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SOLAR ENERGY RESEARCH INSTITUTE
Solar Energy Information Center
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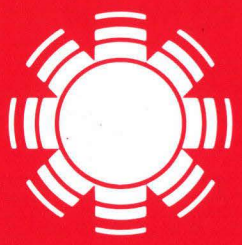
Golden, Colorado 80401

Systems Analysis and Testing (SAT) Program

Progress Report

October 1, 1978 - March 31, 1979

C.J. Bishop



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Solar Energy Research Institute
A Division of Midwest Research Institute

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PROGRESS REPORT

1 OCTOBER 1978 - 31 MARCH 1979

SOLAR ENERGY RESEARCH INSTITUTE
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C. J. BISHOP

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PREPARED UNDER TASK NO. 3525

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FOREWORD

The work discussed in this document has been performed as part of Task 3525, Systems Analysis and Testing. It reflects activities undertaken during the first half of Fiscal Year 1979.

The efforts of the following people are reflected in this report: C. Benham, C. Bingham, J. Cohen, J. M. Connolly, G. Franta, L. Groome, J. Henderson, J. Jayadev, L. Morrison, D. Noreen, F. Perkins, and J. Watkins.

Neil H. Woodley, Branch Chief
Systems Analysis Branch

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Melvin K. Simmons, Assistant Director
Analysis Division

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SECTION 1.0

INTRODUCTION

In late FY78, the Solar Energy Research Institute (SERI) accepted the reponsibility for the development and management of the Systems Analysis and Testing (SAT) Program, a major program element of the National Solar Heating and Cooling Program within the R&D Branch, Conservation and Solar Applications, Department of Energy.

The overall objective of the Systems Analysis and Testing Program is to provide the solar industry and others with methods to predict the performance of optimum solar systems, plus to design/install/operate optimum solar systems for various system configurations, climates, applications, competing energy types, and utility rate structures.

Subordinate objectives of the Systems Analysis and Testing Program are:

- Perform system studies to identify preferred solar systems which are optimized to the intended end use, and which offer potential for early commercialization;
- Develop validated system simulation models, design tools, and handbooks;
- Develop improved control strategies and control systems to increase solar system performance;
- Conduct system tests to evaluate, verify, and optimize system economics and performance behavior; and to develop data to use in the validation process; and
- Disseminate the developed data and design tools to the user community.

This document describes SERI activities for the SAT program during 1 October 1978-31 March 1979. The sections that follow discuss accomplishments in the areas of Systems Analysis, Systems Test, Systems Validation, and Management Support.

SECTION 2.0

HIGHLIGHTS

Highlights of the activites undertaken by SERI during the first half of FY79 in the Systems Analysis and Testing (SAT) Program are summarized below. More detailed information appears in the sections that follow.

- A reevaluation of thermosiphon hot water systems was initiated to quantify their thermal and economic performance behavior.
- A review of existing wind machine performance models was completed. Also, a study of the effects of wind transients, and control system and load management on energy capture was initiated.
- New concepts for solar ponds involving stratified ponds using salts or membranes was started. Three technical papers have been published as a result of the work.
- The SERI Computational Methods Center was established, and procedures for the dissemination of computer codes were developed. The dissemination of F-chart was begun.
- A review of photovoltaic systems analysis methods was completed. The intent was to develop a data base for photovoltaic systems similar to ones that exist for SHAC and Wind Systems.
- A draft SAT Program Plan was generated. The plan describes the objectives of the program, major elements, methodologies/approaches undertaken, activities for FY79, and overall program status.
- A SAT Management Plan was prepared.
- An integrated System Test and Validation Plan was developed. The plan addresses the effective utilization and testing of the various components/subsystems being developed as part of the R&D program. A preliminary draft was issued in October 1978.
- Technical management of DOE contracts in the SAT program were transferred to SERI. Statements-of-Work were developed for three new DOE contracts, and four procurement packages developed for SERI-issued subcontracts.
- Twenty-three preliminary and formal proposals for DOE were reviewed by SERI.

SECTION 3.0

SYSTEMS ANALYSIS

The objective of the Systems Analysis area is to perform objective, consistent systems analyses of various solar systems and technologies. The development and dissemination of new models for systems and components are an important part of this activity. Current SERI activities within the Systems Analysis area are defined in the sections below.

3.1 REEVALUATION OF THERMOSIPHON DOMESTIC HOT WATER SYSTEMS

Side-by-side testing of six domestic hot water systems by the National Bureau of Standards had implied that thermosiphon systems are significantly out-performing other active systems being tested. As a result, SERI undertook a task to reevaluate the thermosiphon hot water system to assess its potential for offering significant cost and performance benefits over active systems. Preliminary findings of this study, based on an intensive literature search to locate side-by-side performance comparisons of thermosiphon and active hot water systems other than the NBS test, and a closer evaluation of the NBS tests concluded that there was no significant thermal performance advantage in the use of thermosiphonic systems. There will be some potential advantages when the issues of parasitic power and system economics are considered. It also was concluded that the single most important disadvantage of the thermosiphon system was its susceptibility to freezing in certain locations. A map of the United States, showing the percentage of time (on an annual basis) that the temperature is above 0°C (32°F), has been developed. Activities during the remainder of the fiscal year will quantify the parasitic power question and economics related to thermosiphon systems when compared to other active systems.

As a result of this study, a conceptual design evolved for an air thermosiphon system that offers freeze protection, a requirement for thermosiphon systems in much of the United States. The concept uses an integral-type collector-storage combination as shown in Fig. 3-1. The collection unit serves as a preheater rather than a primary heater. The insulating layer above the water tank is automatically positioned, using a thermostatic metal coupling between the collector plate and the insulation as depicted in Fig. 3-1. The insulating baffle is positioned so that the tank is completely insulated when there is insufficient solar energy to promote energy transport from collection to storage.

A computer performance program (using MITAS II) was written to predict the air thermosyphon flow rate and collection efficiency. Results show that the unit would operate at efficiency of 15% and 25% for nonselective and selective absorbers, respectively. Though the efficiency is low, the unit's estimated cost is sufficiently low enough that the specific cost (dollars/efficiency) looks very attractive when compared to other solar hot water heaters. A patent application for this idea was filed through DOE with the Office of Patent Counsel on 29 March 1979. Further analysis and developmental work will be carried out to determine if the concept bares continued developmental work.

3.2 WIND ENERGY SYSTEMS STUDIES

Many feel that small wind systems are nearing commercialization. As a result, it was felt that some initial activity was necessary to begin to understand such systems in the

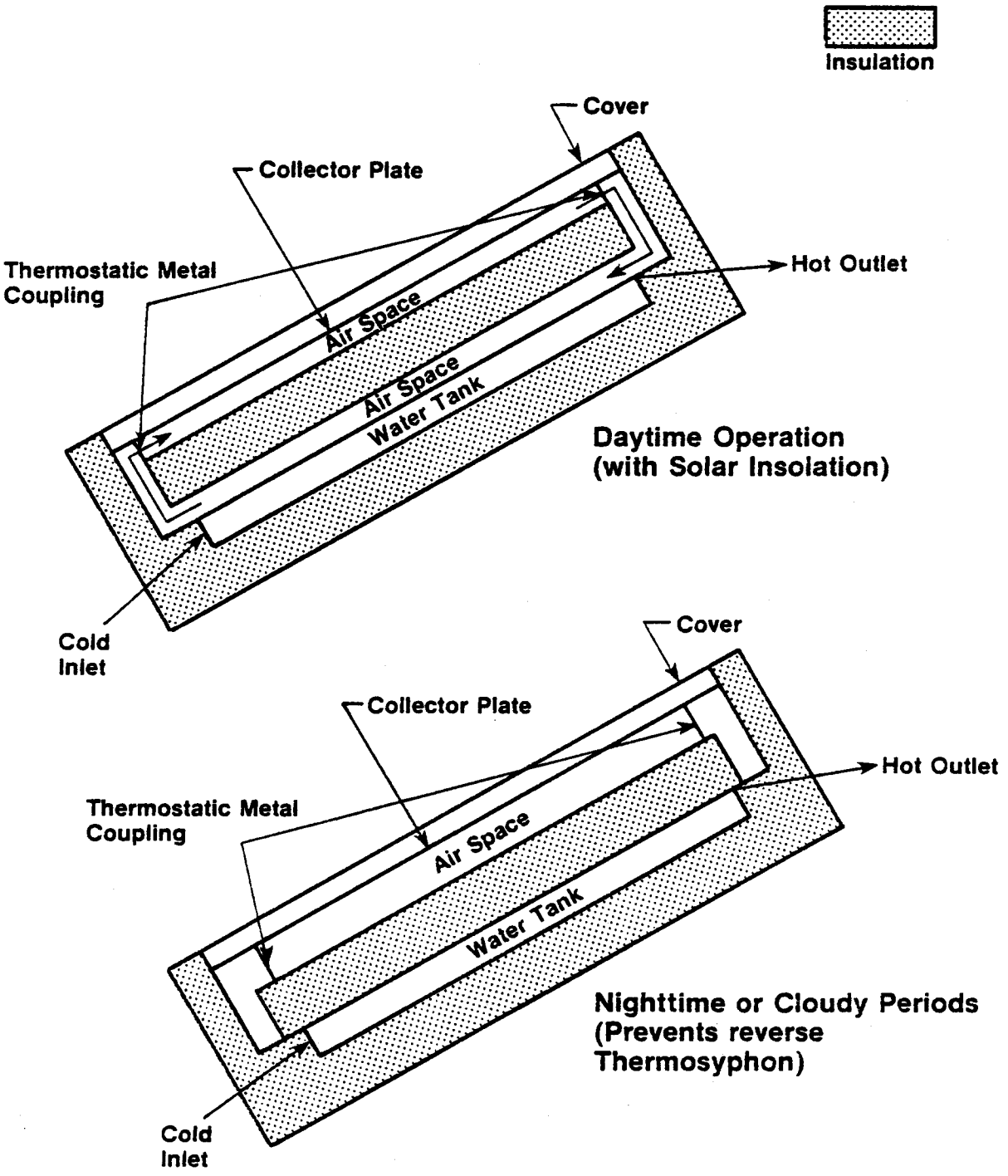

Figure 3-1. Schematic of Thermosiphon Concept

context of the research/designer and various dispersed applications. During the first half of FY79 a survey of existing wind turbine performance models was made. The purpose of this study was to generate a data base, similar to an earlier one developed for SHAC simulation models to help guide future model and code development. The results of this analysis presently are being documented in a separate report [1], and a popularized brochure is being developed for the user community. This latter brochure would be quite similar to the SHAC Analysis Method brochure that was first published in 1978. It is intended to be available for public distribution at the 1979 ISES Meeting in Atlanta.

A second part of the wind systems studies activities revolved around the study of the effects of wind transients, control systems and load management on energy capture. The objective was to determine whether such effects could significantly alter performance of wind machines as presently predicted by steady state models. Variations as large as 20% might be realized, and the effect is especially noted for small wind machines. This study consists of five subtasks: Model Assessment, Aerodynamics, Meteorological Data, Subsystems Analysis, and Systems Analysis.

Model Assessment. The survey mentioned above was used to identify existing codes for wind turbines which would predict performance. The results showed that there is none. The existing codes either predict the performance of an optimally loaded rotor of arbitrary geometry or assume the aerodynamic characteristics of the rotor system and use some form of wind data to project energy capture. Most frequently, the energy capture calculation is done by determining the number of hours in some time interval for which the wind speed has a given mean value, determining the power associated with that mean wind speed, and multiplying by the number of hours in that velocity range. Inaccuracies result because the wind turbine is intended to be a nonlinear device with respect to power and wind speed. The above procedure does not account for the time history of the wind turbine. Because of the nonlinearity of the wind turbine, averaging times for wind data must be much shorter than the common averaging time of one hour if the error introduced by the averaging process is not to govern the overall error.

Aerodynamics. SERI presently does not have the inhouse capability of determining the aerodynamic qualities of a given rotor system. Consequently, the University of Massachusetts and NASA-Lewis were contacted for the acquisition of rotor performance data. The data received from these two sources are similar. The University of Massachusetts data is a plot of power coefficient vs. tip speed ratio and pitch angle for blades of the UMASS Wind Furnace design. These blades are almost aerodynamically optimum (based on the theory of Glauert) and are optimized for operation at a tip speed ratio of 7.5. The NASA data are for blades of the MOD-O design. These blades are twisted and tapered, but not as severely as the UMASS blades. The NASA blades are optimized for a tip speed ratio of 9.5. Two sets of data were gathered to allow the preliminary parametric investigation of aerodynamic effects. The data sets are sufficient to allow the isolation of power and torque coefficients, hence power and torque, at any point within the normal operating range of the wind machines.

Meteorology. The intent of the meteorological subtask was the acquisition of wind data which could be compared to measured machine performance characteristics on a real time basis. The SERI Energy Resource Assessment Branch was contacted to assist in acquiring such data. At least two sources of wind data, Rocky Flats and Pacific Northwest Laboratories, were identified. There is particular interest in the data from Rocky Flats because of its capability to record and reduce data in ways meaningful for system characterization. In addition, Rocky Flats' existing and planned research capabilities will allow the testing of system models that may be developed.

Subsystems. The subsystems analysis subtask involves definitions of Drive System, Generator Performance, Control System, and Statistics.

- Drive System. Specifications for the rotary inertias of the components of the NASA MOD-0 wind turbine were received from NASA Lewis. All of the data are reduced to the low speed end of the system. It has not yet been possible to acquire this inertia information for any other horizontal axis machine. There has not been any attempt to acquire inertia or performance for vertical axis machines to date. These data are necessary so that simulation of the dynamic behavior of the wind turbine can be carried out.
- Generator Performance. Of particular interest are the torque vs. rpm characteristics of induction generators. It is known that the dynamic characteristics of the drive system will be heavily colored by the generator type and size. A prime consideration is that induction generators add viscous damping to the drive system, whereas synchronous generators act as an infinite inertia. The damping of the induction generators will tend to reduce the magnitude of response to high frequency components of the wind. The significance of this effect is uncertain with respect to energy capture. It is expected that this will be a small effect for constant speed machines. It may be much larger for variable speed machines. Data comparing the two types of AC generators have been identified. Work remains to establish scaling factors for generator inertia with respect to rated power, model the damping effects, and develop the software necessary for integration into the system program.
- Control System. The control system effect studies will change blade pitch in response to shaft torque. If possible, various control philosophies will be implemented and the effect of these changes on the system output will be quantified.
- Statistics. Canned programs for the statistical analysis of data exist in the SERI/BOR computer system. The help of the Computer Systems Branch has been enlisted to implement these programs for the data that will be generated. The anticipated form of the statistical output includes displays of mean wind-speed standard deviation of the wind about the mean, mean power output, standard deviation of the power output, energy collected, and transfer function between wind input and power output.

Systems Analysis. The systems analysis subtask will be accomplished by assembling the subsystems and data into a FORTRAN computer program (called WINSYS) for implementation on the SERI/BOR computer system. Much work has been done already on this. The program logic has been completely flowcharted. Some component subroutines have been written and are being checked. The dynamics code ultimately will be able to simulate wind systems under varying atmospheric conditions, varying loads, and with different control systems.

Some literature has been received that describes the performance of the UMASS Wind Furnace in a meaningful way. This information may be used as a benchmark for the system analysis if appropriate. The transfer function of wind turbines can be routinely measured with the present instrumentation at Rocky Flats, which will be useful for system characterization.

3.3 STRATIFIED SOLAR PONDS

As part of the continuing need to evolve and identify new, promising concepts, SERI has undertaken a study of stratified solar ponds which may have potential benefits for both district heating and industrial process heat applications.

Solar ponds are conveniently classified as either salty (i.e., stratified) or saltless ponds. The salty ponds contain a salinity gradient to inhibit thermal buoyancy convection. Saltless solar ponds use schemes other than a salinity gradient to provide transparent insulation. These ponds, which are significantly deeper than the shallow solar ponds developed by Lawrence Livermore Laboratory, have received little previous research attention. However, they have high potential as low-cost, low-temperature collector-storage systems.

The SERI pond research to date has addressed thermal analysis of salty and saltless ponds, conceptual design of saltless ponds, and economic analysis of salty and saltless ponds. Solar pond thermal performance was studied analytically. Computer programs have been developed that account for the effects of thermal storage in the pond-solution and earth, selected solar absorption in the saline solution, and thermal losses to the ground and air. Similar programs for saltless pond computer simulation also have been developed. Computer simulations of large salty ponds have been performed for different pond depth profiles, diverse climates, and varied load profiles. Simulations also have been performed to investigate edge losses for salty and saltless ponds, and to evaluate the performance of saltless ponds.

Since saltless ponds have received little previous research attention, they are presently in the earliest stage of design. The Lawrence Livermore Laboratory's saltless solar ponds have demonstrated some performance success, and significant future design improvements may be realized. SERI investigations have centered on identifying potential areas for design improvements which include:

- Reducing plumbing by eliminating separate thermal storage.
- Reducing plumbing by using large collectors.
- Reducing thermal losses with night insulation.
- Providing long-term storage with deep ponds.

The economics for both salty and saltless ponds are encouraging. Preliminary results indicate:

- Salty ponds can provide low-temperature solar thermal energy for less than 1¢/kWh_{th} in many locations where salt is inexpensive.
- Saltless ponds may provide low-temperature solar thermal energy for about 1.5¢/kWh_{th} in places lacking an inexpensive local salt resource.

Three publications have resulted from the work to date [2,3,4].

3.4 COMPUTATIONAL METHODS CENTER

At the beginning of FY79, SERI was asked to take over the responsibility for the dissemination of F-Chart. It was felt that the most optimal manner to do this would be to

initiate a Computational Methods Center at SERI, with the objective to catalog and understand all of the major computational methods that are presently available in solar energy. It would include also the dissemination of selected computer and noncomputer research simulation models and design methods that are in the public sector.

The Computational Methods Center is a total SERI effort and involves activity within the Technology Commercialization Division, Information Systems Division, Research Division, and Analysis Division. Responsibilities have been delegated and procedures evolved for the dissemination of computer-based codes.

As part of the activity of putting the various computer models onto the SERI/BOR computer, SERI is documenting experiences and problems encountered by those attempting to make the system operational. This information is being documented and will be used to help develop future versions of user manuals, and to identify and correct problems within the programs. Close interaction is being maintained with the authors of the various programs. The following computer codes have been acquired and are presently operational on the SERI/BOR Computer System: F-Chart, SOLCOST, HUD-RSVP, TRNSYS, MITAS, DEROB, DEROB/PASOLE, and PASOLE. In addition, work is underway to acquire the two primary building energy analysis codes: DOE-2 and BLAST (Version 2).

The F-chart dissemination activity is underway. Activities include the development of user-oriented literature describing the method and its capabilities. Questions regarding program use and implementation have been answered. By working in cooperation with the program authors and the users, SERI has been able to identify needs and define problems/errors that need correcting.

In FY78, SERI developed a consumer-oriented brochure on SHAC Analysis Methods [5]. The brochure lists readily available analysis methods and defines how they can be attained. During the past six months, SERI has updated that brochure to reflect new information generated by EPRI and others. The updated brochure will be completed in time for distribution at the 1979 ISES meeting.

3.5 PHOTOVOLTAIC ANALYSIS METHODS

Remote applications of photovoltaic systems are at or near commercialization. As part of an analysis of availability of simulation and design tools for photovoltaics, a study was undertaken to identify currently existing photovoltaic simulation and analysis methods. The purposes of this study were to:

- Establish a base of information regarding existing photovoltaic simulation/design capability;
- make this information available to the user community; and
- assist in identifying future tool development needs/directions.

The results of the photovoltaic model review are being documented [6]. In addition, a popularized brochure was developed as part of a series on design methods (others are Wind and SHAC), and will be distributed at the 1979 ISES meeting. The document is expected to be updated periodically to reflect the latest information regarding the photovoltaic field.

SECTION 4.0

SYSTEMS TEST

The Systems Test area of the SAT program is concerned with the conduct/coordination of system-level tests to verify and optimize system economics and engineering performance, as well as generate data that can be used in the validation process. Most of the testing work is being performed by external organizations such as Colorado State University, University of Pennsylvania, University of Texas, and National Bureau of Standards.

SERI activity in the Systems Test area at present is limited to the development of the Integrated Test and Validation Plan, which is discussed in Section 6.0. It is anticipated that, if funds are available, SERI will implement the plan once it is complete.

SECTION 5.0

SYSTEMS VALIDATION

The Systems Validation area of the SAT program is concerned with the development and utilization of a methodology(s) for validating research and design methods. At present the development of this methodology is being undertaken by SAI as part of their support to the SAT program.

SERI involvement is limited to technical awareness and monitoring of the SAI work. Future SERI work will involve the utilization of this methodology to validate domestic hot water methods during the latter part of FY79.

SECTION 6.0

MANAGEMENT SUPPORT

Because the SAT program is relatively new and involves transfer of management from Sandia Laboratories and DOE/Washington to SERI, a considerable amount of the effort has been expended on management-related functions, such as development of program plans, a management plan, and activities related to management of external research organizations either under DOE or SERI contract. These activities are described in the sections which follow.

6.1 SAT PROGRAM PLAN

A major activity undertaken during this reporting period has been the development of a national plan for the Systems Analysis & Testing (SAT) program. That plan has been completed in draft form and is currently being reviewed [7]. The plan describes the objectives of the SAT program; the major program elements (Systems Analysis, Systems Test, Systems Validation, and Systems Control); the interaction and interrelationships between those elements; their specific near-term and far-term objectives; the status of the various elements regarding meeting those objectives; and FY79 activities/tasks being undertaken in each area. It is intended to finalize the SAT Program Plan before the end of the fiscal year.

6.2 INTEGRATED TEST AND VALIDATION PLAN

The national program in heating and cooling includes the development of many new advanced components and subsystems. In an effort to coordinate the testing and utilization of these various components and subsystems, an effort was undertaken to develop an integrated test plan. The plan also addresses model validation. The objective of the test plan is to identify if all the proper systems are being tested, define data needs, and develop an approach to testing systems. It is also meant to identify additional needs for new test facilities, and to coordinate/schedule future system testing within the R&D branch in DOE. The approach that was taken in developing this plan was to, first, identify the various generic systems within the categories of domestic hot water, space heating, space cooling, and agricultural and industrial process heat. Second, an attempt was made to identify whether these systems have been or presently are being tested within the context of the U.S. solar energy program. Also, if they are being tested, are they being instrumented and are test data being collected that would be useful in the validation process? The report addresses the various test facility capabilities that presently exist in both the government and private sectors as well as the various components and subsystems that are emerging from the R&D program, along with the scheduled availability. A preliminary draft of the plan was issued in October 1978, with a final draft of the plan scheduled for release in July 1979.

6.3 MANAGEMENT PLAN

A Management Plan for the Systems Analysis and Testing (SAT) program has been drafted and is presently in the publication process [8]. The Management Plan addresses the role of the SAT program within the overall SERI organization. It also presents a

description of the SAT program, including organizational elements and their primary functions. Reporting relationships are shown within the plan. The plan describes how the various internal SERI tasks are organized plus external research performed by outside organizations. It will act as an overall guiding document for the management of the SAT program.

6.4 PROGRAM MANAGEMENT ACTIVITIES

Technical management of the DOE contracts in the Systems Analysis and Testing area was transferred from Sandia Laboratories (Albuquerque) to SERI at the end of FY78. During the first half of FY79, SERI has reviewed the work of all the systems contractors and made site visits to all but one. Several meetings have been held to ensure that each contractor was working according to the SAT Program Plan developed at SERI.

In coordination with DOE and the contractors, SERI has prepared a Statement of Work for several DOE renewal contracts for FY79. These are:

- Research and Development in Solar Energy Applications (Colorado State University) — $ 600K
- Performance Analysis and Optimization of the University of Pennsylvania Retrojected Solar Heated Philadelphia Row House (University of Pennsylvania) — $ 19K
- Simulation and Design of Solar Thermal Processes (University of Wisconsin) — $ 300K

Procurement request packages were prepared for these contracts and sent to the DOE Chicago Operations Office.

Several subcontracts are being let by SERI in FY79 as part of the SAT Program. Statements of Work have been prepared for four of them. Two involve follow-up work from previous DOE contracts (SAI, CSU) and two are new efforts (SEEC, Altas). They are:

- Studies and Analyses Advanced Systems for Solar Applications (SAI) — $ 750K
- Checkout and Controls Handbooks for Solar Domestic Hot Water Systems (SEEC) — $ 62K
- Solar Supplement to Laundry Drying (CSU) — $ 18K
- Support for SSEA and IEA Workshops (Altas) — $ 25K

The SAI contract is in the SERI procurement process and is expected to be in place by 17 April, 1979. The others will be in place during May or early June 1979.

During the reporting period SERI conducted two unsolicited proposal evaluations. A total of 12 formal proposals and 11 preliminary proposals were reviewed. Four of the formal proposals were recommended for funding—one will be funded by DOE, the others by SERI. Two formal proposals were requested as a result of the preliminary proposal evaluation.

6.5 F-CHART/SOLCOST PLAN

Early in the fiscal year, an activity was undertaken to evaluate SOLCOST and F-Chart and identify future needs/actions for each program. The results of that activity are summarized below:

- Provide adequate documentation for both programs and a peer review of the SOLCOST methodology.
- Conduct an error analysis for both programs, which should be made part of the program output.
- Modify both programs to include parasitic power losses.
- The SERI Energy Resource Assessment Branch should oversee the weather data base used in both programs to ensure commonality.
- Modify both programs, if possible, to reflect currently marketed solar systems.
- User manuals should be standardized as much as possible.
- Validation of both programs is urgently needed.
- SERI should coordinate development of both programs to maximize effectiveness.

Their activities will be undertaken as time and funds permit.

SECTION 7.0

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7. Bishop, C. J.; Groome, L. Program Plan for Systems Analysis and Testing. Golden, CO: Solar Energy Research Institute; TR-35-233; 1979.

8. Bishop, C. J.; Groome, L. Systems Analysis and Testing Program Management Plan. Golden, CO: Solar Energy Research Institute; MR-35-222; June 1979.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This document describes SERI activities for the SAT program during 1 October 1978 - 31 March 1979. These include (1) a reevaluation of thermosiphon hot water systems; (2) a review of existing wind machine performance models; a study of the effects of wind transients, and control system and load management on energy capture; (3) a study of new concepts for solar ponds involving stratified ponds; (4) establishment of the SERI Computational Methods Center; (5) dissemination of F-chart; (6) a review of photovoltaic systems analysis methods; (7) development of a draft SAT Program Plan, SAT Management Plan, and an integrated System Test and Validation Plan; and (8) transfer of technical management of DOE contracts in the SAT program.

17. Document Analysis

a. Descriptors: Solar Energy Research Institute ; Systems Analysis ; Testing ; Hot Water Systems ; Wind Turbines ; Wind Power ; Load Management ; Solar Ponds ; Calculation Methods ; Photovoltaic Cells ; Management ; Energy Management ; Statistical Models

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