U.S. Department of Energy

Fifth Parabolic Dish Solar Thermal Power Program Review

Conference Abstracts

The Erawan Garden Hotel
Indian Wells, California
December 6-8, 1983

December 1983

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
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FIFTH PARABOLIC DISH SOLAR THERMAL POWER PROGRAM ANNUAL REVIEW
Sponsored by the U.S. Department of Energy

Erawan Garden Hotel
Indian Wells, California

December 6-8, 1983

Program

Monday Evening, December 5, 1983

7:30 - 10:00 pm	REGISTRATION & CONFERENCE CHECK-IN Meeting Handouts Available Set-Up of Exhibits	(Hosted Wine & Cheese Party)

Tuesday, December 6, 1983

Wednesday, December 7, 1983

7:30 am — REGISTRATION (Indonesian Room Foyer)

8:00 am — SESSION V: STIRLING MODULE DEVELOPMENT
(Chmn: F. R. Livingston, JPL)

10:00 am — Wrap-Up, including briefing on Vanguard
Site Visit

10:30am — Depart Hotel for Vanguard Site

FIELD TRIP TO VANGUARD STIRLING MODULE SITE

12:00 noon — ---- LUNCHEON ---- (Deli-Buffet available from
12 to 1 in Seminar Complex)

1:00 pm — SESSION VI: BRAYTON MODULE DEVELOPMENT
(Chmn: H. J. Holbeck, JPL)

1:10 pm	Near-Term Brayton Module Status (S. B. Davis, Sanders Assoc., Inc.)	30
1:35 pm	Sub-Atmospheric Brayton-Cycle Engine Program Review (R. Johnson, AiResearch Manufacturing Co.)	31
2:00 pm	LEC System Development (D. Halbert, La Jet Energy Corporation)	32
2:25 pm	Wrap-Up	
2:30 - 3:00 pm	---- BREAK ----	

<u>3:00 pm</u> <u>SESSION VII: PANEL DISCUSSION</u> (Seminar Complex)

<u>Title</u>:
Business Views of Solar Electric Generation

<u>Introduction</u>:
J. W. Lucas
Jet Propulsion Laboratory

<u>Moderator</u>:
John Stolpe
Southern California Edison Company 33

<u>Panelists</u>:
Edward H. Blum, Merrill Lynch
Robert Danziger, Sunlaw Energy Corp.
Richard J. Faller, McDonnell Douglas Astronautics Co.
Lynn Rasband, Utah Power & Light
Byron Washom, Advanco Corp.
Carl Weinberg, Pacific Gas & Electric

<u>5:00 pm</u> <u>NO-HOST RECEPTION</u> (Poolside)

Thursday, December 8, 1983

FIFTH PARABOLIC DISH SOLAR THERMAL POWER PROGRAM REVIEW

WELCOMING REMARKS

John W. Lucas
General Chairman

Jet Propulsion Laboratory
Pasadena, CA 91109

Welcome to the Fifth Parabolic Dish Solar Thermal Power Program Annual Review. During the next three days, reports on the many significant accomplishments that have occurred during the past year will be presented by the involved contractors. In addition, we have arranged what should be an outstanding panel discussion.

Robert San Martin, Deputy Assistant Secretary for Renewable Energy, Department of Energy, will highlight the first session with an authoritative overview of alternate energy activities.

Also on Tuesday, domestic dish activities not sponsored by DOE will be reported upon.

There will be a field trip to the nearby Vanguard Stirling module site on Wednesday.

John Stolpe, Supervising Research Energy, Southern California Edison Company, will lead the panel, discussing issues affecting solar thermal electric dish development on Wednesday. Manufacturing, utility, and financial perspectives will be represented.

A session on Thursday will present operating experience from the three dish plants currently operational in the world. Also on Thursday, several of our foreign visitors will report on parabolic dish development in their respective countries.

THE PARABOLIC DISH PROJECT AT JPL: A BRIEF HISTORY

A. T. MARRIOTT

Jet Propulsion Laboratory
Pasadena, California 91109

The conversion of solar energy to electricity using paraboloidal collectors in conjunction with focal point-mounted heat engines is unique to the JPL managed DOE Solar Thermal Technology Program. This concept, developed by JPL, has evolved in seven years to become a viable candidate for the production of electricity on a commercial basis. The dish-electric project is now being transferred from JPL to Sandia National Laboratories, Albuquerque (SNLA) and it is an opportune time to look back at its short history.

The idea of producing thermal energy from the sun using a dish collector is not new; early dishes were used for irrigation purposes but could not compete with less expensive fossil fuels. However, interest was renewed after the oil crisis in 1973. JPL, as a result of experience in energy conversion and dish structures in the space program and a growing involvement in civil system activities, began to look at alternatives - one of which was a distributed collector system concept. This idea emerged from work done for NASA between 1974 and 1976 in a comparative assessment of orbital and terrestrial solar central power stations. In 1976 a proposal to the Energy Research and Development Agency (ERDA) was accepted to look at distributed systems as an alternative to the central receiver concept and to perform studies in support of the ERDA solar thermal office.

The parabolic dish project developed and went through several stages including a rather broad charter that included small solar thermal power systems employing a variety of technologies. By 1980 it had evolved to the point that three distinct activities comprised the project and the technology was limited to parabolic dishes. Advanced Subsystem Development was responsible for determining the feasibility of advanced components and materials for future generation systems. Module Development performed the detailed engineering, fabrication and testing of complete power producing modules. Applications Development was responsible for complete power systems and the demonstration of the dish technology through a series of engineering experiments. During this time the groundwork was laid for the Parabolic Dish Test Site (PDTS) at Edwards Air Force Base and the test bed concentrators (TBC) were installed. Also, many contracts were initiated with industry for the development of concentrators, receivers and engines, and for system level activities in preparation for the Small Community Experiments.

In 1981 several major activities were underway. General Electric was designing PDC-1 and Acurex was doing panel development for a concentrator that was to become PDC-2. Garrett Turbine Engine Company and United Stirling of Sweden were involved with the solarization of Brayton and Stirling engines, respectively. Ford Aerospace and Communications Corporation (FACC) was well into Phase II of Small Community Experiment No. 1, using an organic Rankine cycle (ORC) engine being developed by Barber-Nichols.

Fiscal year 1982 saw a cessation of funding for the Advanced Subsystem Development activity with most of this work going to SERI. The project consolidated to include two major areas: Technology Development and Module/System Development. At the same time, the major emphasis was shifted to the three module development activities associated with the Stirling, Brayton and ORC engines, and supporting component and subsystem development. It was during this year that the most significant test results were achieved at PDTS. The United Stirling (USAB) 4-95 engine was tested in conjunction with a USAB receiver on a TBC and produced electricity at a record efficiency of 29% from sunlight to power out of the generator. The ORC was also run on a TBC in a successful test that verified the system including receiver and controls. Sanders Associates and Advanco Corporation were under contract to design, build and test Brayton and Stirling modules, respectively. Power Kinetics Incorporated under contract to Applied Concepts successfully installed and tested a thermal dish at Capitol Concrete in Topeka, Kansas.

Significant progress was made during FY 1983. The Stirling module design was completed as was most of the subsystem fabrication; installation at Rancho Mirage was started. The ORC bearing problem was solved and steps taken toward the completion of a qualification test program. Acurex completed the design of PDC-2 and started fabricating test panels. Sanders Associates selected the LaJet concentrator for the Brayton module and the first one was built late in the year. JPL and GRI reached an agreement whereby two subatmospheric Brayton cycle engines would be made available to the solar thermal program. In other respects, FY 1983 was one of transition. JPL's system contract with FACC was completed and a contract was established between FACC and DOE to continue the ORC development. In July, a decision was made by JPL management to withdraw from the solar thermal project. Subsequent discussions with DOE and SNLA resulted in an approved plan to transfer the dish-electric project to SNLA during FY 1984.

While this is a point of departure for the JPL program, as well as for the people involved over the past several years - we feel confident that the transition will be made smoothly and we rest assured that the dish project will be in good hands as SNLA assumes responsibility for its management.

FUTURE DISH PROJECT ACTIVITIES *
SAND83-2315A

James A. Leonard
Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

The transition of the lead lab responsibility for the DOE Dish Electric Program from JPL to Sandia will create both problems and opportunities. In the near-term the schedule and budget of some of the project elements are being adversely affected. The DOE, JPL, and Sandia are dedicated to minimizing the impact of the transition. We at Sandia are pleased and gratified with the level of dedication, support, and cooperation displayed by the JPL staff. Likewise, we have been impressed with the patience and forbearance of the contractors in the program as we have imposed on most of them to help us familiarize ourselves with their projects.

The opportunity mentioned above has to do with the Dish Program now being planned and managed in a more unified way relative to the spectrum of applications for dish technology - a technology which can collect more energy at a given mid-to-high temperature than any other, bar none. This will allow more of the program budget to be devoted to R & D and less to administration and management.

The applications to be investigated in the future include distributed dish-electric, centralized dish-electric, cogeneration, industrial process heat, and fuels and chemicals production; materials and process development, and component and subsystem development will be pursued for all dish elements such as the concentrator, receiver, controls (including tracking and drive), engines and turbines, and thermal energy transport.

The strategy will generally be to pursue applications at higher and higher temperatures and to pursue technology development in an orderly process from materials studies through component development and field experiments. This does not mean that several of the above elements would not co-exist in the program - some development areas are ahead of others now and some development areas will move ahead more rapidly than others.

Relative to emphasis, it seems justifiable to place high priority on solar specific components such as the concentrator and the receiver. Engine development is inherently expensive and time-consuming. The foreseeable solar thermal budget will not support all-out R & D from the ground up. The current program philosophy of "tagging along" with developers in other

*This work supported by the U. S. Department of Energy

sectors appears prudent. The key technical issue of thermally connected fields of dishes is the thermal transport system. Encouraging progress in development of cost-effective thermal transport systems will be required before substantial commitments to dish-thermal applicatons are made.

Last, but not least, system-level tests and evaluations in realistic settings are an essential final step in any R & D process. In solar these are particularly important, not only because interface problems not foreseeable otherwise can be identified and corrected, but also because credibility and public acceptance and confidence are crucial to industry's ability to market systems commercially. The commitment to real-world sites must be carefully considered and must follow careful system-level shakeout and rigorous non-public qualification tests.

Sandia National Laboratories is pleased to be a part of the Dish Program, albeit disappointed to lose the suport of our good friends at JPL. We look forward to a productive relationship with all the other program participants.

CONCENTRATOR DEVELOPMENT

William A. Owen
Jet Propulsion Laboratory
Pasadena, California

During the six years of technology development by the Parabolic Dish program, the problems peculiar to tracking dishes have been explored in depth with particular emphasis on economics. Starting with the Precursor Concentrator, testing techniques and apparatus such as calorimeters and the flux mapper were developed. At the same time, mirrors were developed to have a long operating life as well as high performance. Commercially available equipment was evaluated as well. Building on all these elements, the Test Bed Concentrators were designed and built. With a peak intensity in the focal plane of over 17,500 suns and an average concentrator ratio over 3,000 on an eight inch diameter aperture, they have proven to be the work horses of the technology. With a readily adjustable mirror array, they have proved to be an essential tool in the development of dish components, receivers, heat transport systems, instrumentation, controls, engines, and materials, all necessary to cost effective modules and plants. Utilizing the lessons learned from this technology, more cost effective systems were designed. These included Parabolic Dish Number 1 (PDC-1) and PDC-2 currently in final design by Acurex Corporation. Even more advanced concepts are being worked on, such as the Cassegranian systems by BDM Corporation.

PARABOLIC DISH CONCENTRATOR (PDC-1)

Edwin W. Dennison/Maurice J. Argoud
Jet Propulsion Laboratory
Pasadena, California

The design, construction and installation of the Parabolic Dish Concentrator, Type 1 (PDC-1) has been one of the most significant JPL concentrator projects because of the knowledge gained about this type of concentrator and the development of design, testing and analysis procedures which are applicable to all solar concentrator projects. The need for these procedures was most clearly understood during the testing period which started with the prototype panel evaluation and ended with the performance characterization of the completed concentrator. For each phase of the test program practical test procedures were required and these procedures defined the mathematical analysis which was essential for successful concentrator development. The concentrator performance appears to be limited only by the distortions resulting from thermal gradients through the reflecting panels. Simple optical testing can be extremely effective, but comprehensive mechanical and optical analysis is essential for cost effective solar concentrator development.

PARABOLIC DISH CONCENTRATOR (PDC-2) DEVELOPMENT

D. Rafinejad

Acurex Corporation

Mountain View, California

The objective of the program is to develop a 12.2m parabolic dish concentrator for use in the small community solar experiment (SCSE-2). The program includes the design, fabrication, and testing of one concentrator at Sandia test facilities in Albuquerque, New Mexico.

The PDC-2 consists of five subsystems: support structure, drive, reflective surface, electrical and controls, and pedestal/foundation. The overall diameter of the dish is 12.2m with a focal length to aperture diameter ratio (f/D) of approximately 0.55. The structure is a lightweight space frame which supports the power conversion assembly (PCA) by a quadripod structure. The relfective surface consists of two concentric rings of 64 independent reflective panels. The panels incorporate a backsilvered glass mirror surface, bonded to a contoured substrate of cellular glass. The concentrator can be driven independently about the elevation and azimuth axes at track and slew speeds. The drive system uses variable speed DC motors with dynamic braking.

The electrical subsystem provides power to the drives and transmits the output power from the PCA to a rectifier mounted near the pedestal. The control subsystem elements consist of a sun sensor, azimuth and elevation encoders, and remote control interface assembly which provides the control commands for the concentrator operation. The PDC-2 foundation support consists of a cylindrical pedestal embedded in a poured-in-place concrete pier.

The concentrator detailed design has been completed. The bid/evaluation cycle for procurement of the drive components and the support structure is also complete. The cellular glass shaping and mirror bonding and sealing techniques were developed that led to fabrication of two partial full-scale panels for evaluation testing. Efforts are underway to set up the facility for fabrication of panels for the first test unit and the other three concentrators for the SCSE plant at Osage City, Kansas.

The current development phase of the SCSE project is scheduled for completion by June 1984. The Osage City construction phase will start immediately thereafter.

A TRANSMITTANCE-OPTIMIZED POINT-FOCUS FRESNEL LENS SOLAR CONCENTRATOR

Mark J. O'Neill

Entech, Inc.
DFW Airport, Texas 75261

Entech (or it's predecessor organization, E-Systems Energy Technology Center) has, for the past several years, been developing a point-focus Fresnel lens solar concentrator for high-temperature solar thermal energy system applications. The concentrator utilizes a transmittance-optimized, short-focal-length, dome-shaped refractive Fresnel lens as the optical element. This unique, patented concentrator combines both excellent optical performance and a large tolerance for manufacturing, deflection, and tracking errors.

Under Jet Propulsion Laboratory funding, Entech has completed the conceptual design of an 11-meter diameter lens concentrator. Additionally, we have completed a thorough optical analysis of the concentrator. Analytical results indicate that the new concentrator should provide an overall collector efficiency (solar-to-thermal) of about 70% at 815 degrees C. (1500 degrees F.) receiver operating temperature and 1500 X geometric concentration ratio (lens aperture area/receiver aperture area).

Since the last annual review meeting, two noteworthy developments have occurred, as summarized below:

(1) We have completed optical testing of a prototype lens panel, which is representataive of the full dome lens in terms of image size, image shape, and transmittance. This prototype panel was made from a parquet of linear lens segments to approximate the desired annular lens geometry. The segments were made of 3M lensfilm, which is an acrylic prismatic sheet made by a low-cost, continuous process. The segments were laminated to a single piece of outdoor-grade extruded acrylic sheet to form the panel. Testing was done under actual solar illumination, with the focal plane radiant flux profile measured by a scanning set of silicon photovoltaic cells. The theoretical lens optical efficiency at 1500 X geometric concentration ratio is 82%. The measured optical efficiency at 1500 X was 77-80%. We believe that these results confirm the excellent performance potential of the new concentrator.

(2) 3M Company, which has made linear lensfilm of excellent optical quality for several years, has now demonstrated the ability to manufacture prismatic sheet with non-linear prisms by their low-cost, continuous lensfilm process. Under contract to Sandia

National Labs-Albuquerque, 3M has made parquets of annular point-focus lenses of good optical quality by the lensfilm process. This development makes the low-cost production of our dome lens panels achievable, by using tooling which consists of a parquet of linear lens elements of the same geometry as our test panel. We believe that low-cost production of the dome lens is now fully pratical.

Together, these two developments indicate that the new concentrator truly offers the potential for excellent performance at low cost. These recent results will be discussed in greater detail in the final paper.

OPTICAL ANALYSIS OF CASSEGRAINIAN POINT FOCUS CONCENTRATORS

S. S. Waterbury and W. E. Schwinkendorf
The BDM Corporation
Albuquerque, New Mexico

The cassegrainian concentrator configuration, consisting of a paraboloidal primary reflector and a confocal hyperboloidal secondary reflector, offers several potential advantages over more conventional point focus single reflector concentrators due to the location of the receiver at the vertex of the paraboloid. Some of the advantages are that the receiver design can be more flexible since there are no weight or size restrictions, the receiver is easily accessible for maintenance, and the structure for the optical system can be built of lighter materials.

This paper examines the cassegrainian configured concentrators in two general classes, being: 1) the standard cassegrainian, as described above; and 2) the Ritchey-Chretien (R-C) modified cassegrainian, which is corrected for coma. In addition, the effect of a hyperbolic tertiary reflector located at the vertex of the primary mirror was determined. The effect of misalignment of the secondary and tertiary reflectors has also been determined to define the tolerances required during fabrication and assembly.

A Monte-Carlo ray trace code has been utilized to analyze the cassegrainian configuration. This code statistically treats the effects of surface errors. Using this code, a parametric study has been performed on the standard and R-C configuration, varying the primary rim angle, spacing between the two reflectors, and the surface errors on the primary and secondary reflectors. Parameters held constant are the primary reflector diameter, and the position of the system focal plane which is located at the vertex of the primary.

Some typical results from the parametric study are:

1. Surface errors on the primary reflector affect the performance of the system much more than errors on the secondary surface.
2. Optical efficiency, defined as the blocking factor times the intercept factor, increases with rim angle, and is optimum for a given rim angle when the spacing between the primary and secondary reflector is 0.65 to 0.75 times the primary focal length.
3. The R-C configuration produces a more intense spot with lower dispersion than the standard cassegrainian. However, major improvements in efficiency and intercept factor were not observed.
4. Addition of a tertiary reflector to the standard cassegrainian configuration improves efficiency and intercept factor significantly.
5. Misalignment of the secondary can cause significant degradation of system performance. Tolerances on the positioning of the secondary should be held to within $\pm .5^{\circ}$ rotational alignment, $\pm$ 1 inch axial alignment, and $\pm$ 1 inch radial alignment.

ENGINE/RECEIVER DEVELOPMENT

Taras Kiceniuk

Jet Propulsion Laboratory
Pasadena, CA 91109

Solar parabolic dishes require small, high efficiency heat engines. These engines need to be compact and to have low operating cost.

The first paper describes development of an organic Rankine engine. Resolution of two key problems - excessive bearing wear and arcing within the alternator - will be reported.

The second paper will review development of several small engines and their possible use with dishes.

Since solar receivers are in the efficiency train with engines, high efficiency receivers are also required.

The third paper will discuss the technological status of solar dish receivers and will suggest a number of approaches to improving their design.

The fourth paper reports on testing of various materials relative to their use on aperture plates of receivers.

CURRENT STATUS OF AN ORGANIC RANKINE CYCLE ENGINE DEVELOPMENT PROGRAM

Robert E. Barber

Barber-Nichols Engr. Co.
Arvada, CO 80002

This paper presents the steps taken to achieve improved bearing life in the organic cycle (ORC) engine being developed for use on solar parabolic dishes. A summary of recent test results is also given.

The Power Conversion Subsystem (PCS) consists of an air-cooled, regenerative 25 kW_e ORC engine/generator unit mounted at the focus of a parabolic dish concentrator. The working fluid, toluene, is circulated in a hermetically-sealed, closed loop system. Toluene vapor at 750 to 800°F drives the turbine-alternator-pump assembly (TAP) at speeds up to 60,000 rpm. Liquid toluene is used as the lubricant in the hydrodynamic fluid-film bearings in the TAP.

Excessive bearing wear was experienced during solar testing of the PCS at the JPL Parabolic Dish Test Site in February and March 1982. As a result, a program was undertaken to diagnose the cause of bearing failure and remedy the problem. This effort was successful and the specific testing approaches and design changes which led to the current successful bearing system configuration are discussed in the paper.

The first series of tests in the Bearing Life Development Program was designed to characterize the performance of the radial bearing and thrust bearing designs (as individual bearings) under various combinations of controlled load, speed, lubricant flow rate and temperature.

The next series of tests utilized the actual TAP assembly. The shaft was mechanically driven at speeds up to 60,000 rpm by a special test rig. Optical proximity probes were installed to monitor shaft orbit behavior. Evidence of rotor dynamic instability (subsynchronous whirl) was observed; this led to further analyses and specific design changes in the radial bearings and lubrication feed system. However, bearing surface damage continued to appear even after the rotor instability problem was solved. This was traced to electrical pitting caused by electromagnetically-induced shaft voltage arcing across the fluid film and was corrected by design changes.

The most recent test series included operation of the entire PCS (with the TAP installed) for 100 hours of total run time in a ground test facility at Barber-Nichols Engr. Co. (B-N) which realistically simulated operation on the sun. Rotor dynamic behavior was recorded continuously during the 100 hours and the TAP was disassembled at predetermined intervals for bearing inspection. Performance of both the 5-shoe, tilting-pad radial bearings and the gimbal-mounted thrust bearings was entirely satisfactory. This test demonstrated that the objective of solving the "infant mortality" bearing problem has been accomplished. The Power Conversion Subsystem also demonstrated reliable operation over a wide range of test conditions.

OVERVIEW OF ADVANCED STIRLING AND GAS TURBINE ENGINE DEVELOPMENT PROGRAMS AND IMPLICATIONS FOR SOLAR THERMAL ELECTRIC APPLICATIONS

Donald Alger

NASA Lewis Research Center
Cleveland, OH 44135

The DOE automotive advanced engine development projects managed by the NASA Lewis Research Center will be described. These include one Stirling cycle engine development and two air Brayton cycle developments. Other engine activities include 1) an air Brayton engine development sponsored by the Gas Research Institute, and 2) plans for development of a Stirling cycle engine for space use. Current and potential use of these various engines with solar parabolic dishes will be discussed.

ADVANCED SOLAR RECEIVERS

William A. Owen
Jet Propulsion Laboratory
Pasadena, California

Because concentrators and engines represent the bulk of the capital investment in a solar module, receiver design has received less attention. But as a direct link in the energy chain, improvements in the efficiency of the receiver have greater cost leverage than the more expensive components. Several directions in receiver design are examined here with special attention to the likelihood of significant cost effectivity on the overall module. Recent examples of these design improvements will be used as illustrations.

Solar Tests of Aperture Plate Materials for Solar Thermal Dish Collectors

Leonard D. Jaffe
Jet Propulsion Laboratory
Pasadena, California

A test program was carried out to evaluate behavior of materials under conditions simulating walk-off of a parabolic dish solar collector; partial results were reported at the 4th Parabolic Dish Program Review. Each test consisted of exposure to concentrated sunlight at a peak flux density of about 7,000 kW/m^2 for 15 minutes. Types of materials tested included graphite, silicon carbide, silica, various silicates, alumina, zirconia, aluminum, copper, steel, and polytetrafluoroethylene. Of these, the only material that neither cracked nor melted was grade G-90 graphite, a premium grade. Grade CS graphite, a lower cost commercial grade, cracked half-way across, but did not fall apart. With proper design, this grade should probably perform satisfactorily as a receiver aperture plate. Both of these grades are medium-grain extruded graphites. A graphite cloth (graphitized polyacrylonitrile) showed fair performance when tested as a single thin ply; it might be useful as a multi-ply assembly.

The only other material tested which appeared promising was high-purity slip-cast silica; samples survived one and one-half to four minutes. This duration is inadequate for walk-off protection, but the material might well be satisfactory at flux densities somewhat lower than those used in these tests.

The other grades of graphite and silica tested, and all the samples of other materials, either melted, slumped or shattered quickly during the walk-off tests.

Coatings of white high-temperature paint or boron nitride did not improve the performance of graphite samples. Immersion in water prior to test, simulating rain, did not affect their performance.

Oxidation of grades CS and G-90 graphite per 15-minute simulated walk-off varied from 0.2 to 8 mm (0.008 to 0.3 in.) of thickness, from 2 to 22% of the mass (normalized to 25 mm (1 in.) thickness). This will probably be acceptable for many applications. The amount of oxidation varied strongly with the wind speed.

Grade CS graphite was tested for up to 2000 cycles simulating 1-second periods of acquisition at the same flux density as the walk-off test. Loss in 2000 cycles at moderate to high winds was about 5 mm in thickness or 0.15% of the sample mass; this appears to be tolerable. Tests under simulated spillage conditions were limited to measurements of the temperature of the lip of a simulated aperture plate of grade CS graphite. They indicate that at spillage levels up to 2% the lip temperature would be below 250°C (480°F), low enough to provide adequate lifetime of this material with respect to oxidation.

NON-DOE-SPONSORED DOMESTIC DISH ACTIVITIES

Toshio Fujita

Jet Propulsion Laboratory
Pasadena, CA 91109

This session is devoted to parabolic dish development activities being undertaken within the private sector of the United States. The primary emphasis of these non-DOE-sponsored activities is placed on the development of commercial products that can penetrate the market in the near term. The exchange of information between these activities and the complementary DOE-sponsored work directed toward developing advancements in technology is considered to be of major importance. The experiences and problems encountered in the private sector serve as inputs that will help guide in the planning of the DOE program. In turn, a principal objective of the DOE program is the transfer findings of its technological development activities to the private sector.

Activities in the private sector are characterized by their diversity in terms of both product design and marketing approach. This diversity is reflected in the five domestic dish activities covered in this session. The differences in the design concepts and the sizes of the dish concentrators under development are particularly noteworthy.

ADVANCED SOLAR POWER SYSTEM

John H. Atkinson/John M. Hobgood

Advanced Solar Power Co.
Anaheim, CA 92806

ASPCO has developed a demonstration prototype of a point-focussing solar power system. The concentrator is a modified Cassegrain system (10th order generalized aspheric mirrors) producing 10,000 suns at the focal point. The integral receiver is an extended, pressurized black body cavity designed to operate at 700 p.s.i. and 503 degrees F. The system tracks on two axes under microprocessor control. The demonstration prototype has a four kWt mirror mounted on a 40 kWt receiver system and is trailer mounted (3-way legal) for experimental use.

Because of the patented black body cavity receiver design, high thermal efficiencies of 80% with aluminum and 90% with silver on the mirrors are calculated. Energy is transferred directly from photons to the molecules of the working fluid (water). The system efficiency is virtually constant in the working range of 350 degrees F. to 2000 degrees F. and 135 p.s.i. to 10,000 p.s.i. because re-radiation is negligible.

Commercial units are sized at 4.0 - 5.0 kWt (highway transportable), 500 kWt (helicopter transportable) and 1 MWt (mirrors manufactured on-site). While tooling is expensive, quantity manufacturing is inexpensive and designed to be automated. Applications considered are oil field use (heater-treater and steam flood), remote location cogeneration, irrigation pumping, industrial process heat and large scale power generation.

On Solar Thermal Electric Power Capacity Sizing

Jeffrey S. Clark
Deltatemp Energy Corporation
Fort Wayne, Indiana

Parabolic dish technology has for the most part to date been borrowed from existing and expensive microwave dish technology rather than designed to accomodate electrical generating schemes with a good probability of success in practical applications. Studies by this author of the possible uses of various engine/generator designs and sizes with dishes, show that the most immediate possibilities for implementation are in a 3Kw (10m2) size capable of versatility of application and marketing, which assists also in compensating for inadequate developmental funding availability.

Innovation in dish design has produced a $10m^2$ dish at a cost level compatible with DOE goals under STPP for 1990 in conjunction with a 3Kw generator design. The production cost problems of a 3Kw size module may soon be solved. It remains for a suitable generator to be developed and tested at what are reasoned to be comparable cost levels in order to achieve the over-all DOE objectives.

(1) The $10m^2$ range has a simplicity and ease of maintenance which is a function of its size.

(2) Existing labor forces and plant capacity now unused are readily available and adaptable to the production of small modules.

(3) Off-site construction will contribute to lower capacity costs.

(4) Average residential energy requirements in the U.S. @ 600+w/Hr make a 3Kw a slight producer in the consumer/retail market.

(5) Versatile markets are available: utility, commercial, and retail consumer - which will speed implementation.

(6) Component hardware is readily available and compatible.

(7) The smaller size is a more productive use of a given land area.

In summary, over-all economic conditions now extant indicate that a 3Kw $10m^2$ dish/generator module stands up against the larger sizings as lending itself to the most rapid development and the greatest marketing versatility. It therfore stands the best chance of success over the next five to ten years for commercialization.

RECENT DEVELOPMENTS ON ENGINEERING SQUARE DISH FOR SOLERAS SYLTHERM PROJECT

William E. Rogers

Power Kinetics, Inc.
Troy, NY 12180

This presentation will include all recent developments on engineering the Power Kinetics, Inc. square dish for the Soleras Syltherm project.

The application uses 730 degrees F. Syltherm which is used to run steam driven desalination project.

PERFORMANCE TEST OF THE SOLAR STEAM, INC. 9-M DEEP DISH SOLAR CONCENTRATING COLLECTORS

Keith Masterson
Solar Energy Research Institute
Golden CO 80401

and

Harry Gaul
Solar Innovations, Inc.
Golden, CO 80401

This report describes a Solar Energy Research Institute (SERI) project funded through the Industrial Process Heat (IPH) program to evaluate a unique deep dish solar concentrating collector fabricated by Solar Steam, Inc. (SSI) of Fox Island, Washington. The objective of this work was to obtain and report on the performance data on the SSI concentrating solar collector. A new technique, the Reverse Illumination Method (RIM) was tested and used to gather data on the optical figure of the concentrator.

ADVANTAGES OF PARABOLIC CONCENTRATORS

H.L. Bohanan

Solartrac, Inc.
Beacon, NY 12508

This presentation will cover the advantages of parabolic concentrators over the present technology in parabolic troughs, and the design to facilitate more accurate molds in the design of the parabolic concentrator.

SPIKE-2 - A Practical Stirling Engine For Kilowatt Level Solar Power

William T. Beale

Sunpower, Inc.

Athens, Ohio USA

Recent advances in the art of free piston Stirling engine design make possible the production of 1-10 kW free piston Stirling-linear alternator engines, hermetically sealed, efficient, durable and simple in construction and operation. These machines can operate either as independent units or ganged together for higher power. They may also operate directly connected to the grid without need of any intermediary.

Power output is in the form of single or three phase 60 hz. AC, or DC. The three phase capability is available from single machines without need of external conditioning. Engine voltage control regains set voltage within 5 cycles in response to any load change.

The existing SPIKE-2 design has the following characteristics and measured performance:

Weight - 30kg
Length - 50 cm
Diameter - 25cm
Power - 1.5kW
Engine-Alternator Efficiency - 25% at 650°C heat head temperature
Life - over three years in solar service
Cost in production - less than $1,000

The same system can be scaled over a range of at least 100 watts to 25 kW.

For longer life, non contact bearings may be used without adding to system complexity or failure modes.

Stirling Module Development Overview

Floyd R. Livingston

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The Solar Parabolic Dish-Stirling Engine Electricity generating module development has been pursued by the Department of Energy with Government laboratories and industrial participants since FY 1978. The solar parabolic dish-Stirling engine electricity generating module consists of a solar collector coupled to a Stirling-engine powered electrical generator. The module has been designed to convert solar power to electrical power in parallel with numerous identical units coupled to an electrical utility power grid.

Presently, the solar parabolic dish-Stirling engine electricity generating module exists as a commercial prototype erected by the Advanco Corporation at the Southern California Edison Company's Santa Rosa Substation located in the city of Rancho Mirage, California. If the commercial prototype, named Vanguard, tests prove the equipment to be effective and reliable, then the participants have planned to construct an electricity generating plant.

In order to prepare for the Vanguard module erection, Advanco Corporation has worked with their subcontractors to design, fabricate, assemble, and test the many components and subsystems over the past year. The Stirling engine/generator consists of an United Stirling Model 4-95 solar engine and a Reliance Model XE286T induction generator. The power conversion assembly generates up to 25 kilowatts at 480 volts potential/3 phase/alternating current. The module electrical power system has been constructed by the Onan Corporation to be fully self-controlled.

The United Stirling/JPL have tested two test bed modules at the Parabolic Dish Test Site, Edwards AFB, California during the past year. Improvements in the reliability and performance of the USAB Model 4-95 solar engine results from knowledge gained in these tests, as well as from the DOE/NASA sponsored Automotive Stirling Engine tests at USAB and MTI, and from the private laboratory tests at USAB Malmo, Sweden. The joint USAB/JPL solar tests of the two Model 4-95 engines provide the only actual environment for function, performance, and endurance measurements needed to improve the hardware and software, and to project the commercial value.

The testing has been very successful during the FY 1983 period. Piston rings and seals with gas leakage have not occurred, however, operator failures resulted in two burnt out receivers, while material fatigue resulted in a broken piston rod between the piston rod seal and the cap seal.

PARABOLIC DISH STIRLING MODULE

Byron Washom

Advanco Corporation
El Segundo, CA

Advanco Corporation and its subcontractors have completed the design, manufacture, and assembly of the first commercially designed parabolic dish Stirling 25 kWe module. The module will begin testing in December 1983 and commence power the following month. The project has been funded by two Cooperative Agreements between Advanco Corporation and the U.S. Department of Energy and Southern California Edison Co. The paper discusses the cost, expected performance, design uniquenesses, and future commercial potential of this module which is regarded as the most technically advanced in the parabolic dish industry.

United Stirling's Solar Engine Development - The Background for the Vanguard Engine

Sten Holgersson
United Stirling AB
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The Vanguard Project engine, named the 4-95 MK II Solar Stirling Engine, represents the result from four years of solar engine development at United Stirling. In these development activities United Stirling has participated in programs on contracts from JPL and DOE, the latest being the Vanguard Project. A major part of the development has also been internally funded.

The development started in 1979 based on the then existing 4-95 laboratory test engine which thru the four years has been converted to a solar version and significantly improved in several areas. The conclusion of the Vanguard Project results in a new engine generation of a design that can be regarded as a preproduction prototype.

The major part of the solar engine development has been concentrated to three different areas, the receiver, the lubrication system and the control systems, but improvements have been made on most components. The new components were first tested on engines in United Stirling's Laboratory in Malmoe. Five such engines are on test within the solar project. Thereafter the function of the components has been validated in actual solar tests. These tests started at Georgia Institute of Technology in 1981 and have then from the beginning of 1982 been performed at JPL's Test Station at Edwards Air Force Base.

This paper describes the development and testing resulting in the Vanguard Engine and some of the characteristics of the Stirling engine based power conversion unit.

Testing of the United Stirling 4-95 Solar Stirling Engine on Test Bed Concentrator

Hans-Goeran Nelving

United Stirling AB

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Testing of the improved 4-95 Solar Stirling Engine in a Parabolic Dish System has been going on in test bed concentrators at Edwards Air Force Base since May 1982. This paper presents the objectives with the testing, test set-ups and component designs and the results of the testing.

Different type of tests have been performed, among the most important have been characterization of receivers, full day performance of complete system, cavity and aperture window test including influence from wind-effects, control system tests, radiator system tests and special temperature measurements with infrared camera.

The maximum output from the system - 24 KW module power output, 28 percent overall conversion efficiency solar to net electric - and the full day performance - 13.5 hours of operation generating over 250 KWH - shows the system capability. Other important results are the influence on performance of flux distribution depending on concentrator alignment, and the optimum receiver operating criteria when balancing flux and temperatures on cooled receiver surface while avoiding flux on uncooled surfaces.

VANGUARD CONCENTRATOR

Terry Hagen

Advanco Corporation
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Advanco Corporation and the United States Department of Energy (DOE), on May 28, 1982, signed a Cooperative Agreement for the design, manufacture, and test of a "solar only" parabolic dish-Stirling system known as Vanguard 1. As a result of this agreement, a Project effort has developed that combines the extensive research and industrial experience of several participants to develop and produce the Vanguard 1, solar energy, electric-generating module that will technically and economically penetrate the small community market as well as the electrical utility market. The design of the Vanguard 1 dish-Stirling engine system features low risk, simple fabrication and assembly, and minimum cost. Due to the fully self-contained nature and relatively simple size of each power generation module, this solar technology lends itself to rapid commercialization. The concept combines United Stirling's USAB 4-95 Solar II Stirling engine, Jet Propulsion Laboratory's (JPL) developed mirror facets which form the reflective surface of the dish, Rockwell/Advanco's low-cost exocentric gimbal mount with the needed structural stiffness to assure tracking accuracy; a low-cost pedestal foundation; and an automatic un-manned concentrator control system. This report is a summary of the results achieved by Advanco on the fabrication and erection of the concentrator since the April 83 Detailed Design Review of the Vanguard I program.

BRAYTON MODULE DEVELOPMENT OVERVIEW

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Pasadena, California

Some reasons for considering Brayton cycle (air turbine) technology for solar thermal applications include:

1. The large, existing gas turbine experience base.
2. A simple rotating assembly with demonstrated long life in engines with foil bearings.
3. Direct incorporation of hybrid combustor with an air receiver.

The Brayton module effort takes advantage of two existing engine development programs. The Advanced Gas Turbine (AGT), being developed for automotive application by the Garrett Turbine Engine Company, will provide a high efficiency engine in the high-temperature, ceramic configuration. The Sub Atmospheric Brayton Cycle (SABC) engine, developed by the AiResearch Manufacturing Company for long life heat pump usage, will be available for near team application.

The near team module development, with Sanders Associates as system contractor, uses the AiResearch 8 kW SABC engine, the LaJet LEC 460 concentrator and a modification of the Sanders high temperature solar receiver. While the program has suffered through several funding deferrals and delays, sufficient funds have been available in FY 1983 to complete the module preliminary design and to start fabrication of developmental subsystems. In FY 1984 these developmental subsystems will be tested both separately and as part of a Development Test Model (DTM), and modified subsystems will be completed preparatory to a module verification test. This module appears to have a strong potential for near-term, reliable, cost effective application.

PARABOLIC DISH MODULE ANNUAL REPORT
NEAR-TERM BRAYTON MODULE STATUS

S. B. Davis

Sanders Associates, Inc.

Nashua, New Hampshire

Sanders Associates, Inc. was selected as system integrator for this program with the responsibility of integrating subsystem components and testing a Parabolic Dish Module (PDM) to convert solar energy to grid compatible electric power.

By March 1983 Trade Studies had been completed and the PDM system components were selected. System components were selected on a basis of current and projected performance efficiencies, technology readiness, future production probabilities and prices, current cost and availability. Though the PDM program was originally oriented toward an 11-12 meter reflector with a 15-20 kWe output, the trade study conclusion led us to downsize the system to include a smaller lightweight reflector with a rated output of 8 kWe. Market potential for this near-term, 8 kW derivative of the PDM is adjudged to be superior to that of a 20 kW system.

Major system components are: 1, the AiResearch/GRI Mark III sub-atmospheric brayton cycle power conversion assembly; 2, the LaJet LEC-460 point focusing concentrator; 3, the Abacus 8 kW DC-AC inverter; 4, the Sanders/JPL low pressure, high temperature ceramic matrix receiver; and 5, the Sanders 8086 micro-processor based control system.

The PDM is suited to both grid connected and standalone applications, and it may be fired by solar, fossil, or solarfossil hybrid means.

Current program plans calls for delivery by Garrett of two engines. The early engine will be utilized in the Development Test Model (DTM) which will be tested in March of 1984 at Sanders, in Merrimack, NH, DTM objectives are to complete:

- System Integration
- Development of Control Algorithms and System Operating Logic.
- Establishment of System Performance Baselines
- Demonstration of System Feasibility

Following the PDM Critical Design Review (CDR) in April 1984, assembly of a Final System will commence. An improved engine will be delivered directly to Sandia Laboratories, Albuquerque, NM and final system integration is scheduled for September 1984. Module verification testing will start in the fourth quarter of calendar 1984.

Subatmospheric Brayton-Cycle Engine Program Review

Richard L. Johnson
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A solar-energy-powered electrical generator has been developed in a program for the Gas Research Institute (GRI). The generator consists of a subatmospheric, solar-powered Brayton-cycle engine and a permanent-magnet (PM) alternator. The alternator is driven directly by the Brayton-cycle engine rotating group to generate electrical power. Unique features that enhance reliability and performance include air foil bearings on both the Brayon-cycle engine rotating group and the PM alternator, an atmospheric-pressure solar receiver and a gas-fired trim heater, and a high-temperature recuperator. The subatmospheric Brayon-cycle engine design is based on that of the GRI gas-fired heat pump engine.

Two generators will be supplied in the program: the first, a feasibility demonstration unit using existing GRI hardware, will produce an electrical power output of 5 kW; the second, with an upgraded engine and PM alternator, will produce 8 kW.

LEC System Development

David D. Halbert

LaJet Energy Company

Abilene, Texas

Abstract

LaJet Energy Company ("LEC") entered the solar energy business in early 1978 funded by its parent company, LaJet, Inc. The first goal of LEC was to identify a viable solar product that had long-term commercial application. After making an economic analysis of solar energy, LEC defined the necessary conditions for developing a cost-effective solar product. With its goal defined, LaJet, Inc. funded a research and development program to create such a product. The result is the LEC System. The latest model of the LEC System is designated the LEC 460.

The LEC 460 is a parabolic dish that incorporates a microprocessor programmed to always point the LEC 460's mirrors toward the sun, automatically, from sunrise to sunset. Instead of using a solid dish, the LEC 460 uses a set of mirrors (each made of highly reflective polymeric film) arrayed in a dish shape on a steel tubing space frame. These mirrors focus and concentrate the sun's energy on a receiver. The steel tubing space frame supporting the mirrors is attached to a cantilevered support structure. The weight of the receiver counterbalances the weight of the mirrors and the frame. This balance reduces the energy (so-called parasitic load) that must be used to move the LEC 460 as it tracks the sun, and permits the use of small, low-powered tracking motors. It also permits tracking on two axes to adjust for changes in the sun's angle as the seasons change as well as to follow the sun across the sky each day.

Each LEC 460 is equipped with its own microcomputer-based controller which represents the state-of-the-art in automated control systems. This controller regulates the system start-up and shutdown procedures--including auxiliary motors, valves, and other support devices--and determines the time of day to perform these functions. The controller also tracks the sun and automatically adjusts for any errors in positioning or placement to ensure optimum performance.

The development and testing of the LEC System has spanned three years. Six models of the concentrator were designed, built, and tested during this period. The LEC 460 incorporates a number of refinements and improvements developed through the testing and operation of the previous models. These improvements include a reflective surface 5.4 times larger than the original model, a substantially stronger support base and space truss frame, improved mirror design permitting greater efficiencies and durability.

The LEC System features advanced engineering focused on reliability, performance, and low cost to produce a sophisticated yet relatively simple product.

PANEL DISCUSSION ON "BUSINESS VIEWS OF SOLAR ELECTRIC GENERATION"

Overview By
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Solar power generation systems, including parabolic dishes, are beginning to make headway as income producing business ventures for supplying meaningful amounts of electric power to the utility grid. In doing so, solar developers are making a difficult transition from the emotionally-based justification for solar R&D "to solve the world energy situation" and are now beginning to face the realities of having to justify solar commercialization based on all the tried and proven rules of economics and free enterprise.

For any given solar power technology which has successfully progressed through all the research, development and demonstration steps to prove its technical value to a utility grid, the technology eventually becomes faced with an entirely different set of formidable business questions from the financial community. Such questions are directed toward establishing the financial feasibility of a possible commercial project, and guaranteeing that both lenders and investors will receive their required financial repayment. Because of the multi-million dollar magnitude of typical proposed solar power projects, solar commercialization is truly entering the domain of "big business." The extent to which any solar power technology will succeed in the open marketplace will be determined by its ability to compete with other energy technologies as well as the degree of financial creativity employed by the organizations which undertake to design, construct, and operate future solar plants.

A panel of recognized experts in the field of solar has been organized to convey views of the continuum of solar business interests--from the manufacturer to the end-user and the all-important area of finance. Each panelist will offer observations based on his particular experience in the overall area of solar and alternate energy systems. These views will be of direct practical value to developers of solar dish hardware.

DISTRIBUTED SYSTEMS OPERATING EXPERIENCE

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Over the past several years, valuable operating experience has been obtained with several distributed systems. The first three papers in this session discuss experience with operations of dish plants in widely separated countries around the world - United States, Australia, and Kuwait. The fourth paper presents both desirable and undesirable design features of operating systems with troughs as well as dishes.

STATUS OF SHENANDOAH'S SOLAR TOTAL ENERGY PROJECT (STEP)

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The Solar Total Energy Project (STEP) at Shenandoah, Georgia is a cooperative effort between the United States Department of Energy (DOE) and Georgia Power Company to help maximize the potential of solar energy. Sandia National Laboratories provides technical management for the U. S. Department of Energy. The design, operation, and analysis of this point focus system have been supported by a wide range of institutional and industrial organizations. When funded by DOE in 1977 as part of the National Solar Thermal Energy Program, it was the world's largest industrial application of solar cogeneration.

There are 114 twenty-three foot diameter parabolic dishes that track the sun in two axes and provide 11 billion BTUs of energy annually. Heat taken from a heat transfer fluid boils water and superheats steam for a Rankine steam turbine-generator. The design output of the system, under maximum insolation, is 400 kW(e), 1380 pounds per hour of extracted steam for pressing clothes, and 257 tons of air conditioning for cooling the Bleyle garment plant to which the energies are provided.

In 1982 a large number of unexpected electrical and mechanical problems limited experimental operations. However, many lessons were learned from these anomalies that have been totally addressed and resolved. The next generation system should profit greatly by this learning experience. In 1983, system performance tests were initiated, and the thermodynamic design has been validated. Each individual subsystem and component have demonstrated a design basis for future larger systems. A number of prescribed tests associated with this Test Operations Phase have been initiated and will be continued to the middle of 1984. These tests will evaluate total system modes of operation for future commercial type operation.

This technical paper will highlight (1) the 1982 milestones and lessons learned; (2) performance in 1983; (3) a typical day's operation; (4) collector field performance and thermal losses; and (5) formal testing. An initial test that involves characterizing the High Temperature Storage (HTS) Subsystem will be emphasized. The primary element is an 11,000 gallon storage tank that can provide energy to the steam generator during transient solar conditions or can extend operating time. Overnight, thermal losses have been analyzed. The length of time the system can be operated at various levels of cogeneration using stored energy will be reviewed.

WHITECLIFFS - OPERATING EXPERIENCE

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AUSTRALIAN NATIONAL UNIVERSITY

CANBERRA ACT, AUSTRALIA

Developmental work for the fourteen-dish Whitecliffs Solar Power Station Project commenced in July 1979. Engineering design started in August 1980, and construction was completed in December 1981. Experimental running of the full system commenced in March 1982. Design specifications were met in June 1982 and robust, reliable operation was achieved by June 1983 to the extent that the station, which is designed for automatic unattended operation, can be handled by local personnel. The area is remote and subject to extreme environmental conditions: temperatures below freezing in winter and regularly above 40 degrees celsius (up to 47 degrees celsius) in summer; frequent dust storms and fine dust-laden atmosphere; haze; regular stong buffetting winds; dew precipitation, which tends to consolidate dust on mirrors; very low rainfall, which often appears as thunderstorms and flashfloods; insolation which, while recorded in meteorogical records as over hours/years, yet is intermittent especially in the afternoons on a surprisingly large number of days. These and other factors ensured that achievement of satisfactory operations required considerable attention and expenditure of resources. Notwithstanding the wide range and harsh conditions encountered, the project has had a very positive outcome. All encountered problems (some predicted, others unsuspected) have been solved without significant changes of the original systems concepts and configurations. The general design philosophy of automotive/agricultural level of technological sophistication has proved practicable. Operation and maintenance by local inhabitants (who are extremely resourceful) is workable. Installed cost for the system was dollars Australian 12,500/KWE. Qualitative and quantitative information and lessons learned are now available to enable considerable simplifications to be made to the system, reducing both hardware and operating and maintenance costs and to produce next generation systems of potentially attractive cost effectiveness. Experience and lessons from the project are presented, particularly in relation to system performance in various environmental conditions. Also presented are design philosophies for collectors, the array, control system, engine and plant operation and maintenance strategies, and cost reducing possibilities. It is concluded that experience so far gives much encouragement for the future of paraboloidal dish systems in appropriate areas.

Distributed Systems Operating Experiences: Kuwait Project

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Kuwait Institute for Scientific Research, Kuwait

Abstracts:

Electricity and process heat generation are the two main objectives of a solar thermal power project which is a part of the mutual cooperation between Kuwait and the Federal Republic of Germany as manifest in the bilateral agreement signed between the Ministry of Research and Technology of the Federal Republic of Germany and the National Committee of Technology of the State of Kuwait.
The project is executed by Messerschmitt-Bölkow-Blohm (MBB) on behalf of the German Party and the Kuwait Institute for Scientific Research (KISR) on behalf of the Kuwait Party.

The parabolic dish distributed collector system consists of a field of 56 high concentrating collectors. These concentrate the solar energy on spherical copper absorbers located at the focal point of each of the collectors. The energy storage is a small thermocline tank, large enough to provide for one hour of turbine generator operation. From the thermal storage the heat transfer fluid is circulated through a heat exchanger unit to vaporize the organic working fluid Toluene. Energy conversion from solar radiation into electricity is accomplished by a Rankine cycle turbine. Nominal gross generator output is approx. 120 KW under design conditions.

In addition to the electricity generation the energy conversion system is designed to deliver enough heat for powering a multi-stage flash desalination unit which delivers in parallel to an electrically driven reverse osmosis desalination unit the fresh water for an agricultural irrigation area.
The plant became operational in summer of 1981. Since that time it has been proceeding through an acceptance and optimization phase and is now in a status where the MSF desalination unit is coupled to the plant. During the last two years operational experiences have been made with the new technology concerning the solar specific items as well as the non-solar specific, conventional components: thermal losses in heat transfer loops and thermal storage tanks, malfunction of absorber control systems, mirror corrosion, dust and sand covers on the collectors and overestimated solar insolation are part of the negative experiences made in two years, but most of the plant technology turned out to be reliable hardware and well adapted to the electricity and process heat generation. The plant works under difficult environmental conditions, can be operated nearly

fully automatically, needs only few manpower for operation and maintainance and delivers, due to its experimental character, all the information with respect to the future technical and economical developments and applications.

The results reported in this paper represent the concerted effort of KISR and MBB to achieve the scope of the project and the generally positive experiences with this plant have proven the basic validity of the distributed collector system for solar energy application and the type of application in remote areas described above.

Operational Experience from Solar Thermal Energy Projects

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Over the past few years, Sandia National Laboratories has been involved in the design, construction, and operation of a number of DOE-sponsored solar thermal energy systems. Among the systems currently in operation are several industrial process heat projects and the Modular Industrial Solar Retrofit qualification test systems, all of which use parabolic troughs, and the Shenandoah Total Energy Project, which uses parabolic dishes. Operational experience has provided insight to both desirable and undesirable features of the designs of these systems. Features of these systems which are also relevant to the design of parabolic concentrator thermal electric systems are discussed.

A key design requirement for all solar systems is the ability to operate in and survive a wide range of environmental conditions. In Albuquerque, wind has been observed to increase from less than 20 mph to 60 mph in less than 60 seconds upon the passage of a front while at the same time insolation was adequate for system operation. Since few concentrators can reach a safe stow position in such a short time, the capability to survive wind speeds well above operational limits, typically 25 to 35 mph, when out of the stow position, is highly desirable. Another effect which has been observed is wind-induced oscillation of some concentrators; this has caused significant damage. This possibility as well as the steady state effects of wind (e.g., overturning moments) must be considered in concentrator design. Wind-borne debris, such as small rocks, have apparently caused damage to certain types of glass mirrors. These mirrors have survived hail tests; however, rock can have sharp points which apparently penetrate the surface of the glass. In addition, temperatures well above ambient due to direct insolation on portions of the systems other than the reflectors have led to various problems including damage to the bond in glass-steel laminates and intermittent operation of electronic components.

Other design features discussed are system control functions which were found to be especially convenient or effective, such as local concentrator controls, rainwash controls, and system response to changing insolation. Drive systems are also discussed with particular emphasis on the need for reliability and the usefulness of a manual drive capability.

Session IX: International Dish System Development

Leonard D. Jaffe
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Pasadena, California

Americans working on development of solar power systems are sometimes unaware of the very significant work underway in other countries. At this session, several papers will be presented describing innovative and advanced projects that are in progress overseas.

DEPLOYMENT OF A SECONDARY CONCENTRATOR TO INCREASE THE INTERCEPT FACTOR OF A DISH WITH LARGE SLOPE ERRORS

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J. O'Gallagher,
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Previous studies by Winston and O'Gallagher (1) and Jaffe (2) have demonstrated the possibility that a secondary concentrator deployed at the focal plane of a parabolic dish can significantly improve the optical performance by increasing the intercept factor. In other words it is possible to obtain higher compound concentration ratios up to a factor of two for a primary dish of given slope errors. Translated into commercial terms, the required tolerances to obtain higher temperatures may be significantly lowered and the cost of the dish proportionally reduced.

Solar Energy Research Centre (SERC) of the University of Queensland and the solar group from the University of Chicago are jointly pursuing a programme to apply the concept to a commercial unit.

An existing Omnium-G system at the premises of SERC has been equipped with a water cooled "trumpet"-type secondary concentrator previously tested by Winston and co-workers on the JPL test bed concentrator. Design details of this trumpet are given in their paper presented at the Fourth Parabolic Dish Solar Thermal Power Program Review. The reflective surface of the primary concentrator consists of 18 petals formed from electropolished aluminium bonded to a polyurethane foam substrate. During the last three years of exposure the specularity of the surface as well as slope errors deteriorated drastically. The resulting effective concentration ratio was 366 and the optical and thermal efficiencies of the dish were 60% and 35% (at 600°C), respectively.

The paper to be presented will involve a new method of aligning the petals, detailed flux mapping and comparative cold-calorimetric measurements with and without the trumpet. For the next series of the experiments the mirror will be resurfaced with 3M-ECP-244 reflective film to improve the specular reflectance while leaving the slope errors the same.

Ref. 1. Winston, R. and O'Gallagher, J., Non-Imaging Secondary Concentrators, Proc. Fourth Parabolic Dish Solar Thermal Power Program Review, Nov. 30 - Dec. 2, 1982.

2. Jaffe, L.D., Optimization of Dish Solar Collectors with and without Secondary Concentrators, DOE/JPL 1060-57. Work Performed Under Contract No. AM04-80AL13137. May 15, 1982.

Recent Advances in Design of Low Cost Film Concentrator and Low Pressure Free Piston Stirling Engines for Solar Power

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Bomin Solar
Lörrach, West Germany

William Beale
Sunpower, Inc.
Athens, Ohio U.S.A.

The rapid development of free piston Stirling engine technology in combination with low weight pneumatically formed plastic film concentrators makes possible solar thermal power plants with a combination of high performance and low cost. Recent improvements in the system allow the production of 10 kW of net electric power to the grid from a dish of approximately 7.3 meter diameter without the need for a cover dome. This system is believed to be practical and cost effective in Sahara environments.

The main power unit is a single cylinder low pressure 50 Hz. free piston engine with hydrodynamic gas bearings of a simple and durable design. This machine is capable of high efficiency and long life without severe constraints on dimensional accuracy of its moving parts. Lower power versions of this machine have been successfully tested and have met their design performance goals.

The alternator driven by the engine has high power density and efficiency at least equal to that of rotary alternators presently available. If desirable, the alternator can be designed to deliver three phase power. Since reciprocating mass of the alternator is low, the operating frequency can be achieved without recourse to gas springing other than that available from the working gas, thus permitting a very simple and durable engine-alternator combination without stringent demands of axial alignment or other mechanical perfections.

It is believed that the combination of simple, low cost concentrator with a single cylinder, low pressure free piston engine and an efficient and durable alternator forms a leading combination for the production of electric power from solar energy.

TESTING AND INSTRUMENTATION OVERVIEW

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There will be five papers presented in the Testing and Instrumentation session. The five papers are: (1) Special Pyrheliometer Shroud Development, (2) Rapid Test Bed concentrator Alignment Techniques, (3) PDC-1 Sun Position Calculation, (4) Recent Solar Measurements Results, and (5) Operational Issues/Concerns. Each paper is described briefly below.

The first paper on "Special Pyrheliometer Shroud Development" will be presented by Dr. Edwin Dennison, Member of the Technical Staff at JPL. The paper concludes that it is possible to build an insolation measurement system which is proportional to the thermal power at the focal plane for dishes that is accurate over a wide range of sky conditions.

The second paper on "Rapid Test Bed concentrator Alignment Techniques" will be presented by Maurice Argoud, Member of the Technical Staff at JPL. The paper details a method of aligning the 220 mirror facets on a Test Bed concentrator in one or two nights, instead of one to two weeks.

The third paper on "PDC-1 Sun position calculation" will be presented by Dr. John Stallkamp, Member of the Technical Staff at JPL. The paper presents the several computational approaches to providing the local azimuth and elevation angles of the sun as a function of local time and then the utilization of the most appropriate method in the PDC-1 microprocessor.

The fourth paper on "Recent Solar Measurements Results" will be presented by Darrell Ross, Task Manager for Test and Evaluation at the PDTS. The paper will describe the effects of the El Chichon volcanic eruption in Mexico in 1982 on the insolation levels at the PDTS.

The fifth and final paper on "Operational Issues/Concerns" will be presented by John Woodbury, site Manager at the PDTS. The paper will describe some of the operational issues/concerns and lessons learned during the operation of the PDTS since 1978.

SPECIAL PYRHELIOMETER SHROUD DEVELOPMENT

Edwin W. Dennison

Jet Propulsion Laboratory

Pasadena, California

The field of view of a Normal Incident Pyrheliometer (NIP) or radiometer which is used to measure insolation can be made to very closely approximate the field of view of a point focus solar concentrator with the use of a suitable shroud. A simple algorithm can be used to calculate the field of view of a radiometer. The field of view of a solar concentrator can be calculated with the use of standard optical ray tracing algorithms. Measurements were made with three shrouded radiometers and a cold water calorimeter mounted on the PDC-1 solar concentrator at the JPL Parabolic Dish Test Site. This type of modified radiometer can improve the accuracy of power conversion efficiency measurements under a wide range of sky conditions and solar elevation angles. Correctly shrouded radiometers can provide realistic data for the evaluation of proposed solar power generation sites.

RAPID TEST BED CONCENTRATOR (TBC) ALIGNMENT TECHNIQUES

Maurice J. Argoud

Jet Propulsion Laboratory
Pasadena, California

A new, labor and cost saving method was developed to eliminate the procedure of covering all (220) mirrors and uncovering them one-by-one in sequence to adjust each to the focal plane. This latest method being used to align mirrors of a parabolic solar concentrator utilizes a computer-derived target of discreet images made up of individual mirror reflections on a plane in front of the intended, nominal, focal point. Incorporating this computer technique increases accuracy and gives potential to develop flux distributions required by different receiver designs.

Implementation of the Sun Position Calculation in the PDC-1 Control Microprocessor

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The major portion of this paper presents the several computational approaches to providing the local azimuth and elevation angles of the sun as a function of local time and then the utilization of the most appropriate method in the PDC-1 microprocessor. The full algorithm, in FORTRAN form, is felt to be very useful in any kind or size of computer. It was used in the PDC-1 unit to generate efficient code for the microprocessor with its floating point arithmetic chip. The balance of the presentation consists of a brief discussion of the tracking requirements for PDC-1, the planetary motion equations from the first to the final version, and the local azimuth-elevation geometry.

RECENT SOLAR MEASUREMENTS RESULTS

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After the Mexican volcanic eruptions of March 28, April 3 and 4, 1982, the question of its effect on insolation levels at the Parabolic Dish Test Site (PDTS) naturally arose. It was decided to look at this question in three steps: First to determine the impact, if any, on total direct normal energy (by month) at the PDTS for the summer of 1982 as compared to the summer of 1981 (after and before the explosion respectively). Secondly, we would look at the effect on peak insolation levels for the same period of time. The results of the first step were the following: A drop of 20%, 9% and 18% in total direct normal energy for the months of June, July and August 1982 respectively, as compared to the same months in 1981 was experienced. For the second step we found a decrease of 4.0%, 5.8% and 7.7% in peak direct normal insolation levels for the months of June, July and August 1982 respectively, as compared to the same months in 1981 (where the peak levels for each month were determined by averaging the top 3 days for each month). The most striking difference noted between the summer of 1981 and 1982 was the following: There were 29 days in June, July and August of 1981 where the insolation level exceeded 1,000 W/m^2. For the same period in 1982 there were zero days that were in excess of 1,000 W/m^2. The third and final step was to compare the results of the summer of 1983 (a year after the explosion) with the summer of 1982. The results show only one day in excess of 1,000 W/m^2 during the summer of 1983 (this was in July 1983, a hiatus of thirteen months since the last one). Clearly, the answer to the original question is that the Mexican volcanic explosion had a significant impact on insolation levels at the PDTS and, furthermore, it has been quite long lasting. The data would seem to suggest that the volcanic explosion had little effect on PDTS insolation until the first of June 1982.