small central receiver systems are defined and hardware development required to deploy such systems in the solar total energy program is recommended. System definition was limited to the energy producing portion of the plant, that is: the heliostat field, the receiver and the tower. One system heated Therminol 66 to 316° C (600° F) while the other produced

superheated steam at 427 ^{o}C and 4.17 mpa (800^{o} F and 600 psia). The first system allows comparison with the performance of line-focusing distributed collectors currently being developed for solar total energy applications. The second system displays the greater performance potential of central receivers due to their higher concentration ratio. The two solar energy systems are described starting with the receivers then covering the heliostat field and tower.

SAND-78-7028: DEVELOPMENT OF A SOLAR MODEL YEAR FROM NATIONAL WEATHER SERVICE CHART DATA; Georgia Institute of Technology; March 1978.

The development of a solar model year directly from National Weather Service chart data archived at the National Climatic Center is described. A procedure is described for constructing a pseudo year model by selecting from all available months those 12 which most nearly match the long term measured characteristcs in a weak statistical sense. The months were selected to most nearly match the monthly means and standard deviations of the daily total global insolation. No attempt was made to match any other meteorological characteristics. The chart data of daily global insolation for each month were digitized at 15 minute intervals and were corrected for long term instrument drift. The correction was based on a linear regression analyses of the daily total insolation measurement for the clearest of each group of 40 days over the lifetime of the particular instrument. Finally, the model year data were assembled into a SOLMET format which included selected surface observations from the TDF-14 series data as well as a decomposition of the global insolation into beam and diffuse components.

SAND-78-7044: DETERMINISTIC INSOLATION MODAL PROGRAM DESCRIPTION AND USER'S GUIDE; E. P. French; July 1978.

A simple mathematical model is described for estimating the monthly average insolation experienced by a fixed or tracking collector. It is designed to fulfill the need for a rapid, economical method of assessing the availability of solar radiation as a basis for site selection and system performance estimation. It attempts to make maximum use of predictable factors, introducing random factors associated with local weather in the simplest way possible. The method lends itself to a formulation in terms of simple mathematical expressions and is suitable for use by hand calculators and small computers. It has been implemented by a three-module program written for the Texas Instruments SR-52 Programmable Slide-Rule Calculator, as described herein. The same mathematical model has been incorporated

into the Fortran Program STESEP. The model described here is intended for the rapid, approximate analysis of solar systems. It does not take the place of the SOLMET data base which provides, in a single FORTRAN-compatible tape, quality controlled hourly insolation and meteorological data for representative sites throughout the United States.

SAND-78-7047: HOURLY INSOLATION AND METEOROLOGICAL DATA BASES INCLUDING IMPROVED DIRECT INSOLATION ESTIMATES. FINAL REPORT; C. M. Randall and M. E. Whitson, Jr.; December 1977.

A new procedure has been developed to estimate hourly direct-normal insolation values from hourly total-hemispheric insolation values. This procedure is based on more than 20,000 simultaneous observations of these two quantities obtained since September of 1974 using carefully calibrated instruments at four different United States locations with widely differing climates. The model includes statistical variation of the estimated direct insolation values for a given hemispheric insolation value. The accuracy of the model has been extensively studied and it has been determined that the annual mean daily direct insolation values are estimated to within 4%. This procedure has been employed to estimate hourly direct-normal insolation from the Standard Year Corrected total-hemispheric insolation values recently generated from historical insolation observations by the National Climatic Center for 27 United States locations. Because of uncertainties in the Standard Year Correction procedure, the annual mean daily direct-normal insolation values estimated from these data have a 10% uncertainty associated with them. New hourly data bases including total-hemispheric and direct-normal insolation with surface meteorological data have been prepared for these 27 locations in the SOLMET format. The time period is 1952 through 1975 for most locations. Monthly mean insolation values have been computed by years from these new data collections and are included in this report. For some locations the present estimates of direct insolation are up to 40% lower than previous estimates based on earlier procedures.

SAND-78-8010: AN INTRODUCTORY COMPARISON OF BRAYTON AND RANKINE POWER CYCLES FOR CENTRAL SOLAR POWER GENERATION; C. C. Hiller; July 1978.

This report presents both a detailed discussion of the characteristics of Brayton and Rankine power cycles, and a discussion of their advantages and disadvantages as applied to central solar power generation. The characteristics of each cycle are discussed for a variety of configurations and are highlighted with numerous examples. Much of the background information presented is available from standard

texts on thermodynamics, gas turbines, and steam turbines. The information has been drawn together here in one convenient reference to serve as an introduction for individuals new to the solar research and development area.

SAND-78-8015: SEMI-ANNUAL REVIEW OF SOLAR THERMAL CENTRAL POWER SYSTEMS; Sandia; April 1978.

This report presents the highlights of the Department of Energy (DOE) Solar Thermal Central Power System semi-annual review held in San Diego, California, on March 2-3, 1978.

SAND-78-8020: A SENSITIVITY STUDY OF BRAYTON CYCLE POWER PLANT PERFORMANCE; C. C. Hiller; August 1978.

This study investigates the efficiency of Brayton cycle power plants under a variety of design configurations. This study is unique in that the range of cycle parameters and configurations examined is beyond that generally discussed in the open literature. The parameters and configurations include: (1) open and closed air cycles, (2) optimum pressure ratio, (3) helium versus air working fluids, (4) turbine and compressor isentropic efficiencies, (5) recuperator effectiveness, (6) turbine inlet temperature, (7) heat rejection temperature, (8) pressure drop losses, (9) with/without intercooling, (10) with/without reheat. Equation derivations, a computer listing, and a hand calculator program listing are included in the Appendices so that variations other than those presented in the report may be studied.

SAND-78-8038: EFFECTS OF BENDING ON THE FATIGUE LIFE OF SOLAR RECEIVER TUBES SUBJECTED TO ONE-SIDED HEATING; J. Jones; February 1979.

The strains due to thermal grading in central receivers are commonly analyzed as 2-dimensional, assuming the results to be conservative with this respect to the realistic 3-dimensional problem. It is the purpose of this report to examine this assumption in detail. Department of Energy's Barstow Pilot Plant is taken as a representative system and studied using simple beam theory, with a simple bar model for comparison. The results indicate that the two supports designed for the protection from wind and earthquakes effectively prevent any bending, except in regions of high axial thermal grading. Lack of generalized plane-drain analysis should accurately reflect the structural strength except in those regions.

SAND-78-8051: ANNUAL SUMMARY (FY 1978) RESEARCH AT SANDIA LABORATORIES FOR SOLAR THERMAL LARGE POWER SYSTEMS PROGRAM; Sandia; February 1979.

The technical activities performed at Sandia Laboratories in support of the Large Power systems portion of the Solar Thermal Power Program are summarized. Heliostat development, thermal storage research, receiver development, and system studies are described.

SAND-78-8054-V.1: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT, VOLUME I - SYSTEM CONSIDERATIONS; Sandia; April 1979.

The system analysis of the proposed design was divided into two parts: (1) compatibility between the subsystems of a given design, (2) the cost/performance of various combinations of subsystems. The first part of the study was performed to determine the ability of each system to function and to simulate commercial plant operations. This phase of the study concentrated on the collector field layout and receiver configurations, because these two subsystems are directly coupled and have the greatest impact on the system's performance. A key selection factor was the cost/performance potential of each contractor's commercial plant design. Each contractor estimated the cost and performance of a commercial sized plant that they designed for this evaluation.

SAND-78-8054-V.2: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT, VOLUME II - COLLECTOR SUBSYSTEM EVALUATIONS; Sandia; August 1978.

The four heliostat designs evaluated for the 10-MW Solar Central Receiver Pilot Plant are shown in Figure 1. The basic heliostat characteristics of each design as proposed by the Contractors are orientation method, control systems, mirror areas, net reflectivity, stress in glass, weight, and cost/performance for both the commercial plant and pilot plant. Each of the heliostat designs is evaluated and rated against the selection criteria as stated above. A points system was initially used as a tool to be sure that all factors were considered and weighed for relative importance. The relative ratings were used to help identify strengths and weaknesses and to initially rate the designs.

SAND-78-8054-V.3: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT, VOLUME III - RECEIVER SUBSYSTEM; Sandia; August 1980.

The objectives of this volume are to present: (a) the various design aspects of the three receiver concepts, (b)

the philosophies used in the evolution of these concepts, (c) the operational and performance aspects of the designs, (d) the assessments of the designs, and (e) a sound basis for the selection of a particular design concept to be pursued in the 10-MW Pilot Plant and subsequently in the commercial plant.

SAND-78-8054-V.4: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT, VOLUME IV - ENERGY STORAGE SUBSYSTEM; Sandia; August 1979.

This technical evaluation of the Thermal Storage Subsystem (TSS) for the 10-MW Solar Central Receiver Pilot Plant includes analyses of several issues studied as part of the technical evaluations; tabular summaries of design features for both the commercial and pilot plant design; and conclusions and recommendations. Additional results used in the evaluations of proposed thermal storage designs are contained in Volumes 1, 5, and 6. Volume 1 describes the interface requirements and presents the details of the commercial plant costs/performance analyses, while Volume 5 discusses control aspects of the proposed designs. Lastly, Volume 6 describes auxiliary power requirements.

SAND-78-8054-V.6: RECOMMENDATIONS FOR THE CONCEPTUAL DESIGN OF THE BARSTOW, CALIFORNIA, SOLAR CENTRAL RECEIVER PILOT PLANT, VOLUME VI - ELECTRICAL POWER GENERATING SUBSYSTEMS; Sandia; August 1979.

The analysis of the Electrical Power Generating Subsystem (EPGS) includes subsystem comparisons, conclusions and recommendations. Auxiliary power requirements and thermal storage designs are also discussed.

SAND-78-8180: 10-MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT HELIOSTAT FOUNDATION AT INTERFACE STRUCTURE INVESTIGATION; R. K. Shogren and J. T. Phillips; August 1978.

System Development Corporation (SDC), under contract to Sandia Laboratories, has conducted a study of foundation design requirements for Heliostats for the 10-MWe Solar Thermal Power Plant Project to be constructed near Daggett, California. This study consists of six tasks as follows:

1. Review available soils data. Prepare soil investigation specifications recommendations as required.
2. Review foundation to collector interface requirements and recommend appropriate deflection budgets consistent with technical and cost considerations.
3. Prepare candidate foundation designs of associated cost studies.

4. Study field grading requirements and provide recommendations consistent with technical and budgetary restrictions.
5. Develop recommendations for construction and tests of prototype foundations.
6. Prepare a comprehensive report for use by Solar Ten-Megawatt Project Office and the A/E firm who will prepare the final design.

Inherent in each task is special consultation and technical assistance to STMPO as required to aid in the timely achievement of program objectives.

SAND-78-8183: PERFORMANCE ANALYSIS FOR THE MDAC/ROCKETDYNE PILOT AND COMMERCIAL PLANT SOLAR RECEIVERS; S. Wolf, K. Chen, T. M. Yang and J. L. Simpson; September 1978.

This report presents the results of analyses and reviews to evaluate selective features of the receiver boiler panel designs proposed by McDonnell Douglas Astronautics Company for a 10-MW pilot and 100-MW commercial solar-electric power plant. Overall thermal performance conditions are predicted for maximum and minimum heat flux conditions with a steady-state code, putting parameters to take into account some of the two-dimensional effects resulting from nonuniform circumferential solar heating. Thermal and stress isolations occurring in the tube walls in the transition boiling region following the critical heat flux point are predicted for the maximum heat flux condition for the pilot plant and for the maximum at 80 percent of maximum heat flux conditions for the commercial plant.

SAND-78-8185-V.1: TOWER COST DATA FOR SOLAR CENTRAL RECEIVER STUDIES. FINAL REPORT; Stearns-Roger Engineering Co.; June 1979.

This report details the work performed to establish solar receiver support tower costs and to investigate the relative importance of the following parameters: (1) materials (concrete and steel), (2) height, (3) weight of the receiver, (4) seismic ground acceleration, (5) wind velocity, (6) soil shear modulus, and (7) soil bearing capacity. The objective of this study was to obtain cost data to be used by Sandia Laboratories in a statistical model to evaluate the effects of the parameters listed. This objective was reached by designing 16 concrete and 17 steel solar receiver support towers, varying the parameters listed above. Twenty-nine of these design cases were intended to provide input to the statistical model; cases 17 through 20 will be used to check the results. The costs of each tower and their foundations are presented. The costs ranged from a low of $40,000 for a structural steel tower, 120 feet high, supporting a receiver weighing 200 kips; to a

high of $16,000,000 for a reinforced concrete tower, 1,000 feet high, supporting a receiver weighing 8,000 kips. The analytical procedure and input are described and itemized estimates are tabulated.

SAND-78-8185-V.2: TOWER COST DATA FOR SOLAR CENTRAL RECEIVER STUDIES, FINAL REPORT; Stearns-Roger Engineering Co.; June 1979.

This report describes the work performed under the contract with Sandia Laboratory to establish solar receiver support tower costs and to investigate the relative importance of the following parameters: (1) materials (concrete and steel), (2) height, (3) weight of the receiver, (4) seismic ground acceleration, (5) wind velocity, (6) soil shear modulus, and (7) soil bearing capacity. The objective of this study was to obtain cost data to be used by Sandia Laboratories in a statistical model to evaluate the effects of the parameters listed. This objective was reached by designing 16 concrete and 17 steel solar receiver support towers, varying the parameters listed above. Twenty-nine of these design cases were intended to provide input to the statistical model; cases 17 through 20 will be used to check the results. This Supplement contains the printouts of the various computer runs that were performed for the study. Thirty-three separate tower designs were fed into the computer program. The resulting printouts are included in sequential order.

SAND-78-8188: MDAC/ROCKETDYNE SOLAR RECEIVER DESIGN REVIEW; H. M. Payne; August 1978.

The results of a review of the MDAC/Rocketdyne solar central receiver designs for both the 100-MWe commercial plant and the 10-MWe pilot plant are presented. The major objective of this design review was to assess the adequacy of the design in meeting the requirements of the solar central receiver (boiler) over a commercial lifetime of 30 years. The MDAC/Rocketdyne design consists of an external solar heated receiver, composed of a multiple of modular panels arranged in parallel and operating on the once-through steam generation principle. Each panel is composed of welded tangent tubes, connected between inlet and outlet headers. Subcooled water enters the bottom headers, flows upward, absorbs heat, produces saturated steam throughout the two-phase region, and exits at the top as superheated steam. Tube size and material are the same for both the commercial and pilot plants. Panel sizes are different between the two plants. Commercial plant heat flux is approximately 2.8 times that of the pilot plant. Structural supports and attachments of both designs are similar. Control of final superheat temperature is maintained by varying the water flow to each of the panels, according to the thermal

absorption of each panel. The pilot and commercial plant receiver designs are, therefore, similar in construction and mode of operation. They differ significantly, however, in thermal loading.

SAND-78-8190: NONINVERTING HELIOSTAT STUDY; J. B. Blackmon; July 1979.

Implications of employing a noninverting heliostat design with a lower capital cost relative to an inverting design are considered from three standpoints: (1) effects of dust buildup, corresponding cleaning frequencies, and resultant cleaning costs; (2) effects of hail impact; and (3) reflected beam safety issues. It is concluded that elimination of the inverted stow hardware and addition of reflector area in the slot required for inverting the reflector provides a direct subsystem cost savings. Since the noninverting heliostat must be stowed face up during high winds, reflectance degradation rates due to dust buildup are increased. The economic optimum cleaning frequency and allowed loss of reflectance due to dust buildup are determined so as to minimize the total system cost, and it is found that an overall cost savings of 12-13 percent results if the inverting capability is eliminated. Hail impact damage and probability of occurrence for the United States are determined within the accuracy of available data. Analysis indicates that the commercial heliostat laminate glass design considered will survive 1-1/2-inch hailstones and is suitable for installation over most of the U.S. with low to negligible risk from hail damage. Reflected beam safety hazards are analyzed for the noninverted design relative to the inverting design. No compelling reason is found to require an inverting stow capability, and therefore, a noninverting stow heliostat is concluded to be a viable cost-effective option.

SAND-78-8191: PHASE II - HELIOSTAT DRIVE MECHANISM, FINAL REPORT; W. D. Mitchell, D. Maxwell, D. Morden, J. C. Graddy and H. E. Felix; May 1980.

The objective of this project has been to design and test the modified azimuth-elevation heliostat drive mechanism generated by SOLARAMICS in the Low Cost Heliostat Preliminary Design Program. The preliminary design has been scaled up to accommodate a larger heliostat of $50m^2$ (524 sq ft) from the $40m^2$ design. The design effort has stressed development of a mechanism possessing low initial cost and low maintenance. The basic design concept utilizing 2 linear actuators with bell crank linkages has been retained and refined. A full-scale assembly has been fabricated and tested to evaluate performance characteristics. The design characteristics, design trade-offs, and test program are detailed.

SAND-78-8192: SECOND GENERATION HELIOSTAT DETAIL DESIGN REPORT; R. K. Knowles; August 1980.

An overview of the Second Generation heliostat design is provided, including a summary of the compliance of the design to the key heliostat requirements. The heliostat hardware is described. The requirements, the hardware and software design used to fulfill these requirements and the analysis and test used to evaluate related performance are presented. The technical feasibility and potential cost savings of a variety of automated mirror inspection techniques are assessed. The installation process design, applicable to both the test units and production, is described. The current maintenance process design is described for the production program.

SAND-78-8193: HELIOSTAT MATERIALS DEVELOPMENT AND EVALUATION. FINAL TECHNICAL REPORT. FEBRUARY 5, 1979-JUNE 20, 1980; General Electric Co.; 1980.

The objective of this program was to produce, characterize, and test enclosure and reflector materials with the purpose of establishing a firm data base for the prediction of useful life cycles and of upgrading the performance of enclosed heliostat systems, leading to a lower cost/performance ratio. The films selected for testing as potential enclosure materials were UV-stabilized poly(ethylene terephthalate) (PET) and poly(vinylidene fluoride) (PVDF). The stabilized polyester film appeared to be a likely candidate considering its cost, optical and mechanical properties, and its apparent weatherability (based on uncontrolled testing). Biaxially oriented PVDF was selected as a candidate because, although not yet in commercial production, it appeared to have tensile strength approaching that of PET, extremely high clarity, and presumably good weathering resistance. While there is a great deal of data on the weatherability of PVDF in the form of protective coatings or of protective or decorative appliques, no data were available concerning the weathering properties of unsupported, biaxially oriented film. A number of second-surface reflectors were investigated, and a laminated aluminized PET reflector available from Martin Processing Co., was selected for testing. First-surface aluminized PET, both unprotected and protected by a thin layer of DOW Corning Q96315 resin, also were selected for testing. Procedures and results of weathering tests are detailed. Also methods for bonding plastic films, specularly optimized film reflectors, and the mechanism of weathering degradation are discussed. Data on the flammability of plastic films are included.

SAND-78-8195: AN ASSESSMENT OF THE USE OF CHEMICAL REACTION SYSTEMS, PHASE II, FINAL REPORT, J. T. Stewart, H. T. Chen, J. C. Hsu, W. R. Mounce and F. D. Nankani; June 1979.

This report documents the work performed during the second phase of an assessment of the use of chemical reaction systems (CRS) as a means to store or transport thermal energy. The Phase I study, which was carried out under contract with EPRI, resulted in a catalogue of potential heat sources, end users, and a number of candidate chemical reaction systems. Four promising combinations of source/reaction/user were selected and the final result was a conceptual design and major equipment cost estimate for each system. The Phase I study is documented in EPRI RP 1086-1.

In the current Phase II study, technical economic assessment of three CRSs were continued under contract with Sandia Laboratories. The objectives were to estimate the life cycle cost of storing or transporting waste heat via these CRSs and to compare it with the cost of heat recovery via conventional technologies. This latter objective was approached by selection and design of a commercially available alternative system for each CRS, as a basis for evaluating attractiveness of CRS.

Estimation of total capital, operating and maintenance costs, and calculation of life cycle cost were then carried out for all systems. In addition, cost sensitivities with respect to system capacity, transmission distance, and plant life were analyzed. Finally, each CRS was contrasted with its conventional alternative and was analyzed for its market potential.

It was found that none of the CRSs studied were economically competitive against a commercially available alternative system nor against fuels (natural gas and oil) at current prices. However, one of the CRSs has the potential for becoming economical in selected applications within the 1980-2000 period, should fuel costs escalate considerably above current levels. In general, CRS appears to have the best potential when coupled with a large, continuous heat source for transport applications within relatively short distances.

SAND-78-8221: THERMAL ENERGY STORAGE FOR ADVANCED SOLAR CENTRAL RECEIVER POWER SYSTEMS; L. G. Radosevich; August 1979.

Thermal energy storage is used in the advanced solar central receiver power systems currently being studied under Department of Energy sponsorship. This report describes: (1) the storage operating requirements imposed by interface

constraints between energy storage and the receiver and electrical power generation systems, (2) several storage concept candidates which may meet these requirements, (3) potential cost differences between each of the storage concepts, and (4) the technical uncertainties associated with each storage concept.

SAND-78-8225: PHYSICAL PROPERTIES OF POTENTIAL HELIOSTAT GLASSES; J.E. Shelby; April 1978.

The thermal expansion, density, and refractive index have been measured for a variety of potential heliostat glasses, including high and low iron float glasses, sheet glass, fusion glass, and iron-free water-white glass. Results indicate that these glasses are very similar in properties and that the quality control maintained for float glass is excellent. As a result of the thermal expansion measurements, it appears that some improvement could be made in the annealing of all these glasses and that an upper working temperature of approximately 350° C should be used for float glasses during processing and use.

SAND-78-8228: OPTICAL STUDIES OF SECOND SURFACE MIRRORS PROPOSED FOR USE IN SOLAR HELIOSTATS; J. Vitko, Jr.; April 1978.

Initial studies centered on characterization of iron-associated absorptive losses in the glass substrate, the reflectivity of the silver-glass interface, and the presences or absence of environmental aging (weathering and solarization) in glasses subject to prolonged (30 to 50 years) outdoor exposures are reported. These studies conclude that: (1) the effective solar-weighted absorption coefficient of Fe^{2+} is approximately 15 times larger than that of Fe^{3+}; (2) although Corning 0317 fusion glass has one of the highest iron contents, it also has the highest transmissivity of any glass studied because all the iron is present as Fe^{3+}; (3) measured reflectivities of the silver-glass interface for chemically deposited silver ranged from 96.2 to 97.5 percent, while that of a vapor deposited silver mirror was 97.6 percent; and (4) the transmissivity of glasses subject to prolonged outdoor exposure was degraded at short wavelengths and improved at long wavelengths, resulting in a maximum observed loss in solar transmissivity of 3.4 percent.

SAND-78-8256: CORROSION OF Fe ALLOYS AND HITEC AT 823K; C. M. Kramer; February 1979.

In support of advanced solar central receiver programs, six commercially available, iron-based construction materials were exposed to molten $MaNO_2NaNO_3$-KNO salt at 823 K for periods of up to six months. After one month of exposure,

oxide coatings had formed on each alloy; the amount of oxidation ranged from 10 mg/cm^2 for low-carbon steel to approximately 0.1-mg/cm^2 for 310 stainless steel. Analysis of the outside surface of a 5 percent chrome alloy indicated a chromia enriched layer was present at the oxide/metal interface. An iron-oxide-rich layer was present at the outer oxide surface which contacted the molten salt.

SAND-78-8265: PROTOTYPE/SECOND-GENERATION HELIOSTAT EVALUATION AND RECOMMENDATIONS - EXECUTIVE SUMMARY; Sandia; October 1978.

As technical manager of the prototype heliostat contracts with the Department of Energy, Sandia Laboratories has evaluated four central receiver heliostat designs. This report summarizes the evaluation and Sandia's recommendations for follow-on heliostat development. The recommendations are relative to the design concept only; they do not represent a rating of the contractors.

SAND-78-8269: PILOT PLANT MIRROR MODULE TESTING AND EVALUATION; W. R. Delameter and V. P. Burolla; October 1978.

Ten styrofoam-core mirror modules designed by McDonnell Douglas Astronautics Company for the Solar Central Receiver Pilot Plant to be built in Barstow, California, were fabricated and tested at the Sandia Laboratories, Livermore. The purpose of the testing was to determine whether the mirror modules could survive the expected environment. The mirror modules passed the survival test with no glass breakage and suffered only minimal damage from a thaw-freeze cycling. An apparent change in curvature of the modules was observed after thermal cycling and further testing is recommended.

SAND-78-8271: FLUFLOW: AN APPENDED CODE FOR CALCULATING HEAT TRANSFER TO A FLUID; L. V. Griffith; October 1978.

This report gives the mathematical formulations used in FLUFLOW, a set of subroutines for calculating heat transfer to a fluid. The formulations include a statement of the energy balance and temperature dependent equations for thermal conductivity, specific heat, density, viscosity, pressure drop, friction factors, and Nusselt number. The ability to calculate these thermophysical properties and hydrodynamic parameters is essential to calculating heat transfer to fluids that experience large temperature changes. The fluids may be quasi-static or moving at velocities up to mach numbers around 0.5. Free convection in a quaso-static fluid is calculated with a user-supplied heat transfer coefficient. For a moving fluid, FLUFLOW calculates the heat transfer due to conduction, convection,

and advection (mass transfer) as a function of the temperature dependent parameters above.

SAND-78-8276: NATURAL CONVECTION HEAT TRANSFER FROM AN EXTERNAL RECEIVER; D. L. Siebers; December 1979.

A numerical solution of turbulent, two-dimensional, natural convection heat transfer for a high temperature, vertical surface is presented in this work. This is relevant to heat tranfer from the receiver of a solar central receiver power plant on a calm day (no wind). It is the lower bound of convective loss from an external receiver. Application of wall suction to the receiver surface is also examined as a means of reducing convective loss. In the Appendix an analysis of the economic impact of energy loss from a receiver is presented. It demonstrates the importance of receiver performance with regard to solar central receiver plant cost.

SAND-78-8500: SUMMARY OF ENERGY STORAGE ACTIVITIES WITHIN ERDA'S DIVISION OF SOLAR ENERGY CENTRAL RECEIVER PROGRAM; T. D. Brumleve; March 1978.

Energy storage activities within the ERDA Solar Central Receiver Program are reviewed. Analyses and moderate-scale experiments were performed by three contractor teams as part of the preliminary design of the Barstow, California 10-MWe Pilot Plant. Other storage investigations related to advanced central receiver systems are also described.

SAND-78-8506: RECENT DEVELOPMENTS IN SOLAR THERMAL CENTRAL RECEIVER POWER PLANTS; A. C. Skinrood; June 1978.

Currently, the main focal point of the central receiver program is the construction of the 10-MW Solar Central Receiver Power Plant in Barstow, California. Concurrent with the detailed design and construction of the Barstow plant, development of more advanced receivers, heliostats, and thermal storage subsystems has begun, and the feasibility of adding solar energy collection systems to existing power plants is being examined.

SAND-78-8511: DEPARTMENT OF ENERGY LARGE SOLAR CENTRAL POWER SYSTEMS SEMI-ANNUAL REVIEW; Sandia; November 1979.

This report presents the highlights of the Department of Energy (DOE) Large Solar Central Power System Semi-Annual Review held in Dallas, Texas, on September 19-21, 1978.

SAND-78-8672: SPECIFIC HEAT VARIATIONS IN OIL ENERGY STORAGE MEDIA AND THEIR ECONOMIC IMPLICATIONS; R. W. Carling and L.G . Radosevich; June 1978.

Hydrocarbon oils have been considered for use as thermal energy storage media in solar thermal electric systems. In systems storing the energy as sensible heat, the energy storage capacity is determined by the specific heat of the oil. Among the oils proposed is Caloria HT-43, a product of Exxon Corporation. Previously reported specific heat data on Caloria HT-43 show values differing by as much as 25 percent. We sought to resolve this discrepancy by measuring the heat from 77 to 327^{o} C. Our results show values from four samples varying by as much as 11 percent. Variations are correlated with differences in average molecular weights and inhomogeneity of the samples. The impact on cost of an 11 percent variation in specific heat is less than 1 percent for oil-rock systems and less than 2 percent for all-oil systems.

SAND-78-8693: MATERIALS PROBLEMS IN REVERSIBLE CHEMICAL REACTION STORAGE SYSTEMS FOR SOLAR ENERGY; R. W. Mar; November 1978.

Materials problems encountered in the development of thermochemical energy storage systems for solar energy are discussed. Concerns with catalyzed reaction systems include effects of thermal cycling on reactor materials, catalyst availability and lifetime, and undesirable side reactions. Problems have arisen in thermal decomposition systems due to poor or variable kinetics, volume expansion effects, and poor intrinsic heat transfer properties. Reactions which make use of the heat of solution suffer least from materials problems; the major concerns are with the corrosive nature of the chemicals involved (e.g., sulfuric acid, sodium hydroxide).

SAND-78-8702: STATUS REPORT ON THE DIRECT ABSORPTION RECEIVER; T. D. Brumleve; July 1978.

A novel receiver concept is described in which concentrated solar energy is absorbed directly in a black, high-temperature, heat transport fluid. Advantages and disadvantages of the method are reviewed, and a summary is presented of the results of investigations on materials stability and corrosion, fluid flow, absorption characteristics, wind effects, and various design studies. Also described are recent high solar flux tests in which levels exceeding 6 MW/m^{2} were directly absorbed in the fluid.

SAND-78-8777: MATERIALS-RELATED DESIGN ISSUES IN THE SOLAR CENTRAL RECEIVER PILOT PLANT; J. C. Swearengen; December 1979.

The Solar Thermal Central Receiver Program for the Department of Energy has for its objective the harnessing of solar thermal energy for generation of electricity (either monolithic or in combination with fossil power) and also the development of solar process heat for various applications. The aim is to develop solar thermal systems to the status of alternative energy sources for utilities by the mid-1980s, and to achieve economic competitiveness with fossil nuclear plants by the 1990s. The first electricity to be generated in the program will come from the 10-MW Pilot Plant which is nearing the start of construction in Barstow, California. Funding for the project is being provided by the Department of Energy, Southern California Edison Company, Los Angeles Department of Water and Power, and the California Energy Commission. The Barstow Pilot Plant represents the full-scale U.S. application of solar central receiver technology and as such is a critical gate in the development program. The design is being developed by an industrial team lead by McDonnell Douglas Astronautics Company. Sandia Laboratories provides technical program management and supporting research and development for the Department of Energy and central receiver technology. The final design for Barstow will be based upon trade off studies and experiments conducted in support of the program. This paper summarizes these studies in the area of materials related issues and describes the emerging technology.

SAND-78-8813: THE COST AND VALUE OF WASHING HELIOSTATS; E. D. Eason; June 1979.

An equation is derived for the washing frequency that minimizes cost per unit energy for solar collectors of any type. Central receiver heliostats of two designs are used in an example, and the results for Albuquerque soiling rates show that washing 15-30 times per year is worthwhile. The optimal frequency depends on the square root of such factors as the cost per wash and the daily loss in reflectivity, but it is not sensitive to number of collectors or plant size. The frequency for minimum cost per unit energy corresponds to the strategy of washing whenever the value of the extra energy from cleaner mirrors will pay for the cost of the wash.

SAND-79-0096: PROBLEMS OF TECHNOLOGY TRANSFER TO INDUSTRY; D. M. Mattox; February 1979.

The following are discussed: solar energy utilization, technology development and technology transfer. Examples of technology development and transfer to industry are given.

SAND-79-0190: METHOD FOR CALCULATING SHADOWS CAST BY TWO-AXIS TRACKING SOLAR COLLECTORS; J. K. Linn and J. C. Zimmerman; November 1979.

A method is described which quickly calculates the shadows cast from two-axis tracking solar collectors onto adjacent collectors. The solar collectors can have either circular or rectangular aperatures.

SAND-79-0246C: CORROSION IN MOLTEN SALTS USED FOR SOLAR THERMAL STORAGE APPLICATIONS; W. H. Smyrl; December 1978.

Some of the broad outlines of corrosion behavior are discussed. The compatibility of materials with the molten nitrate--nitrite class of salts selected for solar thermal storage applications is discussed at some length. A brief summary is given of recommendations for areas of future work on these salts to increase the reliability of materials behavior in solar systems.

SAND-79-0490: FUNDAMENTALS OF SOLAR RADIATION; E. C. Boes; December 1979.

This report gives a complete description of solar radiation as the energy source for solar-energy system. The material in this report is also being published as a chapter of a solar energy handbook by McGraw-Hill.

SAND-79-0697C: HELIOSTAT BEAM CHARACTERIZATION SYSTEM; E. D. Thalhammer and G. S. Phipps; May 1979.

The Beam Characterization System utilizes video radiometer techniques to quantitatively describe the solar energy projected by a heliostat. This system is designed to evaluate prototype heliostats and to improve the performacnce of the Central Receiver Test Facility heliostats. The system consists of a beam target, video camera, analog image analyzer, calibration sytem, video digitizer and a minicomputer system. The calibration technique corrects for background illumination, target irregularities, vidcon shading and camera dark currents. A computer code corrects for off-axis camera angle and converts calibration and beam data into a map of screen irradiance. Post test data analysis provides the geometric centroid, energy versus radius, iso-flux contours, intensity cross sections, and 3-D intensity diagrams which are determined from the data map. The system has a fast data capture mode which can be used to study wind loading and short-term tracking errors. The capabilities of the Beam Characterization System make it a useful heliostat evaluation tool.

SAND-79-0787: SOLAR ENHANCED OIL RECOVERY; AN ASSESSMENT OF ECONOMIC FEASIBILITY; K. D. Bergeron; May 1979.

There are several qualitative reasons why steam Enhanced Oil Recovery (EOR) appears to be well suited to solar energy. These include favorable characteristics with regard to energy utilization, land availability, energy form, and geographical location. A number of technical questions require further research before the characteristics of Solar Enhanced Oil Recovery (SEOR) can be precisely specified or optimum systems designed. However, a cost model based on a number of working assumptions indicates competitiveness with conventional fuel burning EOR systems at crude prices and solar collector system costs which can reasonably be expected to occur in the near future.

SAND-79-1114: SIMULATED HAIL TEST FACILITY; D. W. Miller; February 1980.

A low cost, simulated hail test facility for testing solar mirror and support materials has been developed. The facility was designed to be mounted on an existing 54.8m (180-ft) tower. The facility consists of a 30.5m (100-ft) vertical steel tube, an ice ball transport mechanism, and a release mechanism. It is simple to control and maintain, and it is convenient for a one-man operation. The facility was designed to operate in either a single ball drop mode or a salvo drop mode. Measured velocities of the simulated hail were within 10 percent of the calculated theoretical terminal velocities of hail in still air for diameters up to 1.9 cm (0.75-inch). For larger diameter hail balls, the drop distance is too short to reach terminal velocities. (Deviations from terminal velocity are as high as 14 percent for 2.54 cm (1.0-inch) diameter ice balls). Data generated at this facility aided in the characterization of hail-resistant materials for solar applications. An example of one sample material is included. Test procedures and alternate methods of hail testing are also discussed.

SAND-79-1292C: ADVANTAGE OF LOAN LEVERAGING IN COMMERCIAL SOLAR PROCESS HEAT APPLICATIONS; W. P. Schimmel, Jr. and K. D. Bergeron; October 1979.

In a majority of the solar/thermal studies to date, a utility economic methodology has been used to assess the potential of solar power systems. The utility sector is precluded from taking advantage of loan leveraging because the effective rate of return is artifically set. Utilities are regulated by public commissions and thus must finance new capital investments according to a prescribed set of rules on after tax cost of capital and fixed charge rates. Commercial ventures have no such externally imposed constraints and make decisions for capital expenditures

which include the effect of loan leveraging. The relevant parameters for a commercial institution are interest rate on debt, a discount rate which accounts for risk, and the effect of favorable tax incentives. An expression is developed for a capital cost factor which contains these parameters. Results are shown for various downpayments and discount rates. It will be shown that the effect of loan leveraging can be substantial in affecting the penetration of solar process heat into the commercial energy market. In addition, the relation between loan leveraging and risk is investigated.

SAND-79-1295C: MODELING OF THE BEAM CHARACTERIZATION SYSTEM; F. Biggs, C. N. Vittitoe and D. L. King; October 1979.

The Beam Characterization System (BCS) recently developed for heliostat evaluation at the Central Receiver Test Facility at Sandia Laboratories, measures, digitizes, records, and analyzes a flux-density pattern in a beam of reflected sunlight. Since the BCS collects data with a given set of conditions (geometry, weather, etc.) to determine optical specifications which can predict heliostat behavior under other sets of conditions, it is necessary to use a theoretical model of the sytem to interpret results. This model serves as an aid to define specifications, analyze measurements, calculate performance, and answer other questions about the heliostat. A statistical method is used to handle stochastic variables such as sun-tracking errors and surface-slope errors. A cone-optics technique is used to incorporate the statistics into a consistent model of the optical behavior of a heliostat. An overview of this model is given. Use of the model is unfolding slope-error distributions and sun-tracking statistics is described for measurements both in and out of the focal plane. The importance of auxiliary input information such as the sunshape (angular distribution of sun rays) to the analysis of the BCS in validating heliostats against acceptance criteria is summarized.

SAND-79-1532C: HELIOSTAT BEAM CHARACTERIZATION SYSTEM - CALIBRATION TECHNIQUES; G. S. Phipps; October 1979.

The Beam Characterization System (BCS) used at the Central Receiver Test Facility digitizes the output signal from a standard 525-line video camera to obtain raw data for measurements of solar heliostat images. A rapid data rate and relative availability of off-the-shelf equipment favor the use of a video camera system, but the problem of an accurate absolute radiometric calibration must be addressed. Absolute irradiance values are obtained from a calibrated pyroheliometer included on the target screen. The video camera must measure relative irradiance values of areas of

identical spectral composition, greatly simplifying the calibration procedure. Not only must the camera and digitizer linearity be measured, but imaging screen reflectance, lens and filter effects, and camera spatial sensitivity must also be considered for accurate results. Measurements are made over a two-dimensional spatial array of N screen locations. Calibration corrections must be applied to the data from the N locations to obtain a single calibrated irradiance data matrix. Methods of obtaining these corrections are discussed and measured results are presented to support the various assumptions.

SAND-79-1588C: CENTRAL RECEIVER TEST FACILITY CONTROL AND DATA SYSTEMS; D. B. Davis; October 1979.

The Central Receiver Test Facility (CRTF) is the primary solar test facility for the Department of Energy and is operated by Sandia Laboratories, Albuquerque, New Mexico. The multiple minicomputer control and data systems utilized in CRTF are described.

SAND-79-1730C: SOLAR CENTRAL RECEIVER TEST FACILITY; G. E. Brandvold and J. T. Holmes; September 1979.

The world's largest high-intensity solar experimental facility became fully operational October 1978. The Central Receiver Test Facility is capable of delivering 5 million watts of thermal power to experimental equipment. The primary CRTF testing programs will involve prototype components (receivers and heliostats) for central receiver solar electric power plants. The CRTF also provides unique capabilities for other high solar flux and high temperature research and development work. Two hundred twenty-two sun tracking heliostats are used to concentrate the sun's energy to an experiment located on the 61-meter-tall concrete tower. Testing of the first gas cooled receiver was completed in March 1979. The first steam cooled receiver and prototype power plant heliostats are currently under test at the CRTF.

SAND-79-1803C: COMPARATIVE ANALYSIS OF SOLAR ENERGY CYCLES; C. E. Hackett; September 1979.

A thermodynamic technique is presented which will enable the assessment of the overall performance of various storage options on an absolute basis so that cost effective designs can be developed to obtain the full thermodynamic and system advantages of energy storage. First the underlying thermodynamic principles of entropy production analysis are examined. The various energy storage schemes are classified. Detailed analyses were developed to cover the

various generic types of energy storage which are appropriate for solar power systems.

SAND-79-2043: ACOUSTICAL STUDIES OF BOILING INSTABILITIES IN THE PROTOTYPE RECEIVER FOR THE BARSTOW SOLAR PILOT PLANT; A. G. Beattie; November 1979.

An acoustic technique is used to search for proposed boiling instabilities in the prototype receiver for the Barstow 10-MW Solar Thermal Pilot Plant. The technique is shown to work and should be capable of measuring such instabilities when the receiver is tested at maximum proposed power levels.

SAND-79-2121C: SOLAR RADIATION MODEL VALIDATION; I. J. Hall, R. R. Prarie and E. C. Boes; October 1979.

Three solar radiation models have been used in developing the Augmented SOLMET Solar Data Tapes for the 26 SOLMET sites and the 222 ERSATZ Solar Data Tapes. One of the models, a theoretical one, predicts the solar noon radiation for clear sky conditions from the optical air mass, precipitable water vapor and turbidity variables. This model is referred to as the Clear Solar Noon Model. A second model, an empirical one, also developed by NOAA, predicts the hourly total horizontal radiation from meteorological variables. This model is referred to as the Total Horizontal Regression Model, and a third model, also an empirical one, predicts the hourly direct normal radiation from the hourly total horizontal radiation. This model is referred to as the Aerospace Direct Normal Model. A study of the accuracy of these solar radiation models is reported. To assess the accuracy of these models, data was obtained from several US National Weather Service Stations and other sources and the models were used to estimate the solar radiation. Then, the modeled radiation values were compared with observed radiation values. The most important results of these comparisons for these three models mentioned above are included.

SAND-79-2154C: SOLAR CENTRAL RECEIVER IN PERSPECTIVE; T. A. Dellin; June 1980.

The variation in the energy costs of solar central receiver systems as a function of power level, receiver geometry, heliostat size, and heliostat canting option are presented. The results were obtained using a new version of the DELSOL computer model. A broad minimum in the cost of thermal energy at the base of the tower is observed in systems with power levels from 10 MW_t to over 1,000 MW_t. In addition, this power range can be served by a single heliostat design.

SAND-79-2422: EFFECT OF SOILING ON SOLAR MIRRORS AND TECHNIQUES USED TO MAINTAIN HIGH REFLECTIVITY; E. P. Roth and R. B. Pettit; June 1980.

Solar mirrors are used to concentrate low-level solar radiation to power levels which are practical and efficient for consumption. Any interference with the collection of that energy not only decreases the power level but also increases the cost of the energy available from a solar power system. One of the most immediate and drastic effects of outdoor exposure is the reflectance loss due to the accumulation of foreign particles on the mirror surface. Specular reflectance losses as great as 25% have been observed for mirrors exposed for only a few weeks. The effect of the deposited particles is to reduce the reflected energy by both absorbing and scattering light. The degree to which the particles reduce the collection of reflected energy depends on their composition, number and size distribution. An additional factor is the optics of the collection system. The angular acceptance aperture of the system, defined as the angle subtended by the receiver at the concentrator surface, determines the relative importance of the scattering due to dust accumulation. For flat plate thermal and photovoltaic collectors which have essentially a 180° angular acceptance aperture, scattering of the incident light is not criterical but absorption can be an important factor in the loss of energy. For concentrating collection systems, such as line focus collectors and central receivers, angular acceptance apertures of a few degrees make scattering at the concentrator surface much more important and can result in severe energy losses. Results of a study of each of these areas are presented and discussed.

SAND-79-6000: USE OF SOLAR ENERGY FOR THE PRODUCTION OF ELECTRICITY IN THE ALPS; P. Newman; January 1979.

Means of converting solar energy into electricity are briefly reviewed. Applications of solar energy technology to meet the increasing demand for electricity in Switzerland are considered. A description and discussion of central tower and heliostat field systems is presented. Details concerning steam cycles and solar boilers, turboalternator units and heat exhaust systems, daily and seasonal power variations of a solar plant, and effects on energy output due to cloudiness are considered. Meteorological data for the evaluation of possible solar generating sites is discussed and the solar potential of the Alps is analyzed. Integration of solar plants into the existing power grid is discussed. The economic and environmental impacts of solar power plants are considered in detail and a development program is suggested.

SAND-79-7108: PRELIMINARY OPTICAL DESIGN OF A SECOND-STAGE CONCENTRATOR FOR THE CRTF. FINAL REPORT; K. A. Reed; February 1981.

Sandia Laboratories Albuquerque (SLA) will test an experimental solar receiver designed by McDonnell Douglas/Rocketdyne (MDAC/R) at the Central Receiver Test Facility (CRTF). The 0.89 x 17.1-m receiver panel is to be tested at power levels of 3 MWth and above to provide data for the 24-panel design proposed for the 10-MWe Solar-One plant at Barstow, California. Because of its narrow width, however, the single MDAC/R panel can intercept only about 2.75 MWth out of the more than 5 MWth directed to a 2.5-m-diameter focal zone by the 222 heliostats at the CRTF. Since this focal zone size was fixed in optimizing the facility for full-scale receiver testing, it cannot be reduced practically. It was decided to make the receiver panel appear wider optically by coupling it to a second-stage, or secondary concentrator. The definition and design of a water-cooled, second-stage compound parabolic concentrator to be employed in the MDAC/R receiver panel testing are described. A Simplified Flux Model (SFM) was developed to permit fast computation of the total power normally incident on an arbitrary planar target aperture from some or all of the heliostats in the field. For each second-stage concentrator configuration studied, the total power normally incident on each entrance aperture was calculated using the SFM, and then the net power delivered to the MDAC/R receiver panel was calculated from the optical transmission of the concentrator. The SFM code is included.

SAND-79-8015: A DESCRIPTION AND ASSESSMENT OF LARGE SOLAR POWER SYSTEMS TECHNOLOGY; L. M. Tallerico; August 1979.

This document summarizes the systems being developed by the Department of Energy's Large Solar Thermal Central Power System Program. Included are the technical concepts upon which the systems are based and, to the extent possible, estimated costs, performance and assessment of typical systems. The intent is to provide potential users with an overview of present technologies and those technologies that will be available within the next few years. Sandia Laboratories' assessments of the strengths and weaknesses of each technology have been included in the hope that the developers of the technology will be able to improve component and system designs to the point where they become fully competitive with alternate energy sources.

SAND-79-8034: WIND TUNNEL TEST OF A FULL-SCALE HELIOSTAT; S. G. Peglow; June 1979.

This report describes the wind tunnel tests performed in the NASA facility in December 1978 on a DOE prototype heliostat and presents a comparison of the data with analytically derived results. Testing consists of obtaining loads, moments, dynamic behavior (via servo accelerometers) and flow visualization for the entire range of operational and survival configurations. The data from the test has been used to augment the significant analytical and experimental work done by the various contractors and Sandia in support of heliostat design and development.

SAND-79-8037: 10-MWe SOLAR-THERMAL CENTRAL RECEIVER PILOT PLANT: OPERATIONAL TEST REQUIREMENTS; J. J. Bartel and C. W. Moore; May 1982.

The operational test requirements are defined for the 10-MWe Central Receiver Pilot Plant near Barstow, California. Top-level requirements are presented from which specific tests will be developed, and information is provided on the objectives, test schedule, types and duration of tests, instrumentation and data acquisition requirements, and data reduction and analysis requirements for the operational tests.

SAND-79-8073: DEPARTMENT OF ENERGY SOLAR CENTRAL RECEIVER SEMI-ANNUAL REVIEW; M. A. Lind; November 1979.

This report represents the highlights of the Department of Energy (DOE) Solar Central Power System Semi-Annual Review held in Williamsburg, Virginia, on September 11-12, 1979.

SAND-79-8175: ADVANCED WATER/STEAM RECEIVER PHASE I: CONCEPTUAL DESIGN, FINAL REPORT; Martin Marietta Corporation; January 1980.

The Martin Marietta Corporation and Foster Wheeler Development Corporation have developed a water/steam receiver concept which combines high performance, reliable operational characteristics with efficient, low cost design techniques for the generation of high temperature superheated steam suitable for driving turbine/generator units for the production of electrical powr. The concept will not only cost substantially less than existing water/steam receiver designs, but can provide thermal energy at a lower life-cycle cost than conventional fossil boilers, considering realistic fuel price escalation rates.

SAND-79-8176: CONCEPTUAL DESIGN OF AN ADVANCED WATER/STEAM CENTRAL SOLAR RECEIVER; H. M. Payne, B. C. Jones, T. K. Snyder and M. J. Davidson; June 1980.

The objective of this project was to develop a conceptual design of an advanced water/steam solar central receiver, which would be more cost-effective than the present design employed in the Barstow 10-MWe pilot plant. An experimental program was included in the project to determine the feasibility of using rifled tubing in the high heat flux environment of the proposed solar receiver evaporator section. Rifled tubing has been shown to enhance the boiling heat transfer mechanism at lower heat flux levels in conventional boilers. Conceptual designs of four external water/steam receivers were developed, which consist of drum type boilers, with forced circulation evaporators using rifled tubing to maintain efficient nucleate boiling. Evaporator, Preheater, and Superheater panels are arranged to take advantage of the flux distribution from a biased north field collector subsystem. Final steam temperature is from a biased north field collector subsystem. Final steam temperature is 866K (1100^{o} F), to be compatible with a high temperature storage subsystem. Details are given of the systems analysis and selection of preferred system, parametric analysis, conceptual design, cost/performance estimates, and the rifled tubing test program.

SAND-79-8179: PILOT PLANT RECEIVER PANEL TESTING AT THE CENTRAL RECEIVER TEST FACILITY, FINAL REPORT; M. L. Joy, R. P. Pauckert, T. L. Nielsen, and S. D. Saferstein; December 1980.

The United States Department of Energy is actively engaged in the designing and construction of America's first solar thermal electric pilot plant at Daggett, California. Preconstruction tests of a prototype panel of the pilot plant external, single-pass-to-superheat, water/steam solar reciever under actual operating conditions were conducted at the Central Receiver Testing Facility (CRTF) at Albuquerque, New Mexico. The primary test program objective was to validate the design, at the earliest possible date, to assure the achievement of pilot plant operating goals.

This report documents the results of the test on a prototype panel. The program is summarized, and conclusions regarding the relationship between test results and the design/performance of the pilot plant receiver are presented. A detailed description of the test hardware and a discussion of the instrumentation and controls are provided. Sample data and a tabular summary of the key steady-state operating points are included. Test data evaluation and analyses that verify key test objectives are presented. Finally, the report discusses the evolution of

the receiver panel steam temperature controller at CRTF and presents conclusions relative to the pilot plant.

SAND-79-8181: PRELIMINARY DESIGN REPORT: NEW IDEAS FOR HELIOSTAT REFLECTOR CLEANING SYSTEMS; J. Schumacher, J. Hansen and J. Nevenzel; December 1979.

The feasibility of two new concepts for cleaning heliostat reflectors has been investigated in this program and the results are itemized. In addition, this phase of the program involved the design and construction of a reflectometer and wind tunnel and the performance of some dust accumulation studies, the results of which are also studied.

SAND-79-8182: PREVENTION OF SOILING OF HELIOSTAT SURFACES; B. Baum and M. Binette; December 1980.

The goal of this project was to develop methods of preventing or minimizing soiling of the surface of the glass-mirrored heliostat and the plastic dome over the aluminized Mylar mirror and also to facilitate the cleaning process. The substrates used in this project were float glass, Kynar, and Petra A polyester.

The two general classes of compounds which were being investigated were antistatic and antisoiling agents. The categories of antistatic agents used were amine derivatives, quaternary ammonium salts, phosphate esters, and polyethylene gylcol esters. The soil-release agents were either hydrophilic ionic or hydrophilic nonionic in character. These compounds were attached to the substrate surface by silane or titante coupling agents or as a mixture with a hard, weather-resistant coating. The silanol groups on the surface of glass provided suitable attachment sites; whereas, the plastic substrates required activation by various procedures. Another route to these objectives lay in direct reaction of an organic compound with a functional group in the glass surface.

Evaluation of the various coatings on the three substrates was accomplished by a sequential screening procedure. The tests were performed in the following order with ineffective materials eliminated in each step: (1) clarity, (2) adhesion, (3) antisoiling properties, (4) abrasion resistance, and (5) permanence. Dust was removed by a high-velocity air stream, an air stream in conjunction with gentle brushing, or by small amounts of water on low pressure. Finally, a water wash apparatus was designed and examined for efficiency of dust removal.

SAND-79-8183: INTERIM STRUCTURAL DESIGN STANDARD FOR SOLAR ENERGY APPLICATIONS. FINAL REPORT, PHASES 1 AND 2; I. Berman, A. C. Gangadharan, G. D. Gupta, and T. V. Narayanan; January 1979.

The program is summarized. Central Receiver Solar Thermal Power Systems, relevant ASME Codes, reliability consideration, and the criteria used to develop the Interim Design Standard is reviewed. The Interim Design Standard is presented. All criteria or rules chosen or adapted from other codes are fully stated including all design data. A detailed paragraph-by-paragraph explanation of the Interim Design Standard is provided. The test and development program needed to generate new design data and to update the Interim Design Standard are identified.

SAND-79-8184: DEVELOPMENT OF AN AUTOMATIC HELIOSTAT CLEANING SYSTEM: FINAL TECHNICAL REPORT; P. Tremblay and E. Poulin; December 1980.

An automatic washing system was designed consisting of a water treatment system, a pressurized underground water distribution system, an automatic spray washing module for each heliostat, a water collection system, and appropriate controls to operate this equipment. In order to determine the required values for the various washing parameters, a series of washing tests was undertaken in which mirrors were soiled and then cleaned by a high-pressure water spray. Reflectivity was measured for the clean, soiled and washed conditions to determine the effectiveness of the cleaning. A heliostat spray module was constructed and operated mainly to obtain information on the mechanical operation of one concept. This testing showed that this system was generally satisfactory, but did show some areas for improvement. Water distribution and wastewater systems were designed and evaluated with the main conclusion that conventional wastewater collection is complex and the most expensive part of the system. The total system is shown to be cost-effective if site meteorological conditions do not supply a large number of cycles of natural cleaning occurrences. Continued development of this concept by constructing a small scale washing system within an existing heliostat field is recommended.

SAND-79-8185: PLASTIC FILM PERFORMANCE IMPROVEMENTS FOR HELIOSTATS. FINAL REPORT; Boeing Engineering and Construction; July 1980.

A plastic film improvement program was initiated to improve the BEC enclosed heliostat design and hence its overall performance and cost-effectiveness. An industrial survey was initiated. Suppliers were urged to participate by

providing samples of materials they felt had potential. Suppliers were visited for technical discussions about their products and to become knowledgeable in the processes of plastic film manufacture. The preliminary candidate materials were screen tested in Boeing laboratories. The materials showing promise were sent to Phoenix for desert exposure testing. After three months of accelerated exposure, coupons were withdrawn and tested for degradation. The data were used to eliminate candidates of obvious poor weatherability, and assist the supplier in making modifications for possible second iteration materials. Exposure of first iteration materials continued while second iteration candidates (new materials and modified previously tested materials) were being made available. After six months of real time and accelerated exposure first iteration samples were withdrawn and returned for lab tests. Lab testing of second iteration materials were performed after three months of accelerated exposure. Exposure testing of the most promising materials will be continued after the end of this contract. Test results are presented.

SAND-79-8186: CELLULAR-GLASS CONTINUOUS PROCESS, FINAL REPORT; Solaramics; August 1980.

The objective of the program is to develop and demonstrate feasibility of processing techniques required for continuous production of cellular glass suitable for heliostat reflective module substrates. The concept of utilizing cellular foamed glass for the mirror module substrate is described. Characteristics which need attention are: the availability and cost addressed throughout the continuous process; improved strength and reduced weight achieved by variable density through the thickness, i.e., generation of a dense skin over a lightweight core to achieve a more efficient sandwich structure; and improved environmental and impact resistance which is achieved by closed cell structure and the dense surface skin. Sections cover in detail heliostat application (design consideration and requirements, mechanical properties of cellular glass, sandwich panel design analysis); production process description; operational experience; test material evaluation; and cost projections. A summary of events for a 20-day run for the production of a batch is presented.

SAND-79-8187: TECHNICAL AND ECONOMIC ASSESSMENT OF SOLAR POWERED WATER PUMPING FOR REMOTE AREAS. FINAL REPORT; Bechtel National Inc.; July 1979.

This study reviewed the technology of solar powered water pumping. An overview of the technology and its economics is provided, based on a review and assessment of the open literature. It is shown that pumped water is used most

extensively for irrigation, and that new irrigation methods, such as the center pivot system, have significantly increased the water pumping power demand in recent years. The coincidence of the peak irrigation season and a peak seasonal insolation makes solar energy a good candidate to supplement or displace depletable energy sources currently used for water pumping. Solar powered water pumping demonstration systems with capacities to 50 kWe have been built, utilizing solar thermal, photovoltaic and wind powered energy conversion. The prime movers of these systems either drive the pumps directly or indirectly through electric power generation. A comparative evaluation of these and other proposed solar concepts was conducted and resulted in the selection of a reference system comprised of a number of individual parabolic dish collectors with integral Brayton cycle engines. This reference system provided a basis for economic comparisons with a typical conventional electric pumping system. It was determined that the cost of power from the reference solar concept will probably not break even with present-day utility-powered pumping systems until at least the turn of the century.

SAND-79-8188: METHANOL-BASED HEAT PUMPS FOR STORAGE OF SOLAR THERMAL ENERGY. PHASE I. FINAL REPORT, APRIL 25, 1977 - JUNE 30, 1978; P. O. D. Offenhartz, M. J. Turner, F. C. Brown; R. B. Warren and J. P. Pemsler; January 1979.

Reaction of CH_3OH vapor with a solid-state inorganic salt substrate to produce a solid methanolated salt can be used as the basis of a combined solar heat pump/thermal energy storage system. Such a system should be capable of storing heat indefinitely at ambient temperature, and can be used for heating and air conditioning. In solar heating, the coefficient of performance should be in the range 1.5 to 1.8, thus reducing the size of the solar collector required. In solar air conditioning, the coefficient of performance should be in the range 0.5 to 0.8, comparable with other solar air conditioners; the built-in long-term storage feature should eliminate the need for resistive electrical backup, thus sharply reducing operating costs. Experiments carried out in Phase I of this program indicate that the reaction of $CaCl_2$ with CH_3OH vapor to produce $CaCl_2 .2CH_3OH$ is well suited to heating and cooling applications. The heat of reaction is about 20 kcal per mole of CH_3OH, and kinetics and thermodynamics of the reaction appear adequate down to a CH_3OH pool temperature around -10° C. The required solar collector temperature should be about 150° C. Analytical and experimental work on the design of the heat exchanger for the reacting salt bed indicate that high rates of heat transfer can be accomplished in a reasonably compact system; the indicated energy density for the solid-phase reactant is in excess of 13,000 Btu/ft^3, assuming that the

void fraction for anhydrous $CaCl_2$ is 85% or less. Vapor pressure losses through the bed can be minimized by the use of pelletized $CaCl_2$. This material appears to react without apparent degradation of the rate of methanolation or demethanolation through 300 complete cycles, and does not appear to corrode aluminum. No major technical obstacles to development of a CH_3OH-based solar heat pump/storage system are apparent, and Phase II work is now proceeding on development of a prototype system.

SAND-79-8189: SOLAR CENTRAL RECEIVER HELIOSTAT MIRROR MODULE DEVELOPMENT; R. B. Hobbs, Jr.; May 1981.

The design, development, and fabrication of a low cost, mass producible heliostat mirror module are described. Structural, optical, and economic trade-offs were evaluated in screening candidate materials and processes. A laminated sandwich design concept with aluminum facing sheets and a polystyrene honeycomb core was selected for the baseline design. The Silver-Vestar spray process was selected for direct metalization of 5657-H25 aluminum sheet, as a first-surface silvered reflector system.

SAND-79-8192/1: SECOND-GENERATION HELIOSTAT DEVELOPMENT; DETAILED DESIGN REPORT, VOLUME I; L. P. Oldham; September 1980.

The objective of this report is to present the results of Martin Marietta's second-generation heliostat development program completed to date. This includes a presentation of the detailed design of the second-generation heliostat with the supportive analyses and component test data; preliminary design of the manufacturing plant; and the projected cost to manufacture, transport, install, and maintain 50,000 heliostats per year installed in 50-MWe fields. The heliostat design presented is the mass production design on which the cost estimates were based. The prototype heliostats to be tested at the CRTF will be as close to the mass production design as practical. Due to the absence of mass production tooling, the prototype heliostats have some differences from the mass production heliostats. These differences will be described at the component level where applicable.

Due to the preliminary nature of some aspects of the manufacturing design and the planned design refinement during Task 3, the cost analyses presented in this report are based on a worst-case approach. Therefore, the costs presented in this report should be considered the maximum for this design. The final cost projections to be presented in the final report are expected to decrease by several percentage points.

SAND-79-8192-V.2: SECOND-GENERATION HELIOSTAT DEVELOPMENT; DETAILED DESIGN REPORT, VOLUME II; L. P. Oldham; September 1980.

A drawing tree of the second-generation heliostat assembly is shown. Structural data of the Rack Assembly, Drive Mechanism and Mirror Assemblies are presented and reference material for the discussions in the main section of the report is given. Tests that were performed to evaluate the materials selection for the mirror assembly are described, and their results are given. The design of the pedestal/foundation for the heliostat is summarized. A priced bills of material, labor/tooling cost worksheets, and production cost worksheets used to derive the heliostat cost estimates are included. A design study shows that the edge-support mirror module is not weight and cost-effective, and the design chosen is described.

SAND-79-8193/1: DESIGN REPORT, WESTINGHOUSE SECOND GENERATION HELIOSTAT, VOLUME I - DESIGN ENGINEERING; Westinghouse Electric Corporation; June 1980.

The design of the Second Generation Heliostat for the production and prototype models is presented in this report. Included is the field design of a typical 50 MWe solar power plant.

This volume presents a Second Generation Heliostat design that meets the Sandia Requirements Specification with the exception of operation with two inches of ice. The report is organized to present a design description in Section 2.0; the requirements for performance and structure as well as compliance with the Sandia Specification in Section 3.0; the detailed design and analysis of the heliostat assembly in Section 4.0, the integration of the heliostat into a 50 MWe field in Section 5.0, the trade studies that support the design in Section 6.0, the tests that were performed to support the design in Section 7.0, and finally the conclusions and recommendations in Section 8.0.

The Second Generation Heliostat is a mature design that evolved from the prior Westinghouse-funded Demonstration Heliostat which Sandia tested. Design decisions were made in favor of performance when there was a trade with weight; therefore, the cost and weight of the unit can probably be reduced when feedback from the test program on the two prototypes becomes available.

SAND-79-8193/2: DESIGN REPORT, WESTINGHOUSE SECOND GENERATION HELIOSTAT, VOLUME II - MANUFACTURING, INSTALLATION, TRANSPORATION AND COST ESTIMATES; Westinghouse Electric Corporation; June 1980.

The objective of the manufacturing plan is to define the strategy that will be used to build heliostats in large volume for solar central receiver power plants, generating power commercially in field arrays of 3,956 heliostats to produce 50 megawatts of electric power and to show how the plan will be implemented.

The strategy definition is based on our Manufacturing Engineering department's work on the Second Generation Heliostat and includes several references to trade studies that were done concurrently with the design of the heliostat. These studies, which are listed in the Appendix, support the strategy selected.

Section 1 of this volume has been written to describe the preliminary design of quantity heliostat production, transportation, installation and maintenance, and the equipment required.

Section 2 is the costing plan covering the manufacturing, installation, operation and maintenance cost and the initial capital investment required.

SAND-79-8194-V.1: SECOND GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVER SYSTEMS DETAILED DESIGN REPORT, VOLUME I - TECHNICAL DISCUSSION; Northrup Inc.; May 1980.

This report presents the results obtained in the development of a second generation heliostat. This includes the design of the second generation heliostat, the development of the manufacturing plan, the method of transporting the heliostats from the factory to the installation site, heliostat installation procedures, and the maintenance routines. These plans are then cost estimated to provide inputs required to develop the installed cost of the heliostat and further, the cost of owning, operating and maintaining a collector field.

SAND-79-8194-V.2: SECOND GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVER SYSTEMS DETAILED DESIGN REPORT, VOLUME II - APPENDICES; Northrup, Inc.; May 1980.

Presented are the design of the second generation heliostat, the development of the manufacturing plan, the method of transporting the heliostats from the factory to the installation site, heliostat installation procedures, and the maintenance routines. These plans are then cost

estimated to provide inputs required to develop the installed cost of the heliostat and further, the cost of owning, operating and maintaining a collector field. This volume contains the following appendices: (1) bill of materials; (2) part drawings (subassemblies); (3) assembly drawings, heliostat; (4) trade studies; (5) system studies; (6) control software; (7) test results; (8) specification S-102: surface preparation, application, and inspection of protective coatings for carbon steel heliostat piles; and (9) specification S-101: installation of open-end pipe piles.

SAND-79-8195: CESA-1 RECEIVER DESIGN REVIEW, PHASE 1, FINAL REPORT; Foster Wheeler Development Corp.; July 1980.

The Central Electrica Solar de Almeria CESA-1 is a 1.0-MWe water/steam solar central receiver electric power plant being built by the Spanish in Almeria, Spain. Centro de Estudios de la Energia (CEE) is responsible for the management, design, and construction of the project. At the request of the Solar Energy Research Institute and with the approval of the Department of Energy, Sandia National Laboratories, Livermore is providing technical assistance in areas unique to solar applications to CEE. At the request of CEE, Sandia contracted with Foster Wheeler Development Corporation (FWDC) to critically review and evaluate the CESA-1 receiver design. Foster Wheeler Iberia (FWI) was subcontracted to FWDC to coordinate efforts with CEE in Madrid. The FWDC program which was started on July 9, 1979, was subdivided into three tasks: (1) design basis review: critical review of the receiver design specifications and requirements; (2) design review and analysis: critical review of thermal/hydraulic, structural, and materials aspects of the receiver design and the design and analysis procedures used by the designer in critical areas of the design; and (3) operational review: critical review of receiver instrumentation and controls and the operational and safety aspects of the receiver. Results of the design review and evaluation are presented.

SAND-79-8196: INVESTIGATION OF FREE-FORCED CONVECTION FLOWS IN CAVITY-TYPE RECEIVERS, FINAL YEARLY REPORT, 1979-1980; J. A. C. Humphrey; January 1982.

A summary is provided of the first of three years of experimental and theoretical research on free-forced convection flows in cavity-type solar receivers. New experimental and theoretical results are presented and discussed. The implication of these findings, with respect to the future thrust of the research program, is clarified as well as is possible at the present time. Following

various related conclusions a summary and tenative schedule of work projected for year two of research are presented.

SAND-79-8198: CHEMICAL ENERGY STORAGE FOR SOLAR THERMAL CONVERSION, FINAL REPORT; R. D. Smith; April 1979.

The technical and economic aspects of using reversible chemical reactions to store energy in Solar Thermal Electric Conversion (STEC) facilities have been studied. The study included identification of nine promising chemical reactions from a list of over 550 candidates, preliminary process designs of energy storage subsystems based on these nine reactions, and extensive systems studies of autonomous (100 percent solar) and hybrid (requiring alternate energy backup) STEC plants with energy storage subsystems base on the reversible oxidation of SO_2. Storage round-trip thermal efficiencies for the reactions studied ranged from 20 to 50 percent; power-related unit costs varied between 0.5×10^5 and 10×10^5 \$/MWth maximum storage charging rate; and energy-related unit costs varied between 0.5×10^3 and 24×10^3 \$/MWt-hr storage capacity. Process designs based on the two reactions, $SO_2 + 1/2\ O_2 = SO_3$, and $CaO + H_2O = Ca(OH)_2$, are discussed in detail. The systems studies used a detailed simulation, based on a year-long, hour-by-hour energy balance, of a central-receiver STEC facility. Over a range of alternate energy cost and geographic location, the optimum busbar energy costs from autonomous STEC plants were 15 to 90 percent higher than those from hybrid plants. Optimum storage requirements of autonomous STEC plants were in the range of 200 to 400 hours, while those for hybrid plants were in the range of 15 to 30 hours.

SAND-79-8208: THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT PROGRAM PROGRESS REPORT (OCTOBER 1977 - DECEMBER 1978); T. T. Bramlette; September 1979.

This document summarizes the progress made by the Thermochemical Energy Storage and Transport (TEST) Program in the period October 1977 - December 1978.

SAND-79-8209: PREDICTION OF YEARLY FLUID REPLENISHMENT RATES FOR HYDROCARBON FLUIDS IN THERMAL ENERGY STORAGE SYSTEMS; V. P. Burolla; April 1979.

Economic analysis of any thermal energy storage system using hydrocarbon fluids at or near their operating limit hinges on accurate determinations of fluid losses due to thermal and environmental effects. This work presents representative values for these fluid losses in an operating thermal storage sytem for three different hydrocarbon fluids, Sun 21, Caloria HT43, and Therminol 66.

SAND-79-8215: A USERS' MANUAL FOR DELSOL: A COMPUTER CODE FOR CALCULATING THE OPTICAL PERFORMANCE, FIELD LAYOUT, AND OPTIMAL SYSTEM DESIGN FOR SOLAR CENTRAL RECEIVER PLANTS; T. A. Dellin and M. J. Fish; June 1979.

DELSOL is a quick and accurate computer program for calculating the collector field performance, field layout, and optimal system design for solar central receiver plants. The code consists of a detailed model of the optical performance, a simpler model of the nonoptical performance, an algorithm for field layout, and a searching algorithm to find the best system design. The latter two features are coupled to a cost model of central receiver components and an economic model for calculating energy costs. The code can handle flat, focused and/or canted heliostats, and external cylindrical, multi-aperture cavities, and flat plate receivers. The program optimizes the tower height, receiver size, field layout, and power level.

SAND-79-8222: THE CREDITABILITY OF COST ESTIMATES FOR MASS-PRODUCED HELIOSTATS; E. D. Eason; October 1979.

Five analysis approaches are applied to the McDonnell Douglas second generation prototype heliostat capital cost estimates in an attempt either to justify or to discredit them. The estimates are not discredited by any of these approaches, so they are accepted as credible. A range of credible costs is calculated based on the analyses. This range is $\$100/m^2/R$ to $\$60/m^2/R$ for unit number 350,000 at 25,000/y production rate.

SAND-79-8225: WEATHERING OF LOW IRON FLOAT AND CGW-0317 GLASS; J. E. Shelby; May 1979.

A simple accelerated weathering test was used to evaluate the relative weatherability of glasses which are being considered for use in solar heliostats. Glasses were exposed to 98 to 100 percent humidity at temperatures ranging from 40 to 50° C for periods of one to four weeks. Under these conditions, low-iron float glass exhibits severe surface corrosion, which occurs predominantly on the tin-poor surface. This result indicates that silvering the tin-poor surface will increase the weatherability of mirrors made from this glass. CGW-0317 fusion glass exhibits no detectable signs of surface corrosion.

SAND-79-8239: REVIEW AND ASSESSMENT OF THERMAL ENERGY STORAGE SYSTEMS BASED UPON REVERSIBLE CHEMICAL REACTIONS; J. J. Iannucci, J. D. Fish and T. T. Bramlette; August 1979.

This report presents a summary of a number of projects related to thermal energy storage for solar thermal electric

plants and carried out under DOE's Thermochemical Energy Storage and Transport Program. Technology projects, as well as analytical studies, are reviewed.

Technical problems remain for all of the reaction systems under consideration. More importantly, the analytical studies have led to the conclusion that long-duration (seasonal) storage of any type presently envisioned is not economically attractive and that, for short-duration (diurnal) storage, thermochemical systems would not be competitive with the advanced sensible energy storage systems currently being developed.

It is recommended that future efforts related to thermochemical systems place more emphasis on fundamental research aimed at far-term applications and on systems analyses of other solar/chemical applications such as: energy transport, chemical production (including potential fuels), and chemical heat pumps.

SAND-79-8248: HELIOSTAT DESIGN COST/PERFORMANCE TRADEOFF; M. J. Fish and T. A. Dellin; November 1979.

The heliostat field comprises the most expensive subsystem of a solar central receiver power plant. Cost reductions might be achieved by either total heliostat redesign or component substitution in existing designs. This paper discusses the value of changing any of several design specifications in the current baseline glass/metal heliostat. Results are quantified in terms of the breakeven cost; i.e., the cost of a new design which will yield the same total system energy cost as the baseline system. Changes in mirror reflectivity, pointing accuracy, surface quality, canting and focusing strategy, heliostat size, and stow requirement are evaluated.

SAND-79-8258: SOME CONSIDERATIONS RELATED TO CAPACITY CREDIT FOR CENTRAL STATION SOLAR POWER PLANTS; J. K. Plastiras; September 1979.

Solar power plants will incur both mechanical and insolation outages. This work considers the reliability of a solar electric plant by estimating the likelihood that insolation outages will occur on days when system load is likely to be high. Since high electrical load occurs on the hottest days of the year for many utilities (those designated as "summer peaking"), much insight into solar plant reliability is obtained by analyzing direct normal insolation on these days. The relationship between quantity and reliability of direct normal insolation is examined for sites such as El Paso, Madison, Miami, and Phoenix. The relative impact of mechanical versus insolation specifications is considered

for Miami. Finally, the use of geographic dispersion to improve the reliability of electrical generation via solar energy is examined for Phoenix and El Paso.

SAND-79-8259: MATERIALS PERFORMANCE IN THE SOLAR CENTRAL RECEIVER PILOT PLANT; J. C. Swearengen and S. L. Robinson; October 1979.

The 10-MWe Solar Central Receiver Pilot Plant, which is to be built at Barstow, California, is designed to provide development, fabrication, and operating data necessary to demonstrate the technical feasibility of the solar central receiver concept. The Pilot Plant consists of approximately 2,000 reflecting heliostats which redirect solar insolation to a central receiver mounted on a tower. The energy collected by the receiver is used to produce superheated steam which is then used to generate electricity and/or charge storage. Performance of the plant will be studied during a five year test period scheduled to begin December 1981. The plant is being designed for a thirty-year life. For the Pilot Plant, successful performance requires materials having not only the proper initial properties, but also having long-term stability in the presence of thermal, chemical, and mechanical environments. For purposes of this discussion materials concerns are categorized into four operating subsystems of the plant: collectors, receiver, storage, and electrical power generation.

SAND-79-8266: COMPARISON BETWEEN RESULTS OF THE HELIOS AND MIRVAL COMPUTER CODES APPLIED TO CENTRAL RECEIVER SOLAR-ENERGY COLLECTION: C. N. Vittitoe, F. Biggs, and P. L. Leary; January 1979.

The Sandia computer codes HELIOS and MIRVAL were developed to predict the optical performance of reflecting solar concentrators and to model power collection by central-receiver solar-energy power plants. HELIOS is an analytic code, whereas MIRVAL uses Monte Carlo ray-tracing techniques. They have been used both internally and externally in many studies including evaluation of heliostat-receiver design, parameter studies and safety analyses. The objective of this study was to verify that HELIOS and MIRVAL give the same performance predictions. The sample problem for comparison consists of a rectangular target and alt-azimuth heliostats deployed in a north field. The results indicate that HELIOS and MIRVAL closely agree on predictions of field performance and of power density on the target plane.

SAND-79-8276: SILVER DETERIORATION IN SECOND SURFACE SOLAR MIRRORS; V. P. Burolla and S. L. Roche; January 1980.

The suitability of various heliostat mirror module designs for large solar central power systems, depends in part on

the ability of the reflective surface to survive over the expected lifetime, with little loss in reflectivity. Recent observations on several module designs revealed significant deterioration of the silvered surface in an unexpectedly short time span. This report documents current information on the extent and nature of the deterioration noticed on several mirror module designs, on the accelerated tests designed to simulate field deterioration, on the potential design solutions available, on the parameters necessary for conducting useful accelerated weathering tests, and on the nature of commercially prepared mirrors.

SAND-79-8279-V.1: DESIGN, COST AND PERFORMANCE COMPARISONS OF SEVERAL THERMAL SYSTEMS FOR PROCESS HEAT. VOLUME I. EXECUTIVE SUMMARY; P. J. Eicker, E. D. Eason, J. D. Hankins, L. D. Hostetler, and J. J. Iannucci; March 1981.

Conceptual designs of central receiver, parabolic dish, and parabolic trough systems are obtained for several process heat applications. Cost and performance estimates are made for each of these designs and these are used to calculate levelized delivered process heat costs. The results indicate that central receiver systems will provide energy costs competitive with that afforded by the parabolic trough and parabolic dish systems over the range of demand sizes and temperatures studies - above 3 MWt and above 200^{o} F.

SAND-79-8280: DESIGN, COST AND PERFORMANCE COMPARISONS OF SEVERAL SOLAR-THERMAL SYSTEMS FOR PROCESS HEAT. VOLUME II. CONCENTRATORS; E. D. Eason; March 1981.

The major mechanical design and cost differences between concentrator subsystems are identified. Parabolic dishes and troughs are designed to the same specifications as heliostats, using the same glass mirror/steel structure design concept and their costs are estimated on a consistent, comparable basis, using the heliostat cost data base. The results show inherent cost differences arising from differences in geometry, the cost of providing curvature and wind loadings. The estimated cost increases, relative to heliostats, are 15 percent to 50 percent for dishes and 0 percent to 30 percent for troughs, considering the combined effect of several analysis uncertainties.

SAND-79-8281: DESIGN, COST, AND PERFORMANCE COMPARISIONS OF SEVERAL SOLAR THERMAL SYSTEMS FOR PROCESS HEAT. VOLUME III. RECEIVERS; J. B. Woodard, Jr.; March 1981.

The receiver subsystem converts reflected solar radiation into thermal power by heating a working fluid. The objective of the task described was to estimate the cost and performance of the receiver subsystem for parabolic troughs,

parabolic dishes, and central receivers over a wide range of temperatures and power levels for thermal power applications. This volume presents the fundamental design philosophy employed, the constraints identified, the tradeoffs performed and the cost and performance results obtained for each receiver in the study matrix.

SAND-79-8282: DESIGN, COST, AND PERFORMANCE COMPARISONS OF SEVERAL SOLAR THERMAL SYSTEMS FOR PROCESS HEAT. VOLUME IV. ENERGY CENTRALIZATION; J. J. Iannucci and L. D. Hostetler; March 1981.

A large matrix of self-consistent piping systems for dishes, troughs, and central receivers, are designed, costed, and analyzed for performance. The solar installations collect thermal energy at temperatures ranging from 200° F to 2,000°F, at sizes of 3, 30, 300, and 1,500 megawatts thermal. First order design differences and similarities are highlighted, with special emphasis on the comparison of dish and trough piping. Dishes are found to require the most costly and thermally inefficient piping networks due to the large length of piping required.

SAND-79-8283: DESIGN, COST, AND PERFORMANCE COMPARISONS OF SEVERAL SOLAR THERMAL SYSTEMS FOR PROCESS HEAT. VOLUME V. SYSTEMS; P. J. Eicker, J. D. Hankins, L. D. Hostetler, J. J. Iannucci and J. B. Woodard; April 1981.

Conceptual designs have been obtained for central receiver, parabolic dish and parabolic trough systems used in several industrial process heat applications. The estimated cost of energy from these systems is presented. The system level trade studies which determined the optimal collector spacings are discussed. The assumptions used in the study relative to economics, maturity of technologies, costs of nonsolar equipment, nomenclature, etc., are also presented. Finally, the appendices discuss the models used to calculate field performance and present detailed information on subsystem cost and performance.

SAND-79-8508: DEPARTMENT OF ENERGY LARGE SOLAR CENTRAL POWER SYSTEMS SEMI-ANNUAL REVIEW; C. N. Bolton; May 1979.

This report presents the highlights of the Department of Energy (DOE) Large Solar Central Power System Semi-Annual Review held in Reston, Virginia, on March 21-22, 1979.

SAND-79-8600: PROPERTIES OF CGW-7806 GLASS; J.E. Shelby and J. Vitko, Jr.; February 1979.

Optical, physical, and chemical properties have been measured for CGW-7806 glass, which has been proposed for use

in heliostats. In general, the properties of this glass are similar to those of other potential heliostat materials. Although this glass has not been commercially produced in a low-iron form, research specimens indicate that it can be made with very high optical transmission. Chemical solubility measurements indicate satisfactory durability except in very high pH solutions. This behavior is similar to that of float glasses and other potential heliostat glasses.

SAND-79-8619: AN IMPROVED HERMITE EXPANSION CALCULATION OF THE FLUX DISTRIBUTION FROM HELIOSTATS; T. A. Dellin; June 1979.

An efficient method is presented for calculating the flux distribution reflected by heliostats required in the analysis of solar central receiver systems. The method is based on extensions to and improvements of the method of Walzel, Lipps and Vant Hull which approximates the flux analytically by a truncated series of Hermite polynomials. New features include: (1) the analytical dependence of flux on tower height; (2) more detailed error sources; (3) reduction of computer time and memory; and (4) formulae for canted or focused heliostats. These new capabilities make tractable the large number of calculations required in design optimization studies. The predictions of the method have been found to be in good agreement with those of more time consuming Monte Carlo programs.

SAND-79-8632: SANDIA LABORATORIES MATERIALS TASK GROUP REVIEW OF THE 10-MWe BARSTOW PILOT PLANT CONCEPTUAL DESIGN; J. J. Bartel, F. P. Gerstle, Jr., R. W. Mar, H. J. Rack and S. L. Robinson;September 1979.

A Sandia Materials Task Group reviewed the 10-MWe Barstow Solar Central Receiver Pilot Plant design. No major problems were identified; additional work in several areas is suggested to resolve potential concerns. A Materials Review Tabular Summary and supporting text description have been prepared for each subsystem-receiver, storage and heliostats.

SAND-79-8633: SANDIA LABORATORIES MATERIALS TASK GROUP REVIEW OF THE ADVANCED CENTRAL RECEIVER PRELIMINARY DESIGNS. I. MOLTEN SALT AND LIQUID METAL; J. J. Bartel, H. J. Rack, R. W. Mar, S. L. Robinson, and F. P. Gerstle, Jr.; September 1979.

Potential materials problems associated with the preliminary designs for liquid sodium and molten salt advanced central receivers are identified and recommendations suggested. Appendices which detail generic sodium materials issues and selected bibliographies on each fluid have been included. Liquid sodium systems are well defined technically, and code

certified materials exist. Large components for power plant applications have been developed and tested. Molten nitrate salt systems, while used frequently in process industries, do not have an extensive user history at typical power plant steam temperatures. Significant development and testing will be required to achieve a materials data base comparable to that for water-steam and sodium technologies. At present, no unsolvable materials issues are apparent, however a wide variety of questions need to be resolved before design can be committed to a power plant.

SAND-79-8634: THE HIGH TEMPERATURE COMPATIBILITY OF NITRATE SALTS, GRANITE ROCK AND PELLETIZED IRON ORE; V. P. Burolla and J. J. Bartel; August 1979.

Under the direction of the Department of Energy, high-temperature (550^{o} C) thermal energy storage concepts are being studied for application of second-generation solar central receiver thermal power systems. This report evaluates the compatibility of the current choice of working fluids with common granite rock and a pelletized iron ore. Results indicate that the long-term stability of iron-ore pellets in binary mixtures of potassium and sodium nitrates is superior to granite rock-salt mixtures and salt systems without solid media. Corrosion of the Incoloy 600 vessels was observed.

SAND-79-8754: SOLARIZATION OF HELIOSTAT GLASSES; J. Vitko, Jr., and J. E. Shelby; December 1979.

We have observed a solar-induced decrease in Fe^{2+} absorption in heliostat glasses from the solar furnace at Odeillo, France. This decrease occurs throughout the sampled (not just at the exposed surface) and is of sufficient magnitude to result in an increase of 2.5 percent in solar transmittance in a period of nine years. Optical and ESR studies did not detect a corresponding increase in Fe^{3+} concentration. The implication of these results on a microscopic model for the observed solarization is discussed. Solar simulation studies produced effects of magnitude and sign similar to those observed in the field exposed samples, and appear to offer an attractive means for screening samples for solarization tendencies.

SAND-79-8777: SOLAR CENTRAL RECEIVER SYSTEMS PROGRAM; J. D. Fish; October 1979.

Major elements of the DOE Solar Central Receiver Systems Program include development of storage-coupled and hybrid system concepts: the Central Receiver Test Facility in Albuquerque, New Mexico; the Pilot Plant under construction at Barstow, California; proposed repowering/industrial

retrofit plants; and heliostat, receiver, and storage subsystems development work. Current and proposed activities within each element are discussed.

SAND-79-8791: DETERIORATION OF THE SOLAR/GLASS INTERFACE IN SECOND SURFACE SOLAR MIRRORS; V. P. Burolla; 1980.

The suitability of various heliostat mirror module designs for large solar central power systems depends, in part, on the ability of the reflective surface to survive over the expected lifetime with little loss in reflectivity. Recent observations on several module designs proposed for solar energy applications revealed significant deterioration of the reflective interface in an unexpectedly short time span. The deterioration seen to date is not specific to a particular geographic location or module design and appears in several forms depending upon the geometry of the mirror module and the compatibility of the mirror adhesives and sealants used in its fabrication. There is evidence of more than one deterioration mechanism that may be a function of the mirror backing paint used. There is strong evidence that water plays a dominant role in all observed mechanisms and that silver delamination is a precursor to other effects on the silver layer. Laboratory tests have been successful to an extent in generating mirror deterioration similar to that seen in the field.

SAND-79-8814: SANDIA LABORATORIES IN-HOUSE ACTIVITIES IN SUPPORT OF SOLAR THERMAL LARGE POWER APPLICATIONS; R. W. Mar; 1979.

Research activities have been planned and carried out in direct support of the development of thermal energy storage subsystems for solar thermal large power applications. The emphasis has been on characterizing the behavior of molten nitrate salts with regard to thermal decomposition, environmental interactions, and corrosion. The results to date and future activities are summarized.

SAND-80-0056: CENTRAL RECEIVER TEST FACILITY SOFTWARE PACKAGE FOR BOEING/ELECTRIC POWER RESEARCH INSTITUTE BENCH MODEL SOLAR RECEIVER EXPERIMENT; D. R. Porter; June 1980.

The development of a data acquisition and display system for use at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico, is described. Included is a description of a minicomputer-based network developed for facility control and data acquisition, specific software developed to support the Boeing/Electric Power Research Institute (EPRI) receiver test program, and the solutions to some problems encountered.

SAND-80-0381C: FINITE ELEMENT STRATEGIES FOR THE EFFICIENT ANALYSIS AND EVALUATION OF SOLAR COLLECTOR STRUCTURES; J. R. Koteras; September 1980.

Concentrating or reflecting structures for solar energy systems must be evaluated as to their structural integrity and optical performance. Computer studies can be used as an integral part of these evaluations. The computer studies make use of finite element structural codes coupled with post-processors that calculate optical data. If the analysis of a solar structure is to be carried out in an efficient manner, these computer codes must have certain capabilities. A number of solar energy projects at Sandia National Laboratories have made extensive use of finite element analyses. The analyses have been useful in evaluating design concepts which hold promise for large scale use in solar energy projects. Analysis procedures have been developed for some structures so that evaluations can be carried out in a straightforward manner.

SAND-80-0433: SCRAM: A FAST COMPUTATIONAL MODEL FOR THE OPTICAL PERFORMANCE OF POINT FOCUS SOLAR CENTRAL RECEIVER SYSTEMS; K. D. Bergeron and C. J. Chiang; April 1980.

Because of the complexities of heliostat shadowing and blocking calculations, computational models for the optical performance of Point Focus Central Receiver (PFCR) systems tend to be too slow for many important applications, such as optimization studies based on performance with realistic weather data. In this paper, a mathematical approximation procedure, designated Sandia Central Receiver Approximation Model (SCRAM) will be described. Rather than simulating the system components from first principles, it relies on data generated by the DELSOL code of Dellin and Fish for the optical performance of PFCR systems, and abstracts a mathematical model using a stepwise regression procedure. The result is a computational procedure which allows the user to define the heliostat field boundaries and tower height arbitrarily, generating a model for optical field performance, including shadowing, blocking, cosine, losses, and atmospheric attenuation, and which requires only a polynomial evaluation for each set of sun angles. A comparision with DELSOL for three different fields on three representative days indicates that the rms error of the approximation is 1-3 percent and that the new code is 1,000-3,000 times as fast as DELSOL. It is also shown that one reason that the accuracy in field performance predictions is higher than that of the generating function for the model is that much of the error in the generating function is due to an oscillatory behavior associated with a moire pattern in the optical response of the heliostat field.

SAND-80-0583C: CRTF REAL-TIME APERATURE FLUX SYSTEM; D. B. Davis; May 1980.

The Real-Time Aperture Flux system (RTAF) is a test measurement system designed to determine the input power/unit area (flux density) during solar experiments conducted at the Central Receiver Test Facility, Sandia National Laboratories, Albuquerque, New Mexico. The RTAF is capable of using both thermal sensors and photon sensors to determine the flux densities in the RTAF measuring plane. These data are manipulated in various ways to derive input power and flux density distribution to solar experiments.

SAND-80-0808: PROTECTIVE COATINGS AND SEALANTS FOR SOLAR APPLICATIONS; K. B. Wischmann and M. H. Gonzalas; September 1980.

An aging study has been completed which evaluated a number of polymeric materials for potential use as: (1) protective coatings for back surfaces of mirrors and (2) solar heliostat edge seals. These investigations were conducted in an artificial weathering chamber that accelerated thermal cycling. The primary mirror failure mode was observed to be silver corrosion resulting from moisture exposure. To increase mirror longevity in current heliostat designs, intimate bonding at all the composite interfaces is essential to minimize moisture pathways to the silvered surface. If any voids or delaminations are present, mirror degradation will eventually occur. Delaminations can also occur as the result of mechanical stresses brought about by mismatches in the various materials coefficients of thermal expansion. If good bonding cannot be achieved or mechanical stresses avoided, then improved moisture barriers must be designed to assure mirror longevity. With good adhesion, a KRATON rubber was found to exhibit superior back surface mirror protection (12 months in environmental chamber with no corrosion). An ultraviolet stabilized butyl rubber appeared to be the best edge seal. All heliostats edge sealed with silicones showed silver corrosion which indicated either poor bonding or moisture permeation.

SAND-80-1483C: DEVELOPMENT AND TESTING OF POLYMER REFLECTORS; R. A. Assink; September 1980.

Metallized polymer sheets and films offer the potential of providing a low cost, light weight and easily installed solar reflector surface. Metallized polymers presently available, however, suffer from three disadvantages: (1) low initial reflectance; (2) uv degradation; and (3) surface abrasion. The solar reflectance properties of commercially available aluminized polymers are typically 0.06 to 0.10 reflectance units (1.00 reflectance units = 100 percent reflectance) lower than the solar reflectance properties of

high-quality silvered glasses. This difference results from the inherently lower solar reflectance of aluminum as compared to the solar reflectance of silver. Efforts to deposit and protect silver on a polymer surface have not been successful, uv degradation of polymers can affect the material's optical and mechanical properties. Recent studies, however, indicate that uv degradation may not be a serious problem for acrylic materials. Abrasion of the polymer surface by wind blown sand or contact cleaning methods can cause a substantial reduction in the specularity of the reflector. The purpose of this study is to develop and evaluate several abrasion resistant aluminized polymer reflectors suitable for solar applications. The lower initial reflectance of aluminized polymers may then be offset by the advantages previously mentioned. Results are reported.

SAND-80-1509C: DEVELOPMENT OF A SECOND GENERATION PORTABLE SPECULAR REFLECTOMETER; J. M. Freese; September 1980.

The second generation design of a portable specular reflectometer developed by Sandia National Laboratories (SNL) has been completed together with a detailed drawing package. Two prototype instruments have been fabricated and evaluated. It has been demonstrated that the instruments respond linearly (+0.006 transmission units) to variations in the 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 drift problem due to temperature was observed in the detector/preamp at temperatures >100^{o}F. This drift would probably be eliminated by redesign of the detector/preamp circuitry. A major improvement in the second generation reflectometer is the use of larger optics to allow averaging over a greater surface area (approximately 1 cm^{2}) of a mirror. The new reflectometer 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 specular transmittance of materials. A microprocessor can be added to the output of the detector as an option to display percent reflectance values and mean and standard deviations of measurements made.

SAND-80-1541C: PORTABLE INSTRUMENTATION FOR SOLAR ABSORPTANCE AND EMITTANCE MEASUREMENTS; R. B. Pettit and A. R. Mahoney; September 1980.

Two portable instruments, one designed for solar absorptance and the other for emittance measurements, have been

evaluated. A Solar Spectrum Reflectometer was used for solar absorptance measurements while a model AE Emissometer was used to measure the emittance for an 80°C blackbody. Both instruments are manufactured by Devices and Services Co., Dallas, TX. The Solar Spectrum Reflectometer uses four different detector/filter combinations to match an air mass to solar spectral distribution. The solar absorptance values measured for a variety of solar coatings were determined to an accuracy of ±0.02 absorptance units.

SAND-80-1578C: SOLTES: SIMULATOR OF LARGE THERMAL ENERGY SYSTEMS; M. E. Fewell and N. R. Grandjean; April 1981.

The philosophy, structure, current capabilities and applications of SOLTES, a computer code that 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, are discussed. SOLTES simulates the steady-state response of thermal energy systems to time-varying data such as weather and loads.

SAND-80-1637: SUM-OF-GAUSSIANS REPRESENTATION OF SUNSHAPE; C. N. Vittitoe and F. Biggs; September 1980.

The angular distribution of sunlight reaching the earth varies considerably because of interaction with the atmosphere. Five typical sunshapes, chosen from the widest to the narrowest shape in the Lawrence Berkeley Laboratory data, are approximated by a sum of six Gaussian distributions. In many applications sunshapes are convolved with error-cone distributions that represent a statistical description of uncertainties encountered in an optical concentrating system. Sunshape convolution with a series of circular-normal error cones indicates that the effective sunshape is well represented by analytic convolution between the error cone and the sum of Gaussians. This analytic convolution can replace the more costly (in time and computer storage) numerical methods for convolving the error cone and the experimental sunshape distribution. Results of both calculation methods are found to be consistent with the dispersion of the error cone is greater than 0.0012. A simple prescription indicates how each of the analytic representations may be transformed to approximate sunshapes appropriate for slightly different atmospheric conditions. The analytic form of the effective sunshape is given as a sum of six elliptic-normal distributions when the error cone is an elliptic-normal distribution.

SAND-80-2345C: US CENTRAL RECEIVER TEST FACILITY (CRTF) CONTROL AND DATA SYSTEMS; D. B. Davis; October 1980.

The Central Receiver Test Facility (CRTF) is the primary solar test facility for the Department of Energy and is operated by Sandia National Laboratories, Albuquerque, New Mexico. The CRTF energy collection field consists of 222 heliostats (sun tracking mirror assemblies). The total heliostat field can concentrate more than 5-MWth power under optimal sun, heliostat, and target conditions. For test flexibility, heliostats may be located on either of two general foundation arrays that form a northern or circular distribution with respect to the tower center. Each heliostat has 25 individual mirror facets totaling 37.2m^2 (400 ft^2) of reflective surface per heliostat. The 25 facet reflections are adjusted to coincide at the desired target locations providing a reflected-energy concentration ratio of 1.5-2.1 at its focal length. The facets are mounted on a structure with azimuth and elevation gimbals to allow aiming the reflected energy at the chosen target location. The minicomputer systems used to control the facility and to collect facility and experiment data are connected into a distributed processing network. The many tasks of CRTF are divided among the various computers in the network to provide the total facility capability. The overall operating systems are described in general and then each major subsystem is covered in more detail.

SAND-80-2409: ACOUSTIC MEASUREMENT OF BOILING INSTABILITIES IN A SOLAR RECEIVER; A. G. Beattie; November 1980.

An acoustic technique was developed and used to search for boiling instabilities in the prototype receiver for the Barstow 10-MW Solar Thermal Pilot Plant. Instabilities, consisting of movements of the transition zone between regions of nucleate and film boiling, were observed. The periods of these fluctuations ranged between three and fifteen seconds with no indications of preferred frequencies. The peak-to-peak amplitudes of the fluctuations averaged 0.4 meters under steady state conditions at absorbed power levels between 2.0 and 3.2 MW. Transient fluctuations with amplitudes up to 2.0 meters were also seen. These transients usually lasted between 30 and 300 seconds. It was not possible to pinpoint the causes of these transients.

SAND-80-2477: CENTRAL-RECEIVER TEST FACILITY (CRTF) COST HISTORY; R. G. Lundgren and J. V. Otts; May 1981.

The total cost distribution for the Central Receiver Test Facility is broken down into design, construction, and procurement categories. The percentage of recurring and

nonrecurring costs are given. It is found that concrete and steel totaled 21 percent of the total project cost. The time frames required to complete the major project events are delineated.

SAND-80-2504C: OPERATING EXPERIENCE AT THE CENTRAL RECEIVER TEST FACILITY (CRTF); J. T. Holmes, W. K. Bell, D. L. King, L. K. Matthews and L. O. Seamons; May 1981.

The CRTF, constructed to develop solar central receiver components, began operation in October 1978. To date, three solar receivers that used either air, water/steam, or a molten nitrate salt as their working fluid have been successfully characterized. Also, seven heliostat concepts have been evaluated. These included two competing designs for the 10-MWe solar pilot plant now under construction near Barstow, California, a privately sponsored design, and four advanced designs. Almost three years of operation of the CRTF have provided data and experience on the performance and maintenance requirements for typical components of a solar central receiver system.

SAND-80-2581C: COMPUTER-DRIVEN SOLAR TRACKING MOUNT; H. D. Pruett and T. L. Evans; May 1980.

Measurement of direct-normal insolation requires a solar tracking mount whose tracking accuracy is a small fraction of the angular field of view of the pyroheliometer being used. A two-axis, computer-driven, solar-tracking mount which eliminates the manual-adjustment and cable wrap-up problems associated with traditional single-axis trackers has been developed. The mechanical and electronic features of this mount are described, and the software used to initially position it and to track the sun routinely is discussed.

SAND-80-7009: CIRCUMSOLAR RADIATION; A. D. Watt; April 1980.

The bright ring around the sun, referred to as sun's aureole or circumsolar radiation, occurs when the sky becomes hazy or as the sun enters the edge of clouds. The cause of this bright ring is the conversion of the sun's direct rays into a forward scattered component by large particles in the atmosphere. The existance of this phenomen and its general variation, has been known for many years. It was not, however, until recently that enough carefully taken observations have been made to enable us to obtain quantative understanding of the phenomen. Under severe conditions, the sun's direct rays are reduced and the circumsolar values increased to the point where it becomes difficult to distinguish the optical boundary of the sun. When numerous small particles exist in the atmosphere, the

sky radiants vary slowly with angular distance from the sun's center. When large particles are present, the rate of decrease becomes more rapid. Data shows that the radiants outside the solar disc can approach 10^6 watt/M^2 steradian at 0.4^o, as compared to the solar disc value of somewhat over 10^7. Under very clear sky conditions when there are very few large scatterers, the radiants may drop as low as 10^3 at $.4^o$.

SAND-80-7014-3: CONCEPTUAL DESIGN AND SYSTEM ANALYSIS STUDY FOR A HYBRID SOLAR PHOTOVOLTAIC/SOLAR THERMAL ELECTRIC POWER SYSTEM. VOLUME III. APPENDICES. FINAL REPORT; Sandia; July 1981.

An analysis was done of hybrid photovoltaic/solar thermal electric conversion systems. The study compared several types of hybrid systems, photovoltaic-only systems, and solar thermal electric systems in terms of performance and cost. This study and its results are reported in detail in Volume II, and are summarized in Volume I. This third volume consists entirely of supporting appendices, including a description of the computer code used in the analyses and background information on heat engines, thermal efficiencies of photovoltaic thermal collectors, and optical considerations for central receiver plants.

SAND-80-7081: ACCESS TO SOLAR ENERGY: THE PROBLEM AND ITS CURRENT STATUS; M. Eisenstadt; March 1981.

The problems of providing access to sunshine for solar-energy systems has been seriously addressed in this country during the past five years. Several legal methods for providing such access have been suggested to date. These are easements, restrictive convenants, subdivision statutes and ordinances, nuisance law, permit systems, state statutes creating solar access rights, and zoning. Each has certain advantages and disadvantages which are analyzed. Some methods protect solar access for potential solar-collector sites as well as existing collectors, while others are usable only for collectors that are already installed. The different states, counties, and municipalities that use the various methods are identified. While each of the methods has its problems, zoning appears to be emerging as the most popular. For this reason, zoning for solar access is discussed in some detail. It is necessary to specifically define the extent of the solar access provided by a zoning ordinance. At present, three different means are used to do so. These are hypothetical walls, solar envelopes, and height-and-setback restrictions. All three are shown to be mathematically equivalent. Suggestions are made as to which is best for both high-density and low-density areas. Recommendations are made for further work that is needed in the area of zoning for solar access. 97 references.

SAND-80-8020: FIVE-TUBE TEST REPORT; J. Liebenberg; August 1980.

Sandia National Laboratories conducted an experiment investigating the Departure from Nucleate Boiling/Hydraulic Instability in support of the 10-MW Central Receiver Solar Pilot Plant project in Barstow, California. The experiment provided fundamental fluid dynamics data that will improve the understanding of boiling in a one-side-heated single pass to superheat solar boiler panel. The purpose of this report is to document the test results and the experimental configuration. The data from 167 test runs, each with 250 data channels, have been condensed in summary plots and tables. The description of the apparatus, and the summarized data provide a clear characterization of the flow boiling phenomena unique to the five-tube experiment and the Barstow receiver. Although there are differences between the five-tube test hardware and the actual Barstow receiver panels, the differences are alluded to in this report, but not analyzed. That analysis will be the subject of other reports.

SAND-80-8027: INSTRUCTION MANUAL FOR SHAPEFACTOR; A. F. Emery; October 1980.

A numerical technique is presented for evaluating the geometrical radiant exchange factors (also called shape or view factors) between surfaces with interposed obstructions. Since the program is developed for plane surfaces, arbitrary surfaces are expressed by the juxtaposition of plane surfaces; to simplify the input and output, the program respectively combines and decomposes these elemental surfaces. The data input format, although designed for manual input, is ideally suited for standard three-dimensional mesh-generated programs. When obstructions are not present, the calculated exchange factors are accurate to within tenths of a percent; but when obstructions are present, the accuracy depends on the nature of the problem, the refinement of the elemental area mesh, and the amount of computation called for by the user. This program has been adapted for solving central-receiver cavity problems.

SAND-80-8032: STATUS AND RECOMMENDED FUTURE OF PLASTIC ENCLOSED HELIOSTAT DEVELOPMENT; C. L. Mavis; October 1980.

Tests have shown that biaxially oriented Kynar film has excellent weathering properties as an enclosure material and is practical to manufacture commercially. Reflectors using Kynar or weatherized polyester also appear to be feasible. The projected low cost of properly designed plastic-enclosed heliostats indicates that further development effort should be continued. Both Boeing's one-piece enclosure and General Electric's multipiece enclosure concept should be pursued.

Full-size enclosures and reflectors need to be fabricated and set up at several desert locations to verify the designs and obtain weathering data under actual use conditions.

SAND-80-8047: FATIGUE-CREEP LIFETIME ANALYSIS OF FOUR ADVANCED CENTRAL RECEIVER CONCEPTS; J. Jones and L. Napolitano, Jr.; January 1981.

Four Advanced Central Receiver (ACR) concepts were analyzed for their fatigue-creep design lifetimes under the guidelines of ASME Boiler and Pressure Vessel Code Case N-47 (1592). Using the flux profiles provided by the designers, the thermal hydraulic performance of an individual tube in a receiver panel was ascertained by computer analysis. A linear model of the tube crown strain for the tube on given supports was then constructed. At the location of highest strain two-dimensional thermal and structural finite element analyses were performed. The computed stresses and strains were used in evaluation of the creep and fatigue design lifetimes by N-47 and compared to the desired lifetime of 30 years. Three of the four designs met or exceeded the desired lifetime and the fourth met the desired lifetime when the factor of safety incorporated in N-47 was reduced. All four designs were judged adequate for the current level of design effort.

SAND-80-8049: DEPARTMENT OF ENERGY SOLAR CENTRAL RECEIVER SEMIANNUAL MEETING; Sandia; January 1981.

This report presents the highlights of the Department of Energy's Solar Central Receiver Semiannual Meeting held in San Francisco, California, on October 15-16, 1980.

SAND-80-8052: MOLTEN NITRATE SALT TECHNOLOGY DEVELOPMENT STATUS REPORT; R. W. Carling, C. M. Kramer, R. W. Bradshaw, D. A. Nissen and S. H. Goods; March 1981.

Recognizing thermal energy storage as potentially critical to the successful commercialization of solar thermal power systems, the Department of Energy (DOE) has established a comprehensive and aggressive thermal energy storage technology development program. Of the fluids proposed for heat transfer and energy storage, molten nitrate salts offer significant economic advantages. The nitrate salt with most interest in a binary mixture of $NaNO_3$ and KNO_3. Although nitrate/nitrite mixtures have been used for decades as heat transfer and heat treatment fluids, use has been at temperatures of about 450° C and lower. In solar thermal power systems, the salt will experience a temperature range of 350 to 600° C. Because central receiver applications place more rigorous demands and higher temperatures on nitrate salts a comprehensive experimental program has been

developed to examine what effects, if any, the new demands in temperatures have on the salts. These experiments include corrosion testing, environmental cracking of containment material, and determinations of physical properties and decomposition mechanisms. This report details the work done at Sandia National Laboratories in each area listed. In addition, summaries of the experimental programs at Oak Ridge National Laboratory, the University of New York, EIC Laboratories, Inc., and the Norwegian Institute of Technology and Molten Nitrate Salts are given. Also discussed is how the experimental programs will influence the near-term central reciver programs such as utility repowering/industrial retrofit and cogeneration. The report is designed to provide easy access to the latest information and data on molten $NaNO_3/KNO_3$ for the designers and engineers of future central receiver projects.

SAND-80-8175: INTERNALLY INSULATED THERMAL STORAGE SYSTEM DEVELOPMENT PROGRAM. FINAL REPORT; Martin Marietta Aerospace; December 1979.

The primary objective of this program is to define a cost effective thermal storage system for a solar central receiver power system using molten salt stored in internally insulated carbon steel tanks. This effort was divided into five tasks. The scope of these tasks were; (1) Task 1, internal insulation materials test program: screening tests of candidate insulation materials were conducted by exposing them in 866 ^{o} K (1,100 ^{o} F) molten salt for 500 hours. Materials selected from these tests were exposed to 866^{o} K salt for up to 5,000 hours; (2) Task 2, internally insulated thermocline storage tank analysis: a computer thermal model of internally insulated thermocline tanks was developed to predict thermocline behavior under various operational strategies; (3) Task 3, storage tank design: a preliminary design study and optimization was made of both an externally insulated carbon steel tank for 561^{o} K (550^{o} F) molten salt and an internally/externally insulated carbon steel tank for 839^{o} K (1,050^{o} F) molten salt; (4) Task 4, storage system parametric analysis: a computer cost optimization was performed to find the optimum configuration for each of three different storage concepts - thermocline, dual-tank, and cascade systems. The analyses were done as a function of storage size and considered the following factors: tank geometry; number of tanks; insulation type, thickness, and cost; storage use rate; heat loss rate and its impact on upstream costs (heliostats, etc.); and others; (5) Task 5, storage subsystem research experiment (SRE): based on the conclusions of Tasks 1 through 4, a subsystem research experiment was proposed that would demonstrate both fabrication and performance of the major components of the recommended storage design. Results are detailed.

SAND-80-8177: STEAMFREQ-1: A MODEL FOR DYNAMIC STABILITY ANALYSIS OF STEAM GENERATORS WITH IMPOSED HEAT FLUX DISTRIBUTION; K. C. Chan, S. Wolf, and G. Yadigaroglu; January 1980.

The results of analysis to develop an advanced computer model, STEAMFREQ-1, for the investigation of density-wave instabilities in steam generators with imposed heat flux are presented. The key model features include a drift flux flow model in the boiling region, spatial variation of heat flux, wall dynamics, and variable steam properties in the superheat region. Stability predictions for STEAMFREQ-1 are compared with those from two other codes. In addition, stability predictions are compared with data representing unstable and stable conditions obtained from a solar receiver panel test and with stability threshold data from a sodium-heated steam generator test.

SAND-80-8179: MOLTEN SALT SAFETY STUDY. FINAL REPORT; Martin Marietta Aerospace; January 1980.

The considerations concerning safety in using molten salt (40 percent potassium nitrate, 60 percent sodium nitrate) in a solar central receiver plant are addressed in this report. The considerations are of a general nature and do not cover any details of equipment or plant operation. The study includes salt chemical reaction, experiments with molten salt, dry storage and handling constraints, and includes data from the National Fire Protection Association. The contents of this report were evaluated by two utility companies and they concluded that no major safety problems exist in using a molten salt solar system.

A proposed central receiver solar power plant is shown. The plant generates 300-MW electric power and is described in the Advanced Central Receiver Power System, Phase 1 Final Report. The plant consists of nine collector fields, each with 7,711 heliostats (mirrors) surrounding a central receiver (essentially a heat exchanger atop a 155-m (510-ft) concrete tower), a thermal storage area, and a conventional steam turbine/generator subsystem. Molten salt at 561 K (550° F) is pumped up to the receivers where it is heated to 839 K (1,050° F) by the solar energy reflected from the heliostats. The molten salt is then pumped into salt/steam heat exchangers or storage tanks or both, as required. Steam leaving the heat exchangers enters a reheat turbine at 783 K (950° F) and 16.5 kPa (2,400 psi) and produces a 300-MWe net output. The salt leaves the heat exchangers at 561 K (550° F) and is either returned to the receivers or sent to storage. The storage salt is used to keep the plant operating at night and during cloud interruptions.

SAND-80-8180: ELECTRIC POWER GENERATING SUBSYSTEM STUDY FOR ADVANCED WATER/STEAM RECEIVERS. FINAL TECHNICAL REPORT; G. Oganowski, et al; April 1980.

The objective of this particular program was to evaluate the performance and economics of a range of 1985-vintage Rankin power conversion cycles for advanced water/steam solar plant application. The program output provides sufficient information for selection of the optimum power conversion cycle when integrated with other advanced water/steam solar plant systems being developed under separate Sandia contracts.

The major program efforts included:

- o Cycle screening.
- o Performance analysis.
- o Cost analysis.

SAND-80-8181: CORROSION OF ALLOYS IN MOLTEN NITRATES; R. A. Osteryoung; September 1982.

As a portion of a broad based effort involving studies of heat transfer fluids for solar collectors, work was initiated in support of efforts by Sandia National Laboratory and others to utilize molten nitrates such as fluids. Initially, the intent had been to study the behavior of a variety of metal ions at high temperatures in the (K,Na) NO_3 binary molten salt. In all this work, a gold electrode of relatively large area was employed as a reference electrode and was checked for stability against an Ag/Ag(I) electrode. The behavior of glassy carbon as a potential indicator electrode was investigated first; it behaved rather similarly to prior investigations of Pt and Au indicator electrodes in these melts in that evidence indicated that NO_3^- reduction, passivation and dissolution processes at the glassy carbon electrodes were about the same as those found for Pt or Au electrodes. The anodic limit of the melt, at the electrode, at relatively low temperatures ($<300^{\circ}$ C), was shifted to more cathodic values than at either Pt or Au, and, as the temperature was raised, the behavior of the electrode became sufficiently complex that further studies were abandoned.

The behavior of platinum and gold as indicator electrodes was studied up to 550° C. Although both electrodes behave in a similar manner, with increased complexity of the electrode reactions taking place in the pure melt as the temperature is raised, it was determined that Pt appeared to behave in a simpler, more reproducible manner than did gold. Both electrodes showed evidence of attack if prolonged reduction of NO_3^- were performed at the electrode surface.

As a result of DOE funding limitations, it was decided to initiate corrosion studies on Fe, Ni and Incoloy 800 at a much earlier date than intended, so as to supply as much useful information to Sandia as possible; Incoloy 800 is the material intended for use in the temperature range 550-600° C as container material for the molten nitrates in the solar collector system. Open circuit potentials for Fe, Ni and Incoloy 800 could be obtained, with times varying from a few minutes to several hours. Incoloy 800 open circuit potential was close to, but more noble than that of iron. The presence of chromate in the melt - chromate has been found to be the major soluble corrosion product of Incoloy 800 in a molten nitrate test loop in work performed by Sandia - resulted in open circuit potentials less noble than in its absence.

Current-potential curves at iron, nickel and Incoloy 800 were investigated. Anodic polarization curves on both Fe and Ni exhibited the same general features, an initial jump in potential, followed by a region where the potential changes without appreciable change in current, followed by a region where, it is assumed, nitrite oxidation (only on iron) and Incoloy 800 is observed, followed by a region where the current starts to increase markedly. Potential reversal resulted in, essentially, a retrace of the current-potential curve obtained when scanning the voltage in the anodic direction.

The anodic polarization curves on Incoloy 800 were much different, and much more revealing. The shape resembled that for iron, with an initial potential region to around 0.5 V which is presumed to be a passive region, followed by a NO_2^- oxidation wave, which is followed by a sharp and sudden increase in current, the potential (the breakdown potential) at which this increase in current takes place being less anodic at lower than at higher temperatures. For instance at 250° C, a breakdown potential, where the current increases dramatically, takes place at about 0.9 V; this shifts to about 1.2 V at 450° C. If the scan is reversed once this large increase in current is noted, a very large closed current loop is obtained, i.e., there is significant hysteresis compared to iron or nickel. This closed current loop diminishes markedly as the temperature is raised. Observation of the electrode surface after a series of experiments at various temperatures supports the conclusion that the large current loop is characteristic of an alloy which undergoes crevice and/or pitting corrosion. At 550°C, for instance, a much smaller open current loop is found (less hysteresis), which is suggestive of only pitting corrosion. Observation of the electrode surface after experiments at 550° C showed a brown oxide film, but no evidence of the much greater corrosion found at 250° C. It

can thus be concluded that the higher the temperature, the stronger and more protective is the initially formed surface oxide film.

SAND-80-8182: A STUDY OF THE INTERACTIONS OF MOLTEN SODIUM NITRATE-POTASSIUM NITRATE 50 MOL PERCENT MIXTURE WITH WATER VAPOR AND CARBON DIOXIDE IN THE AIR. FINAL REPORT; S. H. White and V. M. Twardock; September 1981.

The interactions of aerial components such as water, carbon dioxide and oxygen with the binary 50 mol percent mixture of sodium nitrate and potassium nitrate (a potential thermal storage fluid) have been studied in the temperature range 300-600° C using electrochemical methods. In addition, the behavior of nitrite ions in this melt was investigated electrochemically because these ions are a major thermal decompositon product of nitrate and, therefore, represent a further possible reactant with atmospheric components. Essentially it was planned to apply electrochemical techniques as in situ methods to monitor directly any interactive chemistry of the melt-atmosphere system. However, it was recognized early in the program that the electrochemical behavior of water, carbon dioxide, carbonate ions (a product of the interactive chemistry) and nitrite ions was rather complex. Nevertheless, by judicial choice of techniques, in situ electroanalysis was possible and the necessary relevant data to accomplish this has been developed, as well as some new insights into the corresponding electrochemical mechanisms associated with the electroactive species. A feature of this electrochemistry is the coupling of fast multiorder chemical reactions following the electrochemical steps.

Carbonate ions, dissolved water and less easily nitrite ions can be detected by direct in situ electrochemical measurements and relevant data to achieve this are included in the text.

SAND-80-8190: SELECTION AND CONCEPTUAL DESIGN OF AN ADVANCED THERMAL-ENERGY-STORAGE SUBSYSTEM FOR COMMERCIAL-SCALE (100 MWe) SOLAR CENTRAL-RECEIVER POWER PLANT; Babcock and Wilcox Co.; February 1981.

Advanced thermal energy storage concepts were developed and evaluated which are applicable to a 100-MWe solar central receiver plant using water/steam as the working fluid. Operating conditions studied were 510C/10.1 Mpa (950F/1,465 psia) from the receiver and 299C/2.72 MPa (570F/395 psia) from storage. Three concepts were selected that offered potential for cost and performance improvements over the oil/rock concept presently being installed at the Central Receiver 10-MWe Pilot Plant under construction in

Barstow, California. From the three concepts selected, the moving bed thermal energy storage system (MBTESS) using a free-flowing refractory material as the heat transport and storage media was chosen. A conceptual design was developed, including estimates for cost and performance. Suggestions were made for further development work leading to full-scale implementation of the concept.

SAND-80-8193: AN INTERIM STRUCTURAL DESIGN STANDARD FOR SOLAR ENERGY APPLICATIONS (EVALUATION OF ANL TESTS); M.S.M. Rao; February 1982.

Foster Wheeler Development Corporation (FWDC) recently prepared an interim structural design standard for solar energy applications. This included an evaluation of a series of material tests conducted by Argonne National Laboratory (ANL). This report summarizes those evaluations.

The overall objectives of the FWDC program are to perform analytical studies based on the ANL tests, and to relate the test results and analytical studies to solar structural design standards. The program consists of four tasks: (1) Analytical Studies of Zero-Hold-Time Tests, (2) Study of Mean Stress Shift, (3) Analytical Studies of Hold-Time Tests, and (4) Creep Fatigue Life Evaluation.

The ANL test program includes two materials--Type 316H Stainless Steel and Incoloy 800. ANL has completed a series of tests on the two materials, the results of which are shown in Tables 1 and 2. The temperature for all tests is approximately $1,100^{\circ}$ F.

SAND-80-8203: UTILITY VIEWS ON SOLAR THERMAL CENTRAL RECEIVERS: M. J. Fish; April 1980.

The solar thermal central receiver concept has been the topic of discussion in recent meetings with a number of southwestern U.S. utilities. These discussions focused on identifying technical demonstrations and government incentives necessary for commercializing the technology. The content of these meetings is summarized in this report, and the implications for a commercialization plan are discussed.

SAND-80-8205: SIGMA PHASE FORMATION IN ALLOYS FOR SO_2/SO_3 THERMAL ENERGY STORAGE SYSTEMS; D. A. Hughes; February 1980.

A screening test was completed which identifies the tendency for sigma phase formation in alloys for SO_2/SO_3 thermal energy storage systems. The candidate alloys include austenitic and ferritic stainless steels, Fe-Ni Base, and Ni base alloys. Test specimens were aged for 4,000 hours at

ambient temperature, 700, 800, 900 and 1000° C. Aged specimens were tested for Charpy V-notch toughness. Decreases in toughness upon aging correlated well with the observed changes in microstructure.

SAND-80-8212: DESIGN AND OPERATION OF THERMAL CONVECTION LOOPS FOR CORROSION TESTING IN MOLTEN $NaNO_3$-KNO_3; W. S. Winters, R. W. Bradshaw, and F. W. Hart; June 1980.

Convective loop experiments are a valuable and relatively inexpensive method of assessing the effects of mass transport and a fully operational temperature gradient on molten salt materials compatibility. This report documents the design, construction, operation, and preliminary results of three molten draw salt corrosion loop experiments conducted at SLL. The loops were constructed from 304 SS, 316 SS, and Incoloy 800. This effort was undertaken to support the DOE program for Thermal Energy Storage for Solar Thermal Applications.

SAND-80-8214: SOLAR INDUSTRIAL PROCESS HEAT MARKETS FOR CENTRAL RECEIVER TECHNOLOGY; J. D. Fish; April 1980.

Although the emphasis of the Solar Central Receiver Program over the past few years has been electrical generation for utilities, there is renewed interest in the role for central receiver technology within the industrial sector for process heat applications. Process heat accounts, for approximately one-half of industrial energy usage and for approximately one-sixth of the total U.S. energy usage. Based on a synthesis of the available information concerning industrial process heat markets, it is concluded that only two types of central receiver systems need be developed to have significant impact on industry: (1) systems producing saturated steam up to 550° F, and (2) systems delivering air up to 2,000-1,500° F. Applications amenable to near-term penetration are identified for both types of systems. Finally, a number of program elements to define the specific characteristics of the two systems are presented.

SAND-80-8218: THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS PROGRAM PROGRESS REPORT (OCTOBER 1979-MARCH 1980); L. G. Radosevich; May 1980.

This report summarizes the progress made by the Thermal Energy Storage for Solar Thermal Applications (TESSTA) Program in the period October 1979-March 1980.

SAND-80-8228: PLAN FOR THE COMMERCIALIZATION OF SOLAR THERMAL CENTRAL RECEIVER SYSTEMS; M. J. Fish and L. D. Brandt; November 1980.

Concepts for solar thermal central receiver plants have evolved through continuing research and development into designs that are projected to have higher efficiency and lower cost. Recent studies have combined these results with rising costs of fossil-fired plants and fuels to show that solar central receiver plants can be a competitive alternative for large scale electrical production. Because of these findings, commercialization of the concept is now receiving increased attention by both government and private groups involved with development of the technology. Elements of a government program to achieve successful commercialization by the early 1990s are recommended. The recommendations integrate utility requirements for demonstration and risk sharing with supplier needs for manufacturing process development. Program timing and costs are presented, and the effects of program modification are briefly discussed.

SAND-80-8232: FY81 ANNUAL OPERATING PLAN-THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS (TESSTA); L. G. Radosevich; September 1980.

This report describes the FY81 annual operating plan for the application elements of the Thermal Energy Storage for Solar Thermal Applications (TESSTA) program.

SAND-80-8234: SURVEY OF U.S. INDUSTRIAL PROCESS HEAT USAGE DISTRIBUTIONS; J. J. Iannucci; January 1981.

The potential for penetration of solar thermal energy into the industrial process heat (IPH) market depends on many factors, prominent among which are the energy use characteristics of industry. Although the overall IPH market is large, there is presently very little known about typical size and temperature combinations which will be required. Using recently published data on 1972 United States industrial energy consumption (grouped by standard industrial classifications) and the number of energy consuming establishments, estimates can be made of average consumption of rate (megawatts) of energy at any site. Incorporating known temperature requirements for those industrial types, the power ratings required at various temperatures can also be calculated. Combination of these data yields distribution of energy consumption facility sizes at various temperatures. In terms of number of facilities, the small, lower temperature end users dominate. However, in terms of total energy consumed, the larger users (10-MW thermal and above) and higher temperatures dominate.

SAND-80-8235: SOLAR CENTRAL RECEIVER TECHNOLOGY EVALUATION; K. W. Battleson, P. De Laquil, III, J. D. Fish, H. F. Norris, Jr., and J. J. Iannucci; October 1980.

A task force of Sandia National Laboratory's Livermore personnel has reviewed and evaluated the status of solar central receiver technology as of early 1980. The methodology and results of the evaluation are described. The evaluation concentrated on the detailed component and system designs developed by the industrial firms; the conclusions are based on these designs. The task force makes recommendations for the allocations of DOE R&D resources within the Solar Central Receiver Program. Results of the evaluation are also intended to point out to developers of central receiver technology where improvements are necessary. The recommendations emphasized the need for a continuing effort on the nitrate salt technology for large-scale electricity generation. This technology is appears to be capable of producing energy over a wide range of capacity factors at lower costs than the other heat transport fluids. A brief discussion of central receiver technology applied to industrial process heat is presented.

SAND-80-8239: STRATEGY FOR HELIOSTAT COMMERCIALIZATION: L. D. Brandt; November 1980.

Commercial viability of the solar central receiver technology depends in part on the availability of low cost, mass-produced heliostats. This study recommends a path for developing an independent industry capable of producing such heliostats. Conclusions are drawn largely from discussions with firms currently involved in the heliostat research and development program. Evolution of heliostat costs during commercialization and factors that influence near term government demonstration programs are reviewed.

SAND-80-8242: THE IMPACT OF STORAGE UPON SOLAR PLANTS: GENERAL PRINCIPLES AND SEASONAL APPLICATIONS; J. J. Iannucci; February 1981.

In order for central solar electric plants to make a sizable impact on this nation's energy supply, they must first be economically competitive with the alternatives. Such plants will have to contend with daily-, seasonal-, and weather-induced variations in solar availability (insolation). Thus, there will generally be a need for storage of solar energy either to achieve reliability or high-capacity factors. This study examines the worth of the way in which storage should be utilized in nongrid integrated solar plants. Both the solar/fossil hybrid electric plant and, as a special case, the pure solar plant are considered. The approach taken has been to develop general principles for solar energy storage which are widely applicable and useful,

even beyond solar thermal plants. The basic thrust is to explain the rather simple relationships between collector field sizes, storage ratings, and plant output. Where applicable, detailed computer simulation and/or simple analytical tools are used to eliminate storage implementation strategies. These tools are then applied to specific case of "seasonal" energy storage using thermal chemical processes. In the computer model, hour-by-hour insolation data are used for Albuquerque, New Mexico; Miami, Florida; Madison, Wisconsin; and New York, New York. The effective yearly variations is quantified by examining many years of data; and the sensitivity to fossil fuels, heliostat and storage subsystem cost is determined.

SAND-80-8245: COST-PERFORMANCE COMPARISON OF WATER/STEAM RECEIVERS FOR SOLAR CENTRAL ELECTRIC POWER PLANTS: P. De Laquil, III, C. T. Schafer, and S. E. Faas; December 1980.

An evaluation of the relative cost performance of large solar central receiver electric power plants utilizing water/steam receivers has been performed. The investigation consisted of a system integration of receiver conceptual designs from three major boiler manufacturers for advanced turbine inlet conditions in thermal storage designs. The methodology and results of the evaluation are described. The results indicate which combinations of receiver designs, storage types, and thermal dynamic conditions hold promise for significant cost performance improvements when compared to first-generation water/steam technology.

SAND-80-8248: METHODOLOGY FOR ESTIMATING FUTURE MARKET VALUES OF SOLAR THERMAL TECHNOLOGIES; L. D. Brandt; December 1980.

Projections of the future market value of solar systems are needed to derive cost goals for the emerging solar thermal technologies. The research documented in this report has developed a methodology for projecting market values based on economic parity with the estimated future costs of conventional (fossil-fueled) technologies. Representative solar system values are presented for exemplary sets of economic assumptions including those under consideration by the Solar Thermal Cost Goals Committee. The effects on market value of variations in the rates of return required by potential users and the costs of alternative fuels are illustrated.

SAND-80-8502: PHASE DIAGRAM OF $NaNO_3/KNO_3$; C. M. Kramer and C. J. Wilson; April 1980.

The binary phase diagram of $NaNO_3$ and KNO_3 was studied using Differential Scanning Calorimetry (DSC). The phase diagram was modeled with regular solution theory. By fitting the

model to the minimum melting point of the system, the regular solution parameters and the heats of mixing for solid solutions of $NaNO_3$ and KNO_3 were estimated. Good agreement was obtained between our data for the liquidus, the previously determined liquidus, and the liquidus calculated from the model.

SAND-80-8505: DEPARTMENT OF ENERGY LARGE SOLAR CENTRAL POWER SYSTEM SEMIANNUAL REVIEW; Sandia; June 1980.

This report presents the highlights of the Department of Energy Large Solar Central Power System Semiannual Review held in Albuquerque, New Mexico, on March 19-20, 1980.

SAND-80-8620: CENTRAL RECEIVER TEST FACILITY; T. D. Brumleve; April 1980.

The Central Receiver Test Facility (CRTF) was constructed at Albuquerque, New Mexico for the U.S. Department of Energy (DOE) and is operated by Sandia Laboratories. A primary goal of the CRTF is to provide experimental engineering data for the design, construction, and operation of receivers and other components for proposed large scale, solar powered, electrical generation or process heat plants. A secondary goal is to provide a solar test facility for evaluating concepts and processes in high temperature technology.

The basic concept philosophy is outlined for the facility and defines the capabilities of the CRTF. A general description of the facility is given with details of all support systems: the tower, the heliostat array, the control building with its computer control and data acquisition systems, and the meterology station and tower.

Maximum energy delivered is 6.5 MW thermal so the 5 MW can be provided under a reasonable range of conditions. Operating tests with a working receiver absorbing over 1 MW of thermal energy are summarized. Present and future tests are outlined with the listing and proposed high-temperature experiments by university and industrial investigators. Tests completed included evaluation of a 1 MW air receiver and a 3 MW steam generating receiver.

SAND-80-8695: HIGH-TEMPERATURE SOLAR OPTION FOR ELECTRIC UTILITIES AND USERS OF PROCESS HEAT; A. C. Skinrood; June 1980.

Only in the last ten years has there been a significant effort to apply modern technology to the use of solar energy. One of the more promising approaches now receiving world-wide attention is the central receiver concept, in which a field of individually aimed mirrors, or heliostats, focuses the sun's energy onto a tower-mounted receiver where

a concentrated flux heats a fluid used to power a turbine or to heat an industrial process. Energy concentrations greater than 1,000 suns, leading to high efficiencies, are easily attained. Feasibility has been demonstrated, and if present cost trends continue, solar energy costs may soon be competitive with those of fossil fuel--including coal. Land use would be modest. If present process continues over the next five years, the concept will become a practical energy option.

SAND-80-8789: MATERIALS ISSUES IN SOLAR THERMAL ENERGY SYSTEMS; R. W. Mar; May 1981.

The solar central receiver concept for the production of electrical energy or industrial process heat has been the subject of recent system, conceptual and commercial design studies. This paper explores the materials issues likely to be associated with development of this technology. The scope of this paper is limited to concepts using nitrate salts as the heat transfer and energy storage media. Heliostat, fluid and containment materials are discussed with regard to system requirements, candidate materials, performance under simulated and field test experiments, and areas of future research. The emphasis is on the materials which are the leading candidates for use in near-term systems.

SAND-80-8856: CORROSION OF 304SS BY MOLTEN $NaNO_3$-KNO_3 IN A THERMAL CONVECTION LOOP; R. W. Bradshaw; December 1980.

The corrosion behavior of Type 304 stainless steel in molten $NaNO_3$-KNO_3 was studied at temperatures between 600° C and 350° C using thermal convection loops. Corrosion rates were somewhat less than 2.5×10^{-2} mm/year (1 mil/year) at the maximum temperature. Two corrosion processes were observed, formation of oxide scales and depletion of chromium from the alloy. Oxidation products generally consisted of at least two layers, a layer of Fe_3O_4 over an iron-chromium spinel. In addition, a complex oxide was detected which appeared to be a double oxide of iron and, a salt impurity, magnesium. Chromium accumulated as a soluble product in the melt but thermal gradient mass transfer was not observed. Chromium depletion kinetics were approximately parabolic with time suggesting a diffusion controlled process. Autogenous weldments experienced somewhat more corrosion in the heat-affected zone than either the fusion zone or the parent alloy.

SAND-81-0048: INCENTIVES FOR SOLAR ENERGY IN INDUSTRY; K. D. Bergeron; May 1981.

Several issues are analyzed on the effects that government subsidies and other incentives have on the use of solar energy in industry, as well as on other capital-intensive alternative energy supplies. Discounted cash flow analysis is used to compare tax deductions for fuel expenses with tax credits for capital investments for energy. The result is a simple expression for tax equity. The effects that market penetration of solar energy has on conventional energy prices are analyzed with a free market model. It is shown that net costs of a subsidy program to the society can be significantly reduced by price. Several government loan guarantee concepts are evaluated as incentives that may not require direct outlays of government funds; their relative effectiveness in achieving loan leverage through project financing, and their cost and practicality, are discussed.

SAND-81-0075C: STUDIES OF DUST ACCUMULATION ON SOLAR MATERIALS; R. B. Pettit, J. M. Freese and E. P. Roth; January 1981.

During outdoor exposure, solar mirror materials accumulate dust particles that can substantially reduce the intensity of the specularly reflected beam. Studies have shown that there is a complex interaction between significant variables such as the mirror material, local weather conditions, mirror orientation, and cleaning procedures. Investigation of different water spray cleaning techniques has shown that the specular reflectance even after repeated cleanings shows a slow, continued decrease for all cleaning procedures studied. Spraying with deionized or soft water were the most effective cleaning procedures. Cleaning with very dilute HF solutions can, however, restore the reflectance to its original value.

SAND-81-0275 (REV): HELIOSTAT OPERATION AT THE CENTRAL-RECEIVER TEST FACILITY (1978-1980); J. T. Holmes; July 1981.

The data and conclusions reported are for the 222 CRTF heliostats that have been in operation from 1978 through 1980. The CRTF beam produces a total power of 5.5 MWth and a peak intensity of 2,250 kW/m^2 near solar noon. A new operating strategy has recently been implemented. Improvements in the targeting accuracy have been made. The mirror reflectivity is maintained near 80 percent by cleaning with natural rains or snow. The CRTF has logged almost 300,000 operating hours by the end of 1980.

SAND-81-0290: INITIAL EXPERIENCE AND PRELIMINARY RESULTS: SOLAR COLLECTOR MATERIALS EXPOSURE TO THE IPH SITE ENVIRONMENT; D. E. Randall and V. L. Morris; March 1981.

A test program to evaluate the influence of the industrial plant site environment upon the performance characteristics of solar collector reflector and receiver materials is being conducted at Industrial Process Heat solar project sites. This program has demonstrated that the industrial environment offers a variety of sources that can affect the optical characteristics of reflectors and receivers through the mechanisms of soiling and corrosion. Preliminary test results are presented herein.

SAND-81-0402: ANALYSIS OF FIVE-TUBE SOLAR RECEIVER PANEL TEST DATA; L. N. Kmetyk; April 1981.

An analytic model for a radiation-boiler panel has been developed, and the results compared to the experiment. Experimental data are from tests of a radiation-heated 5-tube boiler panel conducted by Sandia Laboratories. Test panel geometry incorporates design features to be used for the Barstow 10-MW Solar Central Receiver Electric Power Plant. Calculations were performed for the 5-tube test using the nuclear plant's system code RELAP4. Studies state operating conditions for a given incident heat flux were calculated from a 0-power cold-water start-up. Thermal-hydraulic isolations were predicted, the period in amplitude agreed well with the experiment, and they were damped out by increasing inlet flow resistance, as expected. The effects of different nodalizations were studied and the detail required for accuracy was determined.

SAND-81-0761: SUN-POINTING PROGRAMS AND THEIR ACCURACY; J. C. Zimmerman; May 1981.

This paper describes several sun-pointing programs and their accuracy. Fortran program listings are given. Program descriptions are given for Hewlett-Packard (HP-67), Texas Instruments (TI-59) and hand-held calculators.

SAND-81-1025: USE OF SANDIAS CENTRAL RECEIVER TEST FACILITY AS A HIGH-INTENSITY HEAT SOURCE FOR TESTING MISSLE NOSE-CONE (RADOME) RADAR SYSTEMS; D. R. Porter; September 1981.

A series of tests at Sandia's Central Receiver Test Facility in support of the U.S. Navy's SM-2 Blk 2 Radome Improvement Program is described. The CRTF was the source of high-intensity solar radiation for testing onboard radar-tracking systems under heating conditions intended to simulate those that occur in supersonic flight. Also discussed are the hardware used and the software developed at the CRTF.

SAND-81-1180: USER'S GUIDE TO HELIOS: A COMPUTER PROGRAM FOR MODELING THE OPTICAL BEHAVIOR OF REFLECTING SOLAR CONCENTRATORS. PART I. INTRODUCTION AND CODE INPUT; C. N. Vittitoe and F. Biggs; August 1981.

HELIOS is a flexible computer code for evaluating designs for central-receiver, parabolic-dish, and other reflecting solar-energy collector systems, for safety calculations on the threat to personnel and to the facility itself, for determination of how various input parameters alter the power collected, for design trade-offs, and for heliostat evaluations. Input variables include atmospheric transmission effects, reflector shape and surface errors, suntracking errors, focusing and alignment strategies, receiver design placement positions of the tower and mirrors, and time of day and day of the year for the calculation. Complete input instructions and a description of the code structure are given. The Code is in use at Sandia National Laboratories, Albuquerque (SNLA) on CDC 6600, CYBER 76, and CDC 7600 computers.

SAND-81-1220: ANALYSIS OF 70-TUBE PILOT PLANT SOLAR RECEIVER PANEL TEST DATA; L. N. Kmetyk and R. K. Byers; August 1981.

An analytic model for a solar receiver boiler panel has been developed, using the RELAP4 nuclear plant systems thermal-hydraulic computer code. Results are compared to other computer calculations and experimental data from tests conducted by McDonnell-Douglas. The test panels were prototypes of panels to be used in the Barstow 10-MWe Solar Central Receiver Electric Pilot Power Plant. Results are also compared to analytic studies done by Combustion Engineering as part of the test data evaluation. Steady state operating conditions for a given incident heat flux were calculated from a zero-power cold-water start-up. The effects of incident flux axial profile shape and of lateral flux gradients were studied, as was the dynamic response of the model to flux and flow transients. The nodalization detail required for accurate simulation was also determined.

SAND-81-1284C: 5 MW FOR SOLAR-CHEMISTRY DEVELOPMENT; J. T. Holmes; 1981.

The US-DOE, 5-MW Solar Central Receiver Test Facility (CRTF) has been operating since 1978 to develop and proof-test high-efficiency solar receivers and collectors (heliostats) for applications such as electricity generation and process heating. The CRTF is available for solar chemical process development studies. DOE is planning a Sun Fuels program. Its goal is process demonstrations for upgrading both nonrenewable and renewable feedstocks into conventional fuels. To additionally benefit from the high-intensity

light source, studies on the direct solar pyrolysis of metal halides and carbonyls to produce high-purity, high-value metals are recommended.

SAND-81-1541: SOLAR ENERGY SYSTEM DESIGN: A SIMPLE METHOD FOR SIZING THE COLLECTOR FIELD AND THERMAL STORAGE; R. R. Peters; July 1981.

The Zero Marginal Cost (ZMC) technique was developed to enable quick, accurate designs of parabolic trough solar systems. The ZMC technique is discussed and it is shown that systems designed with this technique compare quite favorably with those designed using expensive computer codes. Information included allows systems to be designed for four locations: Albuquerque, NM; Dallas, TX; Fresno, CA; and Washington DC.

SAND-81-1547C: FLUX-MAPPING AT CRTF; J. T. Holmes; April 1981.

The Central Receiver Test Facility uses an array of flux density sensors to measure the power and flux density distributions for major receiver test programs. A mechanical device, called the Real Time Aperture Flux system (RTAF), was used to move a row of individual sensors across the aperture of an air-cooled receiver and a molten salt-cooled receiver. The RTAF moving bar system is described, and its control and data computer system are discussed.

SAND-81-1562: A USERS' GUIDE TO HELIOS: A COMPUTER PROGRAM FOR MODELING OF THE OPTICAL BEHAVIOR REFLECTING SOLAR CONCENTRATORS, PART III - APPENDICES CONCERNING HELIOS CODE DETAIL; C. N. Vittitoe and F. Biggs; September 1981.

HELIOS is a flexible computer code for evaluating designs for central-receiver, parabolic-dish, and other reflecting solar-energy collector systems; for safety calculations on the threat to personnel and to the facility itself; for determination of how various input parameters alter the power collected; for design tradeoffs; and for heliostat evaluations. Input variables include atmospheric transmission effects; reflector shape, surface, and suntracking errors; focusing and alignment strategies; receiver design; placement positions of the tower and mirrors; time-of-day and day-of-year for the calculation. Part III is a series of appendices giving code details for subroutine and function descriptions, how common blocks are used, sample jobstreams, and magnetic tape use within the code.

SAND-81-1618: A GAME THEORY APPROACH TO CONSUMER INCENTIVES FOR SOLAR ENERGY; J. K. Sharp; November 1981.

Solar energy is currently not competitive with fossil fuels. Fossil fuel price increases may eventually allow solar to compete, but incentives can change the relative price between fossil fuel and solar energy, and make solar compete sooner. This paper develops examples of a new type of competitive game using solar energy incentives. Competitive games must have players with individual controls and conflicting objectives, but recent work also includes incentives offered by one of the players to the others. In the incentive game presented here, the Government acts as the leader and offers incentives to consumers, who act as followers. The Government incentives offered in this leader-follower (Stackelberg) game reduce the cost of solar energy to the consumer. Both the Government and consumers define their own objectives with the Government determining an incentive (either in the form of a subsidy or tax) that satisfies its objective. The two hypothetical examples developed show how the Government can achieve a stated solar utilization rate with the proper incentives. In the first example, the consumer's utility function guarantees some purchases of solar energy. In the second example, the consumer's utility function allows for no solar purchases because utility is derived only from the amount of energy used and not from the source of the energy. The two examples discuss both subsidy and tax incentives, with the best control over solar uses coming from fossil fuel taxes dependent upon the amount of solar energy used. Future work will expand this static analysis to develop time varying incentives along a time and quantity dependent learning curve for the solar industry.

SAND-81-1717C: DISTRIBUTED COMPUTER CONTROL OF THE CENTRAL RECEIVER TEST FACILITY; D. B. Davis; June 1981.

The computer-based control system is an overall command, control, and data system that performs facility management and supervision as well as data collection, analysis, and presentation. The system uses 10 minicomputers in a modular, function-oriented network. Besides the real time control and data requirements of the facility and experiments, there are background and off-line support tasks that are provided by ancillary systems. These include the focus and alignment subsystem and a meteorological sensor package.

SAND-81-1735: CENTRAL RECEIVER TEST FACILITY ASSEMBLY BUILDING; C. R. Maxwell and J. T. Holmes; January 1982.

The passively solar heated Assembly Building located at the Central Receiver Test Facility and its performance during a one-year data acquisition period are described. The effect of the air changes per hour on the solar savings fraction as well as the performance of the south-facing thermal storage wall when supplementally illuminated are detailed.

SAND-81-1776C: SOLAR FURNACE FOR FLUX GAGE CALIBRATION AND THERMAL-EFFECTS TESTING; R. M. Edgar, E. H. Richards and G. P. Mulholland; October 1981.

The solar furnace consists of a 7.4-m square heliostat, a 6.7-m diameter concentrator, an attenuator designed to vary the flux-density at the test area, and a three-axis positioning table at the test area. Its primary function will be the calibration of flux gages but other tasks and/or experiments will be considered as time permits. The furnace will provide a spot 12 cm in diameter with a peak flux density of 4000 kW/m^2 (100 cal/cm^2 sec).

SAND-81-1831: DEVELOPMENT OF A RELAP MODEL FOR THE BARSTOW THERMAL-STORAGE SUBSYSTEM; R. K. Byers and L. N. Kmetyk; October 1981.

A systems effects plan model is being developed to study operational transient response in the Barstow solar-electric pilot power plant, using the nuclear power plant systems program RELAP. Since most of the major solar plant components are either identical to or closely resemble those found in conventional nuclear plants, no great difficulty is anticipated in developing such a RELAP model. However, in the Barstow plant, the thermal storage system consists of a large tank of oil and rock; thus the oil must be included in RELAP as a separate working fluid. This has been done, and a RELAP model for the thermal storage subsystem has been developed. A finite-difference, predictor-corrector, numerical technique has been included in RELAP to solve for fluid and solid temperature distributions in one-dimensional flow through the dual-media storage tank's packed bed. Nominal flow operating conditions have been calculated from zero-power cold- and hot-oil start-ups for the charging and extraction modes, respectively.

SAND-81-2045C: CARRIER SIGNAL TECHNOLOGY APPLIED TO SOLAR COLLECTOR FIELD CONTROL; R. L. Alvis; 1981.

The development and operational performance are described of a control system designed specifically for solar distributed collector field systems. Carrier technology is employed to eliminate costly field-constructed control wiring and allows

the control system quality to be controlled at system supplier's plants. Prototype hardware has been built and tested in the field with excellent operating results.

SAND-81-2390C: RESULTS OF SOLAR TESTING OF CIRCULAR FOIL HEAT-FLUX SENSORS AT THE WHITE SANDS SOLAR FURNACE; B. L. Bainbridge; October 1982.

A pair of circular foil heat-flux sensors were tested against a Kendall radiometer at the White Sands Solar Furnace facility in September 1981. The gages are a novel form of the circular foil type in that a mirrored ellipsoidal cavity is positioned in front of the foil surface. A small-diameter aperture is used to reduce convective losses and the susceptibility of the gage to handling damage. An error analysis performed on the data acquired during the 5-day test program indicates that atmospheric conditions and limitations of the facility preclude the accurate comparison of the heat-flux sensors to the Kendall radiometer. Details about the data acquisition, error analysis, and considerations about the proper gage calibration procedure are included.

SAND-81-2508C: EXPERIMENTAL STUDY OF SINGLE-MEDIA THERMOCLINE THERMAL-ENERGY STORAGE; R. J. Gross; 1982.

Experiments were conducted on a 1200-gallon single-medium thermocline facility to determine the feasibility of the thermocline thermal-energy storage concept on a large scale and to determine the relative importance of each of the five heat loss mechanisms present in such a system. The results of heat loss tests, static thermocline cool-down tests and charge/discharge tests are presented. A simple one-dimensional model is proposed for the prediction of the temperature field during a cool-down test in which a thermocline is present. The model agrees well with the experiment.

SAND-81-6000: TURBULENT STRUCTURES IN THE WAKE OF A HELIOSTAT; J. M. Germa; January 1981.

The systematic wind tunnel study of the wake revealed a periodic alternating and turbulent phenomenon with a vertical axis whose characteristics are close to those of a Karman channel ($A = B = 0^{o}$). The particular structure of this wake is attributed to the proximity of the ground. The development of alternating structures is maximum in the wake for X/D approx. = 1 and decreases downstream; for $X/D > 3$, no periodicity was observed in the flow. The wake structure is not changed by slight variations in heliostat orientation with respect to the incident wind; the vortex detachment persists when the angles of incidence and sideslip remain

less than about 20^{o}. For velocities greater than 15 to 20 m/s, the Strouhal frequency of the wake approaches the eigen frequencies of the heliostats. The resonance excitation of the first eigen modes of the structure is then possible. The direct influence of incident wind turbulence is limited by the low energy contained in the spectrum of upstream velocity fluctuations to the eigen frequencies of the actual heliostats. Furthermore, these fluctuations are random. The study of turbulent forces confirms the periodic structure of the wake. The phenomenon is magnified when the heliostat is placed downstream of an identical reflector.

SAND-81-7011: CONCEPTUAL DESIGN OF A GLASS-REINFORCED CONCRETE SOLAR COLLECTOR; A. J. Slemmons, D. W. Ploeger and R. Lundgren; July 1981.

An investigation of the properties and characteristics of glassfiber-reinforced concrete (GRC) was made to determine its suitability as a reflector substrate and structure for heliostats and solar collectors. The material properties and characteristics of GRC were established by tests on small, flat panels. A conceptual design of a 2-m x 6-m parabolic trough solar collector module and a preliminary production cost analysis were also completed.

SAND-81-7028/1 and SAND-81-7028/2: SOLAR COLLECTOR MATERIALS EXPOSURE TO THE IPH SITE ENVIRONMENT. VOLUMES 1 AND 2. FINAL REPORT; V. L. Morris; January 1982.

In-situ environmental exposure tests were conducted at nine proposed intermediate-temperature Industrial Process (IPH) sites. Three types of reflector materials were evaluated for survivability at the nine sites: second-surface silvered glass, aluminized acrylic FEK-244 film on aluminum substrate and Alzak (electropolished aluminum) on aluminum substrate. Black chrome absorber material and low-iron float glass were evaluated for thermal photochemical, and environmental degradation. The reflector specimens were monitored for decreases in specular and hemispherical reflectance due to soil buildup. The absorber material was evaluated for changes in solar absorptivity and emissivity, and the float glass was monitored for changes in transmissivity. Surface and subsurface defects on all materials were examined microscopically and where deemed of note, were documented photographically.

SAND-81-7029: SOLAR-COLLECTOR MATERIALS EXPOSURE TO THE IPH SITE ENVIRONMENT TASK 5.0. FINAL REPORT; V. L. Morris; July 1982.

An in-situ environmental exposure test was conducted at Texfel Petroleum Company, Bakersfield, CA. This site

utilizes solar energy for enhanced oil recovery procedures. Two types of reflector materials were evaluated for survivability in this environment: second-surface silvered glass and aluminized acrylic (FEK-244) on an aluminum substrate. Black chrome absorber material and low-iron float glass were evaluated for thermal, photochemical, and environmental degradation. The reflector specimens were monitored for decreases in specular and hemispherical reflectance due to soil buildup. The absorber material was evaluated for changes in solar absorptivity and emissivity and the glass cover plates were evaluated for changes in transmissivity. Surface and subsurface defects on all materials were examined microscopically and where deemed of note, were documented photographically.

SAND-81-8005: SOLAR POWER TOWER DESIGN GUIDE: SOLAR THERMAL CENTRAL RECEIVER POWER SYSTEMS, A SOURCE OF ELECTRICITY AND/OR PROCESS HEAT; K. W. Battleson; April 1981.

The solar power tower design guide provides the information necessary to perform preliminary evaluations of whether a solar thermal central receiver plant is technically and economically feasible, as well as desirable, for the potential users' application. The cost elements, performance, and operation of solar central receiver systems are described.

SAND-81-8007: THE CHEMISTRY OF THE BINARY $NaNO_3$-KNO_3 SYSTEM; D. A. Nissen; June 1981.

By chemical analysis of samples taken under carefully controlled conditions, we have been able to show that the only reaction of any consequence that takes place in the equimolar binary $NaNO_3$ - KNO_3 system over the temperature range 500-600° C is represented by

$$NO_3^- \rightleftharpoons NO_2^- + 1/2(O_2)$$

Over this temperature range there is no evidence of the formation of any anionic oxygen species, such as oxide, peroxide, or superoxide, at concentrations greater than 10^{-6} mole/kg. Equilibrium constants for the above reaction have been determined over the temperaure range 500-620° C. The standard free energy for this reaction (ΔG^o = -23,029 + 20.64T) has been derived from the experimental data and is in good agreement with similar data for the single salts.

SAND-81-8008: TESTING OF THE PROTOTYPE HELIOSTATS FOR THE SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; Sandia; April 1981.

As part of the competition for production of heliostats for the pilot plant, the Martin Marietta Corporation and the

McDonnell Douglas Astronautics Company each built prototype heliostats and components (drive mechanisms and mirror modules) which were subjected to an extensive test program by Sandia National Laboratories in 1979. An overview of the tests and their results are presented. Heliostat and controls tests, structural tests on the drive mechanism, environmental drive assembly tests, and mirror module tests are reported.

SAND-81-8013: A SOLID ELECTROLYTE OXIDE ION ELECTRODE FOR MOLTEN NITRATES; D. A. Nissen; October 1981.

An oxide ion sensitive electrode of the type Pb, $PbO/ZrO_2(Y_2O_3)//$ was constructed and its performance tested in the binary, equimolar molten salt $NaNO_3$-KNO_3 over the temperature range 336-350° C. The response of this electrode to oxide ion concentrations over the range 10^{-6}-10^{-10} moles/kg is linearly dependent upon log [0=], and dE/dlog [0=] corresponds to a two-electron process.

SAND-81-8014: CONVECTIVE LOSSES FROM SOLAR CENTRAL RECEIVERS PROCEEDINGS OF A DOE/SERI/SNLL WORKSHOP; P. K. Falcone; October 1981.

Convective losses are an important part of energy lost from solar central receivers; increases and understanding of such loss processes and thus, and receiver efficiencies through design modifications for the goal of ongoing research programs. A workshop to review research in this area was hosted by Sandia National Laboratories, Livermoor in conjunction with the Department of Energy and the Solar Energy Research Institute on March 25-27, 1981. Presentations and discussions at the workshops are summarized in this report.

SAND-81-8015: SOLAR REPOWERING ASSESSMENT; J. C. Gibson; June 1982.

Provided is the assessment of solar repowering studies that were completed by 1980. The ease of interfacing with existing plants, the interest expressed by plant managers in the central receiver concept, and the awareness on the part of industry of the need to develop alternative energy sources all point to near-term high potential for solar central receiver technology. A major barrier to private investment appeared to be the need for larger experimental projects to establish actual costs and develop initial operating experience.

SAND-81-8017: NONLINEAR THERMAL AND STRUCTURAL ANALYSIS OF A BRAZED SOLAR-CENTRAL RECEIVER; L. M. Napolitano, Jr. and M. P. Kanouf; July 1981.

One part of the evaluation program for a molten-sodium central receiver was to be a test of a reduced-scale panel at Sandia's Central Receiver Test Facility in Albuquerque. The panel incorporates a new way of joining tubes-brazing to intermediate filter strips-which can affect the panel's lifetime. To calculate the stresses and strains for the worst-case section of the experimental panel, we have done a nonlinear elastic-plastic analysis with the MARC finite element computer code, which takes the temperature dependence of the material properties into account. From the results, tube design lifetimes are predicted. The analysis shows that concerns for cracking and reduction in lifetime are warranted, but a more detailed fracture analysis is necessary to determine whether there is a stable-crack-growth problem.

SAND-81-8020: INDUSTRIAL USE OF MOLTEN NITRATE/NITRITE SALTS; R. W. Carling and R. W. Mar; December 1981.

Nitrite salts have been used for years as a high-temperature heat transfer medium in the chemical and metal industries. This experience is often sited as an argument for the use of these salts in large-scale solar energy systems. However, this industrial experience has not been well documented and this study was carried out to provide such information to the solar community and to determine the applicability of this data base. Seven different industrial plants were visited and the plant operators were interviewed with regard to operating history and experience. In all cases the molten salt systems operate without problems. However, it is not possible to apply the base of industrial experience directly to solar thermal energy applications because of differences in operating temperature, salt composition, alloys used, and thermal/mechanical conditions.

SAND-81-8022: CENTRAL-RECEIVER INFRARED TEMPERATURE-MEASUREMENT EXPERIMENT; J. C. Gibson; April 1982.

Instrumenting a central receiver to obtain front surface temperature measurements has been difficult. A system has been investigated that is potentially capable of measuring receiver temperatures by optically monitoring radiated infrared energy. Comparison of the experimental data with the temperature data obtained from receiver-mounted thermocouples indicates satisfactory experimental results; however, the absolute accuracy of these results has not been determined.

SAND-81-8023: STRUCTURAL ANALYSIS OF SECOND-GENERATION HELIOSTATS; V. D. Dunder; December 1981.

As part of the overall evaluation of the four second-generation heliostats, a finite element analysis was performed to evaluate structure performance of the mirror modules subjected to gravity. Operational wind loads and survival wind loads. All designs evaluated were found to be structurally adequate.

SAND-81-8031: HELIOSTAT COST-ANALYSIS TOOL; L. D. Brandt and R. E. Chang; October 1981.

Estimated production costs of solar-energy systems serve as guides for future component development and as measures of the potential economic viability of the technologies. The analysis of heliostat costs is particulary important since the heliostat field is the largest cost component of a solar central receiver plant. A heliostat cost analysis tool (HELCAT) that processes manufacturing, transportation, and installation cost data has been developed to provide a consistent structure for cost analyses. HELCAT calculates a representative product price based on direct input data (e.g., direct materials, direct labor, capital requirements) and various economic, financial, and accounting assumptions. The characteristics of this tool and its initial application in the evaluation of second-generation heliostat cost estimates are discussed. A set of nominal economic and financial parameters is also suggested.

SAND-81-8033: SECOND-GENERATION HELIOSTAT EVALUATION EXECUTIVE SUMMARY; Sandia; January 1982.

As technical manager of the second-generation heliostat development contracts for the Department of Energy, Sandia National Laboratories has evaluated five heliostat designs. Four of the heliostats are viable designs with unique approaches to the same generic design. The designs have varying amounts of risk and additional development required. Minor design changes can benefit all of the designs. Detailed cost estimates indicate that the heliostat cost goal can be met at low production rates. The evaluation and Sandia's conclusions are briefly summarized.

SAND-81-8034: SECOND-GENERATION HELIOSTAT EVALUATION, SUMMARY REPORT; Sandia; January 1982.

As technical manager of the second-generation heliostat development contracts for the Department of Energy, Sandia National Laboratories has evaluated five heliostat designs. Four of the heliostats are viable designs with unique

approaches to the same generic design. The designs have varying amounts of risk and additional development required. Minor design changes can benefit all of the designs. Detailed cost esitmates indicate that the heliostat cost goal can be met at low production rates. The evaluation pertains to the heliostats only and does not rate the contractors (ARCO, Boeing, Martin Marietta, McDonnell Douglas, and Westinghouse). A condensed version of this report is available in the Executive Summary (SAND-81-8033).

SAND-81-8175-V.1: FINAL REPORT, SECOND-GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVERS - VOLUME I, DETAILED DESIGN REPORT; Boeing Engineering and Construction Company; March 1981.

A production heliostat for a 50-MW solar electric power plant is described. The detail design, along with trades, analyses and testing in support of the design are presented. The collector subystems performance is assessed. Fabrication, checkout and installation of two prototypes at the Department of Energy Central Receiver Test Facility is described. Appendices are provided which described details of design, analysis and tests.

SAND-81-8175 V.1-APP.2: FINAL REPORT SECOND-GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVERS - VOLUME I - DETAILED DESIGN REPORT, APPENDICES 2; Boeing Engineering and Construction Company; March 1981.

Trade studies, design analysis, and test procedures for the heliostats are reported. These include trade studies of the azimuth and elevation drives and elevation actuator, azimuth drive and elevation drive design analysis, pointing error analysis, test procedures for the actuator screw and nut, azimuth drive/bearing and gimbal/actuator drive assembly, and information on the electrical drive control and sensors.

SAND-81-8175 V.1-APP.1: FINAL REPORT SECOND-GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVERS - VOLUME 1 - PRODUCTION PLANNING AND COST ESTIMATES AND APPENDICES A, B, C, E, F, G, H, W, Y; Boeing Engineering and Construction Company; March 1981.

Appendices are provided which describe details of design, analysis and test of the heliostats, azimuth drive, bearing assembly, assembled gimbal, actuator drive assembly, reflectors, and the control system.

SAND-81-8175 V.2-APP.I AND J: FINAL REPORT SECOND-GENERATION HELIOSTAT DEVELOPMENT FOR SOLAR CENTRAL RECEIVERS - VOLUME 2 - DETAIL DESIGN REPORT, APPENDICES I AND J; Boeing Engineering and Construction Company; March 1981.

Two appendices are included. The first is a heliostat manufacturing study consisting of evaluations of variable cost and investment costs, program engineering, training, preactivation and launching, savings opportunities, and selling price, and including descriptions of the facilities and manufacturing plan. A large volume of backup data for the study is included, particularly process estimates. General support departments and system and other backup data are included. The second appendix is detailed cost and process description data for the heliostat facet assembly.

SAND-81-8176-V.1: SECOND-GENERATION HELIOSTAT DEVELOPMENT. FINAL REPORT; Martin Marietta Aerospace; April 1981.

The detailed design of the second-generation heliostat is presented with the supportive analyses. Component and system test data are given. The preliminary design of the manufacturing plant is described. Costs to manufacture, transport, install and maintain 50,000 heliostats per year in 50-MWe fields are projected. Cost estimates are made on a worst-case basis.

SAND-81-8176-V.2: SECOND-GENERATION HELIOSTAT DEVELOPMENT. FINAL REPORT; Martin Marietta Aerospace; April 1981.

The design, manufacture, testing and cost analysis of the second-generation heliostat are described in Volume I. Volume II consists of appendices of supporting material. These include the drawing tree for the heliostat, structural data of the rack assembly, drive mechanism, and mirror assemblies, tests and results, a trade study on the pedestal foundation design, cost analysis worksheets, study of an edge-support mirror module, and a study of a single-motor, differential brake heliostat drive mechanism.

SAND-81-8177 EXEC. SUM: SECOND-GENERATION HELIOSTAT PROGRAM; McDonnell Douglas Astronautics Co.; April 1981.

The development and demonstration of a production design and production plans for the MDAC heliostat are summarized, including the selected heliostat configuration and design, site assembly, testing, maintenance, the production facility, volume heliostat price, and possible future cost reductions.

SAND-81-8177-V.1: SECOND-GENERATION HELIOSTAT. FINAL REPORT; D. A. Steinmeyer; April 1981.

The heliostat subsystem design is described. The test program is summarized, including component testing, subsystem operation at MDAC-Huntington Beach, and the shipment and installation at the Central Receiver Test Facility. The production heliostat description, the manufacturing process definitions, and the manufacturing facility definition are summarized. The installation, operations, and maintenance requirements for the 50-MWe field are summarized. Results are given of the cost analysis of the MDAC Second-Generation Heliostat when produced at an annual rate of 50,000 units per year and installed and operated in a field of 5412 heliostats. Possible future development activities aimed at further cost reduction are discussed.

SAND-81-8177-V.2: SECOND-GENERATION HELIOSTAT. VOLUME II. DEFINITION OF A HELIOSTAT MANUFACTURING FACILITY. FINAL REPORT; McDonnell Douglas Astronautics Co.; April 1981.

The heliostat design is described. A study is performed to provide the definition of a heliostat manufacturing facility capable of producing 50,000 heliostats per year and to generate the manufacturing costs associated with that level of production. The heliostat plant site, plant layout, and cost of the plant are discussed. The manufacture of heliostats, including special requirements for the heliostat mirror, and production costs are given.

SAND-81-8178-V.1: SECOND-GENERATION HELIOSTAT DEVELOPMENT. VOLUME II. SECTIONS 1.0 TO 3.0. FINAL REPORT; Northrup Inc.; March 1981.

The Northrup heliostat, the major component elements, and the rationale for the approach selected are described in detail. The performance evaluation is presented, including weight, deflections, stress levels, and in the case of the drive unit, torque, speed, and efficiency performance. System studies are summarized, including wind loads and moments, mirror module trade studies, rack structure trades, drive unit trade studies, and stow position trade studies. The results of the electronic and mechanical tests are summarized. Included in Vol. I is a brief summary of the whole 4-volume report.

SAND-81-8178-V.2: SECOND-GENERATION HELIOSTAT DEVELEOPMENT. VOLUME II. FINAL REPORT. JULY 16, 1979-MARCH 31, 1981; Northrup Inc.; March 1981.

The manufacturing studies completed include site selection and a detailed plan for a manufacturing plant capable of producing 50,000 heliostats per year. These studies identified a 680,000-square-foot plant located in the vicinity of Albuquerque, New Mexico as the desired facility. The heliostat components will be installed at sites within a 400-mile radius of the factory. The factory is located in or adjacent to a major city, and the power plant sites will most likely be remotely located so truck transportation becomes the only reasonable alternative. The designs, methods, and procedures involving the field assembly and installation are described. About 50 percent of the maintenance cost is related to mirror washing. Mechanical maintenance, constituting about 35 percent of the total, involves cleanup and painting of steel parts. Electrical and electronic components maintenance is also discussed. The cost per installed heliostat and the annual cost of owning, operating and maintaining a collector subsystem for a 50-MWe (peak) solar central receiver electrical power plant are determined.

SAND-81-8178-V.3: SECOND-GENERATION HELIOSTAT DEVELOPMENT. VOLUME III. APPENDICES A-E. FINAL REPORT, JULY 16, 1979-MARCH 31, 1981; Northrup, Inc.; March 1981.

The bill of material of the Northrup heliostat is tabulated. Portions of the drawings defining the heliostat subassemblies and assembly drawings are presented. On-site heliostat assembly and installation are summarized. Trade studies are presented that were performed in the course of the design progression which lead to the current configuration. Studies on wind loads, distribution, and moments, wind and gravity deflections, thermal curvature and stress, stress analysis in 90-mph wind, and drive unit performance are presented.

SAND-81-8178-V.4: SECOND-GENERATION HELIOSTAT DEVELOPMENT. VOLUME IV. APPENDICES F TO J. FINAL REPORT. JULY 16, 1979-MARCH 31, 1981; Northrup Inc.; March 1981.

The control software consists of two packages, one handling the external data processing, communication, and control and one handling the internal data processing, communication and direct motor control. The word structure used to communicate control information and status information between the two systems is defined. An overview flow diagram is provided for each package. Results of the electronic and mechanical tests are given and discussed at

length. Cost summaries for the manufacturing process are given. The technical specification for installation of open-end pipe piles is included. Surface preparation, application, and inspection of protective coatings for carbon steel heliostat piles are specified.

SAND-81-8179: DESIGN, HANDLING, OPERATION AND MAINTENANCE PROCEDURES FOR HITEC MOLTEN SALT; Badger Energy Inc.; January 20, 1981.

Presented are short statements on salt handling, initial loading of storage tank, maintaining the salt in a molten state, freezing and remelting, salt analyses, determination of solidification point and turbidity temperature of fused salt, nitrate and nitrite by ultraviolet spectrophotometry, determination of vitrite via sulfamic acid reaction nitrate titration, determination of sodium nitrate, determination of sodium nitrite, potassium nitrate, gravimetric via potassium chloroplatinate, platinum recovery, sodium carbonate via CO_2 evolution, determination of noncarbonate alkalinity and carbonate, determination of free alkali in fused salt, hydroxide and carbonate in heat transfer salt, determination of water by vacuum distillation and Karl Fischer tritation, salt regeneration, hardware, instruments, and a list of vendors.

SAND-81-8180: THERMAL PERFORMANCE, DYNAMIC STABILITY, AND THERMAL-STRESS CYCLING ANALYSIS OF RADIATION-HEATED BOILER TUBES BASED ON A 5-TUBE PANEL TEST; S. Wolf and D. Lo; January 1981.

Thermal performance of a radiation-heated boiler panel is reported. Both experimental and analytical results are given. The experimental data are from a 5-tube radiation-heated boiler panel test conducted by Sandia National Laboratories. The test panel geometry incorporates design features used for the Barstow 10-MWe Solar Electric Pilot Power Plant, and test conditions include simulated pilot plant operating conditions. Thermal performance predictions with computer models are compared with selective data. Overall thermal performance and axial distribution of temperatures and absorbed heat flux are predicted with a steady-state code which includes parameters to take into account two-dimensional effects resulting from nonuniform circumferential heating of the tubes. Differential pressure and temperature oscillations observed in parts of the data are identified as characteristic of density-wave dynamic channel instability. Selective experimentally determined unstable conditions are also predicted to be unstable with a state-of-the-art dynamic stability code, STEAMFREQ-I. The code is a frequency domain model. Stability threshold conditions are predicted and are shown to compare well with the corresponding experimetal values. The temperature oscillations are simulated with a two-dimensional thermal

model. A generalized plane strain elastic model is used for the stress analysis leading to fatigue life predictions. The results yield a conservative fatigue life prediction of 22.9 years, which is less than the 30-year design life of the solar pilot plant.

SAND-81-8181: THERMAL PERFORMANCE AND DYNAMIC STABILITY EVALUATION OF SOLAR PILOT PLANT RECEIVER PANEL TEST AT CRTF; S. Wolf and E. A. Hernandez; January 1981.

Thermal performance of a solar-heated boiler panel is reported. Both experimental and analytical results are given. The experimental data are from a 70-tube solar-heated boiler panel test conducted at the 5-MW Central Receiver Test Facility operated by Sandia National Laboratories. The test panel geometry incorporates design features used for the Barstow 10-MWe Solar Electric Pilot Power Plant, and test conditions include simulated pilot plant operating conditions. Thermal performance predictions with computer models are compared with selective data. Overall thermal performance and axial distribution of temperatures and absorbed heat flux are predicted with a steady-state code which includes parameters to take into account two-dimensional effects resulting from nonuniform circumferential heating of the tubes. Differential pressure and temperature oscillations observed in parts of the data are identified as characteristic of density-wave dynamic channel instability. Selective experimentally determined unstable conditions are also predicted to be unstable with a state-of-the-art dynamic stability code, STEAMFREQ-I. Dynamic instability-induced oscillations are shown to disappear during a test conducted with 1.85-mm (0.073-inch) tube inlet orifices for the pilot plant at approximately 100 percent receiver panel maximum power. However, in this case, severe control system fluctions are identified.

SAND-81-8182: DEVELOPMENT OF A LONG-LIFE HIGH-TEMPERATURE CATALYST FOR THE SO_2/SO_3 ENERGY STORAGE SYSTEM; E. W. Schmidt and W. G. Wilson; March 1982.

Chemical energy storage and/or transmission systems based on the reversible dissociation of sulfur trioxide depend on catalysts capable of operating for extended periods of time at temperatures near 1,089° K (1,500° F) without losing activity or subliming. Based on a review of catalysts currently used for production of sulfuric acid, none of the off-the-shelf catalysts will satisfy these requirements. A total of 50 new catalysts using 21 different active metals and a wide variety of catalyst carriers and preparation methods were prepared and tested for activity in SO_x reactions using differential isothermal reactors and pulsed microreactors. The most active catalyst, a 1 percent

platinum on alumina catalyst, was subjected to a 6-month accelerated life test at 1,144° K (1,600° F). Samples were periodically withdrawn to measure remaining activity. The main degradation mechanism was identified as loss of carrier surface area by sintering and platinum active metal by volatilization. The temperature to which the catalyst was exposed during the life test had been increased to 1,144° K in order to accelerate aging phenomena and in order to demonstrate margin. Based on tests in the differential isothermal reactor, activity remaining after 6 months at 1,144° K was approximately half of that of fresh catalyst.

A kinetic rate equation for the decomposition of undiluted SO_3 on a Pt catalyst at 1,005 to 1,135° K was derived from experimental data. A computer model was developed for the sizing of SO_3 decomposition reactors based on desired conversion and ten other input variables.

SAND-81-8184: CONCEPTUAL DESIGN SELECTION AND DEVELOPMENT OF A LATENT-HEAT THERMAL-ENERGY-STORAGE SUBSYSTEM FOR A SATURATED-STEAM SOLAR RECEIVER AND LOAD; Combustion Engineering Inc.; February 1981.

The following latent heat storage concepts are described and evaluated in comparison with each other and with an oil/rock sensible heat storage system: (1) passive tube intensive (shell-and-tube heat exchanger) with and without heat transfer enhanced by fins; (2) phase change material cans (or chubbs) with a biphenyl intermediate heat transfer fluid; (3) phase change mateial macroencapsulation in a containment tank full of tubes; (4) Microencapsulation in a porous carrier; (5) Direct contact heat exchange; and (6) systems using mechanical scrapers for removing solidified phase change material from container surfaces. A tube intensive system with heat-transfer enhancement was selected, and the conceptual design and cost/performance estimates are given for it. A commercial scale unit is assessed, and design changes and corresponding costs are presented that would be required to make the system meet changed requirements.

SAND-81-8185: FINAL REPORT ON LOW-CYCLE FATIGUE AND CREEP-FATIGUE TESTING OF STEAM-FILLED ALLOY 800 SPECIMENS; J. L. Kaae; November 1981.

Uniaxial low-cycle fatigue and creep fatigue tests have been carried out on hollow alloy 800 specimens that were filled with steam. The creep-fatigue tests were carried out to failure. The imposition of holds in the creep fatigue strain cycle produced substantial reduction from the lives observed in fatigue tests of the same strain ranges.

SAND-81-8186: MANUFACTURE, DISTRIBUTION AND HANDLING OF NITRATE SALTS FOR SOLAR-THERMAL APPLICATIONS; L. C. Fiorucci and S. L. Goldstein; November 1982.

Based on their low cost and attractive physical properties, molten sodium/potassium nitrate salts have been shown to be one of the most cost-effective fluids for heat absorption and thermal energy storage in Solar Central Receiver (SCR) systems. Information relevant to the availability, transport, handling, and utilization of these salts for commercial-size SCR applications is provided. An overview is provided of existing manufacturing processes for natural and synthetic nitrates; the upstream availability of raw materials; downstream existing and projected demand for these products in other sectors of the economy; and relevant handling and distribution technologies. Also reviewed are safety considerations and issues more directly related to the SCR facility, such as initial system charging, salt maintenance and regeneration, and disposal. Options for supply, surge storage, and initial charging are discussed for the 1-MWt to 300-MWe range of solar plant sizes.

SAND-81-8187: LIFE CYCLE AND OPERATIONAL TORQUE CAPABILITY OF THE SECOND-GENERATION AZIMUTH DRIVE. TEST REPORT; R. P. Rappoff; July 1981.

A harmonic drive unit was evaluated for use in an MDAC-HB designed Second-Generation Solar Heliostat. The harmonic drive unit provides rotational capability to a commanded azimuth and reacts loads from the mirror assembly. The harmonic drive operational torque capability was increased from 100,000 in-lbs to 144,000 in-lbs. Evaluation testing consisted of:

1. Demonstration of increased torque capability.
2. Measurement of azimuth drive unit efficiency.
3. Accelerated life testing.

Results of the testing indicate that the azimuth drive will meet the heliostat design requirements. Life testing demonstrated adequate performance over a simulated 30-year life. Torque capability was in excess of 151,000 in-lbs after completing the life tests. The azimuth drive unit efficiency was 7.8 percent driving against a 40,000- and 86,000-in-lb torque load.

The increased torque capacity azimuth drive unit performed satisfactorily, all design requirements were met, and the structural integrity of the unit was proven.

SAND-81-8190: CHEMICAL ENERGY TRANPORT FOR DISTRIBUTED SOLAR THERMAL ELECTRIC CONVERSION; R. D. Smith; July 1981.

This study examined the suitability of using reversible chemical reactions to transport energy, via an articulated pipe network, from distributed parabolic dish solar concentrators to a central power generation plant. Of the 85 chemical reactions initially screened, the reversible oxidation of sulfur dioxide (SO_2/SO_3), and the CO_2 reforming of methane were identified as most promising for distributed solar applications. A preliminary process design of a chemical energy transport subsystem based on the SO_2/SO_3 reaction produced a first law, transport efficiency estimate of 77 percent. Second law considerations reduced this to 62 percent. The SO_2/SO_3 energy transport subsystem capital cost was estimated to be between $160 and $200 per square meter of collector area, which corresponds to $400 to $490 per kW thermal delivered directly to the power cycle.

SAND-81-8191: EFFECTS ON SOILS FROM HOT-STORAGE TANKS; (Kenneth C.) Ko and Associates Inc; March 1982.

The characteristics of foundation soils normally encountered in the continental United States were investigated with respect to reactions at elevated temperatures. Two soils models, a sand soil and a more clayey soil, were developed as being representative of most foundation conditions. Temperature of hot tanks under consideration for the use of solar energy storage range 200° C to 816° C. The behavior of foundation soils under such high temperatures would dictate the design specifications of foundations for direct support of the storage tanks. The effects of the hot tank upon the two soil models were analyzed in terms of soil structure, soil/tank interaction and environmental problems in the case of spillage of the hot liquids.

SAND-81-8192/1: ALTERNATE CENTRAL RECEIVER POWER SYSTEM PHASE II, VOLUME 1 - EXECUTIVE SUMMARY; Martin Marietta Aerospace; January 1984.

The objective of the Phase II Alternate Central Receiver program was to demonstrate the feasibility of the molten salt central receiver power system by conducting a series of experiments and using the results to update the commercial-scale design developed during Phase I of the program. The experiments were directed at two levels of inquiry: the systems level testing of a 5 MW_th molten salt receiver--hereinafter referred to as the receiver SRE; and the investigation of molten salt chemistry and the compatibility of selected materials with molten salt. Chapters II, III and IV of this volume deal with the receiver SRE; Chapter V summarizes the commercial receiver

design update; and Chapters VI and VII present a discussion of the materials tests. Conclusions and recommendations for future work are given in Chapter VIII. Detailed discussion of the receiver testing is contained in Volume II of this report, while the materials tests are the subject of Volume III.

SAND-81-8192/2: ALTERNATE CENTRAL RECEIVER POWER SYSTEM, PHASE II, VOLUME II - MOLTEN SALT CENTRAL RECEIVER TESTS; Martin Marietta Aerospace; January 1984.

The Molten Salt Central Receiver testing was programmed around specific questions which were grouped into the following four catagories:

(1) Evaluation of molten salt (60% $NaNO_3$, 40% KNO_3) as a heat transfer fluid for central receivers. This is a two-sided question pertaining to thermo/hydraulic as well as thermo/structural aspects of molten salt performance: Molten salt as an effective collector of solar energy at acceptable heat transfer coefficients and pumping requirements; and as an effective coolant to the receiver tubes (especially at partial loads and during cloud transients) to maximize the creep-fatigue life of the receiver.

(2) Evaluation of thermal performance and its measurability with molten salt as the heat transfer fluid. The salt-oriented aspects of this question are closely related to Item (1) above and to the availability of appropriate thermophysical data; in a broader context it related to the progressing state-of-the-art of techniques for efficiency determinations by direct measurements.

(3) Operational reliability of components and procedures: the demonstration of sustained operation of the salt-compatible pump, 26 valves, instrumentation, controls, auxiliary systems, and other components of the receiver; in conjunction with acceptable operational procedures in light of the constraints imposed by the high freezing point of salt [221°C (430°F)].

(4) Applicability of existing design-, manufacturing-, and analytical techniques to molten salt receivers. This, in essence, established the state of development of molten salt receiver technology and the ability to predict receiver performance as applied to commercial-scale receiver design.

With some exceptions detailed under Chapter VIII--Conclusions and Recommendations, all of the pre-test

questions outlined above have been resolved affirmatively by the program. It is concluded that the state-of-the-art of molten salt receiver technology is sufficiently advanced to permit full-scale demonstration as the next logical step.

SAND-81-8192/3: ALTERNATE CENTRAL RECEIVER POWER SYSTEM, PHASE II, VOLUME III - MOLTEN SALT MATERIALS TESTS; Martin Marietta Aerospace; January 1984.

The materials and salt chemistry research experiments were designed to answer important questions on the use of molten salt mixtures of sodium and potassium nitrate in solar receiver applications.

The experiments were conducted to provide data in the areas of molten salt stability and materials compatibility which could be used in designing a commercial molten salt solar central receiver power system with a lifetime of 30 years or more. Specific questions addressed in designing these experiments were:

- What materials of construction could meet the design requirements for a solar receiver in a molten salt environment?
- Will molten salt stability be adequate for long term solar use?
- How can the molten salt be repurified or regenerated if degradation occurs?
- What effects may commercial salt impurities have on construction materials?
- Will material surface preparation or finish have an effect on molten salt compatibility?
- Do the mechanical properties of metal alloys change when exposed to molten salt?
- Does a material transport mechanism exist in a flowing molten salt system with a thermal gradient?

Four different categories of tests were conducted: (1) materials compatibility; (2) materials mechanical properties; (3) dynamic testing; and (4) salt chemistry tests. The first two categories were static materials immersion tests. The dynamic testing was conducted in a pumped molten salt loop covering a thermal gradient of 566°C (1050°F) to 288°C (550°F). The molten salt chemistry tests

were carried out in test vessels with controlled thermal and atmospheric environments.

Specific questions not addressed in these tests include long term thermal stability of molten salts, thermal cycling effects on mechanical properties of construction alloys, methods of inhibiting or passivating surfaces to prevent salt corrosion, and the effect of incremental temperature and atmospheric changes on salt stability. These and other areas should be addressed in future work. The remainder of this report is divided into six chapters. Chapters II through V contain descriptions and results of each test conducted. Chapter VI is a discussion of all the results in light of their impact on solar central receiver design, and Chapter VII is a collection of conclusions from the tests and recommendations for future work.

SAND-81-8201: A SIMPLE THOERY FOR PREDICTING THE NATURAL CONVECTIVE ENERGY LOSS FROM SIDE-FACING SOLAR CAVITY RECEIVERS; M. Abrams and R. Greif; January 1981.

A simple theory for predicting the convective energy loss from side-facing cavity receivers in windless environments has been developed. The approach used is to determine the velocity distribution of the incoming air in the aperature plane (and thereby the rate of mass entrainment); and then to estimate the bulk temperature of the heated emerging air. The convective loss is then calculated from an energy balance. To illustrate this theory, numerical results applicable to the 2.15-meter cubic cavity being tested in our laboratory are provided.

SAND-81-8207: COMPARISON OF ALTERNATIVE WASHING SYSTEMS FOR HELIOSTATS; A. Kerstein; April 1981.

Two methods have been proposed for washing heliostat mirrors in a solar central receiver facility. One method involves truck-mounted washing mechanisms continuously traversing the heliostat field, washing mirrors sequentially on a fixed schedule. The other concept involves a washing unit affixed to each heliostat, permitting near-simultaneous washing of all heliostats on demand. The former, scheduled washing system has the advantage of lower capital costs, while the latter, responsive system has more operational flexibility. Cost-benefit evaluation of the two systems, taking into account the random nature of rainfall patterns and soiling processes, indicates that the schedule system is preferable.

SAND-81-8213: DYNAMIC MODELING OF SOLAR CENTRAL RECEIVERS; W. S. Winters; July 1981.

This is the first in a series of reports documenting the receiver dynamic modeling effort at SNLL. The long-term objective of this effort is to produce a transportable well documented generalized computer code which can be used by contractors, utilities, and other interested parties for the purpose of evaluating proposed receiver control strategies. The report discusses the extent to which the physics need to be modeled in order to simulate the receiver dynamic operation. The particular flow loop and receiver configuration selected for initial modeling was that of the Martin-Marietta molten salt subsystem research experiments conducted in CRTF in late 1980. It is shown that a solution of a coupled continuity, momentum, and energy equations from salt flow is necessary for accurate simulation of system behavior during transients. A development plan for the first phase of the long-term modeling effort is also presented.

SAND-81-8216: INTERNATIONAL ENERGY AGENCY SMALL SOLAR POWER SYSTEMS (SSPS) PROJECT REVIEW (JANUARY 1981); A. F. Baker; May 1981.

The International Energy Agency Small Solar Power System Project being built in the Province of Almeria, Spain is reviewed from its beginning to January 1981. It provides background on the project and a definition and technical description of the main subsystems for the Central Receiver System and Distributed Collector System which are included in the project. The current status of the planning for the tests and operation phase of the project are discussed. These two solar-powered electric plants are scheduled to begin operation in August 1981.

SAND-81-8220: AN EVALUATION OF CREEP-FATIGUE LIFE PREDICTION MODELS FOR THE SOLAR CENTRAL RECEIVER; J. M. Hyzak and D. A. Hughes; September 1981.

The applicability of several creep-fatigue models to life prediction of the boiler tubes in a solar central receiver (SCR) is evaluated. The SCR boiler tubes will experience compressive strain dwell loading with hold times up to 6 to 8 hours at temperatures where time-dependent deformation will occur. Under these conditions, compressive dwell cycles can be more damaging than tensile dwell cycles at small strain ranges. Thus, classical life prediction models generally developed from tensile dwell data may not be applicable to the SCR. The evaluation criteria include the ability of the model to account for mean stress effects and to be practical in the long-life, small strain range regime. The review shows that most models including Linear Damage

Summation may be nonconservative because mean stress effects are not included. A correlation between maximum tensile stress and fatigue life is presented which is common to both compressive dwell and continuous-cycling tests. Using this correlation, compressive dwell behavior can be predicted based on more readily obtained continuous-cycling data. The limits of this predictive scheme are addressed. Future predictive models based on crack propagation analysis are also discussed.

SAND-81-8223: CENTRAL RECEIVER STEAM SYSTEMS FOR INDUSTRIAL PROCESS HEAT APPLICATIONS; J. D. Fish, P. De Laquill, III, S. E. Faas, and C. L. Yang; April 1981.

Various central receiver technologies for supplying 550 and 350° F saturated steam for industrial process heat applications are compared. Conceptual designs of systems based on molten salt, water/steam, and oil receivers were derived, where possible, from earlier work within the Department of Energy Solar Thermal Program. Systems include either molten salt or oil/rock storage subsystems. Cost estimates of delivered energy over a capacity factor range from 0.27 to 0.67 are reported. For conditions of little or no storage, several different technologies can be used to supply saturated steam for industrial process heat applications at roughly equal costs. For systems with large amounts of storage, the results clearly demonstrate the advantages of collecting energy at temperatures higher than the application temperature. A significant implication of this study is that process steam represents an additional market for the 1050° F molten salt receiver system currently receiving program emphasis for electrical power production. All of the work in support of that effort is directly applicable and timely for this industrial application.

SAND-81-8225: THERMAL ENERGY STORAGE FOR SOLAR THERMAL APPLICATIONS PROGRAM PROGRESS REPORT (APRIL 1980-MARCH 1981); L. G. Radosevich; May 1981.

This report summarizes the progress made by the Thermal Energy Storage for Solar Thermal Application (TESSTA) Program in the period April 1980-March 1981.

SAND-81-8227: EVALUATION OF INVERTED-STOW CAPABILITY FOR HELIOSTATS; A. Kerstein; June 1981.

A previous assessment of the costs and benefits of inverted-stow capability is updated based on recent developments in heliostat design and washing cost estimation. The previously estimated 12 percent cost advantage of noninverting heliostats is found to be design specific. The present analysis identifies circumstances in which

noninverting and inverting designs may be evenly matched on a cost basis. Therefore, a clear preference between noninverting and inverting designs cannot be established at this time.

SAND-81-8232: SOLAR CENTRAL RECEIVER FUELS AND CHEMICALS PROJECT STATUS REPORT OCTOBER 1980-JUNE 1981; R. W. Carling, J. D. Fish, L. G. Radosevich, and J. Vitko, Jr.; August 1981.

Solar central receiver fuels and chemicals project activities at Sandia National Laboratories, Livermore, in the period October 1980 to June 1981 are described. During this time, several fuels and chemicals processes were studied, and two processes were selected for further study: ethane pyrolysis and steam reforming of methane. The study criteria, status of ongoing work, and future activities are described.

SAND-81-8235: SOLAR THERMAL CENTRAL RECEIVERS FOR INDUSTRIAL PROCESS HEAT GENERATION: USERS' VIEWS AND RECOMMENDATIONS FOR COMMERCIALIZATION; M. J. Fish; August 1981.

Results of recent meetings with several private industrial groups in which solar thermal central receivers were discussed in depth as a potential for industrial process heat generation are summarized. Topics covering potential economics, technical requirements, and actions to promote commercialization of the technology are presented. These findings are then translated into recommendations for commercialization in private industrial markets. Key points include the need for small-scale systems integration projects in addition to the 10-MWe plant under construction at Barstow, CA, and the adoption of financial incentives, such as tax credits, for getting the early commercial palnts built. Finally, a comparison with an earlier study dealing with commercialization of central receivers in electric utility applications points out strong similarities between the two markets.

SAND-81-8236: COMPARATIVE ECONOMICS OF SOLAR THERMAL CENTRAL RECEIVERS; M. J. Fish; August 1981.

For both electrical and industrial process heat (IPH) generation, central receivers compare favorably with oil and gas, and in many cases, coal. Calculational results are presented in which the levelized energy costs from central receiver plants are compared with those from oil-, gas-, and coal-fired plants. Both electrical and IPH applications are discussed. Uncertainties in future capital costs, fuel price escalation rates, and the underlying economic climate are included in the analysis.

SAND-81-8237: A USERS' MANUAL FOR DELSOL 2: A COMPUTER CODE FOR CALCULATING THE OPTICAL PERFORMANCE AND OPTIMAL SYSTEM DESIGN FOR SOLAR-THERMAL CENTRAL-RECEIVER PLANTS; T. A. Dellin, M. J. Fish and C. L. Yang; August 1981.

DELSOL 2 is a revised and substantially extended version of the DELSOL computer program for calculating collector field performance and layout, and optimal system design for solar-thermal central receiver plants. The code consists of a detailed model of the optical performance, a simpler model of the nonoptical performance, an algorithm for field layout, and a searching algorithm to find the best system design. The latter two features are coupled to a cost model of central receiver components and an economic model for calculating energy costs. The code can handle flat, focused and/or canted heliostats, and external cylindrical, multiaperture cavity, and flat plate receivers. The program optimizes the tower height, receiver size, field layout, heliostat spacings, and tower position at user-specified power levels subject to flux limits on the receiver and land constraints for field layout. The advantages of speed and accuracy characteristic of Version I are maintained in DELSOL2.

SAND-81-8248: RADSOLVER - A COMPUTER PROGRAM FOR CALCULATING SPECTRALLY DEPENDENT RADITIVE HEAT TRANSFER IN SOLAR CAVITY RECEIVERS; M. Abrams; September 1981.

RADSOLVER is a computer program which calculates the radiation energy transported in cavity-type receivers having an arbitrary number of aperatures through which collimated beams of solar radiation enter. In contrast to the common assumption of gray (or semi-gray) surfaces used in the modeling of radiation transport, RADSOLVER accounts for the wave lengths-dependence of emission, absorption and reflection with a band model of the radiative properties. It is intended that this report serve both as an instruction manual for the use of the RADSOLVER code and a vehicle for presenting the underlying theory. Illustrated examples along with input and output are presented.

SAND-81-8251: A TECHNIQUE FOR MONITORING THE GROWTH RATE OF FATIGUE CRACKS AT ELEVATED TEMPERATURES; S. H. Goods; September 1981.

In order to assess the effects of multi-nitrate salts (a possible solar receiver coolant) on elevated temperature mechanical properties, an experimental apparatus has been developed which will examine the influence of a 60% $NaNO_3$-40% KNO_3 salt mixture on the fatigue crack growth behavior of Alloy 800. The experimental facility is based upon an Instron servohydraulic materials testing machine with a crosshead mounted actuator. The molten salt is

contained in a water-cooled stainless steel vessel in a wide-bore crucible furnace. Crack length is determined by means of a compliance technique in which the crack opening displacement is monitored during the sinusoidal loading of a specimen.

SAND-81-8252: CHARACTERIZATION OF THE CORROSION ENVIRONMENT OF THE DESERT NEAR BARSTOW, CALIFORNIA; D. A. Hughes; September 1981.

The corrosion characteristics of the desert atmosphere environment near Barstow, CA have been evaluated for the solar pilot plant receiver panel. Potential degradation mechanisms considered were hot corrosion from molten salts and stress corrosion cracking in aqueous environments. The possibility of degradation from these mechanisms depends on the chemical composition of airborne particulates, aerosols, and gases. These particulates and aerosols were collected near the pilot plant site and analyzed for water and acid soluble Na^{+} Mg^{++}, Li^{+}, $S^{=}$, $SO^{4=}$, and Cl^{-}. Comparison and evaluation of the quantities of these ions present with those necessary for corrosion indicate that external corrosion of the receiver due to the desert atmosphere environment is unlikely.

SAND-81-8263: TESTING AND EVALUATION OF SECOND-GENERATION HELIOSTAT MIRROR MODULES; V. P. Burolla and W. R. Delameter; January 1982.

The testing and evaluation of the second-generation heliostat mirror modules are reported here. It was found that all of the previous problems of mirror modules, such as silver corrosion, thermal defocus, and high glass stress, were eliminated by one or more of these designs. The single most important conclusion to be drawn from this program is that laminated glass mirror module designs are the most technically conservative; it is Sandia's recommendation that this concept be used for near-term applications. Two other second-generation designs were found to have potential for reduced weight and improved performance, but one design required some significant design changes, and both require further outdoor testing to better estimate their lifetime potential.

SAND-81-8635: OPTIMAL CONTROL OF A SYSTEM WITH RANDOM SPONTANEOUS CORRECTIONS, WITH APPLICATION TO SOLAR COLLECTOR WASHING STRATEGIES; A. Kerstein; April 1981.

Optimal control stragegies are derived for a system described by nonnegative variable x (t) which is continuous, monotonically increasing, and deterministic except for "spontaneous corrections," negative jump discontinuities which are random both in time of occurrence and in magnitude. Two alternative control mechanisms are

postulated: One which resets x = 0 at regular time intervals I, and one which resets x = 0 whenever x(t) exceeds a threshold value of M. I and M, respectively, are chosen to minimize a penalty function which is a linear combination of the time-average of x(t) of the time-averaged frequency of control implementation. A differential equation approach leads to explicit solutions for I and M assuming that the spontaneous corrections are Poisson-distributed in time. Reference is made to the application of these results to the optmization of washing strategies for solar collector surfaces subject to a deterministic soiling process and random spontaneous corrections due to cleaning by rain.

SAND-81-8636: THE IMPACT OF NATURAL CLEANING ON THE SELECTION OF A WASHING SYSTEM FOR SOLAR COLLECTORS; A. Kerstein; April 1981.

The desired optical properties (reflectivity, transmissivity, etc.) of solar energy collector surfaces such as mirrors and photovoltaic surfaces are degraded over time by soiling. Cost-benefit evaluation of alternative methods for washing the surface or retarding the optical degradation must take into account natural cleaning processes such as precipitation and frost, which impact the scheduling as well as the benefits of washing. A probabilistic method developed to address this question is used to compare truck-mounted versus mirror-mounted washing systems for central receiver plants. The comparison of these systems is shown to be sensitive to the seasonally varying frequency and effectiveness of natural cleaning processes. The implications of this analysis for such diverse issues as cost/benefit evaluation of soil-retardant mirror coatings and formulation of plant site selection criteria are noted.

SAND-81-8655: THERMAL STRESS OSCILLATIONS INDUCED BY DYNAMIC INSTABILITIES AND RADIATION-HEATED BOILER TUBES; S. Wolf, D. Lo and J. Liebenberg; October 1981.

Experimental thermal performance data obtained from a circumferentially nonuniform radiation-heated boiler tube, to simulate solar heating, show that when the tube is subjected to hydro-dynamic instability the oscillating flow causes the critical heat flux (CHF) point to oscillate. This phenomenon, in turn causes temperature and stress oscillations in the tube wall. Appropriate models in finite element computer methods are described to evaluate the thermal stress behavior. The temperature oscillations are described to evaluate the thermal stress behavior. The thermal oscillations are simulated with a two-dimensional thermal model with nonuniform circumferential heating. The generalized plane strain elastic model is used for the

stress analysis, the results of which can be used for predicting fatigue life.

SAND-81-8665: CREEP AND THE CORROSION CHARACTERISTICS OF INCOLOY ALLOY 800 IN MOLTEN NITRATE SALTS; S. H. Goods; March 1981.

Incoloy Alloy 800 (I800) has been proposed for use in the receiver tube panel arrays in a number of advanced solar central receiver (SCR) concepts. Because of their high heat capacity and high thermal energy density, several designs require the use of molten sodium and potassium nitrate salt mixture to act as the cooling or heat transfer fluid. The effects of deformation on the corrosion resistance of Incoloy Alloy 800 in sodium nitrate and potassium nitrate salt mixtures have been studied. Hollow tube specimens filled with the salt mixture (60%-$NaNO_3$-40% KNO_3) were tested in constant-load tension creep at elevated temperatures ($550^{o} \leq 670^{o}$ C). Depending on the temperature and initial stress, fracture times (and therefore salt exposure times) ranged between 300 and 1000 hours. While the fracture strain of specimens tested to failure was only slightly reduced when exposed to the salt environment, metallographic observations of polished cross sections revealed severe surface oxidation. In order to characterize the effect of total imposed strain on oxide morphology, a number of creep tests were terminated prior to fracture. Increasing deformation resulted in a more extensively damaged surface oxide as well as a more rapid rate of corrosion. EDX analysis revealed that the oxide was multiphase, with a near surface iron rich oxide above a chromium-rich oxide layer. Below 630^{o} C, the oxide-metal interface was well defined (although irregular). Above 630^{o} C, the interface was more diffuse with fine oxide intrusions growing into the base metal and small particles of the alloy visible in the oxide near the base metal interface.

SAND-81-8696: MECHANICAL BEHAVIOR OF ALLOY 800 AT 838K; W. B. Jones and R. M. Allen; March 1982.

Three commercial heats of Alloy 800 have been mechanically tested at 838K in simple tension and by fatigue cycling at constant plastic strained ranges from 0.2 percent to 1.4 percent. Although all three heats met the ASTM specifications for Alloy 800, the heats exhibited significant differences in elevated temperature mechanical properties. These differencies were functions not only of heat-to-heat chemistry variations, but also a final and annealing treatment given during their manufacture. The microstructures of several samples cycled to failure in the above tests were examined by transmission electron microscopy and compared with the microstructures of the

as-received units. It was found that significant additional precipitation occurred during the fatigue testing of two of the heats, and this is correlated with secondary hardening behavior found during the mechanical tests. The observed precipitation behavior could be explained using suggested isothermal transformation curves and solvus curves taken from the literature.

SAND-81-8879: THERMOCHEMISTRY OF NITRATE SALTS; A. S. Nagelberg and R. W. Mar; December 1981.

Thermochemical calculations have been carried out to characterize the behavior of nitrate salts when used in solar thermal power generation systems. The ionic compositions of sodium nitrate in equilibrium with air were calculated as a function of temperature from 500K to 1000K. These results were applied to the design and operation of solar central receiver power systems utilizing drawsalt for the heat transfer and thermal energy storage media. Salt stability is not a major concern and the optimal cover gas composition is very near that of air. The thermochemical calculations are shown to be in excellent qualitative agreement with observations made regarding corrosion processes.

SAND-81-8897: THERMAL-ENERGY-STORAGE DEVELOPMENT FOR SOLAR THERMAL APPLICATIONS; L. G. Radosevich; March 1982.

Development of thermal energy storage technologies for solar thermal systems has been conducted since the mid 1970s. This report describes both the status of technology development activities and research needs for the future.

SAND-82-0094: CORRELATIONS OF INSOLATION AND WIND DATA FOR SOLMET STATIONS; D. E. Randall and N. R. Grandjean; April 1982.

Correlations of direct insolation and wind speed data based upon a 12-1/2-year period are presented for 26 SOLMET stations distributed over the contiguous United States. These correlations indicate that for three different solar collector tracking apertures, 97-1/2 percent of the available direct insolation occurs at wind speeds of 15 m/s (33.6 mph) or less for all 26 stations. Selected frequency distributions for these insolation, wind speed, and wind direction data spanning the 1952 to 1964 time frame are also presented.

SAND-82-0181: BEAM QUALITY AND TRACKING-ACCURACY EVALUATION OF SECOND-GENERATION AND BARSTOW PRODUCTION HELIOSTATS; D. L. King; August 1982.

The results are given of the optical performance (beam quality) and tracking accuracy evaluation of the second-generation prototype heliostats and the Barstow production heliostat. Instrumentation, analytical techniques, and performance error sources are discussed in detail. Test results are in a form that will enable full-field performance predictions, and example cases of full-field performance measurements at the CRTF are given.

SAND-82-0263C: HIGH-TEMPERATURE MATERIALS EXPERIENCE AT THE CENTRAL RECEIVER TEST FACILITY; J. T. Holmes; January 1982.

During four years of operation at the Central Receiver Test Facility (CRTF), ceramics have performed well in cyclic solar flux densities of less than 30 W/cm^2. Above 100 W/cm^2, serious limitations exist. Important application considerations include: the geometry, cyclic and long time exposures, flux density gradients, thermal shock, weathering, and soiling.

SAND-82-0578C: CONTROL SYSTEM FOR PROTOTYPE HELIOSTATS; R. D. Aden; May 1982.

A heliostat control system capable of interfacing a host control system to a variety of different prototype heliostats has been developed at Sandia Labs. In the present configuration, the system consists of an H-P 1000 host minicomputer and six Intel microcomputers. The latter provide a programmable interface to translate the uniqueness of five different prototype control schemes (seven heliostats) into one common control scheme. The system is being used to support evaluation activity and long term life cycle testing of prototype heliostats at the Central Receiver Test Facility, Sandia National Laboratories, Albuquerque, New Mexico.

SAND-82-0727: TECHNIQUES FOR ELEVATED TEMPERATURE MECHANICAL TESTING; D. T. Schmale and R. W. Cross; June 1982.

Commercially available standard mechanical tests systems are generally designed to do tension tests at ambient temperatures. Experimental requirements which include the sometimes mutually exclusive requirements of high temperatures, strain measurement and control, precise specimen alignment, and fully reversed loading require substantial modifications to the standard equipment. Programs in solar central receiver technology and advanced nuclear reactor safety require the examination of low-cycle

fatigue and creep-fatigue behaviors in several structural alloys at elevated temperatures. The specialized techniques devised to successfully perform these tests are described here along with a discussion of the differing requirements and behavior of magnetic and nonmagnetic materials.

SAND-82-0850: FATIGUE AND CREEP-FATIGUE TESTING OF STEAM-FILLED TUBULAR ALLOY 800 SPECIMENS; W. B. Jones and J. A. Van Den Avyle; May 1982.

A test program was conducted under contract to Sandia National Laboratories to investigate water/steam effects on elevated temperature low-cycle fatigue and creep-fatigue of Alloy 800. This report presents interpretation and analysis of the test results. Tubular specimens with water sealed inside were cycled to failure under strain control. Tests were conducted at 616K (600^{o} F) and 922K (1,200^{o} F); some at 922K included tensile or compressive hold periods to simulate creep-fatigue conditions. The tubular specimen showed significantly lower lives than solid bar specimens cycled at equivalent strain ranges. Rough internal surfaces contributed to early crack initiation with these specimens. Inclusion of hold periods caused further large reductions in cycle to failures. No effect of water/steam on low cycle fatigue life could be demonstrated independent of specimen geometry. However, metallographic and fractographic evidence was found to enhance oxidation within closed specimens tested at 922K. The stress/strain data taken during the test show that both heats tested are physically and metalurgically stable. One of the heats, HH8579, is very similar to the tubing material for the Solar One project central receiver. Hold periods after each cycle resulted in relaxation of 16 to 18 percent of the peak stresses as well as the development of mean stresses. These effects are typical of Alloy 800 and are larger than the effects observed in other austenitic stainless steel. Mean stress and marked relaxation must be considered in choosing deformation models and failure prediction models for Alloy 800.

SAND-82-0916: DEVELOPMENT OF A SILVER REFLECTIVE - LAYER SUBSURFACE IN CORNING GLASS 7809; S. M. Lappin; March 1983.

Field-assisted bonding (FAB), utilizing 300^{o} C and 1,000-volt conditions, was used to bury a metallic silver layer 1 to 5 mu m below the surface of Corning Glass 7809. Processing variables included time with field applied, quantity of silver supplied during FAB, and post-FAB hydrogen firing temperatures. The glass/reflective metal configuration was evaluated with respect to subsurface mirrors for solar application; the best reflectivity achieved was 53 percent.

SAND-82-0934: SOLAR HEMISPHERICAL REFLECTOMETER MODIFICATION FOR SECOND-SURFACE MIRROR MEASUREMENTS; A. R. Mahoney; May 1982.

A commercial reflectometer has been modified for improved measurement of the solar hemispherical reflectance of second surface mirrors. The Solar Spectrum Reflectometer (SSR) manufactured by Devices and Services Company, Dallas, TX is designed to measure the solar hemispherical reflectance of flat, diffusely reflecting and first surface specular samples. Initial investigation of the device revealed that the SSR yielded significant deviations from the actual solar reflectance of second surface mirrors. The low reflectance values were determined to be caused by the displacement of the reflective surface away from the measurement port caused by the mirror protective layer. Instrument modifications are described which reduce the sensitivity of the instrument to second surface mirror thickness. The modifications involve enlarging both the sample port opening and the specular disk (target) located inside the measurement cavity, adjusting the lamp assembly height, and installing a diffuser over the lamp. The modified SSR demonstrated only a small linear reflectance variation with mirror displacement. It was shown that any mirror of known solar hemispherical reflectance having a thickness within the range. 0 mm (first surface) to 3.2 mm could be used as the reflectance standard. A variety of mirror samples, ranging from the first surface to 6-mm thick, were measured using the modified SSR. All corrected measured SSR solar reflectance values were within $\pm$0.008 reflectance units (1,000 reflectance units = 100 percent reflectance) of the actual solar reflectance, as determined from laboratory hemispherical reflectance measurements.

SAND-82-1714: CHARACTERIZING SOLAR MIRROR MATERIALS USING PORTABLE REFLECTOMETERS; R. B. Pettit, September 1982.

Currently available portable instrumentation for hemispherical and specular reflectance measurements of solar mirror materials is discussed. Particular attention is given to the wavelength dependence of the measurement spectrum, which, in most cases, does not approximate a solar spectral distribution, and to other limitations of each instrument. Because a portable instrument is not available that can determine the solar averaged specular reflectance from a single measurement, two procedures are recommended for obtaining a reasonable estimate for this quantity using the existing portable equipment. Finally, future developments in this area are briefly discussed.

SAND-82-7068/1: ENVIRONMENTAL DEGRADATION OF SOLAR OPTICAL MATERIALS. VOLUME I. LITERATURE SURVEY; V. L. Morris; November 1982.

Exposure of solar optical materials to real use environments in both physical degradation (soiling and abrasion) and chemical degradation (corrosion) of the material. These effects can decrease the appropriate optical property of the material and result in diminished solar system operating efficiency. The ultimate result is an increased cost for the energy produced, thus diminishing the viability of solar energy as a competitor in the energy market. Considerable research has been conducted in the areas of evaluating degradative mechanisms and monitoring the real time effects of exposing these materials to typical solar system environments. A review of available literature on the environmental degradation of solar optical materials, exposed to real or simulated solar use environments, is summarized. Emphasis was placed on the physical and chemical degradative effects of the exposure environment on the optical materials proposed for or used in active solar energy systems. The optical materials investigated were both transmitting and reflecting. Additionally, techniques for monitoring degradation effects and methods for evaluating the appropriate optical properties are reviewed.

SAND-82-8002: DEPARTMENT OF ENERGY SOLAR-CENTRAL-RECEIVER ANNUAL MEETING; Sandia; February 1982.

This document contains the papers presented at the Department of Energy Solar Central Receiver Annual Meeting held in Claremount, California, from October 13 to 15, 1981.

SAND-82-8005: SOLAR COGENERATION ASSESSMENT OF SOLAR CENTRAL RECEIVER COGENERATION CONCEPTUAL DESIGN STUDY PROJECTS; J. S. Anderson; April 1982.

In mid-1980, the Department of Energy solicited proposals for conceptual designs and economic studies applicable to central-receiver-based cogeneration facilities. Seven proposals were selected and have been completed. Presented are a brief description of the conceptual design, a summary of the prime contractor's economic analysis, and the site owner's assessment for each project. In spite of the many variables that make absolute comparisons impossible, the projects indicate that solar central receiver cogeneration has a number of promising applications and merits further study in selected areas.

SAND-82-8007: MANUFACTURING AND COST ANALYSES OF HELIOSTATS BASED ON THE SECOND-GENERATION HELIOSTAT-DEVELOPMENT STUDY; H. F. Norris, Jr., and S. S. White; December 1982.

The manufacturing processes and users' costs were analyzed for the Second Generation Heliostats. Mass production scenarios are examined by comparison and manufacturing analysis, including facility site selection and design, operations, equipment and tooling, and labor. Different transportation scenarios are compared, as are the site assembly and installation procedures. Users' costs are allocated to the central manufacturing facility, to transportation from the central manufacturing facility to the field, and to the field sites. Costs are also compared for these major components: reflective assembly, drive mechanism, controls and field wiring, foundation/pedestal, and support structure. Breakdowns are given for direct materials, direct labor, and other expenses including an estimate of the gross profit. A contractor-estimated capital price to the utility is shown for each heliostat design as well as estimated operations and maintenance (O&M) expenses.

SAND-82-8023: A DESCRIPTION AND ASSESSMENT OF SOLAR CENTRAL RECEIVER SYSTEMS TECHNOLOGY; C. L. Mavis; To Be Published.

This document summarizes the systems being developed by the Department of Energy's Solar Central Receiver Program. It has been prepared to provide potential users of central receiver systems with an overview of the present technology. The report includes the technical concepts upon which central receiver systems are based, as well as information on their estimated cost and performance. Assessments of the strengths and weaknesses of each technology have also been included. With this knowledge, developers of the technology can possibly improve component and system design to the point where they are fully competitive with alternate energy sources.

SAND-82-8025: 10-MWe CENTRAL-RECEIVER SOLAR-THERMAL PILOT-PLANT TEST OPERATION PLAN; J. S. Anderson and J. W. Smith; March 1983.

This plan encompasses the proposed tests that will enable the Pilot Plant to demonstrate stable, controlled operation in each of the steady-state operational modes and that will provide data for performance evaluation. In addition to checking out the operational modes, these tests will demonstrate transitions, emergency shutdowns, preliminary power production, and certain other plant characteristics. The tests are also needed to define the conditions which will establish plant operation at a near-optimum combination

of annual energy output and O&M cost. Test specifications, containing specific test requirements, are provided for those tests that will be conducted during Start-Up and the Experimental Test and Evaluation Phase of the Pilot Plant. Modifications to the test program may be required during the experimental test phase: if so, this document will be updated accordingly.

SAND-82-8027: 10-MWe CENTRAL-RECEIVER SOLAR-THERMAL PILOT PLANT DATA-EVALUATION PLAN: L. G. Radosevich; December 1982.

This report describes the Data Evaluation Plan for the 10-MWe Central Receiver Solar Thermal Pilot Plant near Barstow, California. The objective, test and data needs, approach, applicability, expected output, and planned data dissemination are presented for each evaluation.

SAND-82-8028: PROTECTIVE COATINGS FOR ALLOYS IN CONTACT WITH MOLTEN DRAWSALT ($NaNO_3$-KNO_3); R. W. Carling, R. W. Bradshaw and R. W. Mar; September 1982.

Molten drawsalt ($NaNO_3$-KNO_3) is being considered as the energy transfer and storage medium for many solar central receiver applications. In an effort to reduce the cost of the containment material while maintaining corrosion resistance, alloys with aluminide coatings have been examined while in contact with molten drawsalt for more than 6,000 hours at 600° C. The alloys examined were 2-1/4 Cr-1 Mo, 5 Cr-1/2 Mo, and 9 Cr-1 Mo low-alloy steels, and 316 stainless steel. The results show a steady, albeit slow, net weight loss over the course of the experiment. The weight loss has been attributed to spalling of Al_2O_3 from the surface (the occurrence of Al_2O_3 is a result of the aluminizing process) and dissolution of corrosion products $NaAlO_2$ and/or $NaFeO_2$ during post-immersion handling. Scanning electron micrographs of exposed surfaces revealed little or no corrosion of the base metal. It has been concluded that aluminide-coated alloys could provide significant cost savings (approximately 50 percent) relative to Incoloy 800, and provide at least equivalent corrosion resistance.

SAND-82-8030: SOLAR THERMAL INDUSTRY STATUS AND FUTURE NEEDS; L. G. Radosevich; December 1982.

This report examines the state of the solar thermal industry and its needs for the future. Information from a recent survey of industrial firms, a description of industry's research and development needs as stated through the Solar Thermal Energy Association, and a summary of private initiatives are presented.

SAND-82-8036: WIND LOAD AND LIFE-CYCLE TESTING OF SECOND GENERATION HELIOSTATS; W. S. Rorke, Jr.; November 1983.

As technical manager of the Second Generation Heliostat development contracts for the Department of Energy, Sandia National Laboratories has evaluated four heliostat designs. The evaluation of the heliostats included the life-cycling and simulated wind load testing of prototype heliostats and foundations. All of the heliostats had minor problems during this testing; as a result, specific design improvements were identified for each drive mechanism and for two of the four foundations.

SAND-82-8038: NEAR-TERM LEVERAGED LEASES FOR COMMERCIAL SOLAR INVESTMENTS; J. K. Sharp; December 1982.

The first commercial solar plants can be financed through joint ventures between solar hardware manufacturers and institutions or individuals who can take advantage of the current tax incentives on capital (specifically solar capital equipment). One type of financing that is currently being considered is the leveraged lease. To implement a leveraged lease, the solar hardware manufacturer would first sell the solar plant to third-party owners (investors), who would use a mixture of debt and equity to make the purchase; then the manufacturer would lease the plant back from the investors and operate it for the term of the lease. A hypothetical 12-MWe parabolic trough system is used as an illustrative example of this financing technique. Yearly cash flows for the investors and the manufacturer/plant operator are presented. Sensitivity analyses show the change in the net present value of the investment when the base assumptions are varied over a wide range.

SAND-82-8048: INTERNATIONAL WORKSHOP ON THE DESIGN, CONSTRUCTION, AND OPERATION OF SOLAR CENTRAL RECEIVER PROJECTS; Sandia; May 1983.

The International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects was convened in Claremont, California, from October 19 to October 22, 1982. It was organized by Sandia National Laboratories for the United States Department of Energy. Representatives from the six major international projects--Themis (France), Sunshine (Japan), IEA/SSPS (Spain), Eurelios (Italy), CESA-1 (Spain), and the Barstow Pilot Plant (USA)--exchanged information on their respective central receiver plants. This document contains the papers presented at the Workshop, as well as summaries of the four group sessions and the final panel discussion.

SAND-82-8049: 10-MWe SOLAR CENTRAL RECEIVER PILOT PLANT PREOPERATIONAL READINESS REVIEW MEETING, MARCH 9-10, 1982, BARSTOW, CALIFORNIA; P. N. Smith; January 1983.

A Technical and Readiness Review Panel was convened in March 1982, to determine the readiness of the 10-MWe Pilot Plant for turbine roll and subsequent operational activities. On the basis of their review, the panel concluded that the Construction Phase is complete and that the plant is ready to begin the Test Operations Phase.

SAND-82-8057: INVESTOR AND FEDERAL TREASURY RETURNS FROM INVESTING IN SOLAR THERMAL ENERGY; J. K. Sharp and G. J. Miller; February 1983.

As with any capital-intensive investment, the treasury shares the initial costs of solar thermal investments with investors by providing a tax credit and depreciation deductions. Solar thermal investments have an additional tax credit called the Business Energy Investment Credit (BEIC). This report seeks to explain the probable returns to the federal government, as well as to third-party investors, from investing in the first commercial central receiver plants. The results in this report are a function of parameter assumptions (defined in the text) which were obtained from sources within the solar industry and government laboratories. Even with the increased initial cost to the treasury of the BEIC, a positive revenue will flow to the treasury over the lifetimes of the first solar power plants. Solar plant manufacturers need the BEIC to entice initial investors to accept the risk of investing in these plants. Future plants will be attractive investments without the BEIC. The computer code used in the analysis of expected returns is included in an appendix.

SAND-82-8175: SECOND-GENERATION-HELIOSTAT OPTIMIZATION STUDIES, FINAL REPORT; Martin Marietta Corp.; May 1982.

The objective of this study was to define and quantify cost reductions in the Martin Marietta Denver Aerospace Second-Generation Heliostat resulting from design and cost optimization. These cost reductions were based on optimizing the heliostat performance vs. cost and engineering design, and reviewing the design specification in selected technological areas with a goal of removing nonrealistic requirements and eliminating or minimizing overdesign. Specific technological areas investigated were: (1) designing the heliostat for survival strength rather than stiffness and reducing the operational wind requirements as dictated by this design approach; (2) reducing the pointing accuracy and/or beam quality required for some fraction or all of the heliostat

field; (3) modifying the operational temperature range; (4) relaxing the rate at which the heliostat must move in the slow mode; (5) using alternate beam safety strategies; (6) analyzing actual wind data for selected sites in the southwest United States vs. the heliostat design specification survival wind requirements; (7) estimating heliostat damage for winds in excess of the design specification over a 30-year period; (8) evaluating the impact of designing the heliostat for higher wind loads; and (9) investigating the applicability to heliostat design of the standard engineering practices for designing buildings.

SAND-82-8181: OPTIMIZATION OF THE SECOND-GENERATION HELIOSTAT AND SPECIFICATION; J. J. Dietrich, R. K. Knowles; K. W. Stone; D. A. Steinmeyer, and J. H. Nourse; May 1982.

A study was performed to investigate and identify heliostat cost reductions that would result from modifications to the Sandia Second Generation Heliostat Specification. A parametric analysis of specification requirements and cost benefits was done by determining the effectiveness of the change in terms of heliostat field cost per unit intercepted annual energy on the receiver. The study considered the areas of reduced operational wind requirements, effects of heliostat beam pointing the beam quality requirements, operational range temperature effects, survival wind requirements and criteria, aspect ratio effects, and slue rates. Also considered were the effects of mixing two heliostats with different performance levels in the 50-MWe field and a damage/cost estimate for survival of the baseline heliostat to higher wind loads than the specification. An investigation and analysis of the safety issues associated with beam control during normal heliostat operating and stow conditions was performed using analytical equations for both single and multiple heliostats. Effort in this area was directed toward determining feasibility and implementation methods for safe face-up stow strategies.

SAND-82-8182: FINAL REPORT ON LOW-CYCLE FATIGUE AND CREEP-FATIGUE TESTING OF SALT-FILLED ALLOY 800 SPECIMENS; J. L. Kaae; May 1982.

Uniaxial low-cycle fatigue and creep-fatigue tests have been carried out on hollow Alloy 800 specimens that were either filled with air or with a molten mixture of sodium nitrate, potassium nitrate and an oxidizer. Low-cycle fatigue tests were carried out at 1,200° F and 650° F by cycling the strain continuously between equal magnitude of tensile and compressive values at a rate of 4×10^{-3} sec^{-1} until failure. The creep-fatigue tests were carried out at 1,200° F. The loading cycle differed from that of a low-cycle fatigue testing only in the imposition of a hold

at the peak compressive strain in each cycle. Cracks always initiated on the inner surface of the hollow specimen, and therefore, corrosive effects on crack propagation and initiation were controlled by the environment within the specimen cavity. In common with tests carried out earlier on steam-filled Alloy 800 specimens, at 1,200° F in the presence of molten salt, the heat of Alloy 800 with the lower carbon content had a higher fatigue strength than the heat with the higher carbon content even though different heats were used in the two testing programs. The fatigue strength of the two heats of material in the presence of molten salt at 650° F were about the same. Tests with air-filled specimens indicated that the presence of the molten salt degraded the fatigue life at 1,200° F but did not affect the creep fatigue life, while the presence of steam enhanced both the fatigue life and the creep-fatigue life.

SAND-82-8183: DEVELOPMENT OF A PREDICTIVE COMPUTER CODE FOR HEAT LOSSES FROM SOLAR EXTERNAL RECEIVERS; B. Afshari and J. H. Ferziger; February 1983.

The problem of mixed convection from external receivers is considered. The governing partial differential equations are stated, and numerical solution is obtained using Keller's box method. The computer code developed to predict the heat losses in the attached flow region is described. Special attention is given to treatment of some numerical difficulties that arise. Preliminary computational results for laminar three-dimensional mixed convection are presented and discussed. Future project efforts and planned extensions of the present code are described.

SAND-82-8184: ROTATING FIELD COLLECTOR SUBSYSTEM PHASE I STUDY AND EVALUATION; D. Jones and J. A. Eibling; October 1982.

The rotating field collector system is an alternative concept in which all heliostats are mounted on a single large platform which rotates around a tower to track the azimuthal angle of the sun. Each heliostat is mounted to the platform with appropriate pivots, linkage, and controls to provide the additional positioning required to properly direct the solar radiation onto the receiver. The results are presented of the first phase of a study to investigate the technical and economic merits of a particular type of rotating field collector subsystem. The large pie-shaped platform would revolve over an array of support pedestals by means of a roller at the top of each pedestal. Several heliostats were built to demonstrate their construction features, and the operation of both flat and amphitheatre rotating fields was studied. Work included an analysis of the concepts, development of modifications and additions to

make the system comply with design criteria, and cost estimates to be used for comparison with other heliostat subsystems. Because of considerably high cost estimates, the focus of a large part of the study was directed toward developing lower cost designs of major components.

SAND-82-8190: INVESTIGATION OF FREE-FORCED CONVECTION FLOWS IN CAVITY-TYPE RECEIVERS; J. A. C. Humphrey, F. S. Sherman, K. S. Chen and W. M. To; July 1982.

A numerical calculation procedure applicable to cavity-type receiver configurations and flow conditions was developed. Flow visualization experiments were performed, and experimental measurements of quantities valuable for the development of the numerical calculation procedure were made. The investigation is focused on a configuration which is strongly two-dimensional in the mean flow structure (but turbulent in a truly three-dimensional sense).

SAND-82-8192: FINAL REPORT SODIUM SOLAR RECEIVER EXPERIEMENT; Rockwell International; December 1983.

The test of a company-funded, sodium-cooled receiver panel was successfully conducted during the period from October 10, 1981, through March 12, 1982. Testing was accomplished at the Sandia Central Receiver Test Facility (CRTF) in Albuquerque under a test agreement between the Energy Systems Group (ESG) and Sandia. The test panel was connected to a sodium flow loop supplied by CRTF.

SAND-82-8201: SLOW STRAIN RATE TESTING OF ALLOY 800 IN MOLTEN NITRATE SALTS; S. H. Goods; January 1982.

An experimental technique has been developed to examine the interaction between deformation and the exposure of certain high temperature structural alloys to oxidizing molten salt environments. The experimental program involved performing a series of long-term tensile tests over a wide range of strain rates. Fracture strain reduction in area and ultimate strength (UTS) were monitored as parameters indicative of an alloy's susceptibility to environmental degradation.

For Incoloy Alloy 800 tested at 600^{o} C in the salt medium and at initial strain rates between 2×10^{-7} sec^{-1} and 1×10^{-5} sec^{-1} no appreciable loss of ductility, as measured by reduction in area, was observed relative to control specimens tested in air at the same temperature and strain rates. Similarly, fracture strain and UTS were essentially unaffected by exposure to the oxidizing environment.

The structure of the oxide film formed by contact of the specimens to the molten salt was affected by the imposed continuous deformation. Deformation resulted in an oxide which was thicker than that formed on undeformed salt-exposed surfaces. While this difference in oxide thickness was a measurable phenomenon, the increased rate of oxidation was not great enough to appreciably alter alloy mechanical behavior in the salt compared to that measured in air. In addition, fine subsurface cracks were observed in those oxides formed on deformed surfaces.

SAND-82-8202: CONTOUR-MEASURING DEVICE FOR SOLAR MIRRORS; V. P. Burolla; February 1982.

An inexpensive device for measuring the contour or focal length of large mirrors (1.5 m x 3.5 m) with relatively long focal lengths (about 500 m) is described in detail. Calibration procedures, measurement techniques and performance parameters such as repeatability and temperature dependence, are also included. The data acquisition system and computer program used is described along with options for even less costly systems. Recommendations are made for improvements to the prototype device, and for its use in a production environment.

SAND-82-8203: ASCUAS: A SOLAR CENTRAL RECEIVER UTILIZING A SOLID THERMAL CARRIER; J. Martin and J. Vitko, Jr.; January 1982.

This report documents the preliminary examination of the use of solid carriers, e.g., pebbles or sand, as both a working fluid and storage medium for high temperature (T greater than or equal to 600° C) solar receivers. Advantages of such a scheme include direct absorption of the incident radiation, direct heat transfer, use of the working fluid as a storage medium, and ease of hybridizing with a fossil-fired system. Key parameters and materials concerns for solar as well as for commercial fossil-fired sand or pebble heaters are identified and discussed. Commercial experience in the fuels and the chemical industries attests to the technical and economic viability of this concept, while also defining the most significant materials issue: breaking of the thermal carrier. Subsequent analysis indicates that the problem may be mitigated by careful selection/development of carrier material and processing. Future R&D directions are briefly discussed.

SAND-82-8206: THERMAL FATIGUE TESTS OF SOLAR ONE RECEIVER-TUBE WELDMENTS; D. A. Hughes; March 1982.

Tubing for Solar One receiver panels is joined by longitudinal welds using a low heat input welding process. Concern existed that lack-of-fusion defects (crack-like

notches at the root of the weld) created by this welding process would propagate during diurnal thermal cycling. If crack propagation occurred at these defects, it could shorten the life of the receiver tube panels. An experiment which simulated key elements of the receiver cyclic thermal strain environment was designed to address this concern. During the experiment, receiver tube weldments (welds prepared in the laboratory) were thermally cycled for 15,000 cycles. They were subsequently examined metallographically for crack propagation. Results of this examination revealed that no crack propagation occurred during the test.

SAND-82-8207: INDUSTRY/GOVERNMENT FORUM ON RECENT POLICY AND BUDGET CHANGES; L. G. Radosevich; May 1981.

This report contains a transcript of an industry/government forum presented at the Department of Energy Division of Solar Thermal Energy Systems (now called Division of Solar Thermal Technology) Semiannual Review in Fredricksburg, Virginia on May 6, 1981. The forum addressed recent policy and budget changes and their effect on the solar thermal program.

SAND-82-8210: THERMAL CONVECTION LOOP CORROSION TESTS OF 316SS AND IN800 IN MOLTEN NITRATE SALTS; R. W. Bradshaw; February 1982.

The corrosion behavior of Type 316 stainless steel and Incoloy 800 in molten $NaNO_3$-KNO_3 was studied using thermal convection loops which operated between the temperature limits, 630° C-350° C, for up to 4,000 hours. Corrosion rates were approximately 1 mil/year (2.5×10^{-2} mm/year) at 600° C for 316SS but increased to about 4 mil/year at 630° C. Less extensive results are reported for IN800 but the corrosion rates appear to be similar to 316SS. Corrosion products consisted of the spinels, Fe_3O_4 and $Fe(Fe,Cr)_2O_4$, at temperatures below 600° C, although $NaFeO_2$ and $Fe(Fe,Cr)_2O_4$ were present at higher temperatures. In addition, internal oxide penetration was observed in IN800. Considerable spalling of surface scales was found at temperatures above 600° C and a mass balance was developed to estimate total corrosion rates from weight change and metallographic data. Chromium, but not iron or nickel, accumulated as a solute in the melt as a result of depletion from the alloys, but no thermal gradient mass transfer was detected.

SAND-82-8214: PROCEEDINGS OF THE DOE SOLAR THERMAL TECHNOLOGY PROGRAM PLANNING WORKSHOP; L. G. Radosevich; March 1982.

The workshop reviewed several strategies for solar thermal technology program planning. After the strategy options were presented to the workshop participants, each committee

(user/supplier, system test and evaluation, technology development, and research) was asked to address the following issues: which strategy shows the best potential for meeting the objectives of the solar thermal program; is there an obvious imbalance in the program in terms of emphasis in various areas; are there any activities which should be added or deleted; and, if a funding cut occurs, how should the cut be made. The strategy options are briefly discussed. Summary reports from each committee follow, and a compilation of the committee findings highlights major similarities and differences.

SAND-82-8220: MOLTEN NITRATE SALT TECHNOLOGY DEVELOPMENT PROGRESS REPORT; R. W. Mar, R. W. Bradshaw, R. W. Carling, S. H. Goods and A. S. Nagelberg; April 1982.

A materials research program is being conducted to further the technologies associated with utilizing molten nitrate salts in solar thermal energy systems. Activities have addressed numerous concerns, including the absence of thermophysical and thermochemical data at high temperatures, an inadequate understanding of salt chemistry and how it relates to thermal stability and corrosion, and an inadequate understanding of corrosive interactions between the salt, containment alloys, and the thermal-mechanical environment. Progress made during FY1981 and the first quarter of FY1982 is reported.

SAND-82-8254: SOLAR CENTRAL RECEIVER HIGH TEMPERATURE PROCESS AIR SYSTEMS; P. De Laquil, III, C. L. Yang and J. E. Noring; February 1983.

The cost-effectiveness of solar central receiver high-temperature industrial process air delivery systems is evaluated. Seven solar air-heating receiver concepts are compared at outlet temperatures of 1,000° F (538° C), 1,500° F (816° C), and 2,000° F (1,093° C) and at operating pressures of 1, 5, and 10 atmospheres. A consistent set of receiver cost and performance data, which is derived from a previous study by Pacific Northwest Laboratories, is used in the analysis. Piping and compressor machinery costs are also reported.

The study shows that these air-heating receiver concepts are not particularly attractive technological options for solar central receiver systems. Inherently poor gas heat transfer characteristics make the receivers expensive, and both piping and compressor machinery costs are significant. The study concludes that alternative central receiver systems need to be pursued for the high-temperature process air application.

SAND-82-8627: CORROSION OF THIN SILVER FILMS IN AN AQUEOUS ENVIRONMENT; J. Vitko, Jr.; April 1982.

A laboratory test which produces results similar to those observed in field-corroded heliostats has been developed. Pinhole formation was observed in thin silver films treated in normal distilled water, which contains dissolved oxygen, but not in similar deoxyginated water. These pinholes were not filled with agglomerated silver, as is frequently observed in field-corroded samples. The absence of agglomerated silver may result from the large volumes of water used or from the isothermal nature of the test, and may account for the lack of surface plasmon absorption and surface enhanced Raman effect found for the laboratory treated samples. Results of this study are consistent with a simple silver dissolution mechanism for pinhole formation.

SAND-82-8669: VISCOUS FLOW AND STRUCTURE IN ALKALI METAL NITRATES; D. A. Nissen and R. W. Carling; April 1982.

Precise measurement of the viscosity and heat capacity of the alkali metal nitrates, $NaNO_3$ and KNO_3, and the equimolar binary mixture, have revealed anomalies at 693, 723, and 653K, respectively. These can be ascribed to changes in the degree of rotational freedom of the nitrate ion. Activation energies associated with viscous flow above and below the temperatures of the anomalies have been determined.

SAND-82-8729: HEAT CAPACITIES OF $NaNO_3$, and KNO_3 FROM 350 TO 800K; R. W. Carling; June 1982.

The heat capacities of $NaNO_3$ and KNO_3 were determined from 350 to 800K by differential scanning calorimetry. Solid-solid transitions and melting were observed at 550 and 583K for $NaNO_3$ and 406 and 612K for KNO_3, respectively. The entropies associated with the solid-solid transitions were measured to be (8.43 +0.25) $J\ K^{-1}\ mol^{-1}$ for $NaNO_3$ and (13.8 +0.4) $JK^{-1}\ mol^{-1}$ for KNO_3. At 298.15K, the values of $C^{o}p$, $S^{o}T$, $\{H^{o}(T)-H^{o}(0)\}/T$ and $-\{G^{o}(T)-H^{o}(0)\}/T$, respectively, are 91.94, 116.3, 57.73, and 58.55 $JK^{-1}\ mol^{-1}$ for $NaNO_3$ and 95.39, 133.0, 62.93, and 70.02 $J\ K^{-1}\ mol^{-1}$ for KNO_3. Values for S^{o}_{T}, $\{H^{o}(T) - H^{o}(0)\}/T$, and $-\{G^{o}(T) - H^{o}(0)\}/T$ were calculated and tabulated from 15 to 800K for $NaNO_3$ and KNO_3.

SAND-82-8744: DRAC: A USER-FRIENDLY COMPUTER CODE FOR MODELING TRANSIENT THERMOHYDRAULIC PHENOMENA IN SOLAR-RECEIVER TUBING; W. S. Winters; January 1983.

This document is intended to familiarize potential users with the capabilities of DRAC (Dynamic Receiver Analysis Code). DRAC is the first in a series of user friendly driver programs for the more general code, TOPAZ

(Transient-One-Dimensional Pipe Flow Analyzer). DRAC is a relatively easy-to-use code which permits the user to model both transient and steady-state thermohydraulic phenomena in solar receiver tubing. Users may specify arbitrary, time-dependent, incident heat flux profiles and/or flow rate changes and DRAC will calculate the resulting transient excursions in tube wall temperature and fluid properties. Radiative and convective losses are accounted for and the user may model any receiver fluid (compressible or incompressible) for which thermodynamic data exists. A description of the DRAC code, a comprehensive set of steady-state validation calculations, and detailed user instructions are presented.

SAND-82-8911: THERMAL CONVECTION LOOP STUDY OF CORROSION OF ALLOY 800 IN MOLTEN $NaNO_3$ - KNO_3; R. W. Bradshaw; January 1983.

Maximum metal loss rate of Alloy 800 coupons was about 0.5 mil/year and occurred at the maximum temperature of 600° C. Significantly greater oxide penetration into the alloy occurred in unabraded as-received tubing. Since the corrosion rate of unabraded tubing was less temperature sensitive than polished coupons, and attained a maximum value at temperatures in the range of 550 to 565° C, a value of 1 mil/year should be used as the corrosion rate for design purposes. Because daily thermal cycling is inherent in solar central receiver operation, oxidation and chromium depletion rates can be expected to increase if surface oxide layers spall. The oxide layers formed on Alloy 800 appeared to be adherent, and adherence will benefit further from growth-derived compressive stresses in oxide layers on the salt-exposed inner diameter of receiver tubes. Since the lower duty factor in diurnal solar service may offset the accelerated metal loss due to cyclic spalling of scales, the corrosion rates reported here are probably sufficiently reliable for design purposes. Chromium depletion from the alloy was observed because of the high solubility of chromium in the melt. The chromium depletion is not the major cause of metal loss. Chromium depletion is apparently controlled by diffusion, which leads to decreasing rates of depletion with time. Monitoring the appearance of chromium in the salt reservoirs of a solar receiver system is suggested as a means of detecting the onset of accelerated corrosion. 11 figures, 4 tables.

SAND-83-0263: THE TRANSIENT RESPONSE OF CIRCULAR FOIL HEAT-FLUX GAGES; M. A. Grothus, G. P. Mulholland, R. G. Hills, and B. W. Marshall; July 1983.

The objective of this study was to develop relationships that describe the transient response of circular foil heat-flux gages. Prediction of the gage surface flux for

nonsteady-state conditions based on the measured temperature response of the gage is achieved through application of a numerical deconvolution method. Sensitivity and uncertainty analyses were conducted to examine which gage parameters have the greatest effect on the determination of heat flux; these included the foil thermophysical properties, thickness, and maximum radius.

SAND-83-0883C: CENTRAL RECEIVER TEST FACILITY AS A SIMULATOR FOR THE HYDROGEN-BURN THERMAL ENVIRONMENT; V. J. Dandini; August 1983.

The use of a solar energy facility to simulate the thermal environment produced as a result of hydrogen burns in a full-scale reactor containment building is described. Using a flux profile generated by the HECTR computer code, the Central Receiver Test Facility has produced a temperature rise in a test specimen that closely approximates that predicted by the code. A method for simulating multiple burns associated with the activation of safety ignition systems during a hydrogen-producing accident is also described and preliminary results of tests of safety equipment exposed to such a multiple burn simulation are discussed.

SAND-83-0912C: DEVELOPMENT OF A PORTABLE SPECULAR REFLECTOMETER FOR MONITORING SOLAR-MIRROR MATERIALS; R. B. Pettit, J. M. Freese and A. R. Mahoney; August 1983.

The general design requirements of a portable reflectometer which can determine the specular reflectance properties of solar mirror materials is presented. Based on these considerations, a prototype instrument was developed at Sandia National Laboratories. Because of the interest in this instrument, a competitive contract was placed with Devices and Services Company, Dallas TX for the development of a commercial instrument based on the Sandia design. The operation and performance of this instrument are discussed including the accuracy, stability, reproducibility, temperature response, and outdoor performance. Finally, limitations of this instrument and future developments in this area are briefly discussed.

SAND-83-1631C: SODIUM HEAT TRANSFER SYSTEM MODELING; A. F. Fewell, November 1983.

The sodium heat transfer system of the International Energy Agency (IEA) Small Solar Power Systems (SSPS) Central Receiver System (CRS), which includes the heliostat field, receiver, hot and cold storage vessels, and sodium/water steam generator has been modeled. The computer code SOLTES (Simulator of Large Thermal Energy Systems), developed by

Sandia National Laboratories, was used to model this system. Based on data provided to Sandia by the IEA-SSPS/CRS project, the results from SOLTES are compared to measured data. The comparison between measured data and predictions from SOLTES is very good for the day evaluated.

SAND-83-8005: 10-MWe SOLAR-THERMAL CENTRAL-RECEIVER PILOT-PLANT RECEIVER STEAM GENERATION (TEST 1030) EVALUATION REPORT; A. F. Baker and D. L. Atwood; March 1983.

The Receiver Cold Flow (Test 1010) and Receiver Steam Generation (Test 1030) tests at the 10-MWe Solar Thermal Central Receiver Pilot Plant were preoperational tests to (1) verify receivier operations, (2) develop control functions and field tune controllers, and (3) verify portions of the Plant Operating Procedures. Data from Preoperational Test 1030 have been used to make preliminary estimates of receiver performance. Selected days of operation have been evaluated to make estimates of receiver incident power from the heliostat field, panel efficiencies, and receiver efficiencies. In this report, data from the plant's Data Acquisition System are presented for temperature profiles on several panels and are used for efficiency calculations and comparisons of incident power predictions.

SAND-83-8013: CHARACTERISTICS OF SOLAR CENTRAL RECEIVER PROJECTS. OCTOBER 1982; A. F. Baker and A. C. Skinrood; May 1983.

The information in this summary was prepared for use at the International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects held in Claremont, California, on October 19-22, 1982. Representatives from six international projects responded to a questionnaire sent out by Sandia National Laboratories, Livermore. A glossary of the terms used in this questionnaire follows the summary tables.

SAND-83-8015: 10-MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: THERMAL STORAGE SUBSYSTEM ACTIVATION AND CONTROLS TESTING PHASE; S. E. Faas; July 1983.

This report evaluates data taken on the Thermal Storage Subsystem at Solar One, the 10-MWe Solar Central Receiver Pilot Plant near Daggett, California. The period covered is the activation and initial controls testing phases from May 5, 1982, through September 30, 1982. The data shows the system has been operated frequently, accepting and returning thermal energy as design. The thermal storage tank wall stresses are low, thermal degradation and losses of heat transfer oil are minimal, and solar-related hardware problems that occurred were resolved.

SAND-83-8018: DEPARTMENT OF ENERGY SOLAR CENTRAL RECEIVER ANNUAL MEETING; Sandia; September 1983.

This report presents the highlights of the Department of Energy Solar Central Receiver Annual Meeting held in Albuquerque, New Mexico, on April 26-27, 1983.

SAND-83-8021: OVERVIEW OF THE CONSTRUCTION AND START-UP OF THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; J. J. Bartel and P. E. Skvarna; June 1983.

This report presents and overview of the construction and start-up of the 10-MWe Solar Thermal Central Receiver Pilot Plant in Barstow, California. The costs and schedule of the project are discussed, the planned test program is outlined, and significant experiences to date are presented.

SAND-83-8027: 10-MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: 1982 OPERATIONAL TEST REPORT; J. J. Bartel; November 1983.

The design and construction of the world's largest solar thermal central receiver electric power plant were completed in 1982. Start-up was accomplished, and the plant began the two-year experimental Test and Evaluation phase.

Experiences during 1982 have shown that all parts of the plant--especially solar unique ones--operate as well as or better than expected. It was possible to incorporate routine power production into the Test and Evaluation phase because plant performance yielded high confidence.

The million killowatt-hours net, generated while the plant was grid connected, are an indication of the successful, start-up and test experience in 1982. During 1982, the transfer of the plant to operation by utility personnel was also accomplished. Events reported here are not unique to utility operations; an important lesson learned is that solar technology is amenable to operation in conventional utility practices.

This report contains (1) a brief description of the plant system; (2) a summary of the year's experiences; and (3) a monthly list of principal activities and operation and maintenance costs.

SAND-83-8038: 10-MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MID-TERM TEST AND EVALUATION REVIEW JULY 20-21, 1983; Sandia; January 1984.

A Mid-Term Review of the Barstow pilot plant was held in Barstow, California, in July 1983. At that meeting, a panel of representatives from various utilities and repowering

studies gathered to review the first year of the Test and Evaluation Phase, as well as the planned activities for the second year of that phase. The panel concurred that plant checkout and testing have progressed well, and they fully support next year's test plan. The panel's comments and suggestions for the last year of testing are included in this report.

SAND-83-8202: ECONOMIES OF SCALE IN THE PRODUCTION OF STEAM WITH SOLAR THERMAL-FOSSIL BOILER HYBRID SYSTEMS; F. R. Hansen, D. L. Linder and J. Vitko, Jr.; March 1983.

Levelized energy costs for steam plants in the size range 15 MM Btu/h to 400 MM Btu/h have been estimated for steam produced by several different technologies, including stand-alone oil and coal-burning plants as well as solar central receiver-fossil boiler hybrid plants. Models for the costs of plant subsystems used in these calculations are presented and discussed. Designs of the solar-fossil hybrids examined were optimized with respect to solar fraction and amount of thermal storage used by simulation of plant operation. The resulting levelized energy costs and their sensitivity to various modeling parameters are presented and discussed.

SAND-83-8213: THERMAL-MECHANICAL FATIGUE-TEST APPARATUS FOR SOLAR-RECEIVER TUBING; D. A. Hughes; April 1983.

To assess the effects of thermal versus isothermal fatigue on solar-receiver tubing, a rigid-frame test apparatus was built. A description of this apparatus and the results from thermal-mechanical strain cycling of actual Solar One tubing are reported. The test, which includes cycling between compressive strain limits and a hold period of 6 hours at the peak temperature of 922K, demonstrates that solar thermal cycling produces elastic-strain ramps and a large tensile mean stress. Stress relaxation continues to occur during every temperature hold period and, as a result, a steady-state hysteresis loop is not obtained after 45 cycles.

SAND-83-8214: SLOW STRAIN TESTING OF 2.25CR-1Mo IN MOLTEN NITRATE SALT; S. H. Goods; May 1983.

The influence of an oxidizing molten nitrate salt (60 percent $NaNO_3$ - 40 percent KNO_3) on the mechanical properties of 2.25CR-1Mo has been examined through a series of slow strain rate tests at 450° C and 525° C. By comparing fracture strain, reduction in area and the ultimate strength of air-exposed specimens to these same parameters for specimens tested in the binary salt mixture, the susceptibility of the alloy to environmental degradation could be ascertained.

Exposure to the nitrate resulted in a loss of ductility as measured by either the engineering fracture strain or reduction in area at both temperatures studied. At these temperatures, the ductility loss was most pronounced at the lowest strain rates ($1 \times 10^{-7} sec^{-1}$). In general, for all strain rates examined, the degree of ductility loss was greater at 525^{o} C than at 450^{o} C.

Metallographic observations revealed that severe surface oxidation occurred as the result of exposure to the molten salt. These surface scales were found to be nonadherent and easily spalled. The rapid formation of these corrosion products and the inability of the material to form a protective barrier against further oxidation is consistent with the ductility loss observed in the salt-exposed specimens.

SAND-83-8216: SOLAR ONE: SOLAR-THERMAL CENTRAL-RECEIVER PILOT PLANT. 1982 METEOROLOGICAL DATA REPORT; McDonnell Douglas Astronautics Company; June 1983.

Meteorological data recorded at the Solar One 10 MWe Pilot Plant during a Start-Up and Initial Evaluation Test Program during 1982 are presented. Additionally, a General Plant Description is provided, plus specific information on the type, quantity, and location of meteorological equipment and instrumentation at the Power Plant which are being used to record the meteorological data.

SAND-83-8217: ACCURACY OF THE BARSTOW SOLAR-THERMAL PILOT PLANT COST ESTIMATES; L. G. Radosevich; June 1983.

This report assesses the accuracy of the cost estimates for the 10 MWe Solar Thermal Central Receiver Pilot Plant, located near Barstow, California. A history of the Pilot Plant cost estimates is presented, and the effects of inflation are discussed. The history is also compared to cost estimating histories of other first-of-a-kind energy process plants.

SAND-83-8220: 10-MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT HELIOSTAT EXPERIENCES November 1981-February 1983. Monograph Series No. 1; C. L. Mavis; May 1983.

The heliostat design, installation, and operating experiences and the test and evaluation program are reported for the Solar Thermal Central Receiver Pilot Plant at Barstow, California. Operating and maintenance experiences and preliminary test results are reported from November 1981 through February 1983. Installation of the 1818 heliostats was made over a 10-month period with no major problems. Initial checkout of the heliostats was completed in the nine

days which included making minor software changes. Performance of the control system, including safe control of reflected light, and the heliostat structure and drives has been verified during the first year of operation. Heliostat-maintenance requirements have been less than anticipated and can be accomplished with 160 man-hours per month. Problems with evaluation instrumentation and mirror corrosion have occurred and they have been solved or are being evaluated.

SAND-83-8223: X-RAY DIFFRACTION ANALYSIS OF CORROSION PRODUCTS OF Fe-Ni-Cr ALLOYS FORMED IN MOLTEN NITRATE SALTS; D. R. Boehme and R. W. Bradshaw; May 1983.

Chemical phase identifications of complex, multilayered corrosion products formed on Fe-Ni-Cr alloys immersed in molten $NaNO_3$-KNO_3 and $LiNO_3$-$NaNO_3$-KNO_3 were obtained by X-ray diffraction analysis. Diffraction analyses performed after successive material removal steps provided depth profiles of corrosion products and identified the dominant phases as $NaFeO_2$, Fe_3O_4 and Cr_2O_3 for Alloy 800 and 316SS after immersion in $NaNO_3$-KNO_3. In $LiNO_3$-$NaNO_3$-KNO^3, the major corrosion products identified on Alloy 800 were $LiFeO_2$, Fe_3O_4 and Cr_2O_3. X-ray diffraction results were supplemented by electron microprobe analyses which revealed the solid solution nature of several of the oxide phases.

SAND-83-8224: STATUS OF RESEARCH ON CONVECTIVE LOSSES FROM SOLAR CENTRAL RECEIVERS; M. Abrams; June 1983.

Progress in the worldwide capability of predicting the convective energy loss from solar central receivers is reviewed. The significant advances in the past three years have been in experimental areas. Baseline measurements of the convective heat transfer from large high-temperature surfaces, e.g., a flat plate and a cubical cavity, have been completed and empirical correlations have been obtained. Theoretical modeling activities have not kept pace with the experimental advances, however. Currently, the primary theoretical emphasis is the development and testing of turbulence models suitable for buoyant flows. Three major needs have been identified: the measurement of convective energy losses from operating solar central receivers; the continued development of theoretical models in spite of the relatively slow progress to date; and the quantification of the effects of atmospheric turbulence.

SAND-83-8225: EXPERIMENTAL MIXED CONVECTION HEAT TRANSFER FROM A LARGE, VERTICAL SURFACE IN A HORIZONTAL FLOW; D. L. Siebers, R. G. Schwind and R. J. Moffat; July 1983.

The convective heat transfer from and the boundary layer flow on a vertical, 3 m square surface parallel to a horizontal air flow were studied. The test conditions ranged from pure forced convection driven by a horizontal inertial force induced by the horizontal free-stream flow, to combined forced and free convection (i.e., mixed convection) driven by orthogonal forces, the horizontal inertial force and a vertical buoyant force generated by the heated vertical wall, to pure free convection driven by the vertical buoyant force. The emphasis of the study was on mixed convection. Surface temperatures and free-stream velocities ranged from 40 to 600° C, respectively, resulting in Reynolds numbers (Re) and Grashof numbers (Gr) up to 2×10^6 and 2×10^{12}, respectively.

Convective heat transfer and boundary layer profiles of mean velocity, flow angle, and temperature were measured. The heat transfer results showed the range of conditions for which the heat transfer was characterized either as forced, mixed, or free convection. Correlations for mixed convection heat transfer and for variable properties free convection heat transfer were developed from the heat transfer results. The combined effects of free-stream velocity, buoyancy, and variable properties on the location of the transition from laminar to turbulent flow were also noted from the heat transfer results. The boundary layer profiles demonstrated the variation of mean velocity, flow angle, and temperature through the boundary layer for test conditions ranging from forced, to mixed, to free convection.

DSE-76-162: CENTRAL RECEIVER SOLAR-THERMAL POWER SYSTEM. PHASE I. 10-MWOELECTRIC PILOT PLANT; Sandia; June 1976.

The prime contractors and subcontractors of the Central Receiver Solar Thermal Power System, Phase 1 contract teams are tabulated and the schedules are graphed for the 10 MWe Pilot Plant Project and for the Central Receiver and Test Facilities Program. Preliminary characteristics are listed for preliminary designs of the 10 MWe pilot plant under study by the four contractor teams, and the heliostat field layouts, heliostats, receivers, and power systems proposed by each team are diagrammed. A series of action items and statements by the contractors and Sandia is attached.

DE82018121: ANALYSIS OF SPECIAL HYDRAULICAL EFFECTS IN THE SHTS PIPING SYSTEM; Sandia; August 1980.

An investigation is presented of the fluid dynamical effects in the piping system of the sodium heat transfer system. This concerns pump power failure, valve closure/opening, receiver rupture, dry running of the receiver, and preliminary evaluations of pump speed and gate opening.

DE82018122: REDESIGN OF THE CRS-ALMERIA RECEIVER APERTURE AND COMPARISON OF INTERATOM AND MMC REFERENCE HELIOSTAT-FIELD PERFORMANCE CALCULATIONS. FINAL REPORT; Sandia; November 1980.

The modifications of the central receiver system (CRS) receiver aperture are described and the relevant results confirming the final aperture design are presented. The calculations performed independently by INTERATOM (IA) and MARTIN-MARIETTA CORPORATION (MMC) are compared and the discrepancies are discussed.

DE82018126: DEVICE FOR THE MEASUREMENT OF HEAT-FLUX DISTRIBUTIONS (HFD) NEAR THE RECEIVER APERTURE PLANE OF THE ALMERIA CRS SOLAR POWER STATION: DESIGN AND CONSTRUCTION PHASE; M. Becker, J. Baete and F. Diessner; 1981.

Servious interface considerations between heliostat field and receiver required the control of heat flux entering the receiver aperture. For this reason, a mechanism for an appropriate measurement device was developed which is somewhat similar to the corresponding unit used at CRTF, Albuquerque. Described are the interfaces, the specifications, the mechanical and electrical design of the measurement device, its general set up, and the data acquisition system.

DE82018127: DETERMINATION OF THE SPECTRAL REFLECTIVITY AND THE BIDIRECTIONAL REFLECTANCE CHARACTERISTICS OF SOME WHITE SURFACES; G. P. Goerler; 1981.

Each of the heliostats forming the mirror field of a solar thermal power plant with central tower will generate an image of the sun on the entrance of the central radiation receiver. The quantitative determination of the integral power within this image and its distribution is necessary to check the performance of the mirror array as well as the efficiency of the receiver and the subsequent thermodynamic process. At the solar power plant built by the IEA near Almeria (Spain), a part of this problem is to be solved by viewing the brightness of white surface elements on a movable traverse scanning the image in the entrance area of the receiver cavity. Measurements of the spectral reflectivity and of the spatial distribution of reflected

intensity at various angles of incidence were carried out on a sample of this coating. The results are compared with properties of some other white surfaces. Additionally, the effect of varying temperature of the sample on the spectral reflectivity and its angular distribution was studied as well as the dependence of angular distribution on the wavelength.

DE82020000: CONCENTRATED SOLAR FLUX MEASUREMENTS AT THE IEA-SSPS SOLAR CENTRAL RECEIVER POWER REPORT, TABERNAS ALMERIA (SPAIN). FINAL REPORT, TECHNICAL REPORT; Sandia; August 1980.

A flux analyzing system (F.A.S.) was installed at the central receiver system of the SSPS project to determine the relative flux distribution of the heliostat field and to measure the entire optical solar flux reflected from the heliostat field into the receiver cavity. The functional principles of the F.A.S. are described. The raw data and the evaluation of the measurements of the entire heliostat field are given, and an approach to determine the actual fluxes which hit the receiver tube bundle is presented. A method is described to qualify the performance of each heliostat using a computer code. The data of the measurements of the direct radiation are presented.

DE82020001: IEA SMALL SOLAR-POWER SYSTEMS PROJECT. OPERATION STATUS REPORT; Sandia; April 1982.

Data collected from routine operation of the Small Solar Power Systems Project are summarized, and an overview is given of the data evaluation. The operation status of the data collection system and central receiver system is included as well as the status of the evaluation work organization. Some insolation and wind data are given. Tours by visitors are reported and the status of existing reports is given.

DE83009236: 10-MWe SOLAR-THERMAL CENTRAL-RECEIVER PILOT PLANT: RECEIVER COLD FLOW (TEST 1010) AND THE RECEIVER STEAM GENERATION (TEST 1030) TEST REPORT; McDonnell Douglas Aeronautics Company; January 1983.

This report documents the combined test activities for the 1010 and 1030 receiver start-up tests. The "Test Program and Results" sections describe the testing which was carried out in support of specific test objectives and special studies which are aimed at specific areas of concern.

DOE/NBM-2018132: HELIOSTAT FIELD AND DATA ACQUISITION SUBSYSTEM FOR CRS.SSPS TECHNICAL REPORT NO. 1/79; Sandia; December 1979.

A compilation is presented of the work accomplished for the Small Solar Power Systems/Central Receiver System (SSPS/CRS). The effort performed was to: develop requirements for the Heliostat Field Subsystem (HFS) and Data Acquisition Subsystem (DAS); establish interfaces between the HFS, DAS, and other subsystems of the SSPS/CRS; perform heat flux analysis between the HFS and the receiver of the Sodium Heat Transfer Subsystem; determine HFS field-cable layout requirements; determine HFS and DAS power requirements; determine Sun-Presence Sensor (SPS) requirements and usage; prepare bid packages (Statements-of-Work and Specification) for solicitation of tenders and send them to qualified suppliers; and resolve the operating strategy for the DAS. For each task is given the Statement-of-Work text, discussion of work performed, and data developed for the task.

DOE/NBM-2018154: CRS HELIOSTAT FIELD, INTERFACE CONTROL, AND DATA ACQUISITION SYSTEM. SSPS TECHNICAL REPORT NO. 2/79; Sandia; December 1979.

Results are provided of a Small Solar Power Systems development. The definition of the approach to acquisition and installation of the heliostat field and interface control and data acquisition system (IC/DAS) subsystems for the Central Receiver System (CRS) is covered. Program definition and management is discussed. Extensive heliostat field definition analysis was performed.

DOE/NBM-2019085: SOLAR COGENERATION; Sandia; April 1982.

After a brief introduction to the operational principals and advantages of solar cogeneration, seven cogeneration studies are summarized covering such applications as sulfur mining, copper smelting, enhanced oil recovery, natural gas processing, sugar mill operations, and space heating and cooling. For each plant is given a brief site description, project summary, conceptual design, and functional description, including a picture of the facility and a flow chart. Also listed are the addresses of the companies involved for obtaining additional information.

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