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A Bibliography of Sandia National Laboratories Solar Central Receiver Reports: 1984 - 1987

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A BIBLIOGRAPHY OF SANDIA NATIONAL LABORATORIES SOLAR CENTRAL RECEIVER REPORTS: 1984 - 1987

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ABSTRACT

The 1984-1987 published reports of the technical information developed by the Sandia National Laboratories solar central receiver program are compiled. An abstract of each report is included. Reports are listed by both report number and author.

SOLAR THERMAL TECHNOLOGY
FOREWORD

The research and development described in this document was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.

Solar thermal technology concentrates solar radiation by means of tracking mirrors or lenses onto a receiver where the solar energy is absorbed as heat and converted into electricity or incorporated into products as process heat. The two primary solar thermal technologies, central receivers and distributed receivers, employ various point and line-focus optics to concentrate sunlight. Current central receiver systems use fields of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a single tower-mounted receiver. Parabolic dishes up to 17 meters in diameter track the sun in two axes and use mirrors or Fresnel lenses to focus radiant energy onto a receiver. Troughs and bowls are line-focus tracking reflectors that concentrate sunlight onto receiver tubes along their focal lines. Concentrating collector modules can be used alone or in a multi-module system. The concentrated radiant energy absorbed by the solar thermal receiver is transported to the conversion process by a circulating working fluid. Receiver temperatures range from 100^{o}C in low-temperature troughs to over 1500^{o}C in dish and central receiver systems.

The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems, and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories who work with private industry. Together they have established a comprehensive, goal directed program to improve performance and provide technically proven options for eventual incorporation into the Nation's energy supply.

To be successful in contributing to an adequate national energy supply at reasonable cost, solar thermal energy must eventually be economically competitive with a variety of other energy sources. Component and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and making optimal component developments. These targets will be pursued vigorously to insure a successful program.

This report presents a bibliography of reports generated by Sandia National Laboratories for the solar central receiver program from 1984 through 1987. The report is a continuation of a previously published bibliography, SAND84-8188, which summarized reports published from 1973 to 1983.

ANNOTATED BIBLIOGRAPHY

Listing by Document Number in Numerical Order

SAND-80-8192: MOLTEN SALT THERMAL ENERGY STORAGE SUBSYSTEM RESEARCH EXPERIMENT, VOLUMES I AND II; Martin Marietta Corporation; May 1985.

This report describes the design, fabrication, and testing of a thermal storage subsystem research experiment using molten nitrate salt as the working fluid. The design is based on a two tank system, one tank to hold cold (550°F) salt and one to hold hot (1050°F) salt. The cold tank is a conventional design with a carbon steel wall and external insulation. The hot tank employs new technology: it has firebrick insulation internal to a structural shell, with a corrugated liner inside the insulation to contain the salt. The liner is similar to those used in transportation and storage of liquefied natural gas. The testing showed that this concept of thermal storage is technically feasible and potentially cost effective.

SAND-81-8188: PLASTIC HELIOSTAT AND HELIOSTAT ENCLOSURE ANALYSIS; Boeing Engineering and Construction; December 1984.

This report describes the conceptual design and cost analysis of an plastic-enclosed heliostat for a 50 MWe solar thermal central receiver power plant. The study shows that plastic-enclosed heliostats offer a significant opportunity for collector subsystem cost reduction when compared to second generation glass/metal heliostat designs.

SAND-82-2682: REDIRECTOR DESIGN METHODOLOGY FOR HORIZONTAL TARGET PLANE APPLICATIONS AT THE CENTRAL REVCEIVER TEST FACILITY; D. E. Arvizu and G. P. Mulholland; November 1984.

The equations necessary for designing a multifaceted redirector that directs energy from a heliostat onto a secondary, sometimes horizontal, target have been derived. Although the equations are quite general, the approach has been formulated with specific applications of the Central Receiver Test Facility (CRTF) and the Sandia Solar Furnace in mind. A computer code, ORC, has been developed that applies the derived set of equations to the CRTF heliostat field. The output of ORC is a preliminary design for the redirector. This output is subsequently used as an input to the CRTF facility code, HELIOS, to obtain a complete flux density distribution on both the redirector and receiver surfaces. Upon examination of these results, the redirector design can be modified and the above procedures repeated until a satisfactory design is obtained. The proposed design methodology is illustrated with a preliminary design example. The new capabilities that a redirector can provide to the CRTF or the Solar Furnace represent a powerful new resource for activities and experiments where radiation direction is an important variable.

SAND-82-8177: MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - VOLUMES I AND II; Babcock & Wilcox; October 1984.

Conceptual designs of a molten salt steam generator subsystem were performed for a 100 MWe stand-alone solar thermal central receiver power plant and a 100 MWe hybrid solar thermal central receiver power plant that is 50% powered by solar energy. Evaluation of several concepts resulted in the selection of a four-component (preheater, evaporator, superheater, reheater) forced recirculation, horizontally oriented, shell and U-tube heat exchanger arrangement. A thermal hydraulic analysis of the steam generator was performed, including full and part load performance, circulation requirements, stability, and critical heat flux. Flow-induced tube vibration, tube buckling, fatigue analysis of tubesheet junctions, steady-state tubesheet analysis, and a simplified transient analysis were included in the structural analysis of the system. Operating modes and system dynamic response to load changes were identified. Auxiliary equipment, fabrication, erection, and maintenance requirements were also defined. Installed capital costs and a project schedule were prepared for each design. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size steam generator.

SAND-82-8178: MOLTEN SALT RECEIVER SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - VOLUMES I AND II; Babcock & Wilcox; October 1984.

This report describes the conceptual design of a 320 MWt molten nitrate salt receiver. The receiver design consists of a quad cavity configuration with 98 vertical panels. A thermal hydraulic analysis of the receiver was performed, including design point performance, circulation requirements, stability, and critical heat flux. The receiver panels were analyzed to determine the severity of the thermal stresses and their impact on the structural integrity and creep-fatigue life of the receiver. Operating modes and system dynamic response to load changes were identified. The receiver materials and auxiliary equipment were defined, and panel fabrication development was performed. The receiver weight was estimated, and a construction cost estimate was prepared. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size receiver.

SAND-82-8179: MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - VOLUMES I AND II; Foster Wheeler Solar Development Corporation; October 1984.

Conceptual designs of a molten salt steam generator subsystem were performed for a 100 MWe stand-alone solar thermal central receiver power plant and a 100 MWe hybrid solar thermal central receiver power plant that is 50% powered by solar energy. Evaluation of several concepts resulted in the selection of a four-component (preheater, evaporator, superheater, reheater) natural circulation, vertically oriented, shell and straight tube heat exchanger arrangement. A thermal hydraulic analysis of the steam generator was performed, including full and part load performance, circulation requirements, stability, and critical heat flux. Flow-induced tube vibration, tube buckling, fatigue analysis of tubesheet junctions, steady-state tubesheet analysis, and a simplified transient analysis were included in the structural analysis of the system. Operating modes and system dynamic response to load changes were identified. Auxiliary equipment, fabrication, erection, and maintenance requirements were also defined. Installed capital costs and a project schedule were prepared for each design. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size steam generator.

SAND-82-8180: MOLTEN SALT RECEIVER SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - VOLUMES I, II, AND III; Foster Wheeler Solar Development Corporation; October 1984.

This report describes the conceptual design of a 320 MWt molten nitrate salt receiver. The receiver design consists of a north-facing partial cavity configuration with 20 vertical up-flow panels. Eighteen panels are located internally in the cavity, and two panels are semi-external panels positioned on each side of the aperture. A thermal hydraulic analysis of the receiver was performed, including design point and annual performance, circulation requirements, stability, and critical heat flux. The receiver panels were analyzed to determine the severity of the thermal stresses and their impact on the structural integrity and creep-fatigue life of the receiver. Operating modes and system dynamic response to load changes were identified. The receiver materials and auxiliary equipment were defined, and panel fabrication development was performed. The receiver weight was estimated, and a construction cost estimate was prepared. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size receiver.

SAND-83-8019: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT TOTAL CAPITAL COST; H. F. Norris, Jr.; February 1985.

This report provides a detailed breakdown of the capital cost of the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, California. The total capital requirements of the Pilot Plant are given in four cost breakdown structures: (1) project costs (research and development, design, factory, construction, and start-up); (2) plant system costs (land, structures and improvements, collector system, receiver system, thermal transport system, thermal storage system, turbine-generator plant system, electrical plant system, miscellaneous plant equipment, and plant level); (3) elements of work costs (sitework/earthwork, concrete work, metal work, architectural work, process equipment, piping and electrical work); and (4) recurring and non-recurring costs. For all four structures, the total capital cost is the same ($141,200,000); however, the allocation of costs within each structure is different. These cost breakdown structures have been correlated to show the interaction and the assignment of costs for specific areas.
The detailed breakdown structure presented here for an actual solar facility can be useful in the understanding of the costs of future central receiver plants, and may serve as a basis for standardizing the categories of plant costs. The costs of the Pilot Plant cannot be scaled directly to larger future plants due to the developmental nature of the Pilot Plant.

SAND-83-8034: FEASIBILITY STUDY OF FRONT SURFACE CENTRAL RECEIVER TEMPERATURE MEASUREMENTS USING INFRA-RED THERMOGRAPHY; D. M. Abrahams; April 1985.

This report summarizes a study in which a long focal length telescope and an infrared detector were adapted to obtain relative temperature data for the surface of the receiver at the 10 MWe Solar Thermal Central Receiver Pilot Plant. On the basis of this study, it is recommended that some modifications be made to existing equipment, and some new equipment be purchased.

SAND-83-8035: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: BEAM SAFETY TESTS AND ANALYSES; T. D. Brumleve; June 1984.

This report describes analyses and experiments conducted to evaluate potential eye hazards of reflected heliostat beams and to verify the adequacy of the beam safety control strategy at the 10 MWe Solar Thermal Central Receiver Pilot Plant. Special video techniques were used during helicopter flyovers and at ground level to determine retinal irradiance and image size relative to a reference sun. Receiver brightness was also measured. Measured values were consistent with analyses, and safety provisions at the plant were found to be adequate. Other beam control strategies for heliostats designed to stow face-up in high winds were also studied, and one strategy was checked experimentally during the helicopter flyover tests. Results are presented and recommendations are made for future plants.

SAND-83-8175: SOLAR THERMAL CENTRAL RECEIVER COST DATA MANAGEMENT SYSTEM (CDMS) SOFTWARE USER'S GUIDE CDMS VERSION 1.1; Polydyne, Inc. and Associates; October 1984.

This report presents a user's guide for the Cost Data Management System (CDMS). The CDMS is an interactive computer program for cost data archival and retrieval, cost engineering and analysis, cost comparison and project management. The CDMS was developed as a tool to manage cost data for the solar thermal central receiver program. However, it is highly flexible and can be used to manage cost data for any power generation technology. The CDMS is operational on the Digital Equipment Corporation VAX-11/780 minicomputer using the VMS operating system.

SAND-83-8176: SOLAR THERMAL CENTRAL RECEIVER COST DATA MANAGEMENT SYSTEM (CDMS) - FINAL REPORT; Polydyne, Inc. and Associates; October 1984.

This report describes the Cost Data Management System (CDMS). The CDMS is an interactive computer program for cost data archival and retrieval, cost engineering and analysis, cost comparison and project management. The CDMS was developed as a tool to manage cost data for the solar thermal central receiver program. However, it is highly flexible and can be used to manage cost data for any power generation technology. The CDMS is operational on the Digital Equipment Corporation VAX-11/780 minicomputer using the VMS operating system.

SAND-83-8177: ATMOSPHERIC TRANSMITTANCE MODEL FOR A SOLAR BEAM PROPAGATING BETWEEN A HELIOSTAT AND A RECEIVER; University of Houston; February 1984.

This report describes a model for estimating the percent energy loss (or equivalently, the transmittance) of a solar beam propagating between a heliostat and a receiver. Formulae are presented that are wavelength-independent, functional fits to the results of numerical integrations of spectral transmittance data. A user's guide for computer programs based on the model is also presented.

The transmittance model is based on five explicit physical variables: the site elevation above sea level, the atmospheric water vapor density at the site elevation, the scattering coefficient at the site elevation, the tower focal height, and the slant range. The functional fits agree to within about one percent of the energy loss determined from the numerically integrated data.

SAND-83-8178: IMPACT OF TAX INCENTIVES ON THE COMMERCIALIZATION OF SOLAR THERMAL ELECTRIC TECHNOLOGIES; Polydyne, Inc. and Associates; January 1984.

A study was performed to explore the impacts of the current and proposed tax incentives affecting the commercialization prospects for the solar thermal central receiver concept. The study was carried out using a newly developed methodology for integrated technical, market, economic, and financial analyses of advanced power generation technologies. In particular, detailed financial cash flow analyses of intermediary financing of solar thermal central receiver technology were conducted for a variety of technical, economic, and financial conditions. The analyses established the investor-perceived economic value as compared with the projected installed costs of solar thermal central receiver technology.

A primary conclusion of the study is that, in spite of the rapid pace of technical development, the scheduled termination of the tax incentives will seriously impair commercialization of this technology. Therefore, the Congressionally proposed enhancement and extension of the present federal incentives through 1995, combined with the various state tax credits during the early commercialization period, are essential for successful transfer of the solar thermal central receiver technology to the private sector.

SAND-84-8175: MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - EXECUTIVE SUMMARY; Foster Wheeler Solar Development Corporation; September 1984.

Conceptual designs of a molten salt steam generator subsystem were performed for a 100 MWe stand-alone solar thermal central receiver power plant and a 100 MWe hybrid solar thermal central receiver power plant that is 50% powered by solar energy. Evaluation of several concepts resulted in the selection of a four-component (preheater, evaporator, superheater, reheater) natural circulation, vertically oriented, shell and straight tube heat exchanger arrangement. A thermal hydraulic analysis of the steam generator was performed, including full and part load performance, circulation requirements, stability, and critical heat flux. Flow-induced tube vibration, tube buckling, fatigue analysis of tubesheet junctions, steady-state tubesheet analysis, and a simplified transient analysis were included in the structural analysis of the system. Operating modes and system dynamic response to load changes were identified. Auxiliary equipment, fabrication, erection, and maintenance requirements were also defined. Installed capital costs and a project schedule were prepared for each design. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size steam generator.

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SAND-84-8177: MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - EXECUTIVE SUMMARY; Babcock & Wilcox; September 1984.

Conceptual designs of a molten salt steam generator subsystem were performed for a 100 MWe stand-alone solar thermal central receiver power plant and a 100 MWe hybrid solar thermal central receiver power plant that is 50% powered by solar energy. Evaluation of several concepts resulted in the selection of a four-component (preheater, evaporator, superheater, reheater) forced recirculation, horizontally oriented, shell and U-tube heat exchanger arrangement. A thermal hydraulic analysis of the steam generator was performed, including full and part load performance, circulation requirements, stability, and critical heat flux. Flow-induced tube vibration, tube buckling, fatigue analysis of tubesheet junctions, steady-state tubesheet analysis, and a simplified transient analysis were included in the structural analysis of the system. Operating modes and system dynamic response to load changes were identified. Auxiliary equipment, fabrication, erection, and maintenance requirements were also defined. Installed capital costs and a project schedule were prepared for each design. Finally, a Phase 2 development plan was prepared for the design, construction, testing, and evaluation of a subsystem research experiment that is of sufficient size to ensure successful operation of the full-size steam generator.

SAND-84-8178: MOLTEN SALT RECEIVER SUBSYSTEM RESEARCH EXPERIMENT PHASE 1 FINAL REPORT - EXECUTIVE SUMMARY; Babcock & Wilcox; September 1984.

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SAND-84-8180: SOLAR ONE SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: 1983 METEOROLOGICAL DATA REPORT; McDonnell Douglas Astronautics Company; June 1984.

Meteorological data recorded at the 10 MWe Solar Thermal Central Receiver Pilot Plant during 1983 are presented. A general description of the plant is provided, as well as information on the type, quantity, and location of the meteorological equipment and the instrumentation used to record the data.

SAND-84-8181: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MODE 1 (TEST 1110) TEST REPORT; McDonnell Douglas Astronautics Company; October 1984.

The 10 MWe Solar Thermal Central Receiver Pilot Plant, Solar One, is designed to operate in eight basic modes (including shutdown) which are intended to demonstrate and fully exercise the energy collection, energy storage, and power generation features of a central receiver system. During Mode 1 operation, the subject of this report, all of the collected solar energy is converted into superheated steam in the receiver with the steam then flowing directly to the turbine for electrical power production. Neither the charging nor discharging features of the thermal storage system are involved in this operation.

This report describes plant design information pertinent to Mode 1 operation and presents the results of the Mode 1 test activities. Test results are presented for steady-state plant performance at both design and off design conditions, plant start-up and shutdown transitions, and plant trips.

SAND-84-8183: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MODE 5 CHARGING ONLY ACCEPTANCE TEST PROCEDURE 1150; McDonnell Douglas Astronautics Company; December 1984.

This document provides the detailed test procedure followed for the 10 MWe Solar Thermal Central Receiver Pilot Plant Mode 5 acceptance testing. Test results are reported in SAND86-8175.

SAND-84-8185: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MODE 1 TURBINE DIRECT ACCEPTANCE TEST PROCEDURE 1110; McDonnell Douglas Astronautics Company; December 1984.

This document provides the detailed test procedure followed for the 10 MWe Solar Thermal Central Receiver Pilot Plant Mode 1 acceptance testing. Test results are reported in SAND84-8181.

SAND-84-8186: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT THERMAL STORAGE SYSTEM TEST 1040: PART A, BED CONDITIONING PROCEDURE, PART B, CONTROLS TEST PROCEDURE; McDonnell Douglas Astronautics Company; December 1984.

This report describes the thermal storage system bed conditioning test (Test 1040A) and the controls test (Test 1040B) preoperational test results for the 10 MWe Solar Thermal Central Receiver Pilot Plant. The 1040 test series deals primarily with the thermal storage system and includes the preoperational tests, initial conditioning of the storage tank bed, cleanup of the oil and steam sides of both charging and extraction trains, and controls verification testing of all thermal storage control loops. In Test 1040A the primary energy source was a rental boiler, and the system was exercised at below normal operating conditions to remove contamination and sediment from the oil. In Test 1040B the primary energy source was receiver steam for the charging loops and stored energy for the extraction loops. During this test the thermal storage system was operated throughout its normal range of operating conditions.

SAND-84-8187: USER'S MANUAL FOR THE UNIVERSITY OF HOUSTON INDIVIDUAL HELIOSTAT LAYOUT AND PERFORMANCE CODE; University of Houston; December 1984.

The individual heliostat (IH) computer code developed at the University of Houston determines the location of heliostats for an optimized heliostat collector field and computes in detail the performance of the central receiver system. In order for the IH code to generate optimized fields as specified by the cellwise optimization (RC) code, the IH code requires output from CELLAY. CELLAY is a stand-alone program that takes output from the RC system and generates input for the IH programs. A subroutine called LAYOUT with its associated subroutines is the primary source of heliostat location coordinates. Boundaries, slip planes, and deletes are all controlled by specification of key variables which occur before the general sequence of calculations. The IH performance code is similar to the cellwise performance code (NS) with the sum over cells being replaced by a sum over heliostats. Each heliostat has several associated quantities which are calculated and printed so that the action of the system can be monitored over the course of time. Performance can be determined at any single point in time, or it can be integrated over daily, monthly, or annual performance periods.

SAND-84-8188: A BIBLIOGRAPHY OF SANDIA NATIONAL LABORATORIES SOLAR CENTRAL RECEIVER REPORTS; A. C. Skinrood, L. G. Radosevich, and M. G. Soderstrum; November 1984.

The 1973-1983 published reports of the technical information developed by 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.

SAND-84-8189: SMALL CENTRAL RECEIVER BRAYTON CYCLE STUDY FINAL TECHNICAL REPORT DECEMBER 1, 1982 - JUNE 30, 1983; Boeing Aerospace Company Energy Systems; January 1985.

This report describes the potential of small-scale, central receiver Brayton cycle systems for electrical power production. Open and closed cycles with and without regeneration and/or intercooling were assessed for plant sizes of 2 and 25 MWe. Design point performance was studied as a function of system pressure, turbine inlet temperature, and receiver pressure loss. An open cycle regenerated and intercooled configuration was selected for the 25 MWe plant size because of its high cycle efficiency, reduced heliostat field costs, reduced capital and energy costs, and turbomachinery availability. At the 2 MWe size an open simple cycle was chosen because of its low capital and energy costs, reduced complexity, and turbomachinery availability.

High-temperature receiver concepts were analyzed that are potentially applicable to the air heating requirements of the selected cycles. A ceramic tube receiver was selected for the 25 MWe plant size while a small particle receiver was selected for the 2 MWe plant size.

The preferred receiver designs and cycles were combined to produce system level designs. Cost and performance data were generated for each plant design. The results show that small-scale, remotely-sited, solar central receiver Brayton systems are technically feasible and economically attractive. Relatively straight forward development will be required to implement these solar central receiver designs.

SAND-84-8190: ANALYSIS AND DESIGN OF THE VOLUMETRIC AIR HEATING RECEIVER; Pacific Northwest Laboratory; July 1985.

Pacific Northwest Laboratory (PNL) has performed a preconceptual design and cost evaluation of a volumetric receiver, a novel approach for producing high temperature air for process heat applications. In this central receiver concept, solar energy is concentrated by a field of heliostats onto the receiver which is located on top of a tower. The concentrated flux is intercepted throughout a matrix of fins or fibers rather than on the surface of the receiver, hence the reference to "volumetric" absorption. An exterior row of reflecting fins which act as a "light valve" to allow energy to enter the receiver but inhibit thermal radiation and reflection from leaving the receiver is a critical feature of the concept. Ambient air is drawn in through the absorbing array, cooling the receiver and heating the air. The air is then drawn through downcomer piping to heat exchangers.

Through the design evolution of this receiver, several qualitative advantages that made the concept attractive were lost. What had originally been envisioned to be a compact and simple air receiver design turned out to be much larger and more complicated when the preliminary engineering design was completed. A much lower efficiency was also predicted at the end of the study. Due to the complexity of the design, the lower efficiency, and a list of major technical uncertainties discussed in this report, PNL has recommended that the volumetric receiver project be discontinued.

SAND-84-8192: EXPERIMENTAL STUDY OF FREE AND MIXED CONVECTIVE FLOW OF AIR IN A HEATED CAVITY; Mechanical Engineering Department, University of California at Berkeley; April 1985.

This report describes experimental results for the free and mixed convection in a strongly heated rectangular open cavity. Data were recorded for the effects of cavity shape, cavity inclination, and ambient wind speed on the velocity and temperature distribution. Cavity shape was studied by varying the ratio of aperture height to cavity depth for a fixed aperture height. The aperture plane was positioned vertically or inclined downward to study the effect of cavity inclination. Finally, wind speed was varied to obtain Reynolds numbers where either free or forced convection was dominant. Thermocouple, shadowgraph, and laser-Doppler velocimeter measurement techniques were used to obtain the experimental data.

SAND-84-8214: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MIRROR MODULE CORROSION SURVEY; J. E. Noring, C. L. Mavis, E. V. Decker, and P. E. Skvarna; March 1984.

This report documents the results of the survey of mirror module corrosion at the 10 MWe Solar Thermal Central Receiver Pilot Plant. As of August 1983, 0.015 percent of the total reflective area of the heliostat field was corroded. The present growth rate of this corrosion is approximately a factor of ten per year.

SAND-84-8228: AN ASSESSMENT OF SOLAR THERMAL CONCENTRATOR RESEARCH AND DEVELOPMENT; L. G. Radosevich and R. S. Caputo; June 1984.

Concentrator research and development has been an integral part of the solar thermal technology program since its beginning. Within the central and distributed receiver programs, a considerable amount of research and development has been successfully concluded: over twenty-five line focus (mostly parabolic trough) designs, thirteen heliostat designs, and eight parabolic dish designs have been fabricated and tested under Department of Energy sponsorship; mass-production costs have been estimated for several of these designs; and materials and components research is under way to identify areas for both cost and performance improvements. An overall assessment of this work has recently been performed to determine future research and development needs. This report describes the results of this assessment and presents recommendations for future concentrator research and development.

SAND-84-8229: TECHNICAL REVIEW OF THE SOLID PARTICLE RECEIVER PROGRAM JANUARY 25-26, 1984; P. K. Falcone; July 1984.

A technical review of the solid particle receiver program was conducted on January 25-26, 1984, at Sandia National Laboratories in Livermore, California. The meeting was held to discuss the status of the technical feasibility investigations one year into the study and to set direction for the future. This document includes summaries of the presentations made at the meeting as well as an overview of the program.

SAND-84-8233: THE PERFORMANCE OF HIGH-TEMPERATURE CENTRAL RECEIVER SYSTEMS; P. De Laquil III and J. V. Anderson; July 1984.

The development of central receiver technology for the production of electricity is reasonably well established. One possible direction for the future research and development efforts funded by the Department of Energy is high-temperature, high-performance systems. In this paper, the performance of central receiver systems is investigated for a range of heliostat sizes, field configurations, plant sizes, and receiver temperatures. The maximum plant efficiency achievable in a central receiver system that uses simple cavity geometry is shown for a range of receiver temperatures. The impact of changes in heliostat size, field packing density, and canting and focusing strategies on system efficiency is investigated over a range of plant sizes. The results of the study underscore the importance of accommodating high absorber plane fluxes in order to efficiently produce working temperatures at or above 1200°C.

SAND-84-8237: DATA EVALUATION PLAN FOR THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT POWER PRODUCTION PHASE; L. G. Radosevich; October 1984.

This report describes the planned data evaluation for the three-year Power Production Phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California. The Power Production Phase, which began in August 1984, will demonstrate the operational capability of the plant to reliably supply electrical power to the utility grid. Data evaluation will be performed for design point and annual plant energy output; heliostat optical performance and mirror module corrosion; receiver tube life and absorber coating life; storage fluid degradation and storage tank thermal stresses; plant availability; operating procedures and costs; and component reliability and maintenance costs. The objective, test needs, data needs, approach, expected output, and planned data dissemination are presented for each evaluation.

SAND-84-8238: SOLID PARTICLE RECEIVER EXPERIMENTS: VELOCITY MEASUREMENTS; J. M. Hruby and V. P. Burolla; October 1984.

Laser Doppler velocimetry and other photometric techniques are evaluated for measuring the average particle velocity in an ensemble of free-falling particles. The ability to obtain measurements in the presence of a radiant flux as high as 0.6 MW/m^2 was part of the evaluation. Optically dissimilar particles with diameters ranging from 0.1 mm to 1 mm were used in the study. Experimental results indicate that ensembles of particles do not behave as single isolated particles. The particle motion is dependent on particle volume fraction, and is quite unstable for falls greater than one meter.

SAND-84-8251: SOLID PARTICLE RECEIVER EXPERIMENTS: RADIANT HEAT TEST; J. M. Hruby, B. R. Steele, and V. P. Burolla; December 1984.

In tests designed to simulate the fundamental characteristics of a solar thermal solid particle central receiver, a continuous stream of free-falling particles has been heated to temperatures in excess of 1300 K over a ten meter fall height in the presence of a radiant flux of 0.50 MW/m^2. The ability to heat particles to temperatures this high is a major step in demonstrating the technical feasibility of the solid particle receiver concept. Particle temperatures were varied by altering mass flow rate, incident radiant flux, and particle size and optical properties. Flux levels were varied between 0.10 and 0.50 MW/m^2 for silicon carbide and silica sand particles with nominal sizes of 300, 500 and 1000 microns. Particle-generated convection currents increased particle residence times by as much as a factor of three. No particle sintering effects were observed.

SAND-84-8255: A PARTICLE CURTAIN GENERATOR FOR OPTICAL PROPERTY MEASUREMENTS OF SOLID PARTICLES; G. H. Prescott and B. R. Steele; January 1985.

A device to form a particle curtain that is one inch in width and one particle in thickness has been designed, fabricated and tested. This particle curtain generator will form curtains using free flowing spherical or poor flowing angular particles. Particle sizes varying from 100 to 1000 microns were tested at various flow rates. This device is being used at Battelle Pacific Northwest Laboratory to aid in making optical property measurements on candidate materials for the solid particle receiver work being done by Sandia.

SAND-84-8256: BIOMASS PROCESSING AND SOLAR PROCESS HEAT; R. Sizmann; January 1985.

The rate at which biomass can supply useful energy depends on the available integrated solar flux density Gt_a over the year, the photosynthesis yield e_p, the harvest factor (1-r), the energy gain g, and the conversion efficiency e_c of biomass into the desired energy carrier. The area required for a given annual energy demand E is

$$A = gE/e_p e_c Gt_a(1-r)(g-1)$$

In particular, the production of ethanol from biomass is considered, based on recent data from the national alcohol program "Proalcool" in Brazil.

Finally, an estimate is given how solar process heat can improve the yield of alcohol or provide other base material for the chemical industry such as ethylene and synthesis gas from biomass.

SAND-84-8717: ESTIMATING CONVECTIVE ENERGY LOSSES FROM SOLAR CENTRAL RECEIVERS; D. L. Siebers and J. S. Kraabel; April 1984.

This report outlines a method for estimating the total convective energy loss from a receiver of a solar central receiver power plant. Two types of receivers are considered in detail: a cylindrical, external-type receiver and a cavity-type receiver. The method is intended to provide the designer with a tool for estimating the total convective energy loss that is based on current knowledge of convective heat transfer from receivers to the environment and that is adaptable to new information as it becomes available. The current knowledge consists of information from two recent large-scale experiments, as well as information already in the literature. Also outlined is a method for estimating the uncertainty in the convective loss estimates. Sample estimations of the total convective enery loss and the uncertainties in those convective energy loss estimates for the external receiver of the 10 MWe Solar Thermal Central Receiver Pilot Plant (Barstow, California) and the cavity receiver of the International Energy Agency Small Solar Power Systems Project (Almeria, Spain) are included in the appendices.

SAND-84-8929: RADIATIVE TRANSFER IN A SOLAR ABSORBING PARTICLE LADEN FLOW; W. G. Houf and R. Greif; November 1985.

Solar central receivers which utilize solid thermal carriers such as sand or small refractory particles for direct absorption of concentrated solar radiation are under investigation at Sandia National Laboratories Livermore. In the central receiver concept a field of tracking mirrors (heliostats) is used to focus solar energy onto a receiver mounted atop a tower. A possible receiver configuration is a cavity in which a falling sheet of solid particles is directly irradiated by the concentrated solar flux passing through the aperture. Regardless of the particular geometry, the radiative transfer within the falling particle curtain must be studied in order to determine the net radiative heating rate for the particles.

A discrete ordinate radiative transfer model has been developed to predict the radiative coupling within the falling particle curtain. The model determines how much energy is absorbed by the particles, how much is transmitted to the rear wall of the receiver, and determines the effects of particle scattering and thermal emission on the net radiation absorbed by the particles. The model accounts for the directional nature of the radiation field, particle scattering, and the wavelength dependence of the optical properties.

The discrete ordinate model has been used to assess the influence of the pertinent radiation transfer parameters in determining the local and overall particle heating rates. The results of this study are discussed as well as the analysis.

SAND-85-0970: EVALUATION OF HELIOSTAT CHARACTERIZATION SYSTEM FOR USE AT THE CENTRAL RECEIVER TEST FACILITY; C. Maxwell and J. V. Otts; June 1986.

The Heliostat Characterization System is a new system that has been used to align and focus heliostats at the Central Receiver Test Facility. The system produces results comparable to those obtained with the original focus and alignment system but is faster and requires less labor.

SAND-85-2422: A RELIABILITY STUDY OF SOLAR ONE, THE CENTRAL RECEIVER PILOT PLANT; J. F. Nagel, Jr.; July 1986.

Solar One, the world's largest solar central receiver electric power plant, is well into its commercial power production phase. A reliability model of the plant was developed, and the reliabilities of the plant and its systems and subsystems, including an individual heliostat, were assessed. As a result of the assessments, equipment problems were identified, and the reasons for the problems were studied. Recommendations are presented for similar future designs.

SAND-85-8015: FINAL REPORT ON THE EXPERIMENTAL TEST AND EVALUATION PHASE OF THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; L. G. Radosevich; September 1985.

This report describes the evaluations of the performance of Solar One, the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California. The Pilot Plant project is a cooperative effort of the U.S. Department of Energy and a group of utilities led by the Southern California Edison Company. Construction of the Pilot Plant was completed in 1981, and the plant is now undergoing a five-year Operational Test Period. The Operational Test Period consists of a two-year Experimental Test and Evaluation Phase followed by a three-year Power Production Phase. The Experimental Test and Evaluation Phase, which began in mid-1982, was completed on July 31, 1984. The Power Production Phase, which began on August 1, 1984, will primarily demonstrate the operational capability of the Pilot Plant to reliably supply electrical power. Sandia National Laboratories has the primary responsibility for the evaluation of both phases of plant operation.

During the Experimental Test and Evaluation Phase the Pilot Plant was successfully operated in all its steady-state operating modes. Transitions to and from each steady-state mode were accomplished, and, during the course of testing, significant improvements were made in the plant's start-up and shutdown times. Emergency shutdowns were also demonstrated, and preliminary power production testing was begun. Considering the first-of-a-kind nature of the Pilot Plant and the high level of technology involved, the plant has operated well. However, as with any new technology, some problems have occurred, such as receiver tube leaks and mirror corrosion. The problems encountered have not prevented the plant from operating reliably or from achieving the objective of demonstrating the feasibility, safety, and environmental acceptability of such plants. The Pilot Plant has provided valuable lessons which will aid in the design of future solar central receiver plants.

SAND-85-8019: REVIEW OF THERMAL LOSS EVALUATIONS OF SOLAR CENTRAL RECEIVERS; R. F. Boehm; April 1986.

This paper summarizes previous evaluations of thermal losses from solar central receivers. Two basic types of evaluations have been done: (1) efficiency tests, which use performance data, and (2) loss tests which infer losses directly. In either type of evaluation, the radiation loss must first be calculated. This study also reviews the techniques used for calculating these radiation losses. Special attention is given to physical parameters such as Grashof or Rayleigh number and Reynolds number. Thermal loss uncertainties and predictions are also studied. Finally, this report draws a number of conclusions and makes recommendations for further study.

SAND-85-8022: SOUTHWEST UTILITY EXPANSION PLANS: IMPLICATIONS FOR SOLAR THERMAL ELECTRIC TECHNOLOGIES; J. A. Dirks; June 1986.

This study documents the capacity expansion plans of the major Southwest Utilities with an emphasis on California. Included in this report, for these utilities, are the current total capacities and projected capacities through the end of this century, generic capacity additions, solar capacity additions, and a list of solar thermal projects that are in various stages of development. Also discussed are a number of factors that could affect the rate and the magnitude of solar thermal electric market penetration. Among these factors are future energy demand growth, the cost of producing energy from all potential sources, conservation and more stringent pollution control laws.

New capacity additions will be required in the desert Southwest during the rest of this century. The California Energy Commission and the major California utilities have demonstrated their commitment to installing alternative forms of electricity production during this time period. Hence, it is recommended that the solar thermal community aggressively pursue the Southwest utilities as an area of early market penetration.

SAND-85-8175: MOLTEN SALT ELECTRIC EXPERIMENT (MSEE) - PHASE I REPORT: VOLUMES I, II, AND III; Martin Marietta Corporation; August 1985.

The Molten Salt Electric Experiment (MSEE) conducted at the Central Receiver Test Facility in Albuquerque, New Mexico, is the first large-scale demonstration in the United States of the technical feasibility of operating a solar central receiver power plant with molten nitrate salt as the receiver heat transfer fluid and thermal storage medium. This report documents the design, construction, and checkout (Phase I) of the project.

This final report consists of three volumes. Volume I is an abbreviated summary of the Phase I activities in the MSEE program. Volume II presents the historical development of the program and a detailed account of the test activities and results. Volume III summarizes the key documentation generated to support MSEE.

SAND-85-8176: RECEIVER LOSS STUDY; OPTICS OF OPTIMIZED SOLAR CENTRAL RECEIVER SYSTEMS AS A FUNCTION OF RECEIVER THERMAL LOSS PER UNIT AREA; University of Houston; March 1985.

Recent efforts in solar central receiver research have been directed toward high temperature applications. Associated with high temperature processes are greater receiver thermal losses due to reradiation and convection. This report examines the performance of central receiver systems having optimum heliostat fields and receiver aperture areas as a function of receiver thermal loss per unit area of receiver aperture. The results address the problem of application optimization (where the loss per unit area varies) as opposed to the problem of merely optimizing a design for a specific application (where the loss per unit area is approximately fixed).

SAND-85-8177: THEORY OF CELLWISE OPTIMIZATION FOR SOLAR CENTRAL RECEIVER SYSTEMS; University of Houston; May 1985.

The cost effective optimization of a solar central receiver system is primarily concerned with the distribution of heliostats in the collector field, including the boundaries of the field. The cellwise optimization procedure determines the optimum cell usage and heliostat spacing parameters for each cell in the collector field. The spacing parameters determine the heliostat density and neighborhood structure uniformly in each cell. Consequently, the cellwise approach ignores heliostat mismatch at cell boundaries. Ignoring the cell boundary problem permits an easy solution for the optimum in terms of appropriately defined annual average data. Insolation, receiver interception, shading and blocking, cosine effects, and the cost parameters combine to control the optimum. Many trade-offs are represented. Outputs include the receiver flux density distribution for design time, coefficients for an actual layout, the optimum boundary, and various performance and cost estimates for the optimum field. It is also possible to optimize receiver size and tower height by a repeated application of the field optimization procedure.

SAND-85-8178: COST DATA MANAGEMENT SYSTEM CDMS VERSION 2.2 FINAL REPORT; Polydyne, Inc. and Associates; December 1985.

The Cost Data Management System (CDMS) is a cost data base computer program developed by Polydyne, Inc. and Associates for Sandia National Laboratories Livermore (SNLL). The program constitutes a unique and powerful tool for interactive development and documentation of complex cost data bases for power plants and other construction projects. The program is operational on the Digital Equipment Corporation's VAX computers operating under the latest version (4.1) of the VMS operating system.

The original version of the CDMS (Version 1.1) has been extensively used by SNLL in the development, documentation, and analysis of the cost data base for Solar One. As a result of this work, a number of desirable enhancements to the CDMS were identified, and as a follow-on effort, Polydyne, Inc. has revised the original software. This report summarizes the extensive revisions and enhancements made to the CDMS and discusses the features of the new program (CDMS Version 2.2).

SAND-85-8179: COST DATA MANAGEMENT SYSTEM USER'S GUIDE SUPPLEMENT CDMS VERSION 2.2; Polydyne, Inc. and Associates; December 1985.

The Cost Data Management System (CDMS) is a cost data base computer program developed by Polydyne, Inc. and Associates for Sandia National Laboratories Livermore (SNLL). The program constitutes a unique and powerful tool for interactive development and documentation of complex cost data bases for power plants and other construction projects. The program is operational on the Digital Equipment Corporation's VAX computers operating under the latest version (4.1) of the VMS operating system.

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SAND-85-8180: NUMERICAL SIMULATION OF BUOYANT TURBULENT FLOW; Mechanical Engineering Department, University of California at Berkeley; August 1985.

Two models have been developed for predicting low Reynolds number turbulent flows in free and mixed convective regimes. Predictions for the case of the vertical flat plate show excellent agreement of mean velocity, temperature, and Nusselt number. In the free convection regime it is shown that when the cavity is tilted forward stable stratification of fluid dampens the turbulence fluctuations which works to reduce heat transfer. In the forced convection regime, calculations reveal a minimum in the heat loss from a cavity when opposing inertial and buoyant forces are roughly of equal magnitude.

SAND-85-8181: MOLTEN SALT ELECTRIC EXPERIMENT STEAM GENERATOR SUBSYSTEM FINAL REPORT; Babcock & Wilcox; April 1986.

The Molten Salt Electric Experiment (MSEE) is a full system demonstration of a solar central receiver power generation plant which uses molten nitrate salt as the primary heat transfer fluid and also as the thermal storage medium. The MSEE receiver has a thermal capacity of 5 MWt, and the turbine-generator is rated at 750 kWe. The system has a two-tank thermal storage subsystem with a capacity of 6 MWt-hr, and a steam generator rated at 3.1 MWt. The MSEE began in mid-1982, and testing was completed in July 1985 at the Central Receiver Test Facility in Albuquerque, New Mexico. Babcock & Wilcox was awarded the contract to supply a steam generator for the MSEE capable of producing superheated steam using molten salt as a heat source. This report covers the design, fabrication, installation, and testing of the Steam Generation Subsystem beginning in September 1982 and ending in June 1984.

SAND-85-8182: IMPACT OF TAX INCENTIVES ON THE COMMERCIALIZATION OF SOLAR THERMAL ELECTRIC TECHNOLOGIES - VOLUME II, FEDERAL REVENUE CONSIDERATIONS; Polydyne, Inc. and Associates; November 1985.

The purpose of this study was to quantify the impact of the Solar Thermal Central Receiver (STCR) tax incentives and commercialization on the federal treasury revenues. The initial STCR market penetration was assumed to take place in California, because of favorable local conditions. The initial financing was assumed to be underwritten by intermediary partnerships under long-term avoided cost contracts with the local utility companies with subsequent sale of the plants to utilities at competitive prices.

To estimate the impacts of these various tax incentives associated with the commercialization of the STCR technology, the tax revenues and costs for the STCR plants were compared with the tax revenues and costs for the displaced conventional power plants. This differential analysis takes into account the different operating expenses, as well as the different depreciation charges, financing costs and tax credits, associated with STCR and conventional plants. The study also evaluated the impact of both the previous (1983) and current (1984) proposed federal energy tax credits. The resulting total annual tax cash flows were subsequently cumulated to determine the aggregate tax revenues and costs throughout the 1985 to 2034 time period.

The results of this analysis indicate that the initial federal tax revenues are negative. With increasing market penetration, the installed costs of the STCR plants decrease rapidly and the net present values of the tax revenue cash flows associated with plants constructed after 1995 are positive, and become significantly larger than those for the corresponding displaced conventional plants.

The energy tax credits for STCR systems have the potential to provide the necessary incentives to commercialize a very attractive renewable energy resource at a very low total initial cost to the government as compared with the previous incentives provided for the commercialization of the current conventional energy technologies. In the long run, the commercialization of the STCR technology would save about 800 million barrels of oil or its gas equivalent through 2034, while providing long-term positive tax revenues to the treasury.

SAND-85-8183: A PRELIMINARY ASSESSMENT OF THE POTENTIAL FOR INTEGRATING SOLAR THERMAL CENTRAL RECEIVER TECHNOLOGY WITH FUELS AND CHEMICALS PROCESSES; Pacific Northwest Laboratory; July 1986.

Most solar thermal systems are designed to concentrate the sun's energy and transfer it to a working fluid. The energy in the working fluid is usually converted to electricity or used as process heat in an industrial application. An alternative to conventional process heat applications would be to pass the object of process heating directly through the solar receiver and eliminate the intermediate heat transfer loop. This approach to process heating could potentially work for a broad range of industrial process heat applications and solar thermal technologies. This report focuses on the prospects for integrating solar thermal central receivers with fuels and chemicals processes.

SAND-85-8184: SOLAR REFORMER EXPERIMENT DESIGN STUDY; Resource Analysis International; July 1986.

This report describes the design of an experiment in which solar energy is provided to a steam-hydrocarbon reforming reactor placed inside a solar central receiver. The hardware design, process, and operation options are analyzed along with the critical development issues. A construction cost estimate and a development plan are also included.

SAND-85-8202: PROCEEDINGS OF THE DEPARTMENT OF ENERGY SOLAR CENTRAL RECEIVER ANNUAL MEETING; Sandia National Laboratories; February 1985.

This document includes papers and presentation materials presented at the Solar Central Receiver Technology Annual Meeting held in San Diego, California, on April 24-26, 1984.

SAND-85-8206: THERMAL PERFORMANCE AND DESIGN OF A SOLID PARTICLE CAVITY RECEIVER; C. A. LaJeunesse; April 1985.

A model for energy transport in a solid particle cavity receiver is developed and applied to the design and analysis of a receiver for testing at the Central Receiver Test Facility (CRTF), Albuquerque, New Mexico. The model gives thermal performance results - including particle temperatures, cavity efficiencies, and wall temperatures - which directly affect the economic and technical feasibility of a solid particle receiver. In addition, design criteria relevant to the configuration of a solid particle cavity receiver are developed. Results for the CRTF indicate that at design conditions particle temperatures will exceed 1200^{o}K with cavity efficiencies on the order of 75%.

SAND-85-8207: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT DESIGN DAY PERFORMANCE MONOGRAPH; C. L. Yang; June 1985.

The performance of the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, is evaluated against the design day performance predictions. Actual conditions at the plant were assessed and used to calculate plant performance. The effects of weather, available heliostats, mirror reflectivity, field/receiver efficiency, and turbine efficiency are presented and discussed.

SAND-85-8208: ASSESSMENT OF A SOLID PARTICLE RECEIVER FOR A HIGH TEMPERATURE SOLAR CENTRAL RECEIVER SYSTEM; P. K. Falcone, J. E. Noring, and J. M. Hruby; February 1985.

The use of small refractory pebbles or sand as the working media in a high temperature solar central receiver system has been examined. Such a receiver appears to have significant advantages over current designs for high temperature receivers which use air or gas as the working fluid. A conceptual design is proposed and analyzed, candidate materials are examined, system components are explored, and the cost of a central receiver system employing a solid particle receiver is estimated. The areas of principal technical uncertainties are identified and a plan for further work is proposed.

SAND-85-8211: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MAINTENANCE EXPERIENCE: JANUARY 1982 - MARCH 1983; J. W. Smith; May 1985.

This report presents a description of the maintenance experience at the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, during the period January 1982 through March 1983. The plant systems are briefly described, and statistical data on maintenance orders, labor requirements, and maintenance costs are presented. The data presented have been extracted from Southern California Edison historical maintenance records accumulated at the plant. Pilot Plant systems requiring the most maintenance activity are identified so that efforts to reduce plant maintenance costs can be properly identified. The information is analyzed for the purpose of developing a data base for general use during the economic assessment, design, and staff planning of future solar central receiver plants. However, data presented here from the Pilot Plant should not be used for direct scaling of larger power production plants. The number and size of equipment items for larger plants will not scale, the designs will vary, and the Pilot Plant includes special testing and evaluation equipment which would not be necessary in plants built for the sole purpose of power production.

Data taken at the Pilot Plant during the early plant start-up and operational phase show an annual maintenance cost of approximately one percent of the recurring plant capital cost. Similar costs for recent technology steam electric generating plants are estimated to range from 1.5 to 3 percent. The Pilot Plant maintenance cost will not appear as favorable if based on energy produced during power production due to the small plant size and equipment intensive nature of the plant. The solar-unique systems of the plant required 45 percent of the total plant maintenance labor and 39 percent of the total maintenance cost, both percentages being lower than anticipated.

SAND-85-8212: A STUDY OF ALTERNATIVE SYSTEM CONVERSIONS FOR THE SOLAR ONE PILOT PLANT; Systems Evaluation Division; March 1985.

This report describes a study of alternatives for the conversion of Solar One, the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, to an advanced molten salt or liquid sodium central receiver system. These advanced systems offer a potential 25% reduction in the cost of delivered electricity at a utility plant scale. The results of this study indicate that several options exist for reducing the technical and economic risks associated with advanced central receiver systems. For all options studied, startup of the converted plant could begin approximately three years after the project is authorized. Because all of the conversion options have similar technical advantages and have costs in the range of $55-64M, a comparison did not identify a clear choice. Therefore, the electrical utility preferences should play a strong role in selecting the conversion option.

SAND-85-8216: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: 1984 SUMMER SOLSTICE POWER PRODUCTION TEST; E. H. Carrell; May 1985.

The 1984 summer solstice power production test for the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California, was conducted June 14-28, 1984. This report presents the actual operating parameters and results of the test, compares those parameters and results to the plant's original design point conditions, and analyzes the differences.

SAND-85-8224: MONOGRAPH SERIES NO. 2: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT AND RECEIVER PERFORMANCE EVALUATION; A. F. Baker and D. L. Atwood; May 1985.

The plant and receiver performances of the 10 MWe Solar Thermal Central Receiver Pilot Plant located in Barstow, California, are evaluated based on measured and calculated data. An extended data base is used to update the receiver performance reported in March 1983. Full and part load results and trends in receiver performance when operating at varying outlet temperatures and pressures are provided. The plant and receiver performances are compared to design predictions. Data are included for both points in time and average values of performance.

SAND-85-8225: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MIRROR MODULE CORROSION, TORQUE TUBE DAMAGE, AND MIRROR REFLECTANCE SURVEY; E. V. Decker, C. W. Lopez, C. L. Mavis, and J. E. Noring; July 1985.

This report documents the results of the 1984 survey of mirror module corrosion, mirror reflective area, and torque tube damage at the 10 MWe Solar Thermal Central Receiver Pilot Plant. As of July 1984, 0.029% of the total reflective area of the heliostat field was corroded. However, the 1984 growth rate of the corrosion is much less than the 1983 rate: 92% for 1984 compared with 1000% for 1983. In the 1984 survey, the average reflective area for a heliostat was 420.94 square feet compared to the design value of 430.00 square feet. In addition, we determined that the reflective area must be measured after the edge seals are installed, and that ten data points on each module are sufficient to measure the reflectivity. Also, in the survey, we found thirty-five damaged torque tubes; these damages were due to gear box travel beyond the limit switches.

SAND-85-8229: MAXIMUM PERFORMANCE OF SOLAR HEAT ENGINES: DISCUSSION OF THERMODYNAMIC AVAILABILITY AND OTHER SECOND LAW CONSIDERATIONS AND THEIR IMPLICATIONS; R. F. Boehm; September 1985.

A review of thermodynamic priniciples is given in an effort to see if these concepts may indicate possibilities for improvements in solar central receiver power plants. Aspects related to rate limitations in cycles, thermodynamic availability of solar radiation, and sink temperature considerations are noted. It appears that considerably higher instantaneous plant efficiencies are possible by raising the maximum temperature and lowering the minimum temperature of the cycles. Of course, many practical engineering problems will have to be solved to realize the promised benefits.

SAND-85-8241: PROCEEDINGS OF THE DEPARTMENT OF ENERGY SOLAR CENTRAL RECEIVER TECHNOLOGY ANNUAL MEETING; Sandia National Laboratories; December 1985.

This document includes papers and presentation materials presented at the Solar Central Receiver Technology Annual Meeting held in Williamsburg, Virginia, on October 2-3, 1985.

SAND-85-8244: MONOGRAPH SERIES NO. 4: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT HELIOSTAT FIELD AIMPOINT IMPROVEMENTS; A. F. Baker and D. L. Atwood; January 1986.

New early morning and late afternoon heliostat aimpoints have been developed for the 10 MWe Solar Thermal Central Receiver Pilot Plant. These new heliostat aimpoints increase the fraction of the total receiver incident solar energy on selected panels to reduce the early morning start-up time and extend the late afternoon operating time, compared to those in current use at the Pilot Plant. Preliminary results from tests using the new morning start-up aimpoint file indicates that the winter start-up time was reduced by 30 to 45 minutes.

SAND-85-8249: NUMERICAL MODELING OF A SOLID PARTICLE SOLAR CENTRAL RECEIVER; G. H. Evans, W. G. Houf, R. Greif, and C. T. Crowe; December 1985.

The flow of air and particles and the heat transfer inside a solar heated, open cavity containing a falling cloud of 100-1000 micron solid particles have been studied. Two-way momentum and thermal coupling between the particles and the air is included in the analysis along with the effects of radiative transport within the particle cloud, among the cavity surfaces, and between the cloud and the surfaces. The flow field is assumed to be two dimensional with steady mean quantities. The

PSI-Cell (particle source in cell) computer code is used to describe the gas-particle interaction. The method of discrete ordinates is used to obtain the radiative transfer within te cloud.

The results include the velocity and temperature profiles of the particles and the air. In addition, the thermal performance of the solid particle solar receiver has been determined as a function of the following particle parameters: size, mass flow rate, absorptivity, and infrared scattering albedo. Other parameters which have been varied include the incident solar flux (both magnitude and distribution) and receiver size. A forced flow, applied across the cavity aperture, has also been investigated as a means of decreasing convective heat loss from the cavity.

Comparison of the results from the model has been made with an experiment performed at the Sandia radiant heat facility in Albuquerque, New Mexico. The model has also been used to predict the entrainment of air and the decrease in particle drag which has been observed when measurements were made of particle velocity in a cloud of particles in free fall.

SAND-85-8250: CONVECTIVE LOSS MEASUREMENTS AT THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; M. C. Stoddard; January 1986.

Experiments were performed at the 10 MWe Solar Thermal Central Receiver Pilot Plant to measure the convective heat transfer from the receiver. Determining the convective loss will help reduce the uncertainty in the calculation of thermal efficiency for solar central receivers. Two types of results are presented from the data: (1) the overall receiver convective coefficient; and (2) detailed information on the local (panel) losses as a function of wind direction. The overall measured convective coefficient is also compared with predictions from correlations developed to calculate the convective coefficient. The comparison between the measured and predicted convective coefficients is good, although the correlations tend to overpredict the measured data by about 10%.

SAND-85-8602: CRACKING OF ALLOY 800 TUBING IN SUPERHEATED STEAM SECTIONS OF THE SOLAR ONE CENTRAL RECEIVER; J. C. Lippold; July 1985.

The solar central receiver at the Barstow Pilot Plant is a once-through steam boiler consisting of vertical arrays of Alloy 800 tubes. Water/steam leaks associated with tube bends near the receiver outlet were observed after 16 months of service. The leaks resulted from through-wall cracks localized in the crown of tube bends which operated in the temperature range from 550 to 650^{o}C. Initiation occurred on the I.D. (steam side) of the tube and propagated transgranularly through the tube wall. Cracking was both axial and circumferential; in general, the circumferential cracks were more severe than the axial cracks.

Thick oxide layers were observed on the I.D. of the receiver tubes; for instance, a 25-micron thick oxide layer had formed on tubing which operated at 650°C. In addition, an enhanced oxidation layer was observed along a narrow band in the crown of the tube. This oxidation band was up to five times thicker than the oxide elsewhere in the tube. All the cracking was associated with this enhanced oxidation layer. Several mechanisms are proposed to explain the premature tube bend failures. These mechanisms are critically reviewed in light of the observed failure scenario.

SAND-86-0536: PROCEEDINGS OF THE SOLAR THERMAL TECHNOLOGY CONFERENCE - ALBUQUERQUE, NEW MEXICO, JUNE 17-19, 1986; R. B. Diver, ed.; June 1986.

The Solar Thermal Technology Conference was held on June 17-19, 1986, at the Marriott Hotel, Albuquerque, New Mexico. The meeting was sponsored by the United States Department of Energy and Sandia National Laboratories. Topics covered during the conference included a status summary of the Sandia Solar Thermal Development Project, perspectives on central and distributed receiver technology including energy collection and conversion technologies, systems analyses and applications experiments. The proceedings contain summaries (abstracts plus principal visual aids) of the presentations made at the conference.

SAND-86-0852: APPLICATION OF RELAP4/MOD6 TO ANALYSIS OF SOLAR THERMAL POWER PLANTS: CONTROL SYSTEM MODELLING; R. K. Byers; April 1986.

A systems effects computer program may provide a convenient means of analyzing the transient response of solar thermal plants. Many of the components in such plants are similar, or identical, to those used in nuclear power plants; therefore, the reactor thermal/hydraulics program RELAP has been modified for application to solar thermal plant analysis. Because of the similarities, no great difficulties were anticipated, or encountered. However, many solar thermal plant and experiment designs include an extensive system for automatic control, and the capabilities of the particular version of RELAP being used were very limited in this regard. Thus, it was necessary to include the capability of control system modelling in the code.

We have modified RELAP4/MOD6 so that it is able to model control systems and subsystems, and their effects on overall system response. This was done in such a way that the basic numerical solution scheme in the code was not altered. This report documents the additions and changes to RELAP and its associated output processing code. The code runs on

SNLA's CRAY1-S using COS. This report includes an example of control function use, in the form of a test calculation for the Molten Salt Electric Experiment (MSEE) receiver. The results of the analysis agree reasonably well with data, and were obtained at a small expense in computer time; this version of RELAP, therefore, shoud be useful for more complete analyses of solar thermal systems designs.

SAND-86-0981: EVALUATION OF SPHERICAL CERAMIC PARTICLES FOR SOLAR THERMAL TRANSFER MEDIA; J. R. Hellmann, M. O. Eatough, P. F. Hlava, and A. R. Mahoney; January 1987.

Two ceramic materials, spheroidized sintered bauxite and fused zircon, were evaluated for potential use as thermal transfer media in an advanced high-temperature solid particle solar receiver. Both materials were sufficiently resistant to aggregation via sintering to permit repeated cycling of the particle charge to temperatures approaching 1400°C provided no pressure was applied to the particle bed. Application of pressure dramatically enhanced sintering above 1100°C and yielded non-flowable sintered particle masses. This indicates that moving particle bed storage configurations must be employed for temperatures in excess of 1100°C.

The sintered bauxite material exhibited a higher solar absorptance (0.94) than the fused zircon (0.74) for all conditions investigated. Extended thermal treatments in air markedly degraded the solar absorptance of both materials. Degradation was attributed to modifications in crystalline phase assemblages and distribution of multi-valent iron and titanium cations. High solar absorptances could be restored by reheating the "oxidized" specimens in mildly reducing atmospheres. Potential improvements in the solar absorptance of the fused zircon material may be possible through doping the material with higher concentrations of transition metal and rare earth cations.

SAND-86-1492: CENTRAL RECEIVER TEST FACILITY EXPERIMENT MANUAL; C. Maxwell and J. Holmes; January 1987.

This manual provides potential users with detailed information about the Central Receiver Test Facility operated by Sandia National Laboratories for the U.S. Department of Energy. This installation is the primary solar test facility for component and subsystem evaluations within the Department of Energy's Solar Central Receiver development program, and can also be used for thermal effects testing. Administrative procedures, facility capabilities and interfaces, and the information required from potential experimenters by site personnel are described.

SAND-86-1873: CHARACTERIZATION OF SPHERICAL CERAMIC PARTICLES FOR SOLAR THERMAL TRANSFER MEDIA: A MARKET SURVEY; J. R. Hellmann and V. S. McConnell; October 1986.

Several candidates from a broad class of ceramic materials were evaluated for possible application as a solid thermal transfer medium in a high-temperature solid particle solar receiver. This report documents the suppliers of the materials, the materials' characteristics, and comments regarding the suitability of each of the materials for solid thermal transfer media.

SAND-86-2165: SUNBURN: A COMPUTER CODE FOR EVALUATING THE ECONOMIC VIABILITY OF HYBRID SOLAR CENTRAL RECEIVER ELECTRIC POWER PLANTS; C. J. Chiang; June 1987.

The computer program SUNBURN simulates the annual performance of solar-only, solar-hybrid, and fuel-only electric power plants. SUNBURN calculates the levelized value of electricity generated by, and the levelized cost of, these plants. Central receiver solar technology is represented, with molten salt as the receiver coolant and thermal storage medium. For each hour of a year, the thermal energy use, or dispatch, strategy of SUNBURN maximizes the value of electricity by operating the turbine when the demand for electricity is greatest and by minimizing overflow of thermal storage. Fuel is burned to augment solar energy if the value of electricity generated by using fuel is greater than the cost of the fuel consumed. SUNBURN was used to determine the optimal power plant configuration, based on value-to-cost ratio, for dates of initial plant operation from 1990 to 1998. The turbine size for all plants was 80 MWe net. Before 1994, fuel-only was found to be the preferred plant configuration. After 1994, a solar-only plant was found to have the greatest value-to-cost ratio. A hybrid configuration was never found to be better than both fuel-only and solar-only configurations. The value of electricity was calculated as The Southern California Edison Company's avoided generation costs of electricity. These costs vary with time of day. Utility ownership of the power plants was assumed. The simulation was performed using weather data recorded in Barstow, California, in 1984.

SAND-86-7107: SINTERING OF COARSE CERAMIC PARTICULATES; Pennsylvania State University; July 1986.

The primary objective of this program was the selection of a particulate media for use in a solid particle solar receiver (SPSR). In the first year of the program it was determined that zircon and alumina industrial grains fulfilled the criteria established for the SPSR. These criteria included: (1) availability in commercial quantities (i.e. tons); (2) a particle size >100 micron; (3) a high melting temperature; and (4) the absence of aggregation (i.e., sintering) during application.

This report describes two different assessments carried out on: (1) two of the industrial minerals examined in the first year, and (2) proppants. The first half of this year's effort involved an assessment of particle size on aggregation of alumina and zircon industrial minerals to simulate the effect of particle attrition on aggregation. A sub-population of finer particles could result in enhanced aggregation as sintering is inversely related to particle size. Mixtures of coarse and fine particles of alumina and zircon were tested at 1000 to 1200^oC and pressures of 0.68 and 1.4 MPa for times to 24h. The alumina powder was also doped with iron oxide to simulate contamination and to determine whether iron oxide additions to increase optical absorptivity had any adverse effects on aggregation.

The second half of the project was focussed on the sinterability of another class of materials called proppants. Proppant materials provide an interesting alternative to the industrial minerals because of their availability in large sizes (e.g., 100 microns) and refractory compositions. The proppant materials studied for the SPSR included one stabilized zirconia and six bauxite-derived proppants.

SAND-86-8002: TOTAL CAPITAL COST DATA BASE - 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; H. F. Norris, Jr.; May 1986.

This report describes the total capital cost data base of the 10 MWe Solar Thermal Central Receiver Pilot Plant. The Pilot Plant cost data base was created using the computer code "Cost Data Management System (CDMS)". The cost data base format was developed to be used as a common method of presentation of capital costs for power plants.

The basic format is a plant system cost breakdown structure. Major accounts are land; structures and improvements; collector, receiver, thermal transport, thermal storage, and steam generation systems; turbine plant; electrical plant; miscellaneous plant systems and equipment; and plant-level indirect costs. Each major account includes subaccounts to as many as nine levels of detail.

The data base can be accessed to provide elements-of-work costs at any subaccount level or at the plant level. The elements-of-work include sitework/earthwork; concrete work; metal work; architectural; process equipment; piping; electrical; and miscellaneous work. Each of these elements-of-work can be or are broken into finer detail and costs can be accumulated to identify more specfic needs, e.g., pipe insulation or heat exchangers.

The cost data base can be accessed and various reports can be generated. These vary from a single page summary to detailed listings of costs and notes. Reported costs can be stated in dollars, dollars per kilowatt or percentage of the total plant cost. Reports or samples of reports for the Pilot Plant capital cost are included.

SAND-86-8007: AN EVALUATION OF HELIOSTAT FIELD/RECEIVER CONFIGURATIONS; S. E. Faas and W. S. Winters; March 1986.

This report evaluates and compares north heliostat field/cavity receiver configurations and surround heliostat field/external receiver configurations. The receiver coolants are molten nitrate salts and liquid sodium. Both field/receiver configurations use molten salt thermal storage; the sodium receiver is thermally connected to thermal storage by a sodium-to-salt heat exchanger. The heliostat field size is fixed at 1,000,000 square meters of reflective area, and the delivered molten salt temperature is fixed at 566°C. The delivered thermal power varies from 500 to 600 MWt, depending on the overall system efficiency.

The generic north heliostat field/cavity receiver configurations were found to be 6 to 10 percent more efficient than a generic surround field/external receiver configuration. There was little or no difference found in the transient performance of a molten salt receiver compared to a sodium receiver connected to a sodium-to-salt heat exchanger.

Four configurations were of particular interest: (1) a north heliostat field/single cavity molten salt receiver; (2) a surround heliostat field/external cylinder molten salt receiver; (3) a surround heliostat field/external cylinder liquid sodium receiver; and (4) a north heliostat field/single cavity liquid sodium receiver. It was found that the surround field/liquid sodium external receiver configuration may provide energy at a 14 percent lower levelized energy cost than a north field/molten salt cavity receiver configuration. However, the cost advantage of the surround field/liquid sodium external receiver is not conclusive because of uncertainties in system component costs.

SAND-86-8009: A HANDBOOK FOR SOLAR CENTRAL RECEIVER DESIGN; P. K. Falcone; December 1986.

This Handbook describes central receiver technology for solar thermal power plants. It contains a description and assessment of the major components in a central receiver system configured for utility scale production of electricity using Rankine-cycle steam turbines. It also describes procedures to size and optimize a plant and discusses examples from recent system analyses. Information concerning site selection criteria, cost estimation, construction, and operation and maintenance is also included, which should enable readers to perform design analyses for specific applications.

SAND-86-8010: TESTING OF THE MOLTEN SALT ELECTRIC EXPERIMENT SOLAR CENTRAL RECEIVER IN AN EXTERNAL CONFIGURATION; N. E. Bergan; October 1986.

The cavity surrounding the MSEE solar central receiver was removed and the receiver was tested in an external configuration to compare external and cavity performance. The thermal efficiency of the external receiver was slightly less than that of the cavity receiver. However, operationally, the external receiver was easier to start up. Convective losses were measured from the external receiver and compared to analytical correlations. Measured convective losses were found to be 10 to 100% lower than predictions, most likely due to correction factors used in the predictions to account for surface roughness and wind direction.

Four demonstration tests were performed on the external receiver. A high flux test exposed the receiver to flux levels of $1MW/m^2$. The receiver was successfully filled in a serpentine rather than the customary flood pattern; and in another test the receiver was filled at temperatures below the freezing point of salt (470^oF). In the final demonstration test, hot salt was used to keep the receiver warm overnight to allow sunrise start-up. Receiver thermal losses overnight exceeded energy saved by reduced parasitics and energy collected from the sunrise start-up, making overnight conditioning uneconomical for this receiver.

SAND-86-8011: UTILIZING SPREADSHEETS FOR ANALYZING SOLAR THERMAL CENTRAL RECEIVER POWER PLANT DESIGNS; H. F. Norris, Jr.; July 1986.

Spreadsheets have been used to collect and understand existing solar thermal central receiver design data. Correlation of these data have led to the development of many useful algorithms. The algorithms provide the basis for calculating performance efficiencies, annual energy production, plant cost, and levelized energy cost. Variations in design details are evaluated with example results of the effect of plant location, collector field efficiencies for North and surround configurations as a function of field size, efficiencies of external and cavity receivers for similar operating conditions, and interactions of the collector field and receiver design.

Examples are also presented for the plant total capital investment and levelized energy cost as a function of the annual energy produced. Sensitivities to various parameters affecting the net annual energy production and levelized energy cost are also discussed.

The performance and cost characteristics of large and small plants are considered. Use of the spreadsheet analysis is demonstrated where one possible design utilizes modular solar systems. The design includes a single steam generator and turbine plant. This optimizes the performance and cost attributes of both small solar and large non-solar systems to arrive at a more cost-effective plant.

SAND-86-8017: FATIGUE ANALYSIS OF A SOLAR CENTRAL RECEIVER DESIGN USING MEASURED WEATHER DATA; B. L. Kistler; April 1987.

Solar central receivers using tubes to contain the cooling fluid are designed to withstand a specified number of thermal fatigue cycles of a specified magnitude, usually determined by design point conditions. However, actual cycle magnitudes will vary, depending on weather conditions over the lifetime of the receiver. Actual weather data were used to determine the fraction of fatigue life used in an existing solar central receiver design. From that information, the number of design point fatigue cycles for which any future receivers should be designed was determined. The weather data and receiver design examined in this study were used to justify a fatigue life of only 10,000 design point cycles. However, uncertainties in the study encourage the use of a safety factor of 2 in the design. Therefore, it is suggested that future solar central receivers be designed for a fatigue life of 20,000 design point cycles.

SAND-86-8018: A USER'S MANUAL FOR DELSOL3: A COMPUTER CODE FOR CALCULATING THE OPTICAL PERFORMANCE AND OPTIMAL SYSTEM DESIGN FOR SOLAR THERMAL CENTRAL RECEIVER PLANTS; B. L. Kistler; November 1986.

DELSOL3 is a revised and updated version of the DELSOL2 computer program (SAND81-8237) 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 non-optical performance, an algorithm for field layout, and a searching algorithm to find the best system design based on energy cost. 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 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. DELSOL3 maintains the advantages of speed and accuracy which are characteristic of DELSOL2.

SAND-86-8019: AN ASSESSMENT OF SOLAR CENTRAL RECEIVER SYSTEMS FOR FUELS AND CHEMICALS APPLICATIONS; L. G. Radosevich, C. W. Pretzel, E. H. Carrell, and C. E. Tyner; October 1986.

This report assesses the results of studies conducted to date for solar central receiver fuels and chemicals applications. Conceptual system designs using central receivers have been completed for ammonia/nitric acid, ammonia, and activated carbon production. Limited design and experimental information has also been developed for hydrogen production. A technical assessment of these applications revealed several technically deficient areas including molten carbonate salt materials research and technology development; reactor/receiver development; and thermochemical hydrogen process optimization, system design, and technology development. An economic assessment of the applications showed that none were currently attractive although the data for hydrogen production are too incomplete to draw meaningful conclusions. To further explore the potential of solar central receivers for fuels and chemicals applications, additional work on thermochemical hydrogen development is recommended along with the development of reactor/receiver concepts that have the potential for simplicity and increasing process efficiency.

SAND-86-8056: THE DEVELOPMENTAL STATUS OF SOLAR THERMOCHEMICAL HYDROGEN PRODUCTION; C. W. Pretzel and J. E. Funk; September 1987.

This report discusses the status of development on solar thermochemical hydrogen production. It discusses the results of recent experiments of components for the solar interface. Various process designs that have been proposed are examined and areas of technical concern are discussed.

The process has the potential for having the highest efficiency for producing hydrogen from water. Development has consisted of process flowsheet designs using nuclear heat sources, several solar interface conceptual designs, and experiments for solar central receiver components. Conceptually, the flowsheets show how the chemical process plant is to actually be built. Each stream is identified and temperature, pressure, and composition are specified. The function of each piece of process equipment -- reactors, heat exchangers -- is defined. Design requirements such as conversion, heat transfer, etc., and materials of construction are established.

While many uncertainties still exist, we have identified no major technical problems that will prevent the production of solar thermochemical hydrogen if additional analysis and experimentation are completed. An economic assessment was performed by determining hydrogen product costs using realistic solar availability conditions. The conclusions list the major areas that need continuing work.

SAND-86-8058: CHARACTERISTICS OF CURRENT SOLAR CENTRAL RECEIVER PROJECTS; A. F. Baker and A. C. Skinrood; October 1987.

This report summarizes the characteristics and status of six experimental solar central receiver projects. These are Eurelios (located in Italy), CESA-I (Spain), International Energy Agency Small Solar Power Systems Project (Spain), Sunshine (Japan), Themis (France), and Solar One (United States).

SAND-86-8060: SOLERGY - A COMPUTER CODE FOR CALCULATING THE ANNUAL ENERGY FROM CENTRAL RECEIVER POWER PLANTS; M. C. Stoddard, S. E. Faas, C. J. Chiang, and J. A. Dirks; May 1987.

The program SOLERGY was designed to simulate the operation and power output of a user-defined solar central receiver power plant for a time period of up to one year. SOLERGY utilizes recorded or simulated weather data and plant component performance models to calculate the power flowing through each part of the solar plant. A plant control subroutine monitors these powers and determines when to operate the various plant subsystems. Parasitic electrical power is computed on a 24-hour basis.

SAND-86-8175: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MODE 5 (TEST 1150) AND MODE 6 (TEST 1160) TEST REPORT; McDonnell Douglas Astronautics Company; June 1986.

The purpose of this report is to document the test results and conclusions pertinent to operating Mode 5 (charging only) and Mode 6 (extraction) of the thermal storage subsystem of Solar One. Mode 5 was demonstrated successfully, particularly during periods of cloud passages over the sun. Dual charging train testing, while successful, revealed that dual train operation was not often necessary or desirable. Mode 6 testing was demonstrated for both single and dual train operation; stable single train operation was demonstrated at 0.7 MWe (gross). During Mode 6 testing the extractable energy capacity of the thermal storage tank was demonstrated to exceed the design requirements.

SAND-86-8176: SOLAR THERMAL CENTRAL RECEIVER INTEGRATED COMMERCIALIZATION ANALYSIS - EXECUTIVE SUMMARY, VOLUMES 1 AND 2; Polydyne, Inc. and Associates; March 1986.

This report presents information, data, and analysis for developing a commercialization strategy for solar thermal central receiver technologies. A consistent set of economic and performance data was developed for eight central receiver engineering design projects and was used as input to an integrated market, technical, economic, and financial analysis. A case study review of successful and unsuccessful solar and wind energy projects was conducted to provide insight into the process by which advanced, risky new energy technologies can be commercialized, and to identify the factors that lead both to success and failure in implementing a new energy technology project.

SAND-86-8177: APPLICATION OF RELIABILITY-CENTERED MAINTENANCE TO SOLAR CENTRAL RECEIVER PLANTS; Saratoga Engineering Consultants, Inc.; September 1986.

Reliability-centered maintenance (RCM) methodology has been broadly applied for almost 20 years in establishing preventive maintenance (PM) programs for commercial aircraft and DOD systems. RCM focuses on functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable (it works) and effective (it's worth doing) PM tasks. An illustration of RCM as applied to part of the receiver is briefly described. Results indicate that the RCM approach could be broadly applied to Solar One-type plants with a reasonable expectation that PM costs would be significantly reduced with a commensurate reduction in corrective maintenance actions and costs.

SAND-86-8178: SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY (AMMONIA/NITRIC ACID PRODUCTION PROCESS) FINAL REPORT, VOLUME 1 - EXECUTIVE SUMMARY, VOLUME 2 - CONCEPTUAL DESIGN, VOLUME 3 - APPENDICES; Foster Wheeler Solar Development Corporation; June 1986.

This report describes the conceptual design of a solar thermal central receiver system that produces both ammonia and nitric acid. The system design uses molten carbonate salt that is heated in the receiver to transfer heat to an ammonia plant located near the base of the receiver tower. Ammonia is produced by the steam reforming of methane reaction while nitric acid is produced by combusting ammonia with air. Capital and operating cost estimates are described, and market and economic analyses are presented to assess the attractiveness of the proposed system. Technical uncertainties are identified as the basis for a development plan to bring the proposed system to maturity.

SAND-86-8179: SOLAR ONE BEAM CHARACTERIZATION SYSTEM DESIGN DESCRIPTION AND REQUIREMENTS DOCUMENT; McDonnell Douglas Astronautics Company; October 1986.

A comprehensive description is provided for the Solar One Beam Characterization System. The principal uses of this system are to provide an automatic measurement of heliostat tracking errors and the optical quality of the reflected image. Measured tracking errors are used to determine bias values for the heliostat control system which compensates for the errors. Detailed descriptions are provided for the hardware, software, supporting analysis, operational sequences, and the fundamental principles involved.

SAND-86-8181: SOLAR ONE SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT 1984 METEOROLOGICAL DATA REPORT; McDonnell Douglas Astronautics Company; July 1986.

Meteorological data recorded at the 10 MWe Solar Thermal Central Receiver Pilot Plant during 1984 are presented. A general description of the plant is provided, as well as information on the type, quantity, and location of the meteorological equipment and the instrumentation used to record the data.

SAND-86-8182: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: MODES 2, 3, 4, AND 7 (TESTS 1120, 1130, 1140, AND 1170) TEST REPORT; McDonnell Douglas Astronautics Company; August 1986.

This report documents the test results and conclusions pertaining to operating Mode 2 (Turbine Direct and Charging), Mode 3 (Storage Boosted), Mode 4 (In-Line Flow), and Mode 7 (Dual Flow) of Solar One. Operations in each mode were successfully demonstrated. Alternate transition sequences to and from each operating mode were evaluated and preferred approaches are identified. Plant performance data are presented which indicate preferred operating regions within individual operating modes and permit a relative evaluation to be made between operating modes. System related problems, particularly those associated with flowmeters are reviewed in detail. Finally, plant parasitic power data are presented for each mode and comparisons to design predictions are made.

SAND-86-8183: REVIEW OF THE SOLAR THERMAL POWER INDUSTRY: FUTURE OUTLOOK; Analysis Review & Critique and the Solar Energy Industries Association; October 1986.

The Solar Energy Industries Association reviewed most of the companies in the solar thermal power industry to establish current activities and plans for the future. Interviews provided information on the industry's size, composition, profitability, and R&D needs. The technologies currently being developed and marketed are identified and industry's plans for future R&D and marketing are examined. Industry-identified marketing problems and barriers to commercialization are described.

The status of the industry in 1985 is compared with its status in 1981. At least 30 percent of the industry has dropped out since that time. Their reasons for leaving are examined as are the conditions for their reentry.

R&D needs and technical barriers to commercialization are examined. The industry's evaluation of the Department of Energy solar thermal program is described and needs for other federal support are identified.

SAND-86-8184: SOLAR THERMAL CENTRAL RECEIVER TECHNOLOGY TRANSFER STRATEGY ANALYSIS, EXECUTIVE SUMMARY AND FINAL REPORT; Polydyne, Inc. and Associates; August 1986.

This report presents an integrated market, economic and financial analysis for developing a technology transfer strategy for solar thermal central receiver (STCR) technologies. A consistent set of economic and performance data based upon previous STCR engineering design projects was used as input to the integrated analysis. Three alternative STCR concepts, Hybrid Brayton Cycle, Hybrid Rankine Cycle and Rankine Cycle with Storage were analyzed in terms of module size scaling and learning. Based upon the analysis a set of market derived STCR design performance and cost goals was determined. These STCR design goals combined with high value individual market applications provide for a potentially feasible STCR commercialization strategy under the current stringent economic conditions.

SAND-86-8185: CENTRAL RECEIVER PLANT EVALUATION: I) INSOLATION DATA FROM ODEILLO AND TARGASONNE; C. Etievant, A. Amri, M. Izygon, and B. Tedjiza; Ecole Centrale des Arts et Manufactures, Geser Group; September 1987.

This report presents the meteorological data of interest for the evaluation of the THEMIS central receiver experimental plant and describes the meteorological measuring equipment of THEMIS. The direct insolation data recorded at THEMIS during 1984 are listed and analyzed. The Odeillo records of 1983 and 1984 are also presented for comparison. Finally the distributions of the daily insolation are established for Odeillo (1983 and 1984) and THEMIS (1984). These distributions are a basic tool for our evaluation of the yearly energy production of THEMIS.

SAND-86-8187: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT CONTROL SYSTEM DESCRIPTION; McDonnell Douglas Astronautics Company; December 1986.

This report describes the control system for the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, CA. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. The report provides an overview of the plant control system including the rationale for the design approach and the configuration which resulted in response to program requirements.

SAND-86-8188: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT CONTROL SYSTEM AUTOMATION TEST REPORT; McDonnell Douglas Astronautics Company; February 1987.

This report describes results of tests on the automatic features added to the control system for the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, Ca. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. The report provides an overview of the automation features added to the plant control system, a description of tests performed on the system, and the results of the tests.

SAND-86-8203: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT 1983 OPERATIONS REPORT; J. J. Bartel; January 1986.

The design and construction of the world's largest solar thermal central receiver electric power plant, the 10 MWe Solar Thermal Central Receiver Pilot Plant, "Solar One," located near Barstow, California, were completed in 1982. The plant continued in the two-year Experimental Test and Evaluation Phase throughout 1983.

Experiences during 1983 have shown that all parts of the plant, especially solar unique ones, operated as well as or better than expected. It was possible to incorporate routine power production into the Experimental Test and Evaluation Phase because plant performance yielded high confidence. All operational modes were tested and plant automation activities began in earnest.

This report contains: (1) a brief description of the plant system; (2) a summary of the year's experiences; (3) topical sections covering preliminary power production, automation activities, and receiver leak repairs; (4) a monthly list of principal activities; and (5) operation and maintenance costs.

SAND-86-8207: AN EVALUATION OF VALVE PACKING MATERIALS FOR LONG-TERM USE IN MOLTEN NITRATE SALT; R. W. Bradshaw; March 1986.

Chemical compatibility between a number of compression packings and molten sodium nitrate-potassium nitrate was evaluated at temperatures of 288^{o}C (550^{o}F), 399^{o}C (750^{o}F), and 565^{o}C (1050^{o}F). The types of packing materials tested included graphite filaments, graphite ribbon, asbestos, teflon, aramid, glass and ceramic fibers, perfluoroelastomers, and boron nitride. Packings were immersed for periods up to 1000 hours in a static test fixture which simulated their installation in a flow control valve stuffing box. Characteristics evaluated were visual indications of deterioration and salt absorption, weight change and microscopy of cross-sectioned samples. Several packings were chemically resistant to the molten salt at 288°C, but the compatibility of packings at 399°C and 565°C was not adequate. Thermogravimetric analysis demonstrated that oxidation of graphite by nitrate salt was slow at 288°C but increased rapidly at higher temperatures. The chemical and physical phenomena affecting compatibility are discussed and recommendations concerning materials selection are made.

SAND-86-8210: MONOGRAPH SERIES NO. 3: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT RECEIVER SOLAR ABSORPTANCE MEASUREMENTS AND RESULTS; A. F. Baker; June 1986.

Solar absorptance data on Pyromark painted receiver panels at the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, California are reported. Measurements were made in 1982, 1983, and 1984. Selected measurements were made in 1985 after one receiver panel was repainted with Pyromark. The results show a linear decrease in the solar absorptance with time from an original average value of 0.92 to 0.88 after 663 days. The decrease in solar absorptance correlated with the higher incident solar flux levels on the receiver panels and not with the operating temperature of the panels. Repainting of one receiver panel successfully increased the solar absorptance to a value above 0.96.

SAND-86-8211: A TECHNICAL FEASIBILITY STUDY OF A SOLID PARTICLE SOLAR CENTRAL RECEIVER FOR HIGH TEMPERATURE APPLICATIONS; J. M. Hruby; March 1986.

This report summarizes work performed during a technical feasibility study of a solar central receiver in which free-falling solid particles directly absorb insolation and achieve temperatures greater than 550°C. The emphasis has been on receiver design and particle material selection, and the associated topics of free-falling particle cloud behavior and material evaluation techniques. The results of the study indicate that a free-falling solid particle receiver requires high incident flux levels, a small receiver aperture, and large particle volume fractions to achieve high efficiency. Terminal concentrators and aperture windows significantly increase solid particle receiver efficiency over traditional, north-facing cavity receiver designs. An inexpensive, alumina-based particle material has been identified for use in a solid particle receiver at temperatures up to 1000°C. System components other than the receiver have also been briefly examined.

SAND-86-8212: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT: THERMAL STORAGE SUBSYSTEM EVALUATION - FINAL REPORT; S. E. Faas, L. R. Thorne, E. A. Fuchs, and N. D. Gilbertsen; June 1986.

This report presents an evaluation of the thermal storage subsystem at Solar One, the 10 MWe Solar Thermal Central Receiver Pilot Plant near Daggett, California. The thermal storage subsystem has an availablity of around 90 percent, a first law thermal efficiency of 83 percent, and can achieve its design discharge capability of 7 MWe (net) for four hours. The heat transfer oil mass loss due to thermal decomposition at its elevated temperature is between 5 and 7 percent of the oil inventory per year -- a loss within the range predicted by laboratory experiments. The thermal storage tank wall stresses appear to have risen slightly; however, inaccuracy of the strain gages makes conclusive statements impossible. Heat exchanger leaks appeared in the flange seals and the tube-to-tubesheet rolled joints of the charging heat exchangers. Repairs were successful on the flange joint seals, but were unsuccessful on the tube-to-tubesheet seals. Overall, the thermal storage subsystem has functioned well and has met design specifications.

SAND-86-8239: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT CONTROL SYSTEM EVALUATION; D. N. Tanner; September 1986.

This report describes the results of the evaluation of the Master Control System for the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, CA. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. The report provides a description of the plant and its control systems and compares the original control system requirements with the actual operation. It provides a qualitative evaluation of various plant control systems and summarizes an independent evaluation of the plant displays provided by Honeywell on contract to the Electric Power Research Institute. Finally the report describes the desired features of a future control system. The control system with its automated features has substantially increased electrical output of the plant by extending the number of hours of operation and increasing reliability over that which could be obtained with a conventional control system.

SAND-86-8249: REVIEW OF THE MOLTEN SALT ELECTRIC EXPERIMENT: A SOLAR CENTRAL RECEIVER PROJECT; W. R. Delameter and N. E. Bergan; December 1986.

The Molten Salt Electric Experiment was the first full solar-to-electric central receiver system to use molten nitrate salt as a primary working fluid. The experiment was built and tested at the Central Receiver Test

Facility in Albuquerque, New Mexico, between 1982 and 1985. The purpose of the project was to demonstrate the technical feasibility of a molten salt central receiver system.

The Molten Salt Electric Experiment was operated through a year of successful testing; system performance was measured, operating procedures and an effective receiver control algorithm were developed, and personnel from participating electrical utilities and solar industries were trained to operate the system. The testing culminated in a one-month power production campaign to measure daily performance, component reliability and system availability. This paper discusses the major accomplishments and some of the more significant problems of the project.

SAND-86-8714: AN EXPERIMENTAL AND NUMERICAL STUDY OF FLOW AND CONVECTIVE HEAT TRANSFER IN A FREELY FALLING CURTAIN OF PARTICLES; J. M. Hruby, R. R. Steeper, G. H. Evans, and C. T. Crowe; April 1986.

The flow characteristics and convective heat transfer in a freely falling curtain of spherical particles with an average diameter of 650 microns has been studied experimentally and numerically. Both heated and unheated particle flows have been considered. This work is part of a larger study to determine the feasibility of using particles to directly absorb the insolation in a solar central receiver for high temperature applications. The particles of interest are Norton Master Beads^{tm} which are primarily aluminum oxide. Measurements have been made of particle velocity in heated and unheated particle flows, and particle temperature and air temperature in heated particle flows. Comparison of the measurements with calculations has been made for two particle mass flow rates at room temperature and at two initial elevated particle temperatures. Excellent agreement between numerical and experimental results is obtained for particle velocity in the unheated flow. For the heated particles, both data and predictions show the same trends with regard to particle velocity, particle temperature, and air temperature. However, the calculations of these quantities overpredict the data. The results suggest that the drag coefficient in flows where the particles are hot compared to the air is larger than predicted using conventional methods to account for nonisothermal effects. The prediction of particle temperature and air temperature attained with a drag coefficient that is larger than the standard drag coefficient agrees well with the data.

SAND-86-9009: OXIDATION AND CHROMIUM DEPLETION OF ALLOY 800 AND 316SS BY MOLTEN $NaNO_3$-KNO_3 AT TEMPERATURES ABOVE 600^oC; R. W. Bradshaw; January 1987.

The corrosion behavior of Alloy 800 and Type 316 stainless steel in molten $NaNO_3$-KNO_3 was studied at temperatures from 605^oC to 630^oC.

Corrosion behavior was significantly different from that previously reported in nitrate melts at temperatures up to 600°C and involved a combination of oxidation, internal nitridation and sodium metallate formation. Corrosion kinetics, determined metallographically, switched from a parabolic to a linear rate equation as temperature increased. Corrosion was uniform and resulted in metal losses on the order of 100 microns/year at 630°C. Among the alloying elements, chromium was depleted from the alloy as the result of a basic fluxing process. The kinetic equations describing chromium depletion also changed from parabolic to linear with increasing temperature. The effect of the equilibrium chemistry of the melt on the corrosion behavior of the alloys is analyzed and possible corrosion mechanisms are discussed.

SAND-87-0131: PROCEEDINGS OF THE CONCENTRATING SOLAR COLLECTOR WORKSHOP: KEY TECHNICAL ISSUES; J. A. Leonard, R. B. Diver, and T. R. Mancini; June 1987.

This report comprises the proceedings of a solar thermal workshop on the key technical issues involved in the research and development of concentrating solar collectors. The workshop was held at Sandia National Laboratories on October 7 and 8, 1986. The major topic areas were solar concentrator optics, soiling of optical surfaces, wind loads on collectors, and solar receiver issues.

SAND-87-0696: THERMAL FATIGUE OF STAINLESS STEEL; W. B. Jones, R. J. Bourcier, and J. A. Van Den Avyle; December 1987.

Two austenitic steels, 316 Stainless Steel and Alloy 800, have been examined under conditions of both isothermal low cycle fatigue (LCF) and thermomechanical fatigue (TMF). The TMF tests were conducted between 649 and 360°C with a carefully controlled triangular waveform. The LCF tests were performed at 649°C and both kinds of tests were subjected to a strain range of 0.5%. TMF shortened life to 40% for 316 Stainless Steel and to 5% for Alloy 800. The microstructural evolution occurring in both alloys has been examined and we conclude these do not play a role in the life shortening caused by TMF. The TMF does produce asymmetric hysteresis loops with large tensile peak stresses in tests where the maximum temperature corresponded with the peak compressive stress. The influence of TMF on fatigue crack growth rates has been measured and it was found that TMF accelerated crack growth in Alloy 800 and slowed it down slightly in 316 Stainless Steel. The dominant influence of TMF appears to be in fatigue crack initiation, with the tensile peak stress development driving early crack initiation.

SAND-87-1258: PROCEEDINGS OF THE SOLAR THERMAL TECHNOLOGY CONFERENCE; C. E. Tyner, ed.; August 1987.

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

SAND-87-1787: THE EFFECT OF ASYMMETRIC HEATING ON FLOW STABILITY AND HEAT TRANSFER FOR FLOW IN A VERTICAL TUBE; C. H. Tappan; November 1987.

This study presents experimental results of combined free and forced convection heat transfer in a vertical tube with a circumferentially nonuniform constant wall heat flux. The effect of an asymmetric wall heat flux on flow stability and on the rate of heat transfer for water flowing downward in a vertical tube was investigated. Experimental results were used to develop two stability maps which identify various flow regimes, corresponding to different thermal and hyraulic conditions. Heat transfer coefficients were also determined. Experimental results in the present investigation were compared to those with uniform heating in horizontal and vertical tube flow situations discussed in the literature.

SAND-87-8008: AN ANALYSIS OF POWER PRODUCTION OPERATION FOR SOLAR ONE, THE 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT; L. G. Radosevich; June 1987.

This report describes an analysis of power production performance for Solar One, the 10 MWe Solar Thermal Central Receiver Pilot Plant near Barstow, California. Solar One has been undergoing power production testing since August 1984. During this period plant performance indicators, such as capacity factor and system efficiency, have been studied to assess the capability of Solar One to supply electrical power.

Solar One has shown an improvement in performance since power production testing began. Considerable increases in capacity factor and system efficiency were achieved. The factors contributing to these increases and approaches for achieving further increases are discussed.

SAND-87-8021: INTERNATIONAL ENERGY AGENCY (IEA) SMALL SOLAR POWER SYSTEMS (SSPS) SODIUM CAVITY AND EXTERNAL RECEIVER PERFORMANCE COMPARISON; A. F. Baker; October 1987.

This report uses experimental data to compare the performance of two sodium-cooled solar central receivers operated at the International Energy Agency Small Solar Power Systems project near Almeria, Spain. Performance includes point-in-time steady state efficiency, average efficiency, start-up time, and operation time. Point-in-time steady state efficiency calculations were based on the statistical method of least squares using receiver incident and absorbed powers. One receiver, a cavity type, showed a peak steady state receiver efficiency of 87% $\pm$ 5% and an average efficiency of about 67%. The other receiver, an external "billboard" type, had a peak steady state receiver efficiency of 96% $\pm$ 4% and an average efficiency of about 79%. The original design peak steady state efficiency predictions for both receivers were within the experimentally determined 95% probability interval.

Thermal loss test data were evaluated for the external receiver to confirm its point-in-time steady state efficiency independent of the receiver incident power. The thermal loss, which includes emitted radiation, convection, and conduction from the external receiver, was less than 100 kWt with the receiver operating at normal design conditions and having an absorbed power of over 2200 kWt.

SAND-87-8175: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT REPAINT OF A SINGLE RECEIVER PANEL TEST REPORT; McDonnell Douglas Astronautics Company; February 1987.

This report describes the repainting of a receiver panel at the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, Ca. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. This report describes the painting preparation, painting process, and evaluation conducted following the actual painting. The receiver panel was repainted to restore the absorptance. The panel absorptance increased from 0.875 to 0.96 following the painting.

SAND-87-8177: SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY - PRODUCTION AND REGENERATION OF ACTIVATED CARBON FINAL REPORT, VOLUME 1 - EXECUTIVE SUMMARY, VOLUME 2 - CONCEPTUAL DESIGN, VOLUME 3 - APPENDICES; Babcock & Wilcox; March 1987.

This report describes the conceptual design of a solar thermal central receiver system that both produces activated carbon from coal and regenerates spent activated carbon. The system design uses molten carbonate salt that is heated in the receiver to transfer heat to an activated carbon plant located near the base of the receiver tower. Capital and operating cost estimates are described, and market and economic analyses are presented to assess the attractiveness of the proposed system. Technical uncertainties are identified as the basis for a development plan to bring the proposed system to maturity.

SAND-87-8178: ASSESSMENT OF CENTRAL RECEIVER SOLAR THERMAL ENHANCED OIL RECOVERY SYSTEMS; Thermal Power Systems; July 1987.

In November 1982, ARCO Solar, Incorporated, with the cooperation of ARCO Oil and Gas Company, completed installation and began operation of a central receiver solar thermal pilot plant to produce steam for enhanced oil recovery. The highly automated plant can produce approximately one megawatt of thermal power in the form of 80 percent quality steam, which is delivered to a distribution header for injection into heavy oil formations.

An engineering evaluation of data from the ARCO plant has been performed, with the conclusion that central receiver solar systems can be very effective sources of power to generate steam for the enhanced recovery of heavy oil. The highly automated pilot plant exhibited outstanding reliability of the solar power conversion components while operating routinely with a single attendant. Plant operation demonstrated the capability for very low operating and maintenance costs for these systems relative to the use of conventional oil-burning steam generators.

This document reports the operating and performance characteristics of the ARCO solar thermal enhanced oil recovery (STEOR) system over a full year of operation. System sizing and performance projections for a much larger commercial plant are also presented.

SAND-87-8179: DEVELOPMENT OF STRESSED MEMBRANE HELIOSTAT MIRROR MODULE - FINAL REPORT; Science Applications International Corporation; April 1987.

The design of a commercial stressed membrane 150 m^2 heliostat mirror module based on thin 0.0762 mm (0.003 in) stainless steel is reported. The fabrication and initial evaluations of a 50 m^2 first-of-a-kind prototype are described and represent the first proof of principle for this advanced heliostat concept. The baseline design, manufacturing and installation of vacuum-focused double membrane "thin drum" heliostats have been established. The results of the prototype testing will allow the designs and manufacturing scenarios for these 10.7 kg/m^2 (2.2 lb/ft^2) $\$65/m^2$ heliostats to be refined and installation costs reduced.

SAND-87-8180: DEVELOPMENT OF THE STRESSED MEMBRANE HELIOSTAT; Solar Kinetics, Inc.; April 1987.

The stressed membrane reflective assembly offers a unique and innovative approach to heliostat design and fabrication. The concept is simple: two circular membranes or diaphragms are attached at their perimeter to a ring. The plenum formed by the membranes and ring is evacuated to privide focus. Stiffness is provided through membrane tension; the ring prevents collapse of the structure.

The stressed membrane design provides for a substantial cost and weight reduction over conventional structures. The first generation of stressed membrane design provides more than a twenty percent cost reduction (from $71 to $55 per square meter) over second generation glass/metal concentrators of similar size. Weight reduction is achieved through the unique fashion in which the concentrator carries its load.

The stressed membrane concentrator offers many benefits including lower weight, lower cost and simplicity. Our analysis indicates these benefits are gained without impairing performance.

SAND-87-8181: INTEGRATED SOLAR REFORMING FOR THERMOCHEMICAL ENERGY TRANSPORT; Resource Analysis International (RAI); December 1987.

This report presents a design study of two reforming processes as applied to the concept of solar thermochemical energy transport. Conceptual designs were carried out for steam-methane and CO^2-methane reforming plants. A solar central receiver reformer was designed as an integrated reactor with the chemical reaction tubes placed inside the receiver cavity. The two plant designs were compared for their energy efficiency and capital cost. The CO^2 reforming plant design results in higher energy efficiency but requires a catalyst which is still in an experimental state of development. A third design was performed as a modification of the steam reforming plant utilizing a "direct contact" system, in which the process steam is generated by utilizing the heat of condensation. This system resulted in the highest energy efficiency. A comparison of the capital cost of these three plant designs shows them to be equivalent within the estimation accuracy of 25%.

SAND-87-8226: 10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MIRROR MODULE CORROSION TORQUE TUBE DAMAGE AND VENT TUBE ASSESSMENT SURVEY JULY 1985 AND JULY 1986; M. A. Danzo, R. L. Velazquez, and C. L. Mavis; September 1987.

This report documents the results of the July 1985 and July 1986 surveys of mirror module corrosion and torque tube damage at the 10 MWe Solar

Thermal Central Receiver Pilot Plant. It also assesses the effect of vent tubes on the corrosion growth rate. Results show that 0.052% and 0.061% of the total reflective area of the heliostat field was corroded in 1985 and 1986, respectively. However, the corrosion growth rate is much less than in previous years, primarily because of the effect of mirror module vent tubes.

In the July 1984 survey, 35 torque tubes were damaged due to impact with the gear box. The 1985 survey showed that 14 of those same torque tubes were re-damaged. In addition, 9 newly dented ones were found. In the July 1986 survey, 39 torque tubes were dented, of which 4 were redented from 1985. The denting is caused when the gear-drive travels past the limit switch due to a shorted diode in parallel with the limit switch.

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