ALO-4271-01

FORT HOOD SOLAR TOTAL ENERGY PROJECT

Technical Support and Systems Integration

First Semiannual Report for May 1—October 31, 1978

Work Performed Under Contract No. ET-78-C-04-4271

The Aerospace Corporation
Energy and Resources Division
El Segundo, California

U.S. Department of Energy

Solar Energy

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy ~~$6.50~~ 9.00
Microfiche $3.~~00~~50

Aerospace No. ATR-79(7743)-1

ALO-4271-01
Distribution Category UC-59c

FORT HOOD SOLAR TOTAL ENERGY PROJECT

Technical Support and Systems Integration

FIRST SEMI-ANNUAL REPORT
FOR THE PERIOD
1 MAY 1978 - 31 OCTOBER 1978

THE AEROSPACE CORPORATION
ENERGY PROJECTS DIRECTORATE
ENERGY AND RESOURCES DIVISION
EL SEGUNDO, CA. 90245

PREPARED FOR THE
U. S. DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
UNDER CONTRACT ET-78-C-04-4271

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

FOREWORD

This report presents a summary of technical project support efforts and results of various technical analyses for the Fort Hood Solar Total Energy Project conducted under the Department of Energy, Albuquerque Operations Office (DOE/ALO), Contract No. ET-78-C-04-4271. The time period for this contract is 1 May 1978 through 30 April 1979. This report is the First Semi-Annual Report covering the first six months of progress on the contract.

The project support effort and technical analyses are being conducted by The Aerospace Corporation under the cognizance of Mr. D. K. Nowlin, Director of the Special Programs Division, and under the general direction of Mr. E. A. Walker, Senior Program Coordinator, at DOE/ALO.

This report was prepared by the Energy Projects Directorate of the Energy and Resources Division of The Aerospace Corporation, Mr. S. D. Huffman, General Manager. Dr. E. L. Katz, Director of the Energy Projects Directorate, is the Principal Investigator. Mr. J. T. Ator, Manager, Solar Thermal Projects, provides day-to-day management of the project.

This report represents the results of the combined efforts of many staff members of The Aerospace Corporation. Their task responsibilities are shown on the following page.

FORT HOOD PROJECT TEAM

Project Management	J. Ator/E. L. Katz
Overall System Design Assessment	R. Merkle D. Ross
Measurement and Test Planning Assessment	D. Ross
System Simulation and Energy Management Analyses	R. Waldron
Heat Transfer Analyses	R. DeBiase H. Yoshikawa
Dynamic Control Studies	R. Leatherman A. Mager
Power Conversion Subsystem and Environmental Impact Analyses	O. Hamberg R. Laube
Supporting Specialists:	
Insolation Modeling	C. Randall
Collector Optics	C. Laurence
Economic Analysis	J. Kamin

CONTENTS

CONTENTS (Continued)

1.0 INTRODUCTION

1.1 PROJECT HISTORY

The Fort Hood Solar Total Energy Project began in 1974 under auspices of the National Science Foundation. The objective is to design, install, and operate for a two-year test period a Solar Total Energy System (STES) which will supply a significant portion of the energy requirements of a troop housing complex at Fort Hood, Texas. The history of contractual efforts on the project is illustrated in Chart 1-1. American Technological University (ATU) was initially funded to conduct Phase I studies of solar energy availability and the electrical and thermal energy requirements at Fort Hood. A Phase II effort was conducted by ATU from April 1975 to November 1976, which resulted in a conceptual system design.

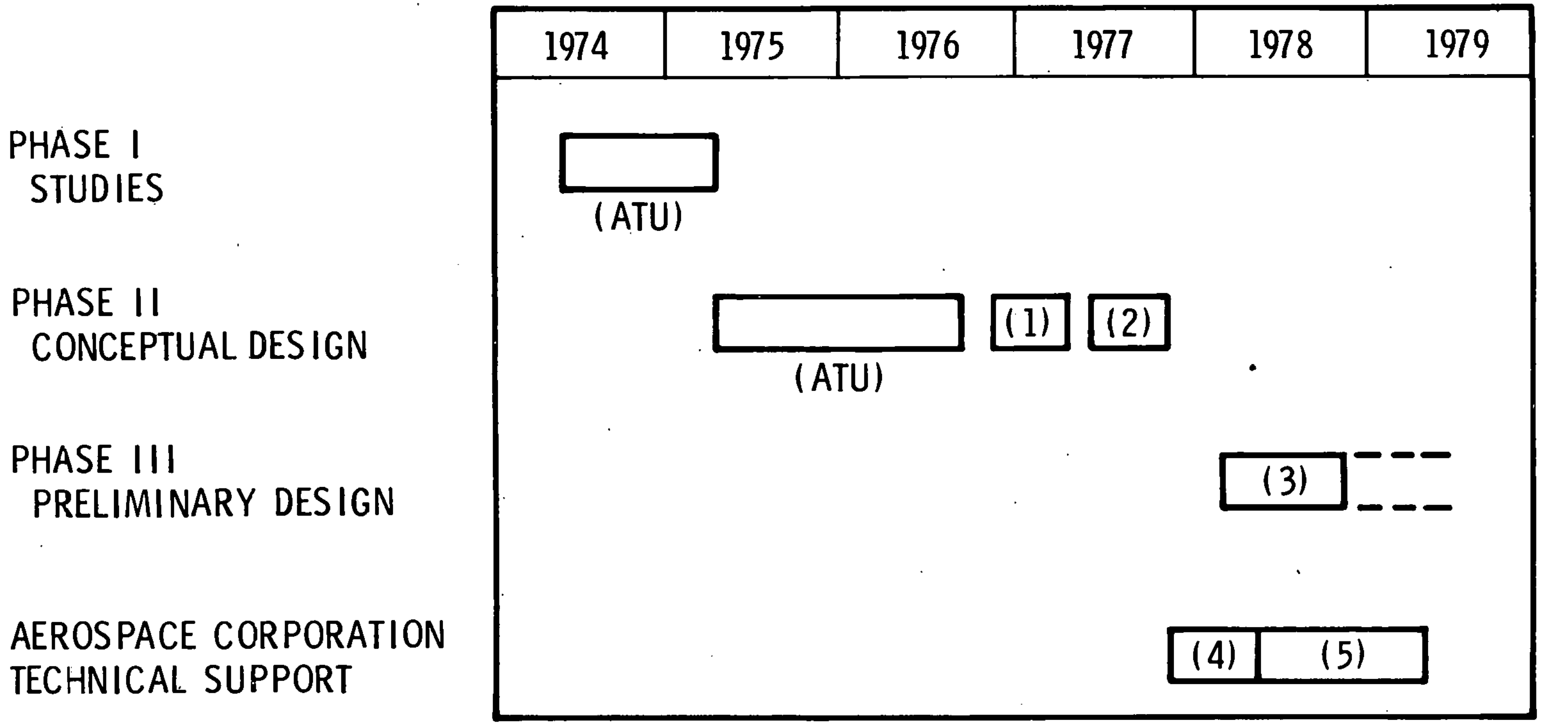
The initial conceptual design utilized water as a heat transfer and working fluid and incorporated a distributed solar collector field of 220,000 ft^2 total aperture. Its performance predictions included an electrical output of 1.33 MW_e and a thermal output of 185 million Btu per day.

From October 1976 through November 1977, a refinement of that conceptual design was undertaken, under ERDA sponsorship, first by ATU with the assistance of Brown and Root Development, Inc. and later by TRW and Westinghouse in competitive design efforts. Sandia Laboratories in Albuquerque assisted ERDA (now DOE) in the technical direction of those studies.

DOE chose Westinghouse as the winner of that design competition. The concept Westinghouse proposed utilizes a paraffinic oil (Sun 21) as the heat transfer medium, a collector field of 150,000 ft^2 aperture, an electrical output capacity of 250 kW_e, and a peak thermal output of about 70 million Btu per day. An absorption chiller unit provides chilled water to meet air conditioning requirements.

A Preliminary Design Phase of the Fort Hood STES began officially on March 1, 1978 with ATU as the prime contractor and Westinghouse as the design subcontractor. Sub-tier contractors supporting Westinghouse are Heery and Heery, Inc. and Georgia Institute of Technology. The Preliminary Design was substantially completed in October 1978 with submittal of a Draft Final Report by ATU.

Fort Hood Project History



Notes:

(1) ATU + Brown and Root
(2) Competitive Studies by TRW and Westinghouse
(3) ATU / Westinghouse Team
(4) DOE / SAN Contract
(5) DOE / ALO Contract

Chart 1-1

1.2 PROJECT ORGANIZATION

The project organization for the Preliminary Design Phase of the Fort Hood project is shown in Chart 1-2.

The cognizant field office for the Fort Hood project is the DOE Albuquerque Operations Office (DOE/ALO). The Aerospace Corporation is providing technical project support to DOE/ALO. The Aerospace efforts are divided into three general task areas: (1) independent technical analyses, (2) monitoring the performance of the prime contractor (ATU), and (3) project support activities. No technical direction is given to ATU or Westinghouse by Aerospace, but access is provided for any technical information needed in the performance of the Aerospace technical support function.

In addition to being the prime contractor, ATU is responsible for coordinating all meetings with and information requests from the Fort Hood command, the U.S. Army Corps of Engineers, Texas Power and Light Company, and the Army Atmospheric Sciences Laboratory. The latter unit is a contingent at West Fort Hood which is acquiring meteorological and insolation data.

Fort Hood Project Organization

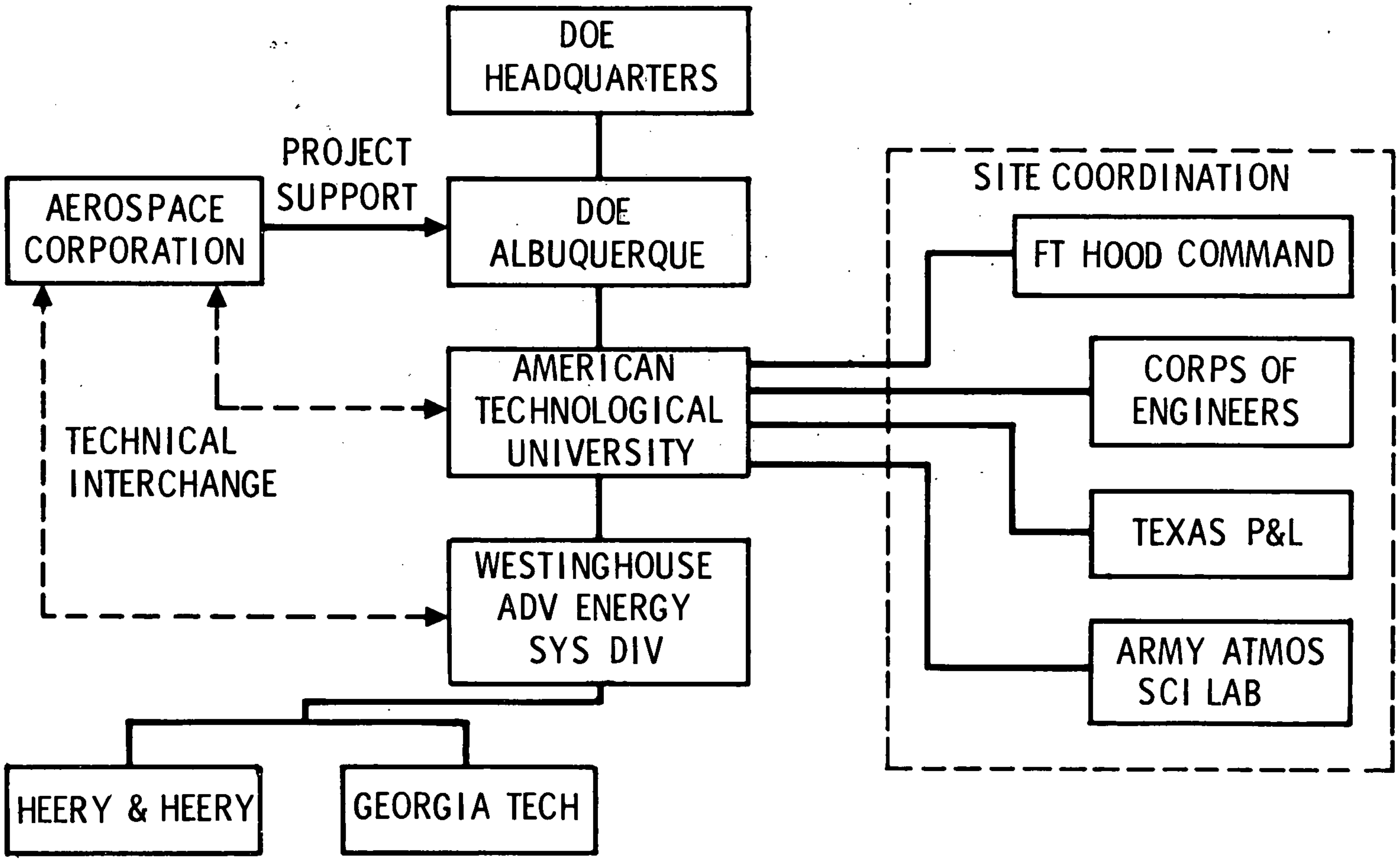


Chart 1-2

1.3 CURRENT SYSTEM CONCEPT

The system design for the Fort Hood Solar Total Energy System at the conclusion of the Preliminary Design Phase is represented by the block diagram in Chart 1-3.

From the highly simplified block diagram, a basic understanding of the operation of the Fort Hood STES can be obtained. Energy from the sun is acquired by the collector field in periods of high insolation. During low insolation periods, thermal energy is supplied by an auxiliary oil-fired heater. In either case, heat transfer oil is heated and pumped to a series of thermal storage tanks. In the normal daytime operating mode, 550°F oil is sent to the steam generator producing superheated steam to drive the steam turbine. During the air conditioning season, steam is extracted and flows through an absorption chiller. Exhaust heat is recovered by means of the condenser for space heating in winter and for supplying domestic hot water all year. Any excess exhaust heat is dissipated by the cooling tower. The same tank is used for summer storage of chilled water and winter storage of heated water.

Fort Hood Solar Total Energy System

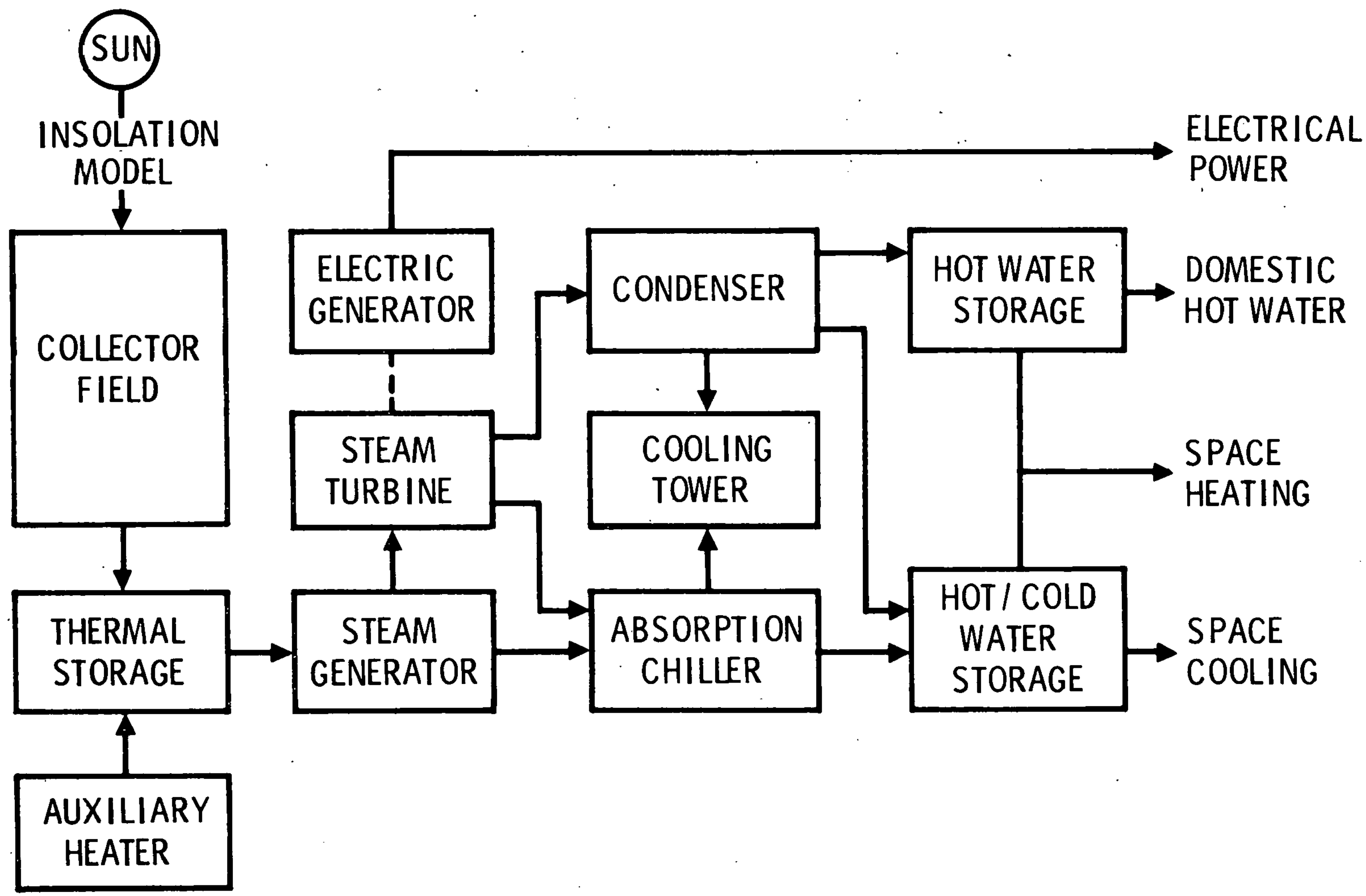


Chart 1-3

1.4 SUMMARY OF TECHNICAL SUPPORT ACTIVITIES

The technical support provided to DOE/ALO by The Aerospace Corporation, in addition to acting as technical advisor during contract negotiations with ATU and drafting technical correspondence and briefing charts, consisted of the items listed in Chart 1-4.

The tasks listed in Chart 1-4 represent a combination of technical activities identified prior to the report period and those which arose as issues during the course of the project. Results of Aerospace efforts in those areas listed are presented in detail in Sections 2 through 5 of this report.

SUMMARY OF TECHNICAL SUPPORT ACTIVITIES

RESOLUTION OF TECHNICAL AND PROGRAMMATIC ISSUES
- Field Size Determination
- Schedule Acceleration
- Pilot Test Array Site Location and Benefits Analysis
- Approval / Disapproval of New Field Design

VALIDATION OF DATA BASE ELEMENTS
- Energy Load Measurements
- Insolation Model

TECHNICAL REVIEW OF CONTRACTOR DELIVERABLES
- Environmental Impact Assessment
- Equipment Specifications
- Life Cycle Cost Analyses
- Interim and Final Technical Reports
- Project Plans for Future Phases

Chart 1-4

2.0 TECHNICAL AND PROGRAMMATIC ISSUES

2.1 FIELD SIZING

This section presents a review of the independent analysis of the collector field sizing issue conducted by Aerospace and the resulting recommendation given to the Fort Hood Sizing Task Force.

2.1 FIELD SIZING

The optimum size of a distributed solar collector field obviously depends on the intended uses of the energy (the application) and the characteristics of the insolation and weather at the plant site. Some of the interfaces and operational constraints unique to the Fort Hood experiment can be visualized by reference to the simplified schematic in Chart 2-1.

The components of the system were sized during Conceptual Design to satisfy the peak thermal load of five selected buildings with energy supplied either by solar or the fossil-fueled heater. Also, a ground rule adopted during Conceptual Design was that thermal loads will take precedence over electrical output generation.

Ideally, the thermal output of the STES is derived from exhaust heat extracted from steam after passing through the turbine-generator set, and that mode of operation is used during periods of high insolation. However, if availability of solar energy is low due to reduced insolation and/or depleted high temperature storage, electrical output is cut to a low level or stopped completely in order to assure that the full thermal demands are met. Alternate paths are provided for steam to flow directly from the steam generator to the thermal load elements.

In addition, the interrelationship of the insolation model, the assumed thermal storage capacity, and the varying but bounded five-building thermal load must be considered in determining the appropriate size of the collector field. The amount of electric power which can be generated is strongly affected by field size and the energy management philosophy employed. The ground rule giving second priority to electric power generation requires that STES generating capacity and the total electricity to be generated annually be established before field sizing can proceed.

Fort Hood Solar Total Energy Plant Schematic

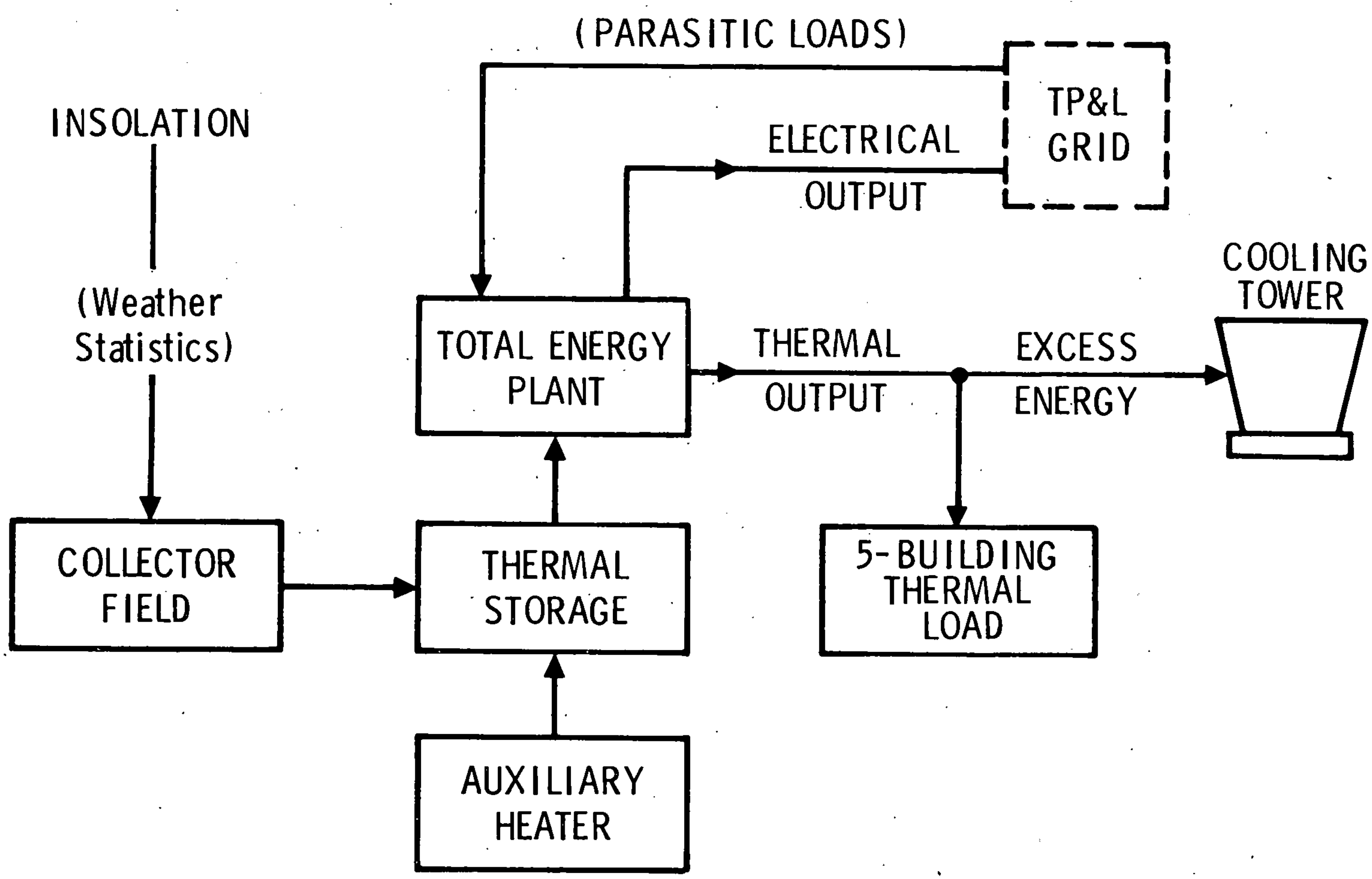


Chart 2-1

SIZING CRITERIA AND GUIDELINES

The criteria and guidelines issued by DOE/Hq. in March 1978 are listed in Chart 2-2.

A survey of collector manufacturers accomplished during Conceptual Design revealed their position that unit manufacturing costs would not be significantly reduced by increased sizes of an order. Thus, price reductions should not be counted on when procuring larger quantities of collectors.

Considerations of technical risk led to the judgment that the area of the Fort Hood field should not exceed by a factor of 10 the field area of technology demonstrations already underway with trough collectors. Based on the Shallow Well Irrigation Project size at Willard, New Mexico, that would place an upper bound near 140,000 ft^2.

The "applicability" criterion has previously been explored by Sandia Laboratories with the conclusion being reached that the Fort Hood STES electrical generator should have a capacity between 200 and 500 kW_e to be considered scalable to the 1-10 MW_e range of anticipated demonstration-sized solar total energy plants.

Restricting the thermal loads to those in the five selected buildings places an upper bound on the STES-produced thermal energy that can be utilized without excessive waste via the cooling tower. The Conceptual Design provided for peaking, normal, and storage modes of operation and three temperature levels of thermal storage.

BASIS FOR FORT HOOD STES SIZE DETERMINATION

CRITERIA

- **SCHEDULE** - The size selected should not contribute to a delay in schedule
- **COST** - The influence of field size on collector manufacturing cost per unit area must be considered
- **TECHNICAL RISK** - The risk of introducing unknown control problems with greatly increased field area should be minimized
- **APPLICABILITY** - The applicability to demonstration-scale plants must be preserved in sizing the experiment

GUIDELINES

Assuming Westinghouse Conceptual Design characteristics, determine the most cost-effective field size on the basis of the highest ratio of percent thermal loads displaced by solar energy to plant capital cost that produces as a minimum:

(1) 50 percent of the average annual thermal load for the five selected buildings (from solar input)

(2) 200 kW_e in a peak shaving mode and total annual electrical output averaging 1600 kWh/day

THERMAL LOAD DISPLACEMENT VARIATION WITH FIELD SIZE

Since DOE set forth an objective for the Fort Hood STES in terms of thermal load displacement, that will establish a lower bound on field size.

Westinghouse used a computer simulation to generate a curve of Percent of Thermal Load Displacement versus Collector Area. DOE/ALO asked Aerospace to conduct an independent analysis to validate the general characteristic of a decreasing return for incremental increases in collector area for large field sizes. A product of the Aerospace calculation is plotted on Chart 2-3 along with the Westinghouse curve and validates the characteristic of the Westinghouse result. The Aerospace simulation assumed a simplified STES model and hence does not exactly duplicate the Westinghouse curve.

For the Aerospace analytic model, the thermal loads were taken from Reference 2. For the curve shown in Chart 2-3, storage was assumed to be depleted at 6:00 a.m. each day. The differing demands of the heating, cooling, and transition seasons were incorporated to simulate a full year of operation. Additional curves were generated with the model, assuming different storage capacities and depletion times and are included in a Topical Report (Reference 1).

From the Westinghouse curve, it can be seen that a minimum field size for displacing 50 percent of the thermal load is about 90,000 ft^2 which establishes a lower bound.

Thermal Load Displacement as a Function of Collector Area

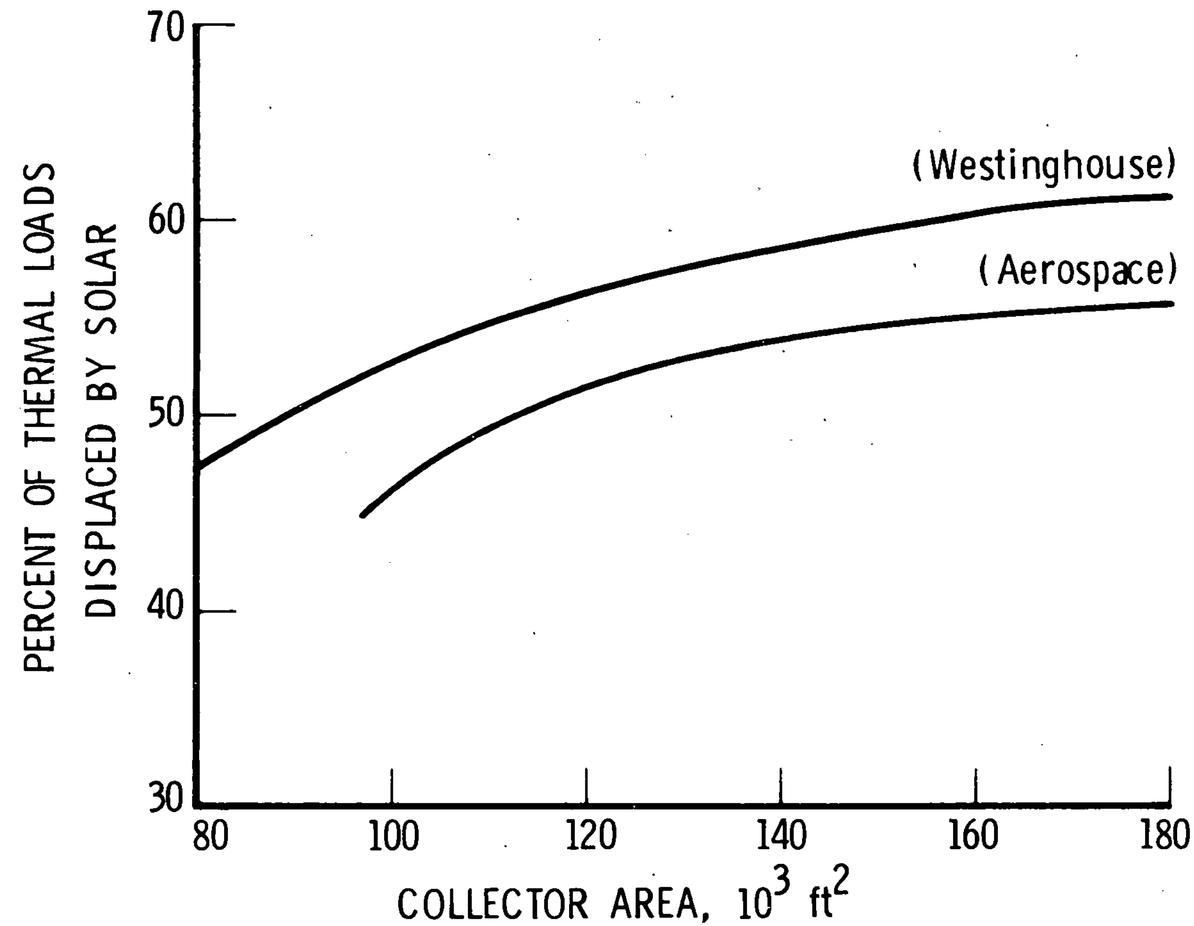


Chart 2-3

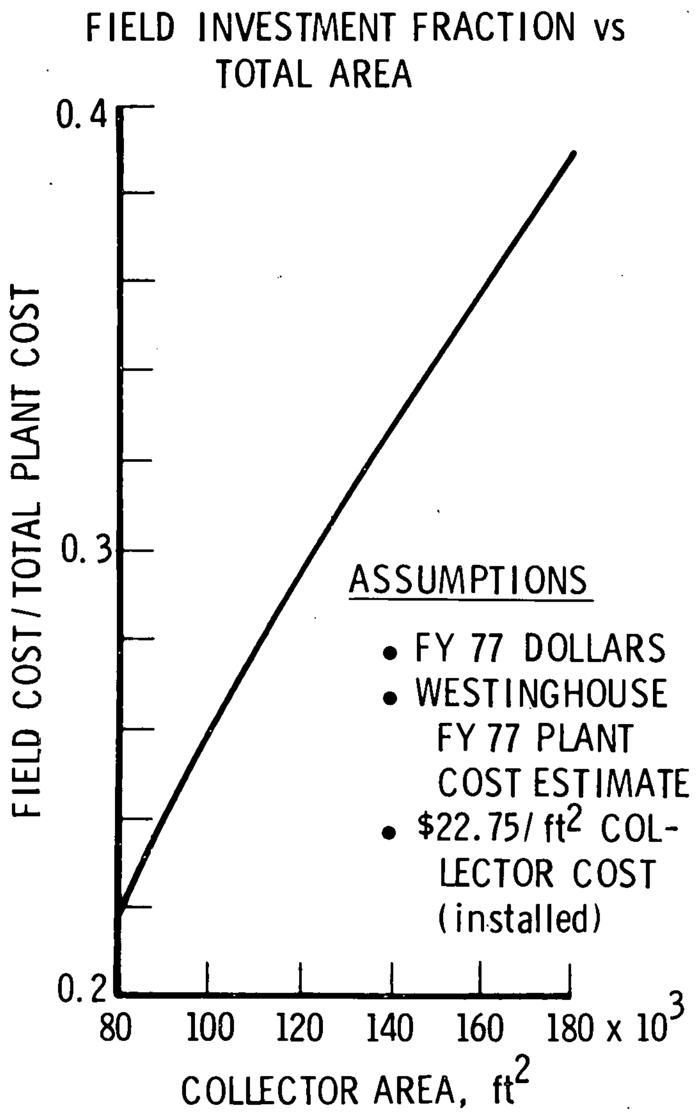
COST VERSUS BENEFIT ANALYSIS OF FIELD SIZE

To investigate the sensitivity of thermal load displacement to the initial capital cost of the Fort Hood STES, Aerospace reasoned that the key economic parameter is not the capital cost of the entire STES or the absolute cost of the collector field, but rather what fraction of the total STES cost is represented by the cost of the field. The results of an analysis based on that parameter are shown in Chart 2-4.

Using the Westinghouse FY 77 cost data, the curve on the left in Chart 2-4 was developed which shows the Field Investment Fraction, R, as a function of the total field area. In the series of curves on the right, the rate of return in terms of thermal load displacement versus R is portrayed. The bottom graph is a basic curve of Percent Thermal Load Displaced, Q, as a function of R, which was generated by the Westinghouse model. The two curves above it are the first and second derivatives of that basic function.

It is seen from the top curve that the rate of increase in energy "gain" for incremental increases in R has a broad peak at R = 0.30 corresponding to a field size at ~123,000 ft^2. The rate of increase falls off rapidly beginning at R = 0.31, where the corresponding field size is 127,000 ft^2. On the basis of this result and the criteria previously discussed, Aerospace recommended a field size of 125,000 ft^2 for the Fort Hood experiment. That recommendation was accepted by DOE.

Cost vs Benefit Analysis of Field Size



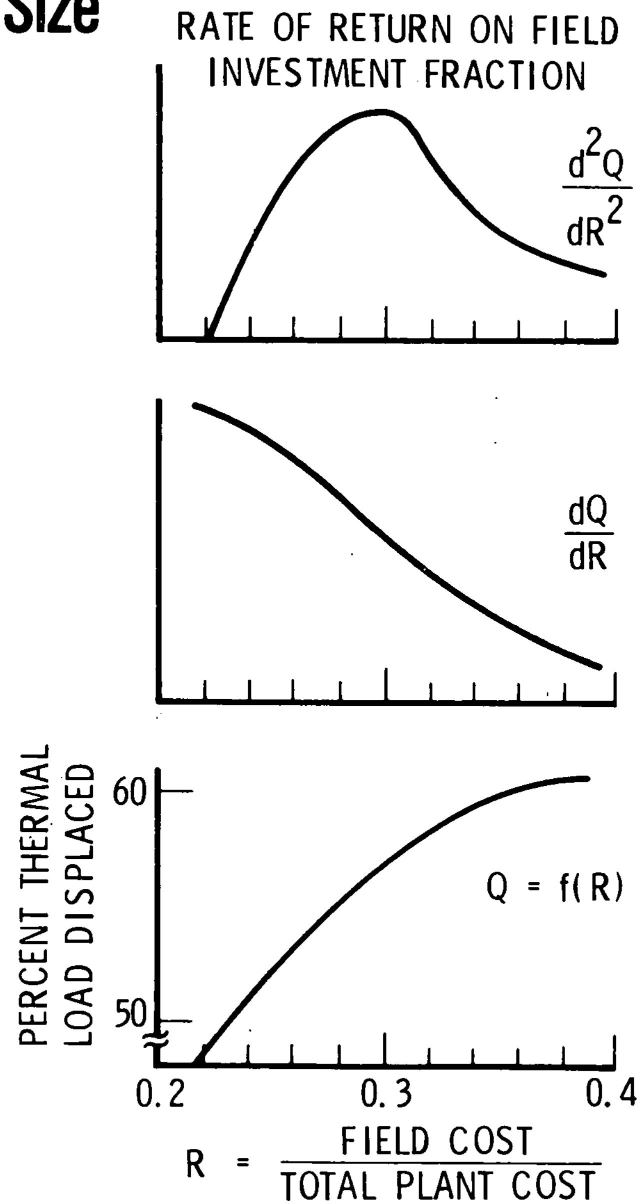


Chart 2-4

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

2.2 SCHEDULE ACCELERATION

This section presents a summary of the analysis to determine a strategy and funding schedule that would be required to achieve a September 1980 startup date for the Fort Hood STES versus an original startup date of January 1981.

SCHEDULE ACCELERATION

On March 31, 1978, DOE/ALO was tasked with developing a strategy and funding schedule for achieving a Fort Hood STES operation (startup) date of September 1980 as opposed to an originally planned startup date of January 1981. Chart 2-5 represents an Aerospace contribution toward fulfilling that task.

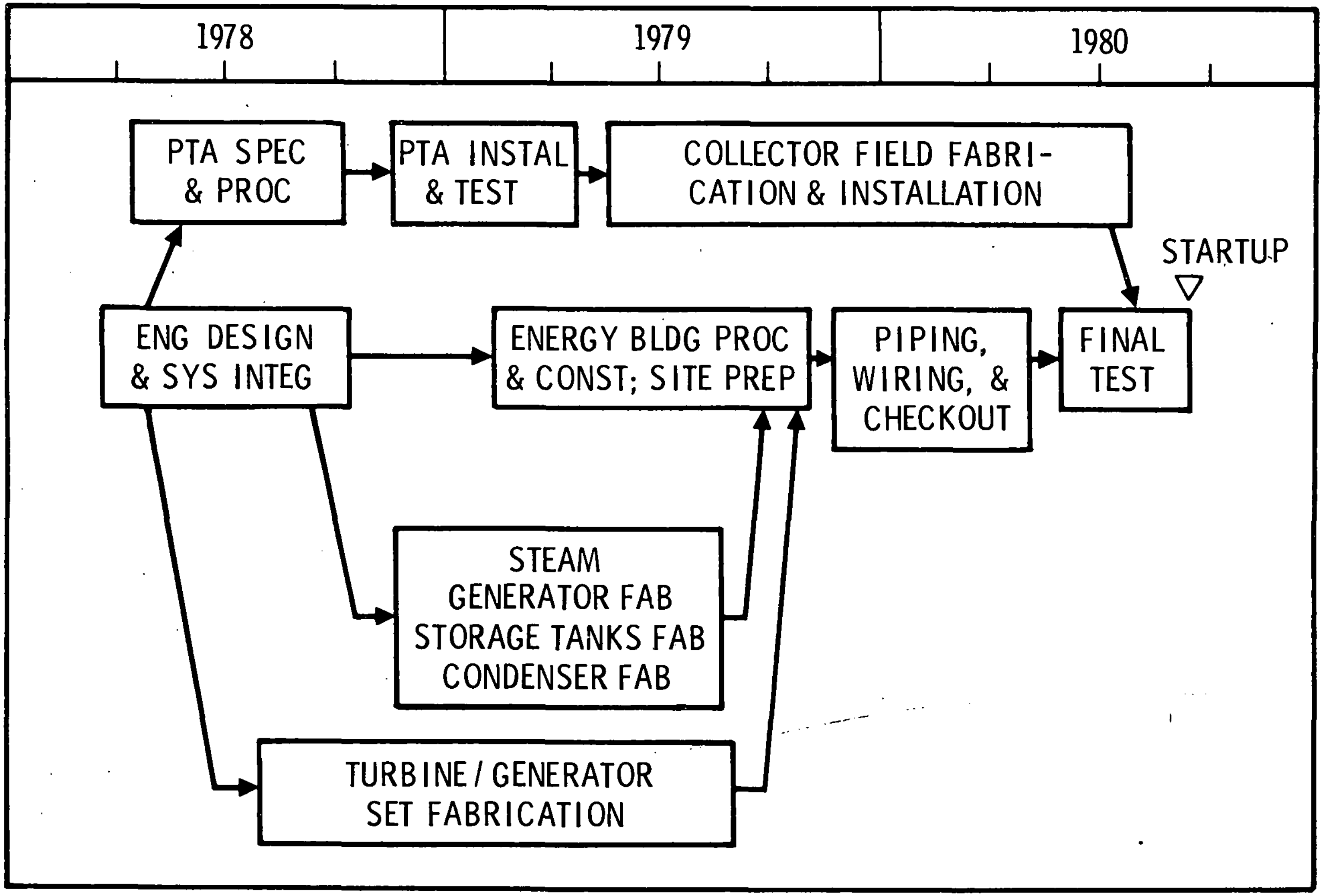
Aerospace examined the basic tasks and activities in the ATU Critical Path Network Plan and compressed the schedule by a phasing of design, procurement, and construction activities. A simplified form of the resulting plan is shown in Chart 2-5.

The revised plan called for an eight-month Preliminary Design Phase, a seven-month Definitive Design Phase, and a 15-month Construction Phase, with overlapping activities as required to accomplish procurement of long-lead items. The time allotted for many tasks was shortened, the most severe case being the time for preparation of a turbine-generator specification.

The Aerospace plan was submitted to DOE/ALO and considered in conjunction with an independent submittal by ATU/Westinghouse. Subsequently, a working session at DOE/ALO resulted in the generation of three project schedules and the conclusion that a September 1980 date did not appear to be feasible.

Aerospace drafted a comprehensive formal response to DOE/Hq. for DOE/ALO on the subject.

Fort Hood Project Accelerated Schedule



COMPARISON OF PROJECT SCHEDULES

Three project schedules and corresponding budgetary requirements were prepared in concert with ATU and DOE/ALO. Their comparison, shown in Chart 2-6, illustrates the dramatic differences in funding flow in relation to modest differences in completion dates.

The Current Schedule corresponds to the project schedule and funding plan being followed by DOE/ALO as of June 1978.

The dramatic impact on funding requirements of implementing the Enhanced Schedule is evident. The operational date achievable via that procedure would occur, at the most, four months earlier than with the current schedule. Aerospace accordingly advised DOE/ALO that the Enhanced Schedule was indefensible.

Comparison of Funding Requirements for Different Fort Hood Project Schedules

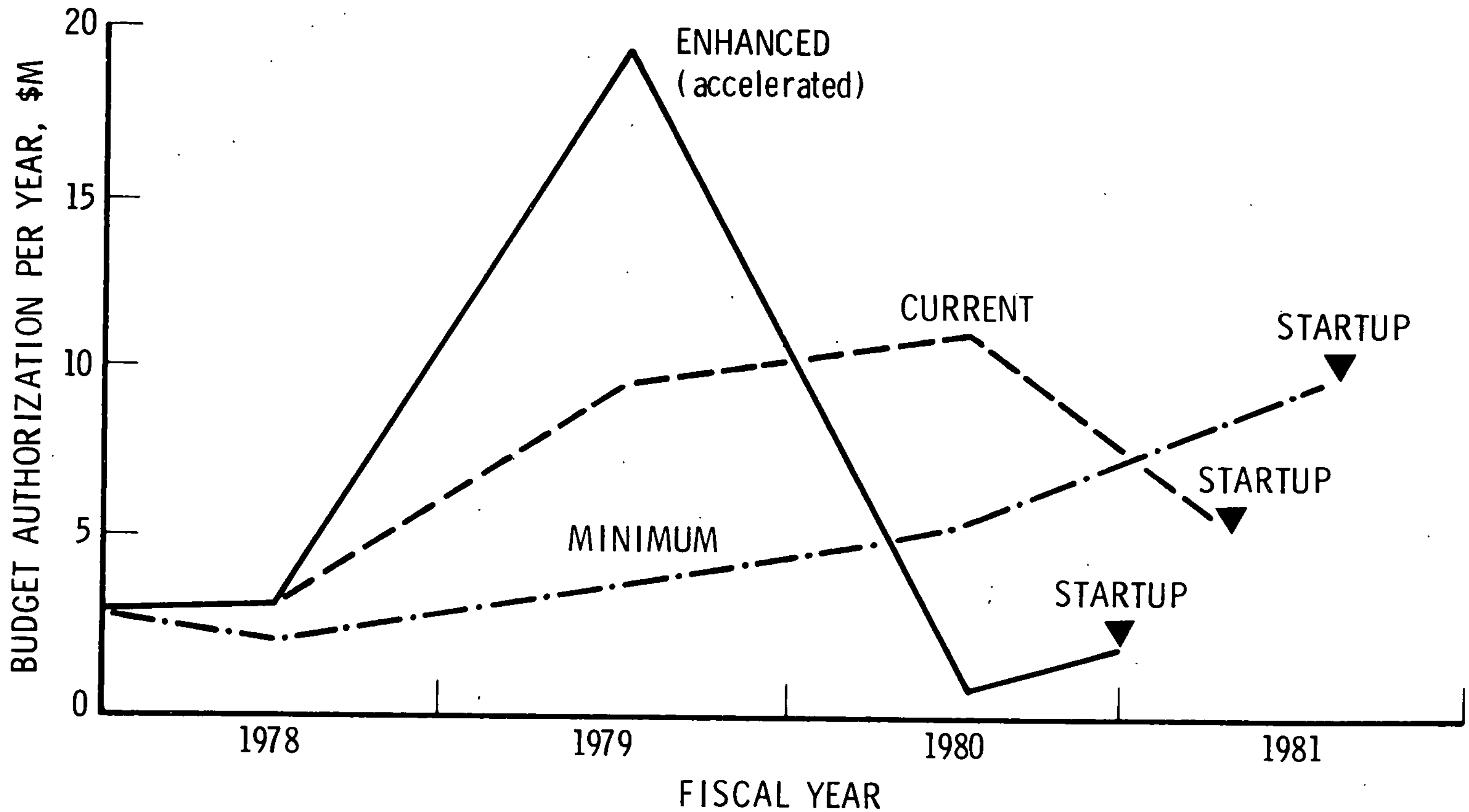


Chart 2-6

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

2.3 PILOT TEST ARRAY

This section presents a summary of activities dealing with the general subject of the Pilot Test Array. Issues on that subject related to the selection of its location and its value to the Fort Hood project.

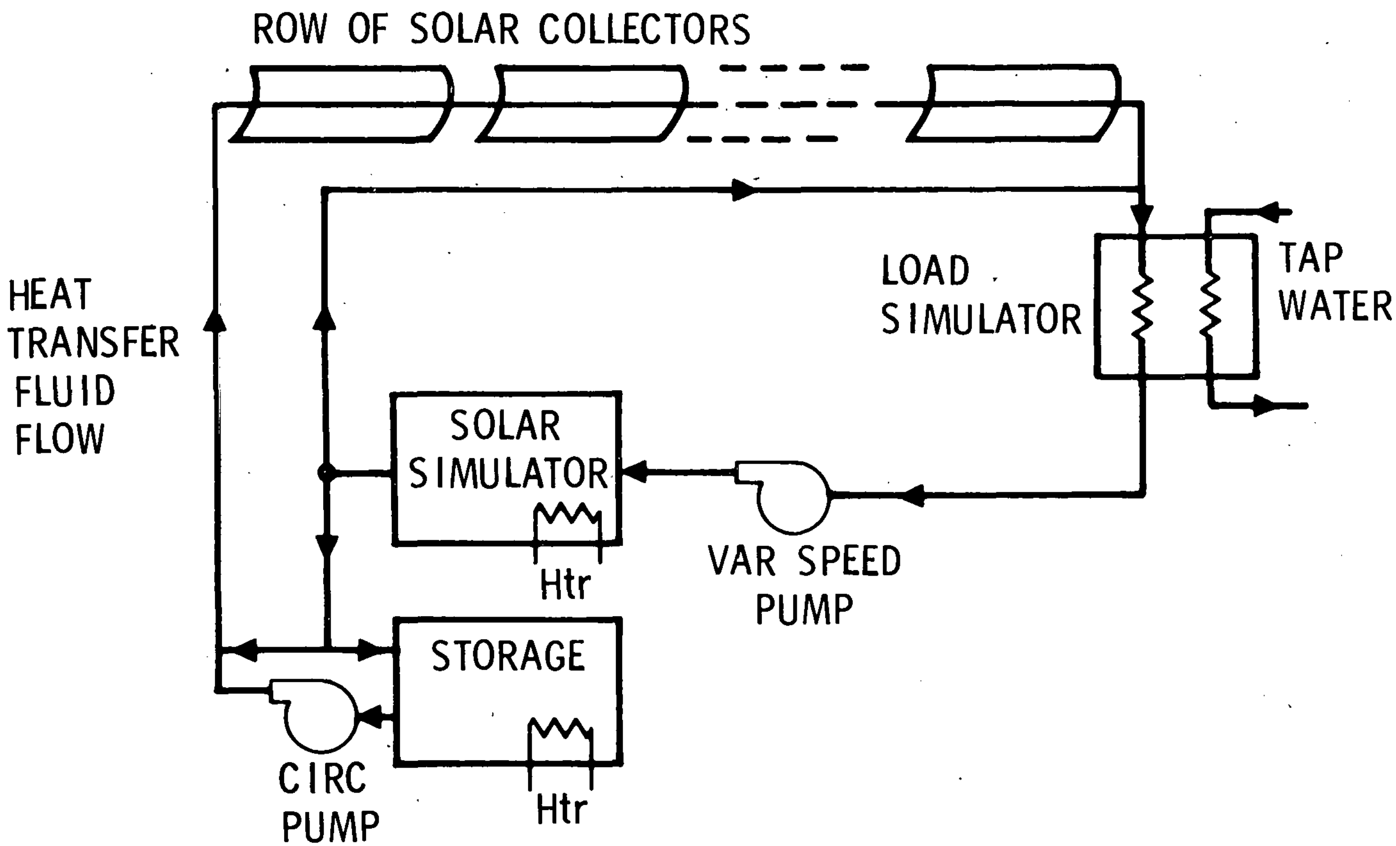
PILOT TEST ARRAY

Chart 2-7 presents a simplified schematic of the Pilot Test Array (PTA) concept.

The PTA task in the ATU contract required the contractor to design and prepare a bid package for an instrumented heat transfer fluid test loop incorporating a row of parabolic trough collectors in which the fluid would experience a temperature rise from absorbed radiant energy. After exiting the collector row, the heated fluid would be passed through a heat sink (simulating a thermal load), and then pumped through the collectors again. The trough collectors were to be prototypical of those which would eventually be procured for the main Fort Hood LSE-1 field and should comprise the "smallest independent operational entity" of the main field. The rationale was that the test activity would reduce technical risk and reveal any needed design changes before ordering the main field collectors.

Pilot Test Array

SIMPLIFIED SCHEMATIC



PILOT TEST ARRAY SITE LOCATION

The first issue that arose with respect to the PTA was in regard to its location. Chart 2-8 is a map showing the two potential sites which were considered.

At the first Design and Project Review, May 18-19, 1978, ATU announced the selection of the West Fort Hood Solar Test Area for the PTA location. As the map shows, that location is only about eight miles distant from the planned site for the Large Scale Experiment, so insolation values would not likely be different.

Alternate Locations Considered for the PTA

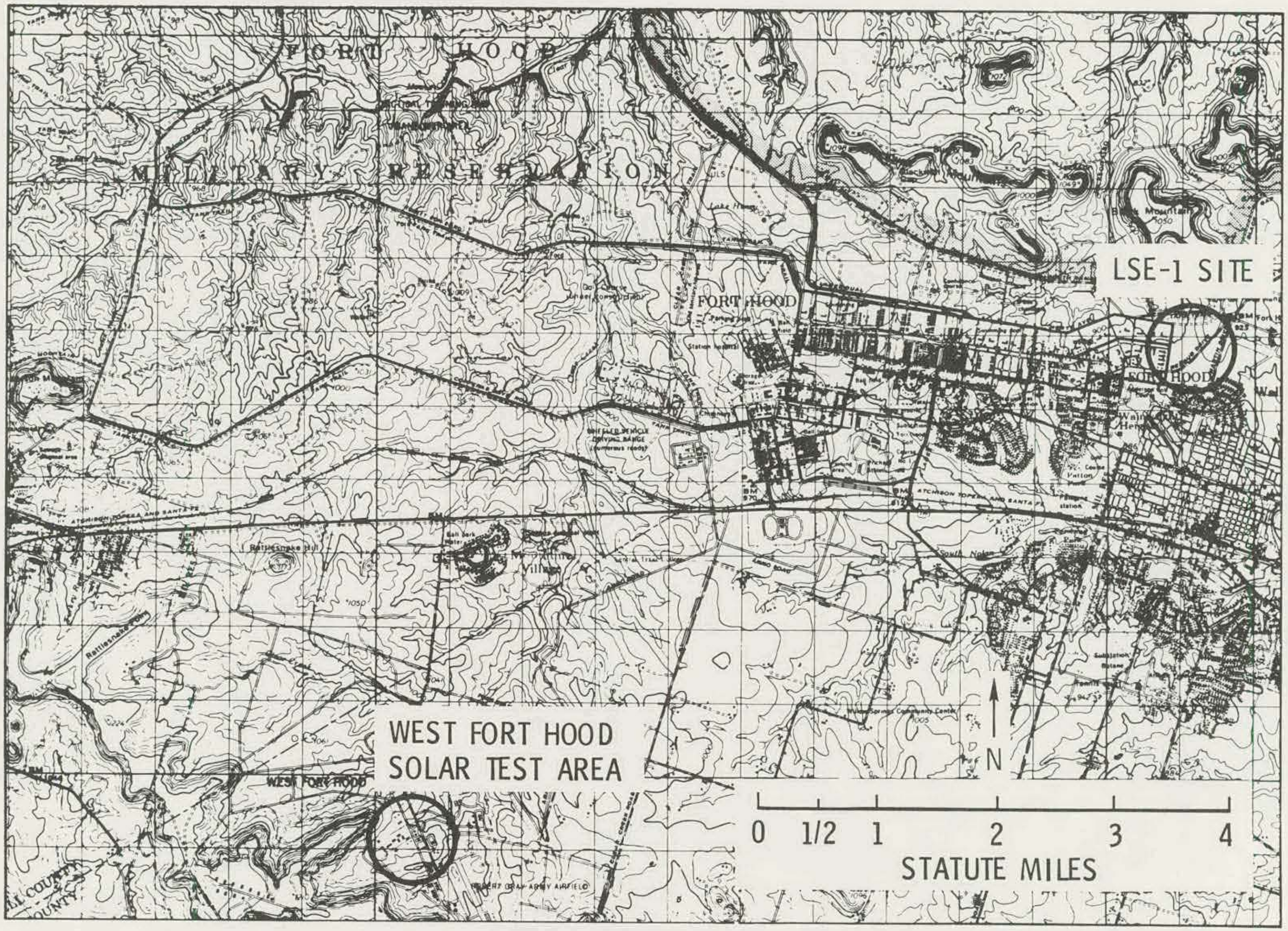


Chart 2-8

INITIALLY PROPOSED PTA SITE PLAN

The PTA layout recommended by ATU if it were located at West Fort Hood is shown in Chart 2-9.

The initial plan by ATU for installing the PTA at the West Fort Hood site involved a serpentine arrangement of the collectors in order to accommodate the equivalent of a full collector row (nominally 400 ft) and still fit within the existing fenced enclosure. That layout exemplifies some of the objections Aerospace found with that location: the serpentine arrangement unavoidably introduces an excess of plumbing (and thermal mass) since the row segments must be interconnected.

Site Plan Proposed for the PTA at West Fort Hood

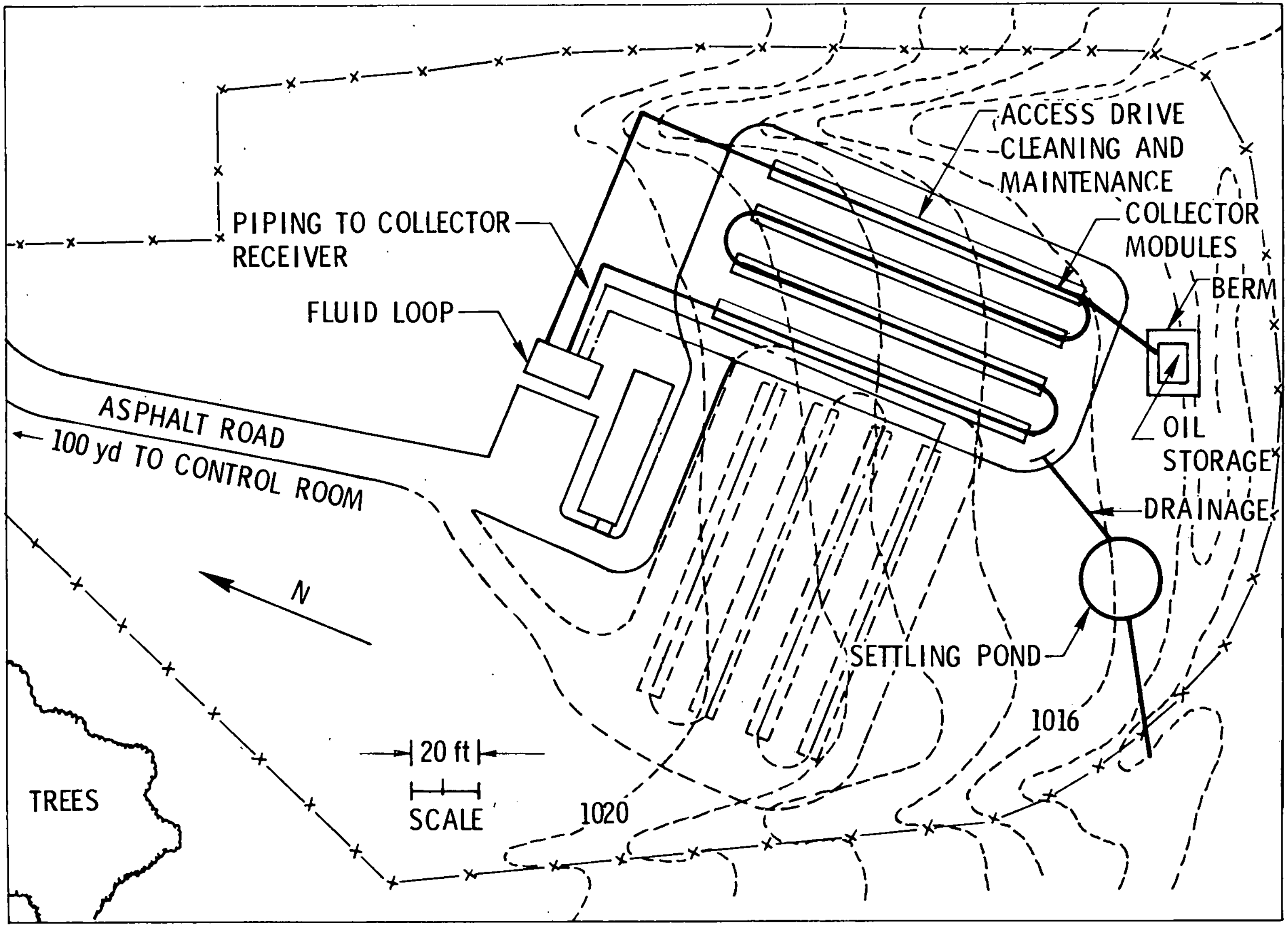


Chart 2-9

ALTERNATE PTA SITE PLAN

As part of its independent study of the PTA siting issue, Aerospace inspected the facilities at West Fort Hood and verified that with fence extensions, a full 400 ft collector row, could be installed at that site as indicated in Chart 2-10.

As an Action Item from the May 18-19, 1978 Design and Project Review, ATU conducted a study to trade off the two potential locations and to supply data and rationale to support their results. The ATU conclusion was to retain the West Fort Hood site but to modify the site plan to accommodate a continuous line of collectors.

Aerospace noted the absence of wind obstructions and of any serious shadow-producing structures. Further, it was determined that Army Atmospheric Sciences Laboratory insolation sensors and data recording equipment were still available at the site for use by ATU so that a solar meteorological station proposal by ATU for use with the PTA was probably not needed.

An Alternate PTA Site Plan for West Fort Hood

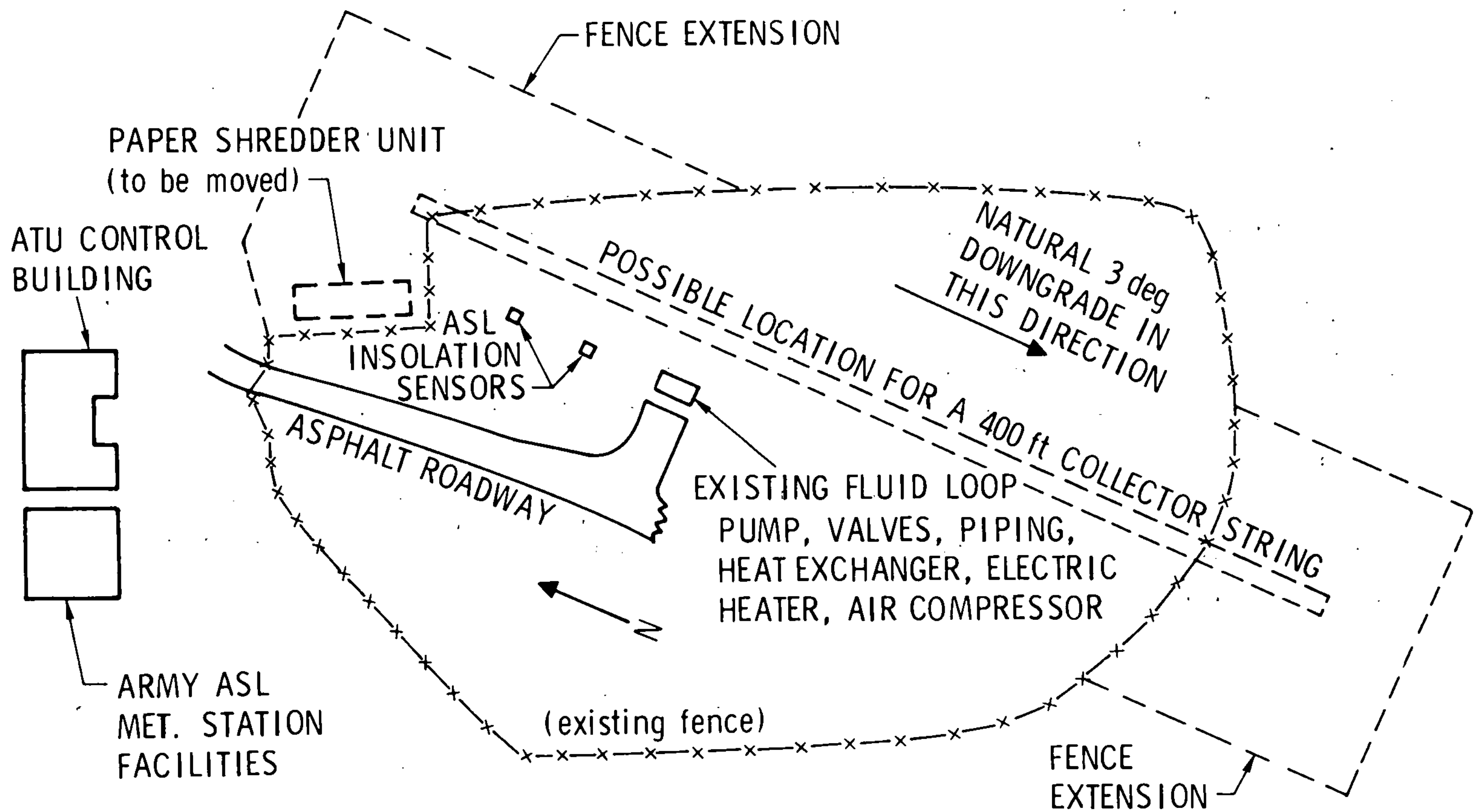


Chart 2-10

SUMMARY OF PTA ISSUES

A summary of the PTA issues is presented in Chart 2-11.

Aerospace summarized for DOE consideration all issues related to the PTA as shown in Chart 2-11. The site initially recommended by Aerospace was the 87000 troop housing complex area where the main collector field is to be located.

However, as it turned out, an analysis of the schedule and considerations of the costs in material and manhours to the Fort Hood project made the choice of location a moot point. The project benefits to be gained by it are rather modest compared to its cost.

Aerospace recommended to DOE/ALO that the PTA task be deleted primarily because of project cost, schedule, and timing considerations. The recommendation was accepted by DOE.

SUMMARY OF PTA ISSUES

LOCATION	(WEST FORT HOOD VERSUS 87000 COMPLEX)
	• DIFFERING ENVIRONMENTAL FACTORS SPACE LIMITATIONS AT WEST FORT HOOD
TIMING	• TESTING COULD BEGIN AT THE EARLIEST 4 MONTHS PRIOR TO DESIGN FREEZE ON THE MAIN FIELD COLLECTORS
	• TEST RESULTS WILL NOT LIKELY AFFECT DESIGN BECAUSE OF THE SCHEDULE
	• RAPIDLY MATURING COLLECTOR TECHNOLOGY GREATLY DIMINISHES POTENTIAL VALUE OF PTA TEST DATA
COSTS	• INITIAL COST ESTIMATE FOR THE PTA HARDWARE WAS ABOUT $170,000
	• O&M COSTS FOR ITS (ANTICIPATED) CONTINUED TESTING AFTER DESIGN FREEZE ON THE MAIN FIELD COLLECTORS ARE NOT JUSTIFIABLE, BECAUSE SUCH TEST ACTIVITY WOULD DUPLICATE THAT AT SANDIA LABS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

2.4 NEW COLLECTOR FIELD DESIGN

This section reviews technical support activities performed in conjunction with a new collector field design concept proposed by the design subcontractor, Westinghouse.

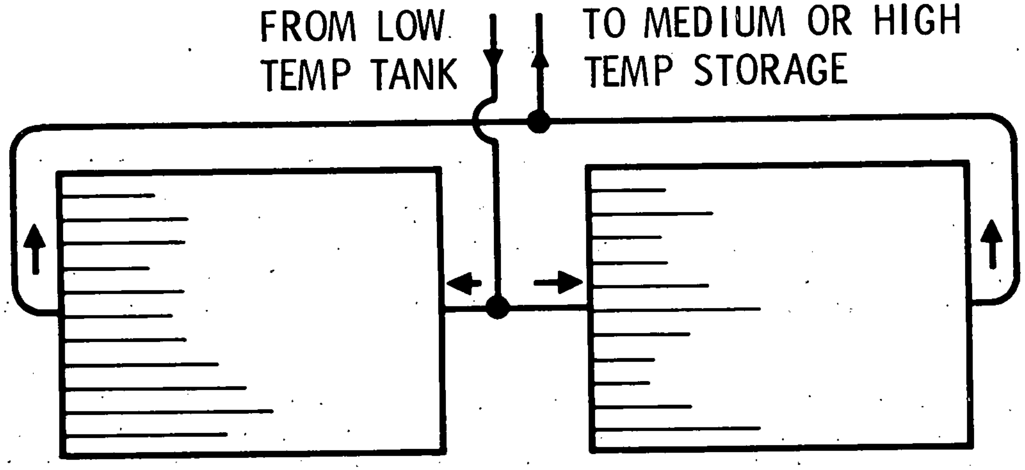
NEW COLLECTOR FIELD DESIGN

Two different configurations and control concepts using parabolic trough collectors have been under consideration for the Fort Hood solar collector field. They are the Parallel Split-Field Concept and the Series-Feedforward Field Concept, schematically shown in Chart 2-12.

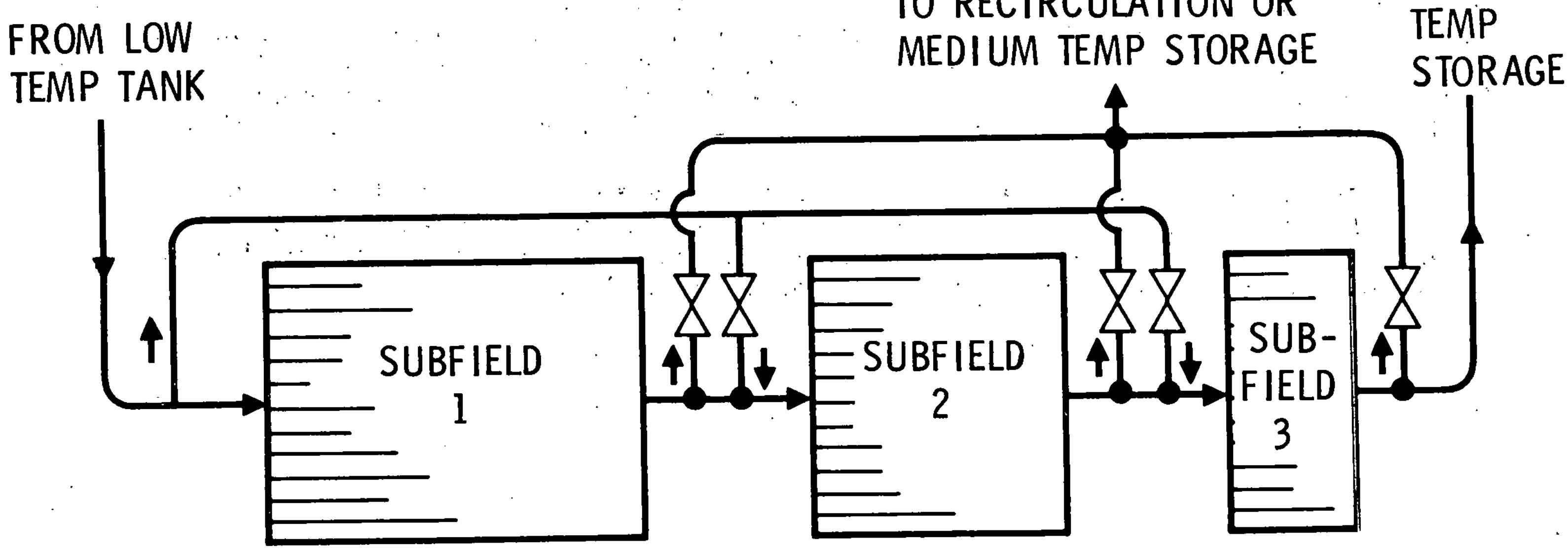
Following the August 3-4 Design Review, Aerospace was asked by DOE to investigate the proposed change from a parallel split-field concept with conventional feedback control to the series field concept with feedforward control. Westinghouse claimed that the large transport lag associated with the first concept would create oil overtemperature conditions when abrupt insolation transients occur. In the new concept, the flow of heat transfer oil is basically serial through the three subfields except that provision is made for "tempering" the oil exiting subfields 1 and 2 with oil from the low temperature tank before it enters the subsequent subfield.

The principal advantages claimed for the new design are that it prevents the development of overtemperature conditions and allows continued operation of the field during periods when insolation levels would be considered below threshold for the old concept. Furthermore, there is a significant reduction in the quantity of control valves and thermocouples required.

Collector Field Configurations Considered for Fort Hood



A. PARALLEL SPLIT-FIELD CONCEPT



B. SERIES - FEEDFORWARD FIELD CONCEPT

Chart 2-12

ANALYSIS OF NEW COLLECTOR FIELD DESIGN

Some general behavior characteristics of the new field design are depicted in Chart 2-13.

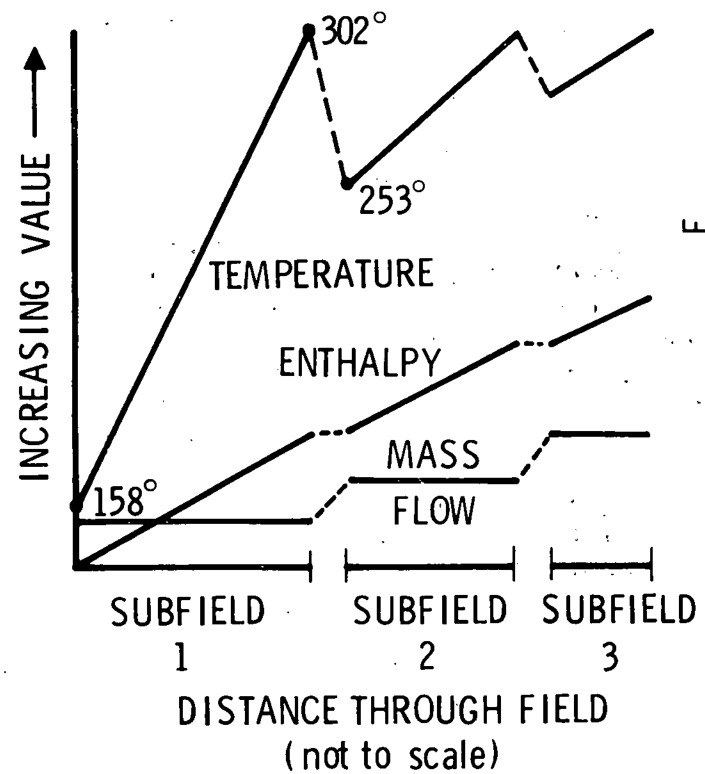
Aerospace reviewed the results of Westinghouse static performance calculations for the new field design and analyzed the new design from the standpoints of thermodynamic efficiency and temperature controllability. Technical interchange meetings primarily addressing this topic were held with Westinghouse on August 21, 1978 at El Segundo and October 4, 1978 at Pittsburgh.

The predicted behavior of the thermodynamic variables in the new field design is shown qualitatively in the graph on the left-hand side of Chart 2-13. Under full sun conditions the oil in subfield 1 is heated (from 158°C) to 302°C, then mixed with a selected flow of cooler oil to reduce its temperature to 253°C. In that mixing action there is theoretically no loss in energy content of the combined oils referenced to oil at 158° C. However, if subfield 1 attained a temperature of only 253°C, it would have been achieved at a higher collection efficiency. That point is illustrated in the graph of normalized collector efficiency on the right-hand side of the chart. Aerospace calculated that the overall reduction in efficiency translates into a slight increase in collector area (3. 7 percent) to collect the same number of Btu's as the parallel split-field design.

In spite of this liability, after all aspects of the issue were considered, a provisional go-ahead was recommended for the new design pending results of Westinghouse transient analyses. Its apparent principal advantage is the ability to prevent the heat transfer fluid from overheating under any foreseen conditions.

Analysis of New Collector Field Design

TEMPERATURE, ENTHALPY, AND MASS FLOW CHARACTERISTICS
(full sun condition)



NORMALIZED COLLECTOR EFFICIENCY vs EXIT TEMPERATURE
(subfield 1)

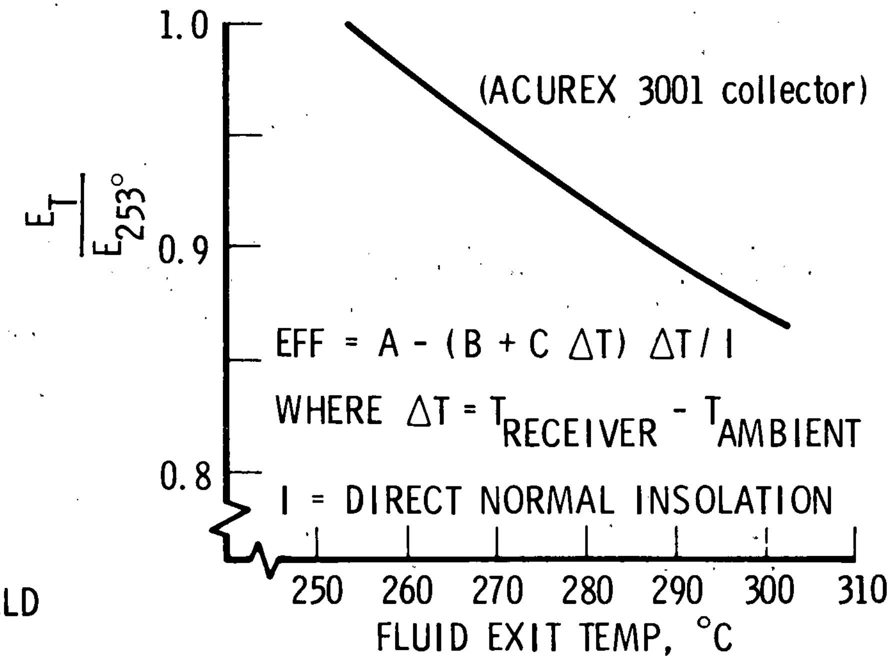


Chart 2-13

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

3.0 PARABOLIC TROUGH COLLECTOR TECHNOLOGY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

3.1 STATE-OF-THE-ART ASSESSMENT

This section presents a review of field trips taken and technical presentations attended during the report period to assist in the evaluation of trough collector designs and their potential operating problems.

STATE-OF-THE-ART ASSESSMENT

To acquire an up-to-date picture of the current manufacturing quality, problems encountered in operation, and the quality of field service support provided by vendors of parabolic trough solar collectors, Aerospace engaged in the activities listed on Chart 3-1.

Field trips to the parabolic trough solar collector facilities operated by Sandia Laboratories at Albuquerque and Willard, New Mexico were of great value in determining the practical problems associated with installation, startup, and maintenance of systems using those collectors. Collector design, manufacturing methods, and field applications experience topics were covered in a thorough technical presentation by a leading manufacturer, the Acurex Corporation.

Aerospace attended portions of the special seminar that was conducted by Sandia/Albuquerque primarily for the benefit of Westinghouse. It covered advanced trough designs, performance evaluation methods, tracking system designs, receiver coatings, reflector materials, cleaning methods, heat transfer fluid management, insulation maintenance, and field applications experience with the irrigation projects.

PARABOLIC TROUGH COLLECTOR TECHNOLOGY

State-of-the-Art Familiarization Activities

• FIELD TRIP, MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY (MSSTF)	ALBUQUERQUE	15 FEB 78
• SPECIAL SEMINAR CONDUCTED BY SANDIA LABS FOR FORT HOOD CONTRACTORS	ALBUQUERQUE	19 APR 78
• TECHNICAL PRESENTATION BY ACUREX CORP	EL SEGUNDO	16 MAY 78
• FIELD TRIP, SHALLOW WELL SOLAR IRRIGATION PROJECT	WILLARD	11 OCT 78

Chart 3-1

TROUGH COLLECTOR INSTALLATIONS AT WILLARD, NEW MEXICO

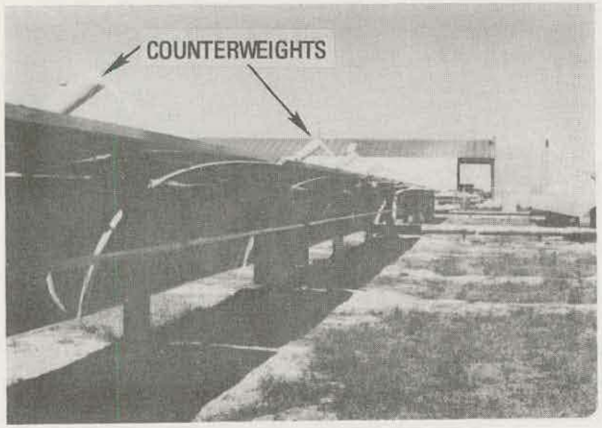
Typical of the equipment studied in the field trip to the Shallow Well Irrigation Project at Willard, New Mexico are the strings of Solar Kinetics and Acurex collectors pictured in Chart 3-2.

The Solar Kinetics troughs are of a monocoque design and each module is 7.16 ft x 20 ft in aperture. Five such modules are driven about the common axis of rotation by a hydraulic motor coupled through a sprocket and chain. The Acurex collectors are made in modules 6 ft x 10 ft in aperture. Eight such modules are driven by a single electric motor and gearing at the midpoint of the "string." Both of these collector models are delivered to the field preassembled.

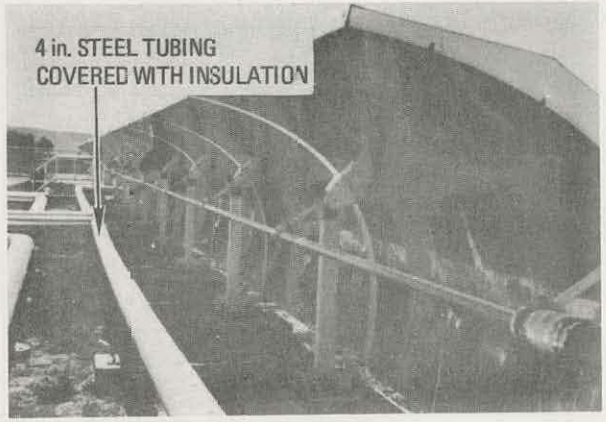
Lack of stiffness in the modules connected into a string contributes to some degradation in pointing accuracy; the counterweights were added to the Solar Kinetics troughs partly to offset the twisting action caused by torsional strain. The torsional strain in both collector models, combined with effects of repeated cycling through day/night temperature extremes, has caused a considerable amount of breakage of the glass envelopes. Even minor cracks create a loss of dust sealing capability with consequent degradation of efficiency due to dust on the interior of the glass envelopes. Mechanical design improvements have now essentially stopped the breakage. Dust on the outside also degrades efficiency such that receiver glass cleaning has been noted to have a more pronounced effect on performance than cleaning of the trough.

Low carbon steel pipe in the Willard field has been replaced with four-inch stainless steel tubing with a consequent startup time of a cold system of 10 minutes as opposed to more than an hour with the four-inch pipe. The use of tubing introduces the requirement for welding of joints, and it has been found necessary to insist on tungsten inert gas (TIG) welding to avoid leaks of the heat transfer fluid.

Trough Collector Installations - Willard, NM



A. SOLAR KINETICS COLLECTORS (stowed position)



B. ACUREX COLLECTORS (stowed position)

C. SOLAR KINETICS RECEIVER JOINT

D. END OF ACUREX COLLECTOR STRING

Chart 3-2

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

3.2 OIL OVERTEMPERATURE ANALYSIS

This section provides a brief summary of a theoretical analysis of the overheating problems which may arise in the heat transfer oil flowing through trough collector receivers.

OIL OVERTEMPERATURE ANALYSIS

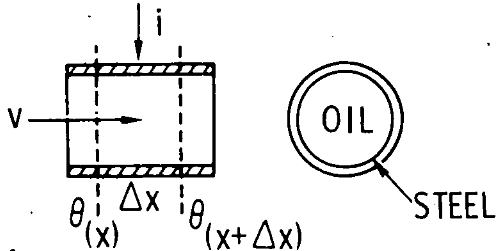
Because of overtemperature conditions which might be caused by cloud-induced insolation transients on the planned Fort Hood collector field, an analysis was made of one of the methods available to ameliorate the risk of excessive temperatures in the heat transfer oil.

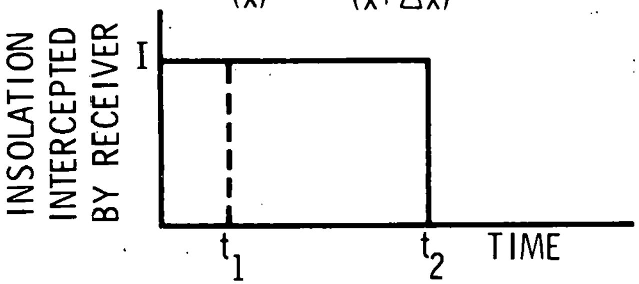
Considering a section of a parabolic trough solar collector pipe, a theoretical heat-balance analysis was made taking into account insolation, heat conduction of the pipe, fluid velocity, fluid density, and fluid specific heat. After analytical modeling (see Reference 2), the change in output temperature from an initial temperature distribution caused by a step change in insolation was calculated.

First, it was assumed that the insolation is uniform over x, steps up instantaneously to a level, I, at time t = o, and then is removed at time t = a. The analysis showed that the inlet temperature does not change. At a distance $x = \ell$ (the pipe outlet), the temperature response to an insolation pulse of amplitude I is plotted on the left side of Chart 3-3. The parameters k_1 and k_2 are temperature propagation parameters.

Next, an analysis was made of the extent to which oil temperature can be limited to some fixed upper bound by collector defocusing while monitoring only the outlet temperature. It was assumed that the temperature, θ, reaches a critical value θ_{CRIT}, at t = o due to a positive step change in insolation and that the insolation can only be reduced at a finite rate. It was assumed arbitrarily that, as the collectors rotate, the insolation decreases according to a cosine function. The result of that analysis (for a finite defocusing rate as opposed to an instantaneous removal of insolation) is plotted in the right hand side of Chart 3-3.

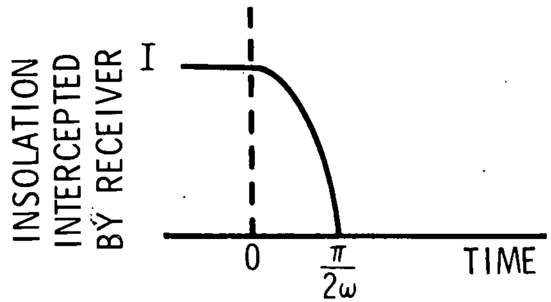
Temperature Response to Insolation Transients



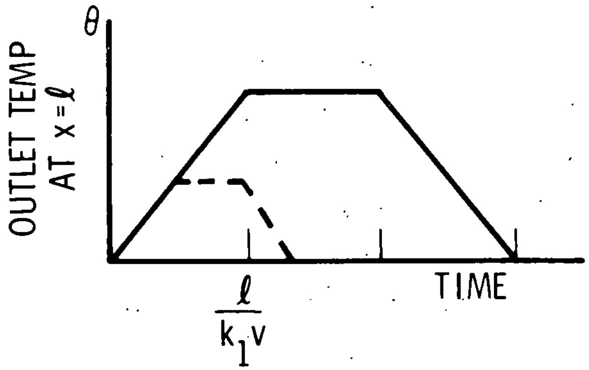


t = TIME INSOLATION REMOVED

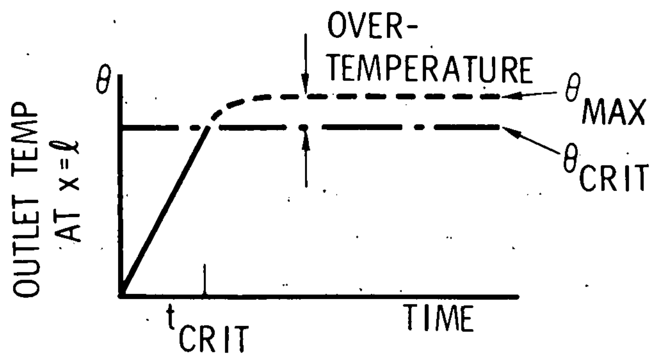
$t_1 = \frac{1}{2}\frac{\ell}{k_1 v}$ (dashed line); $t_2 = 2\frac{\ell}{k_1 v}$ (solid line)



ω = DEFOCUSING RATE



TEMPERATURE RESPONSE TO INSOLATION PULSE



TEMPERATURE RESPONSE WITH FINITE DEFOCUSING RATE

OIL OVERTEMPERATURE ANALYSIS

The theoretical variation with time of the temperature increment above the critical temperature, i.e., overtemperature, is shown in the lower left curve of Chart 3-4 for the case of a finite defocusing rate. The overtemperature condition prevails until the oil passes through the full length, ℓ, of the collector string.

In applying the model to a typical system design, the insolation lag and velocity lag parameters for Sun 21 oil may be calculated. For a 1-1/4 inch pipe at a nominal 500°F temperature, the temperature propagation parameters k_1 and k_2 are plotted in the upper right portion of Chart 3-4. With this information, the overtemperature history can be computed for the case of any given defocusing rate.

Using typical design values, including a continuous collector string length of 430 ft, and assuming that the pipe wall is very thin, calculations showed that the overtemperature impulse for a typical high noon insolation level at Fort Hood would last for a period in excess of seven minutes, which might cause degradation of the heat transfer oil.

The solid curve in the lower right of Chart 3-4 is the resulting plot of overtemperature versus effective defocusing rate for the assumed system parameters. That assumes the cosine function for the rate of insolation decrease on the receiver (90 deg for full reduction). Subsequent investigation has developed the criterion that the insolation impinging on the receiver will be effectively reduced to zero when the collector rotation displaces the receiver laterally by an amount equal to its own width. For the Acurex collector geometry, that amounts to a rotation of about six degrees to achieve effective defocusing. The dashed curve represents an estimated overtemperature vs. defocusing rate model using that criterion. It indicates that a rate of about 15 deg/min would be needed to keep the overtemperature less than 25°F.

Oil Overtemperature Calculation Results

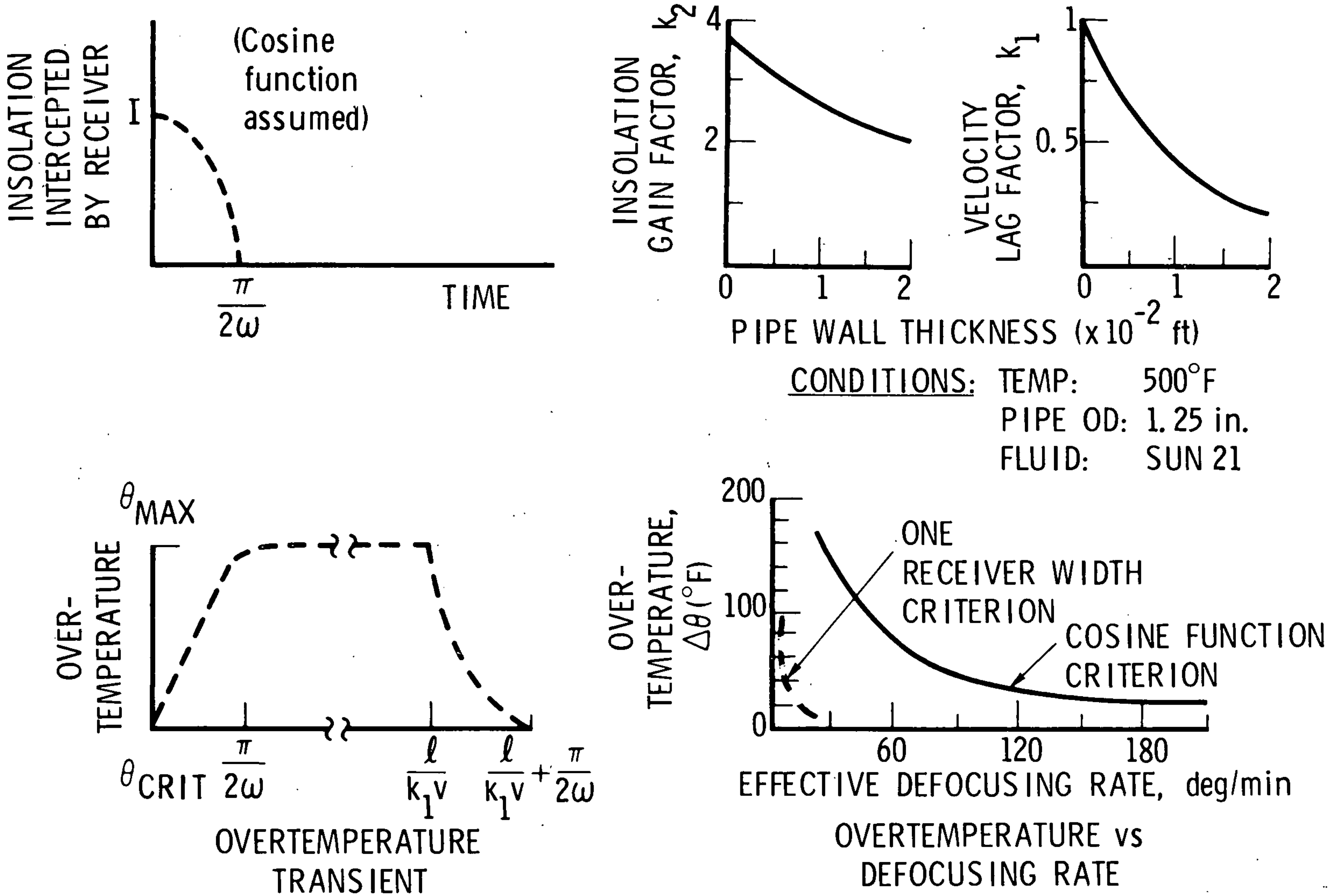


Chart 3-4

3.3 OPTICAL ANALYSIS OF SLEW RATE REQUIREMENTS

This section presents a brief summary of an analysis conducted to determine the rates of slew required to remove the amount of insolation intercepted by a trough collector receiver rapidly enough to avoid series over-temperature conditions.

OPTICAL ANALYSIS OF SLEW RATE REQUIREMENTS

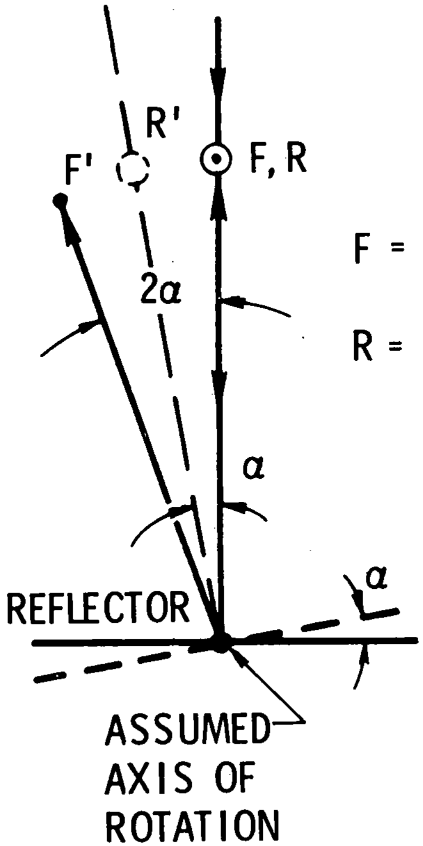
The oil overtemperature analysis showed that a serious control problem may result if adequate slew rates are not incorporated in the Fort Hood collector field specifications. A brief first-order analysis was made to check the adequacy of the specified slew rate.

The optical energy is removed from the receiver of a parabolic trough collector by slewing the collector about its tracking axis. The collector specification prepared by ATU/Westinghouse calls for a slew rate of 15 deg/min.

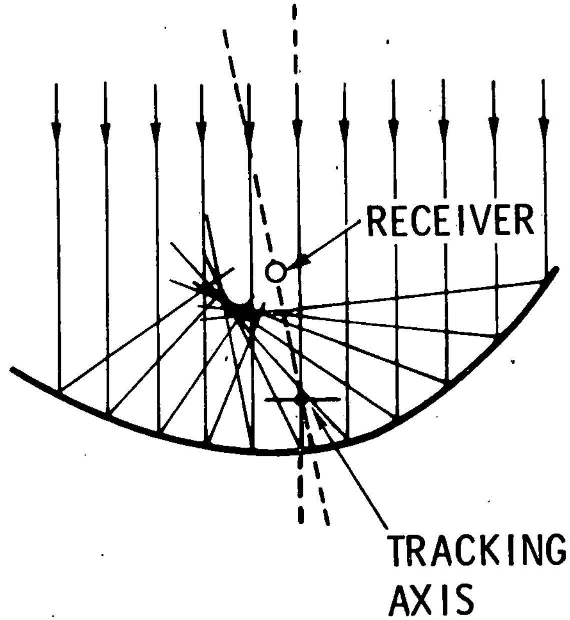
Using the simplified (flat mirror) model on the left side of Chart 3-5, as the collector slews, the reflective surface and receiver rotate at the slew rate and the focus of energy rotates at twice the slew rate. Thus, in this model the focus of energy moves at the slew rate with respect to the receiver. It was estimated that at least 90 percent of the energy will be off the receiver once the focus of energy has moved one receiver diameter. If the receiver diameter is 1.25 inches and the distance from the mirror to the receiver is approximately 18 inches (Acurex dimensions), the required rotation is four degrees. At the specified slew rate of 15 deg/min, that would take 16 seconds.

That rate appears to be adequate but a more rigorous analysis of the rate of attenuation of energy intercepted by the receiver is planned. Examination of the baseline collector design (Acurex) shows that the receiver's moment arm is actually 13.75 inches, and 5.2 degrees of defocus are needed to displace it 1.25 inches. That would require 20.8 seconds. Actually, the optical focus quality drops off rapidly with rotation of the parabolic trough, as can be seen in the sketch in the right hand side of Chart 3-5.

Parabolic Trough Defocusing



SIMPLIFIED MODEL



BASELINE COLLECTOR
(Acurex) DEFOCUSED
AT 10 deg

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

4.0 ENERGY LOAD MEASUREMENTS ACCURACY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

4.1 PROJECT SITE INSTRUMENTATION

This section presents the arrangement of sensors installed under ATU's supervision to acquire actual data on the energy loads at the Fort Hood project site.

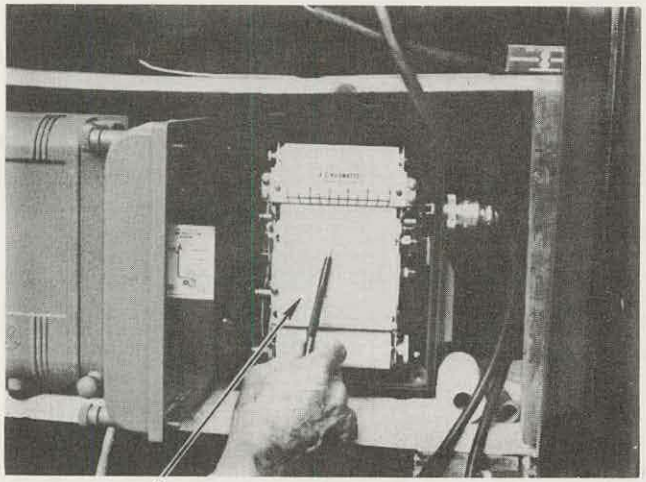
PROJECT SITE INSTRUMENTATION - ELECTRICAL LOADS

The five buildings selected to be served by the Fort Hood STES are indicated on the diagram on Chart 4-1; also noted are the electrical distribution transformers serving that portion of the 87000 troop housing complex.

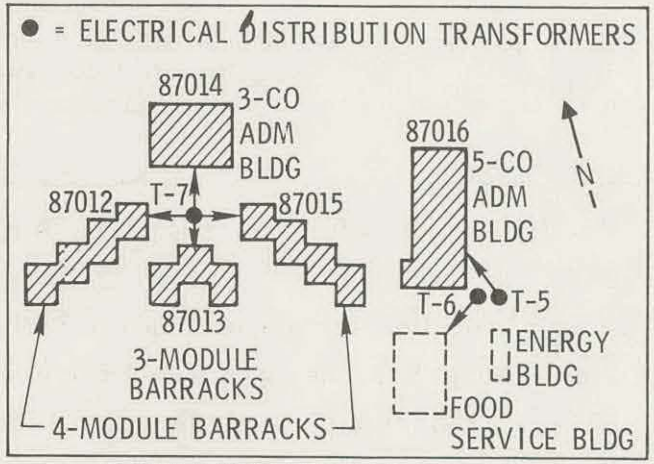
Two types of instruments were installed by ATU for electrical load measurements. The simpler type was the General Electric "Amprobe" recording ammeter. Those are installed on transformer secondary windings (one of the three phases), and from the resulting analog chart records the full three-phase KVA load is calculated. The bottom photo shows a representative installation on transformer T-7. The resulting data turn out to be inaccurate because of severely unbalanced loads on the three phases.

Another type of instrument used by ATU is the G.E. kilowatt/kilovolt ampere reactive (KW/KVAR) recorder which simultaneously measures all three phases of the current, all records, both the power in kilowatts and reactive power. The upper photo shows the KW/KVAR recorder installed on transformer T-6.

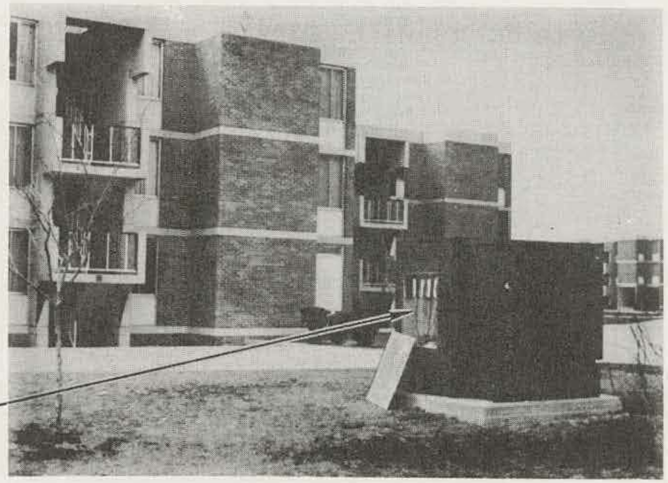
Electrical Load Measurement Sensors



KW / KVAR RECORDER
INSTALLED IN T-6
TRANSFORMER BOX



5 BUILDINGS SELECTED FOR SOLAR
TOTAL ENERGY EXPERIMENT



AMPROBE RECORDING
AMMETERS INSTALLED
ON T-7 TRANSFORMER
SECONDARY WINDINGS

MEASUREMENT OF THE HEATING LOAD

Chart 4-2 presents a schematic of the existing space heating system for the five selected buildings in the 87000 troop housing complex and the location of sensors installed to measure the steam supply and condensate return parameters.

Energy supplied for space heating is measured by recording on analog recorders the pressure and temperature of steam generated by a pair of gas-fired 350 hp boilers in the Energy Building and recording the temperature and flow of the returning condensate after the energy has been extracted for heating purposes.

All the sensors and recorders are located in the mechanical room of the Food Services Building. Aerospace verified that measurement probes for flow sensing were installed with the proper number of clear equivalent pipe diameters being maintained upstream and downstream from the installation point.

Domestic hot water for the three barracks buildings is supplied via steam-driven hot water generators in each building which heat tap water to 130°F. The overall measurement of steam pressure and temperature and the condensate flow and temperature provide data for computing the hot water load.

Measurement of Space Heating Load

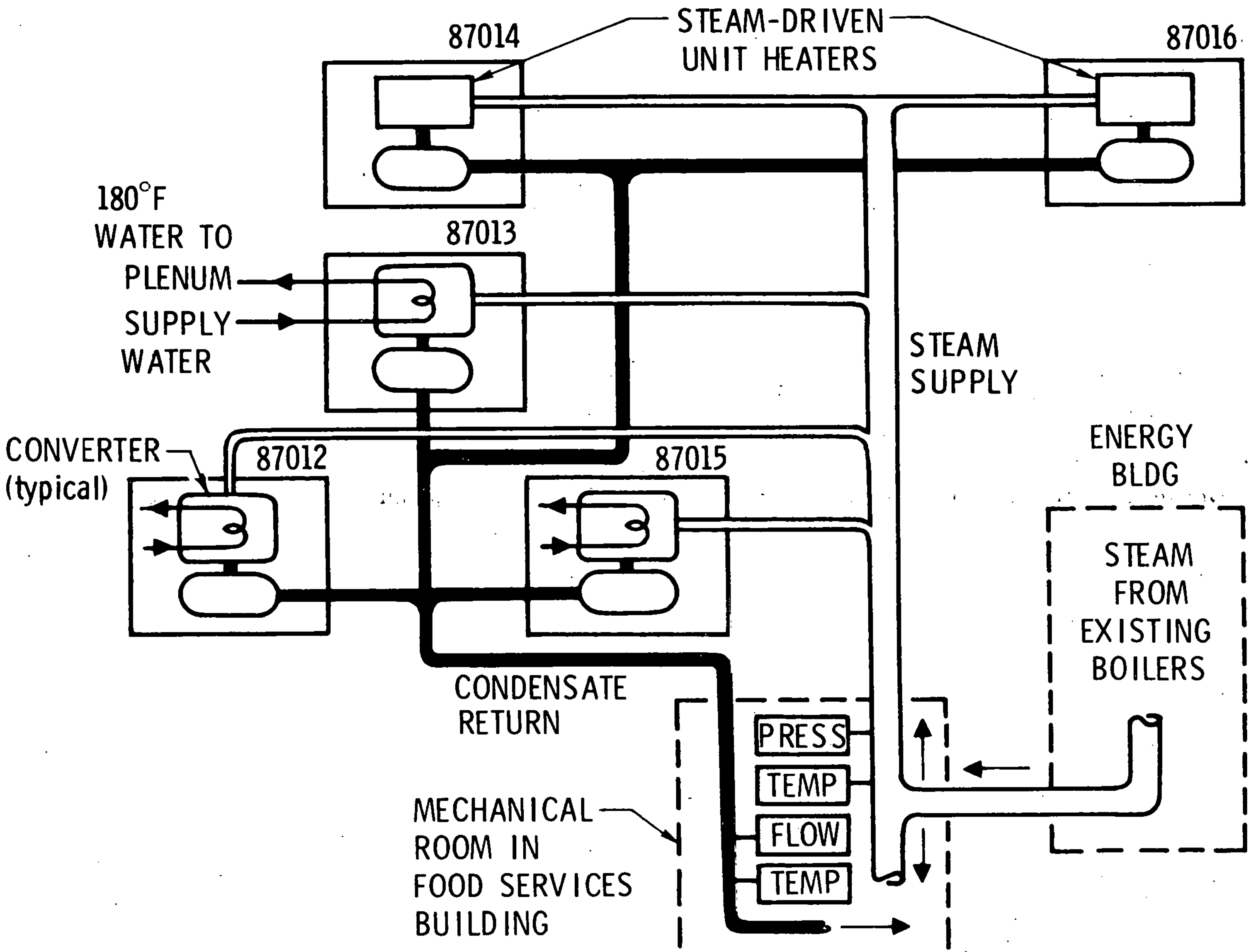


Chart 4-2

MEASUREMENT OF THE AIR CONDITIONING LOAD

A schematic of the air conditioning system presently in use in the five selected buildings is shown in Chart 4-3. Also shown are the temperature and flow sensor locations used by ATU for measuring the space cooling load.

Electrically-driven chillers in the Energy Building supply chilled water for circulation through the copper tubing cooling coils distributed throughout the five buildings. The temperature of this chilled water (about 44^{O}F) is monitored as it flows through the mechanical room of the Food Services Building. After energy is added to the water by absorption of heat in the cooling coils, it flows back through the chilled water return line where its flow rate and temperature (about 58^{O}F) are continuously recorded.

An aspect of the air conditioning load not being monitored by this arrangement is the actual room temperatures achieved in the rooms being cooled, i.e., a measurement of the efficacy of the existing system. Measurements of this aspect may be done in the future on a spot-check basis.

Measurement of Air Conditioning Load

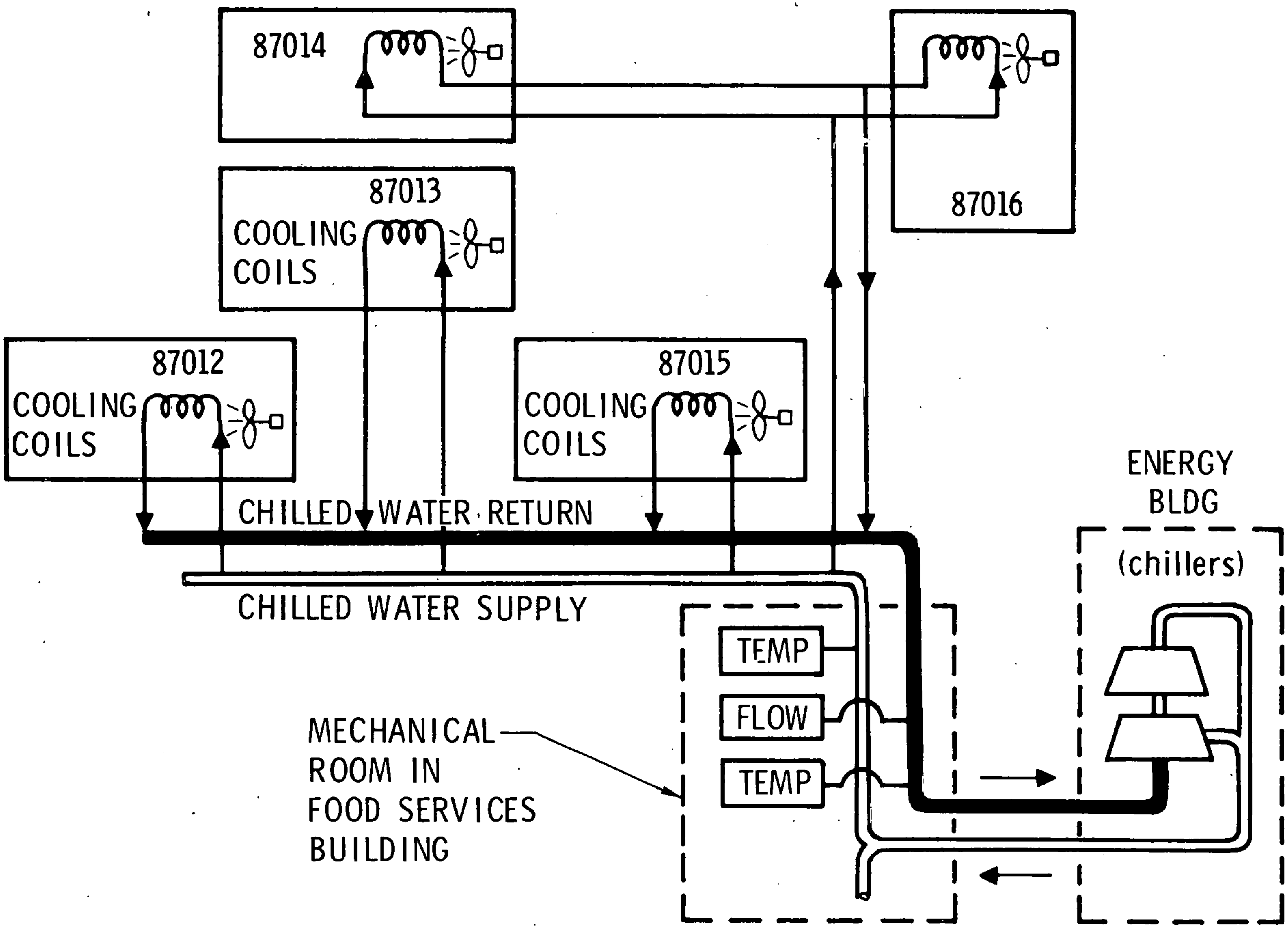


Chart 4-3

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

4.2 ACCURACY ASSESSMENT

This section presents a summary of the analysis and conclusions reached regarding the accuracy of the energy load measurements conducted by ATU at Fort Hood.

ENERGY LOAD MEASUREMENTS ACCURACY ASSESSMENT

For the electrical loads, Aerospace collected manufacturers' specifications for the instruments being used. After a review of their basic accuracy and the data reduction methods in use by ATU, Aerospace assessed the overall accuracy for data acquired with the KW/KVAR recorder to be within ±4 to 5 percent of the true value. Data acquired with the single phase Amprobe ammeters were not considered usable because of a constantly changing load distribution among the three phases.

For the thermal load measurements, the accuracy analysis was based upon an evaluation of the error involved in determining the change in enthalpy in the measured working fluid between two measuring stations (supply and return). Instrument manufacturers' accuracy specifications, estimates of the accuracy where data were not available, and estimates of readout errors were evaluated for the various elements of the space heating and air conditioning load measurement system. These error estimates were then combined using a simple form of the mathematical theory of observations to yield an estimate of the total system error in determining the working fluid's enthalpy change to one standard deviation. The major error source was flow rate error, about ±5 percent of full scale conditions. Operation at flow levels well below full scale can degrade the accuracy to ±20 percent. The average accuracy is assessed to be ±10 percent for the thermal load measurements. The full range of variation is shown in Chart 4-4 (taken from Reference 3) for cases with and without phase change in the working fluid.

Effect of Flow Operating Regime on Measurement Error

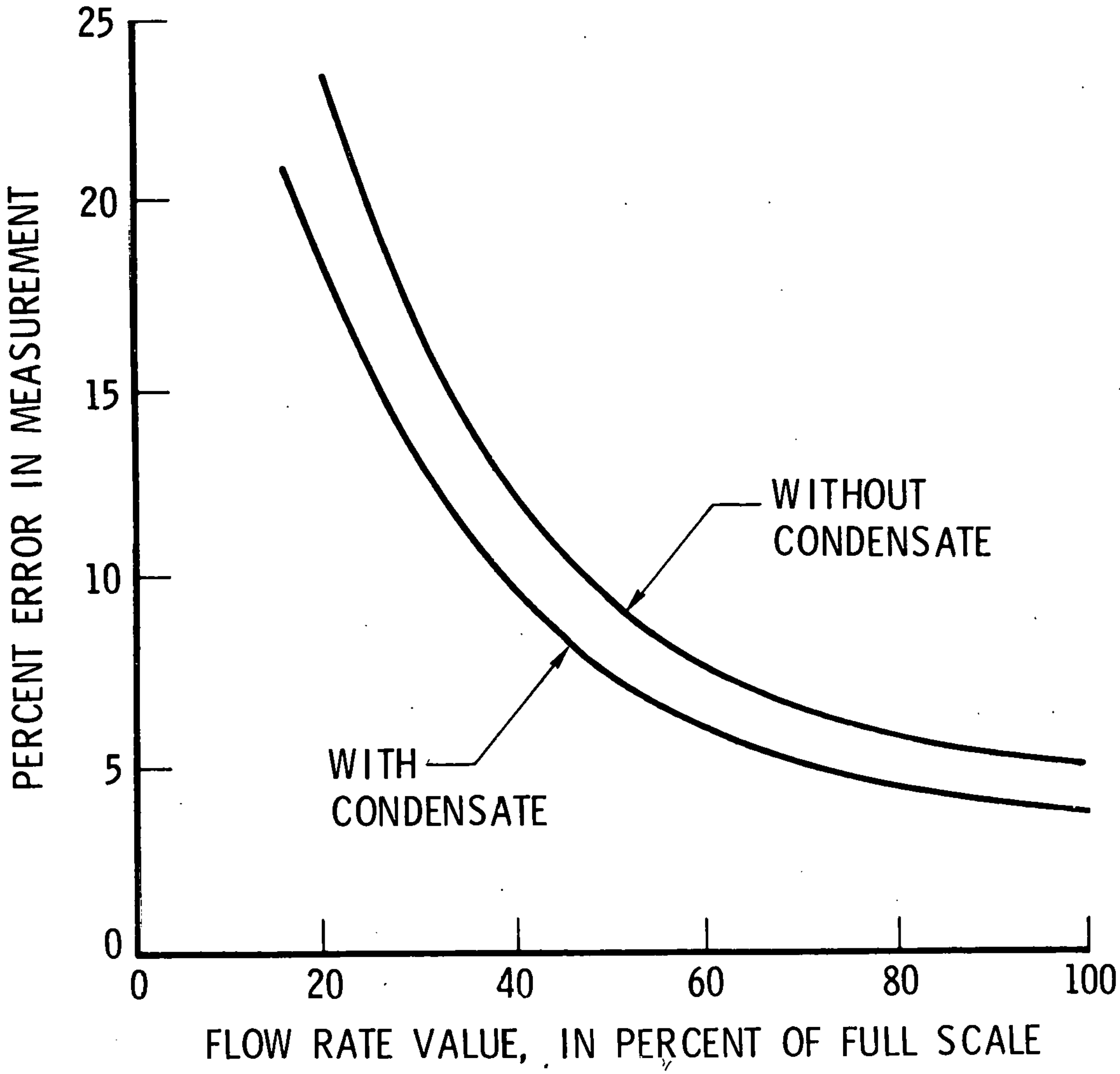


Chart 4-4

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

5.0 INSOLATION MODEL ACCURACY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

5.0 INSOLATION MODEL ACCURACY

This section presents a summary of an accuracy check made on the ATU "model year" weather tape which is the insolation model used for the Preliminary System Design of the Fort Hood STES experiment.

INSOLATION MODEL ACCURACY - AVERAGE DAILY INSOLATION

Early in the report period Aerospace was informally requested by the design subcontractor to assess the accuracy of the ATU insolation model year used in analyses of system performance. A magnetic tape copy of the ATU model year was given to Aerospace, and the data were compared with a set of measured insolation values for one particular year at Fort Hood in Aerospace files. The comparison is shown graphically in Chart 5-1.

The average daily insolation for each month of the year was computed using both sets of data. The results as shown in Chart 5-1 indicate that the model year data utilized by ATU is nearly symmetric about June while the measured data show a shift slightly away from the model year. The symmetry of the model year is a reasonable outgrowth of the synthesization of various years of data. The lower peak value of the measured data, as compared to the model data, is not cause for concern as the variation is only about seven percent. The lower values of measured data early in the year are obviously short term anomalies in the measured data and do not indicate any trends which might invalidate the model year.

Comparison of the total annual insolation amounts represented by the two curves indicates that the measured data curve differs from the model year by about four percent, which is certainly within the range of variation from one year to another.

Fort Hood Average Daily Insolation Profile

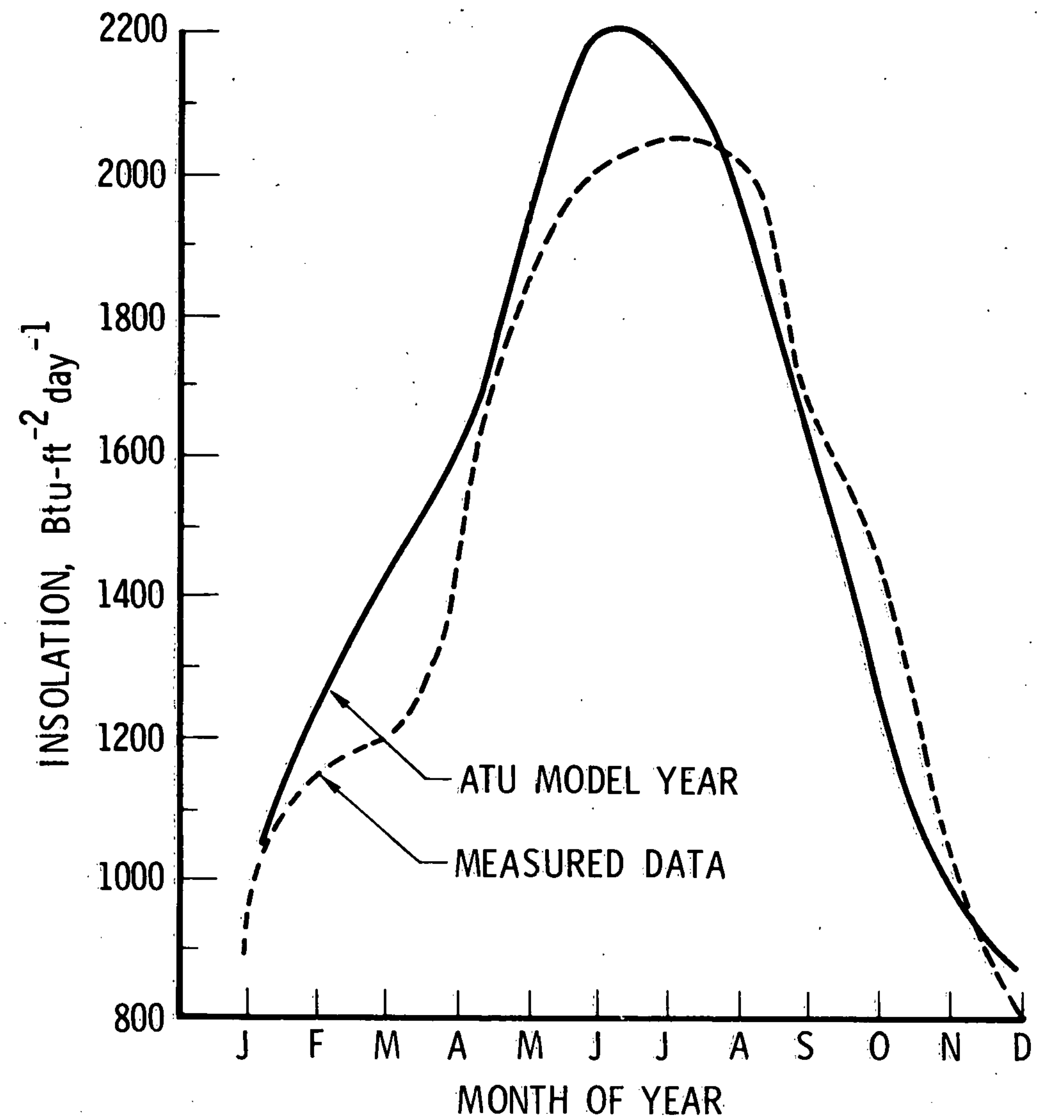


Chart 5-1

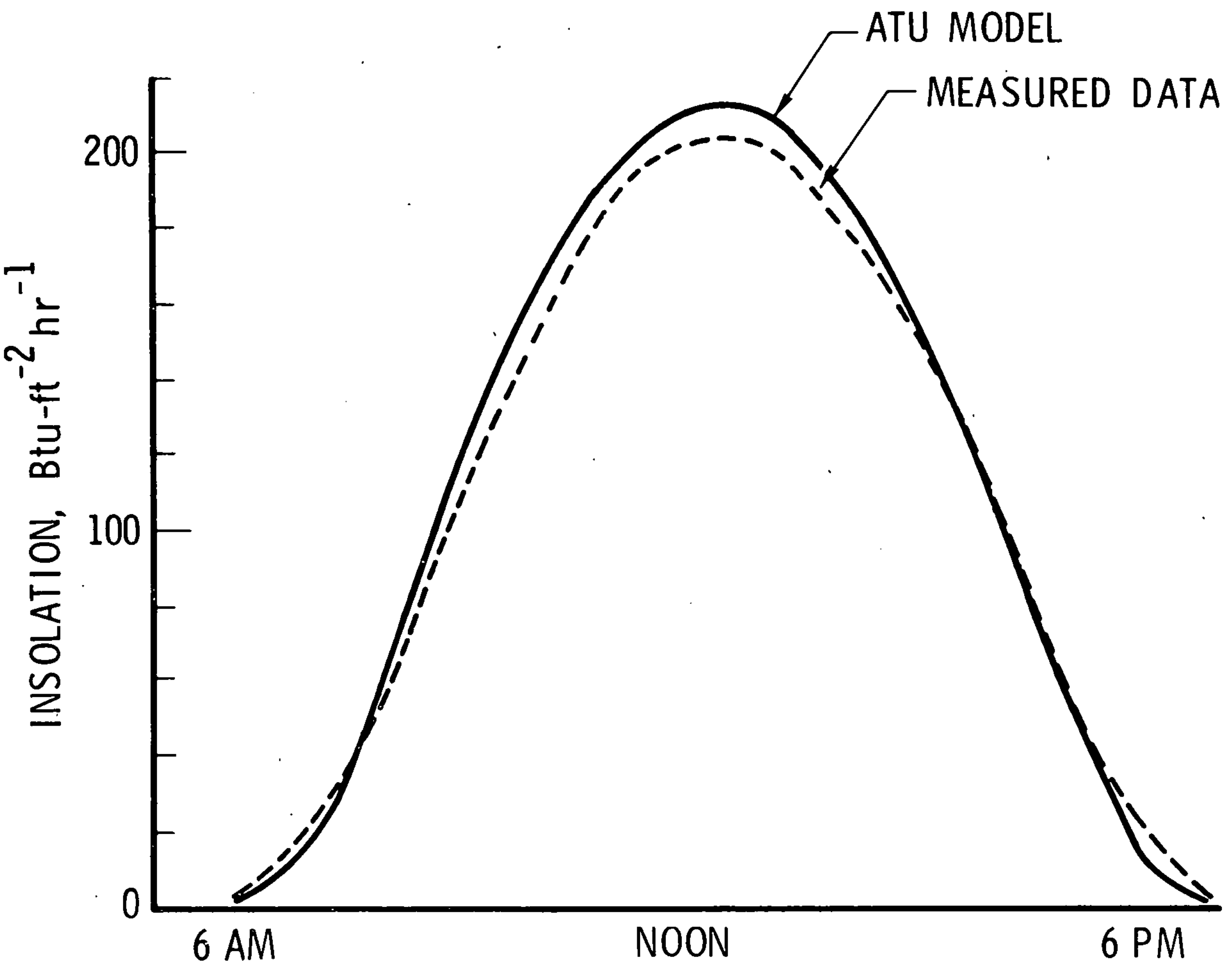
INSOLATION MODEL ACCURACY - AVERAGE HOURLY VALUES

A comparison of the average daily insolation profile in the ATU model year is compared with measured data from Aerospace files in Chart 5-2.

In a second analysis, an examination was made of the average hourly insolation values during the entire year, e.g., the average value of all the readings at 10 a.m. for both sets of data. The intent of this comparison was to determine if there were some dramatic shift in the insolation values during the day. Such a shift might be hidden in the monthly averages but might affect the performance of a system which was intended to meet peak demands at a particular time of day. The data presented in Chart 5-2 indicate that there is very close tracking of the model year to the measured data and that there is little or no shifting of the peak from the model year to the measured year. In addition, the peak values differ by three percent, which is reasonable variation in any sort of weather statistic.

In summary, Aerospace concluded there should be no cause for concern with the model year insolation values which have been used in the performance analysis of the Fort Hood experiment. Not only are the averages, peaks, and total values in close agreement, but the general trends, shape, and profile of the two sets of data are similar.

Fort Hood Average Daily Insolation Profile



THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

6.0 TECHNICAL REVIEW OF CONTRACTOR DELIVERABLES

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

6.0 TECHNICAL REVIEW OF CONTRACTOR DELIVERABLES

This section summarizes the most significant comments which were incorporated in formal technical review documentation submitted to DOE/ALO during the report period. The ATU/Westinghouse contract deliverables covered in this section are:

(1) Environmental Impact Assessment
(2) Equipment Specification-Parabolic Trough Collectors
(3) Equipment Specification-Turbine Generator
(4) Life Cycle Cost Analyses
(5) Draft Final Report for Preliminary Design Phase
(6) Project Plan for Definitive Design and Construction Phases

6.1 ENVIRONMENTAL IMPACT ASSESSMENT

The major deficiencies noted in the Environmental Impact Assessment document (Reference 4) are listed in Chart 6-1.

The cooling tower will have potential effects of producing localized fog and moisture deposition on nearby vehicles. Mitigation measures should be addressed.

The auxiliary oil-fired heater will have a 35-40 ft stack and must meet state and federal requirements on emission standards, but such standards are designed to apply on a region-wide basis. The localized effects should therefore be identified and considered in the environmental impact assessment.

A glare hazard may exist for the uncontrolled region outside the fenced area and in the region above the field.

The dismantling and relocation of certain features of Yellow Ribbon Park, where the STES Energy Building and the collector field will be located, are not mentioned.

ENVIRONMENTAL IMPACT ASSESSMENT

- MAJOR DEFICIENCIES NOTED -

- EFFECTS OF THE COOLING TOWER ARE NOT DISCUSSED
- EFFECTS OF THE OIL-FIRED AUXILIARY HEATER ARE NOT DISCUSSED
- EFFECTS OF GLARE ABOVE AND AROUND COLLECTOR FIELD ARE NOT DISCUSSED
- IMPACT OF ELIMINATING YELLOW RIBBON PARK IS NOT DISCUSSED
- SCALE DRAWINGS OF THE PROJECT ARE MISSING

Chart 6-1

6.2 EQUIPMENT SPECIFICATION - PARABOLIC TROUGH COLLECTORS

The major comments submitted by Aerospace on the Equipment Specification for Parabolic Trough Collectors (Reference 5) are listed in Chart 6-2.

The specification calls for angular position devices, e.g., shaft encoders, to be provided for sensing the orientation of the collectors. However, the location of the device is not specified nor is there any guarantee that the sensed pointing angle is consistently held for the entire mechanically coupled length of the receiver and collector.

The last item was added as a recommendation following the field trip made to inspect the trough collector installations at Willard, New Mexico.

EQUIPMENT SPECIFICATION FOR PARABOLIC TROUGH COLLECTORS

- MAJOR COMMENTS -

- A PLAN VIEW OF THE BASELINE FIELD LAYOUT SHOULD BE INCLUDED
- THE TERM "OVERALL POINTING ACCURACY" SHOULD BE DEFINED IN THE SPECIFICATION
- POTENTIAL CONTRIBUTIONS TO POINTING ERROR CAUSED BY THERMAL CYCLING OR SEISMIC MOVEMENT SHOULD HAVE COMPENSATION/ADJUSTMENT MEANS PROVIDED
- THE 10-YEAR LIFETIME REQUIREMENT FOR RECEIVERS IS QUESTIONED IN VIEW OF PRESENT TECHNOLOGY
- PROVISION SHOULD BE ADDED FOR VENDOR GUARANTEE OF FULL MECHANICAL OPERATION WITHOUT COMPONENT FAILURES AFTER REPEATED THERMAL CYCLING OF COLLECTORS BETWEEN ANTICIPATED TEMPERATURE EXTREMES

6.3 EQUIPMENT SPECIFICATION - TURBINE GENERATOR

Chart 6-3 presents the most significant comments made by Aerospace on the technical review of the Equipment Specification for a Turbine Generator for the Fort Hood project (Reference 6).

The turbine generator specification was assessed to be deficient when one considers the stage of the overall system design at the time it was presented. Substantial preliminary design of this subsystem would have to be accomplished by any vendor bidding against such a specification. The resulting lack of a complete vendor-backed design at this point reflects on the credibility of the overall STES simulation results which use the present design parameters.

There is concern about turbine blade erosion if the moisture content of the inlet steam is too high. Aerospace believes that detail specification requirements for components of the turbine generator set should be set by the supplier subject to review by the customer.

EQUIPMENT SPECIFICATION FOR TURBINE GENERATOR

- MAJOR COMMENTS -

- INCOMPLETE TURBINE GENERATOR DESIGN AT THIS STAGE REDUCES VALIDITY OF OVERALL SYSTEM MODELING
- MAXIMUM ALLOWABLE PERCENT MOISTURE IN INLET STEAM SHOULD BE SPECIFIED FOR ALL OPERATING MODES
- ELECTRIC MOTOR AND GEAR BOX SHOULD BE ADDED FOR AUTOMATIC STARTUP CAPABILITY
- NUMBER OF STARTUPS REQUIRED PER YEAR SHOULD BE ESTIMATED IN CONNECTION WITH THE 20-YEAR WARRANTY
- PERFORMANCE TESTS IN ALL SEVEN OPERATING MODES SHOULD BE REQUIRED
- ACCURACY OF ALL METERS, GAUGES, INSTRUMENTS SHOULD BE SPECIFIED

Chart 6-3

6.4 LIFE CYCLE COST ANALYSIS

The comments in Chart 6-4 are taken from the Aerospace review of a Westinghouse technical memorandum (Reference 7) and ATU presentation material on the subject presented at the Second Design and Project Review, August 4, 1978.

The Westinghouse analysis, using a formula developed by ATU during the Conceptual Design Phase, evaluated the Fort Hood experiment from the perspective of government, utility, and commercial ownership. Most of the comments in Chart 6-4 relate to the assumptions and methodology used in the ATU Life Cycle Cost Model.

In an FPC type of tariff calculation, referred to in the first item, the cost of service covers all operating expenses, capital costs and allowed returns to capital. That would be appropriate when assuming utility ownership of the plant.

LIFE CYCLE COST ANALYSES

- MAJOR COMMENTS -

- ATU METHODOLOGY DOES NOT INCLUDE FPC TYPE OF TARIFF CALCULATIONS IN MODELING UTILITY SERVICE COSTS
- THE METHOD USED LACKS THE CAPABILITY TO PROPERLY MODEL COSTS OVER AN EXTENDED CONSTRUCTION PERIOD
- WITH RESPECT TO CAPITAL COST ACCOUNTING, THE ATU METHODOLOGY WILL TEND TO IMPART A DOWNWARD BIAS TO THE COST OF THE SOLAR ENERGY SYSTEM
- ESCALATION RATES FOR FUEL AND ELECTRICITY ASSUMED BY WESTINGHOUSE WILL TEND TO MAKE SOLAR LOOK MORE FAVORABLE THAN IT WOULD IF AEROSPACE/SHERMAN CLARK ASSOCIATES' RATES WERE USED
- COST/kWh OF SOLAR-DERIVED ELECTRICITY SHOULD BE COMPUTED ONLY FROM COSTS CLEARLY RELATED TO ELECTRIC GENERATION
- COSTS OF CONVENTIONAL THERMAL ENERGY GENERATION EQUIPMENT SHOULD BE EXCLUDED WHEN EVALUATING FORT HOOD TYPE OF SOLAR ENERGY SYSTEM FOR OTHER INSTALLATIONS

Chart 6-4

6.5 DRAFT FINAL REPORT FOR PRELIMINARY DESIGN PHASE

Evaluation of the Preliminary Design effort was accomplished by the procedure in Chart 6-5.

For the technical review of the Preliminary Design of the Fort Hood STES, as described in the ATU/Westinghouse Draft Final Report (Reference 8) and as presented at the third and final Design and Project Review in October 1978, DOE/ALO asked Aerospace to chair a specially appointed Review Committee to accomplish not only that technical review but also a detailed review of the construction cost estimates submitted by the contractor in Reference 10.

Aerospace established the evaluation procedure diagrammed in Chart 6-5. The 10-member Review Committee appointed by DOE consisted of representatives from DOE Headquarters, DOE/ALO, Oak Ridge National Laboratories, Sandia Laboratories, Army Corps of Engineers, and The Aerospace Corporation.

Aerospace issued detailed guidelines and instructions for the review procedure, made assignments for individual evaluation of distinct areas of the system design and the detailed cost estimates, chaired the meetings of the committee (October 17-19, 1978 at Albuquerque), and handled communications with the contractor to obtain answers to questions raised by the committee. The 81-page summary report was published on November 1978 (Reference 9).

Preliminary Design Evaluation Procedure

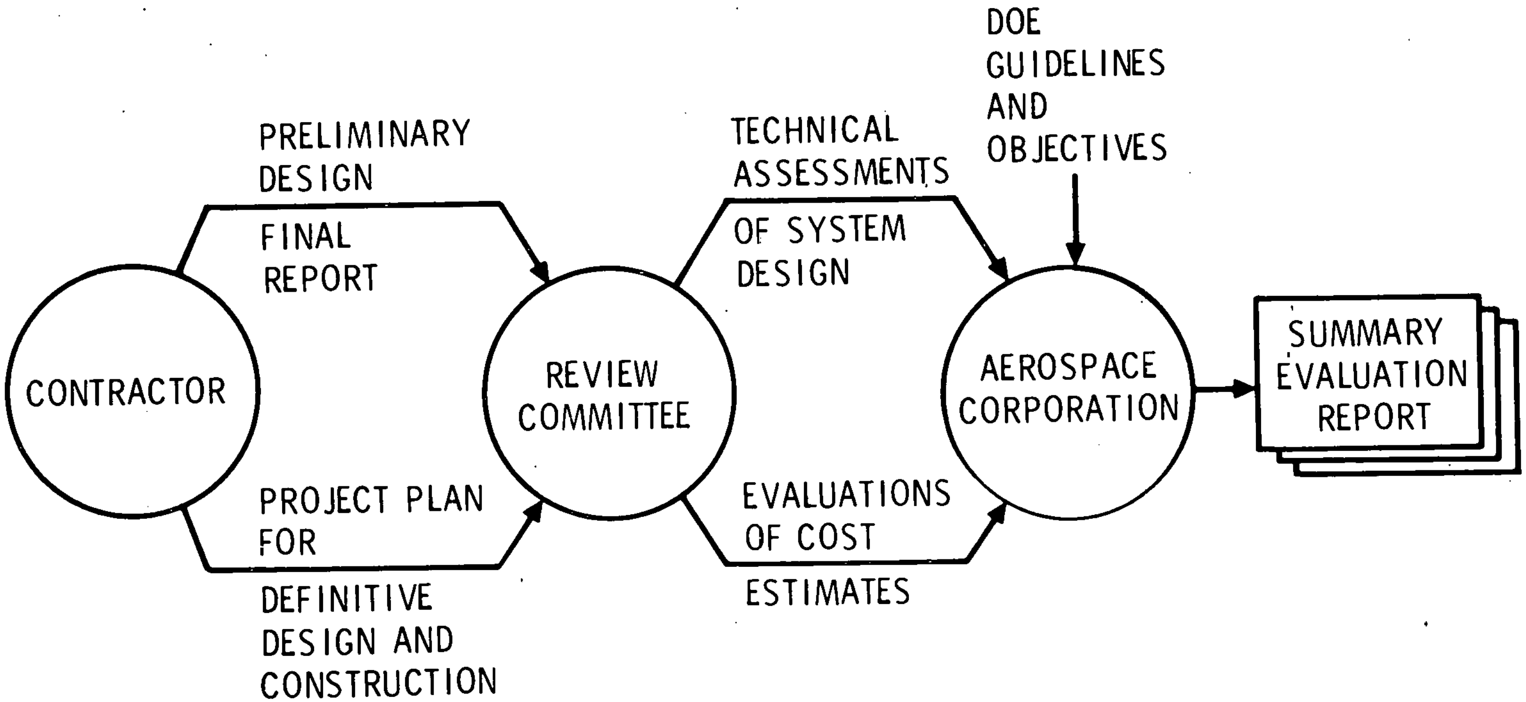


Chart 6-5

TECHNICAL ASSESSMENT OF PRELIMINARY SYSTEM DESIGN

The technical review of the Fort Hood STES Preliminary Design was apportioned among the Review Committee members according to their areas of expertise for the eight topics listed in Chart 6-6.

A format for written evaluations was used for all system design categories soliciting reviewers' comments in the following categories:

(a) Weak Points in Design

(b) Strong Points in Design

(c) High Technical Risk Areas

(d) Other Comments

SYSTEM DESIGN CATEGORIES EVALUATED BY REVIEW COMMITTEE

- SOLAR COLLECTOR SUBSYSTEM
- THERMAL STORAGE SUBSYSTEM
- POWER CONVERSION SUBSYSTEM
- INSTRUMENTATION AND CONTROL SUBSYSTEM
- HEATING/CHILLING AND DOMESTIC HOT WATER SUBSYSTEM
- ELECTRICAL INTERFACES AND POWER OUTAGE PROVISIONS
- FACILITY AND BUILDING DESIGNS
- OPERATING STRATEGY AND OVERALL SYSTEM DESIGN APPROACH

Chart 6-6

SUMMARY OF REVIEW COMMITTEE COMMENTS

A summary of the major strong and weak points noted in the Fort Hood system design by the Review Committee are listed in Chart 6-7.

Outstanding strong points in the design which are major innovations since the 1977 Conceptual Design are believed to be the increase in temperature differential across the collector field and the three-subfield feedforward control arrangement. The change in temperature differential from 380°F to 550°F to a spread from 316°F to 575°F allows greater collection efficiency, a potentially higher capacity thermal storage subsystem, and the extraction of more energy from the heat transfer fluid before it reenters the collector field. The feedforward field control concept (discussed in Section 2.4 of this report) allows lowering the insolation threshold for useful collection and prevents the occurrence of oil overheating in the collector strings during cloud-induced transients.

Weak points centered mainly around the deficiency in system simulation under transient conditions and inadequate documentation of trade studies and criteria used in the selection of various key component designs. In some cases, poor judgment was used in selection of components and materials.

REVIEW OF PRELIMINARY DESIGN

STRONG POINTS

- GOOD FLEXIBILITY IN ENERGY USAGE PROVIDED FOR IN SYSTEM DESIGN
- PROVISIONS FOR AVOIDING OVER-TEMPERATURE CONDITIONS IN COLLECTOR FIELD
- FIELD DESIGN ALLOWS OPERATION WITH LOW INSOLATION LEVELS
- 3-LEVEL THERMAL STORAGE ALLOWS GREATER ΔT ACROSS COLLECTORS
- INSTRUMENTATION AND CONTROL SYSTEM USES OFF-THE-SHELF HARDWARE AND SHOWS GOOD BALANCE BETWEEN CENTRAL AND LOCAL CONTROL
- JOINT STORAGE FACILITIES FOR HEATED/CHILLED WATER
- MINIMIZED IMPACT TO EXISTING ROADS AND FACILITIES

WEAK POINTS

- INCOMPLETE SIMULATION TESTING AND TRANSIENT ANALYSES OF FIELD CONCEPTS
- INADEQUATE ATTENTION WAS GIVEN TO ENERGY CONSERVATION IN STES BUILDING DESIGN
- MORE ATTENTION SHOULD BE GIVEN TO USE OF THIN-WALLED TUBING AND LOW DENSITY INSULATION
- CONTROL LAWS FOR NEW FIELD DESIGN NOT ADEQUATELY STATED
- SYSTEM DESIGN FORCES OCCASIONAL STOWING OF COLLECTORS WITH FULL SUN CONDITIONS
- PUMPS CHOSEN FOR MOVING HOT OIL ARE OF INADEQUATE QUALITY
- TURBINE GENERATOR SELECTION PROCESS AND SUBSTANTIATING VENDOR DATA ARE NOT PRESENTED

Chart 6-7

6.6 PROJECT PLAN FOR DEFINITIVE DESIGN AND CONSTRUCTION PHASES

Reference 10 presented the contractor's plan for the Definitive Design Phase showing tasks, schedules, and costs. That was not dealt with by the Review Committee but rather by Aerospace as a part of its normal DOE/ALO project support. Substantial changes to the plan presented in Reference 10, with options, were recommended by Aerospace and are summarized in Chart 6-8.

For a 10-month Definitive Design effort, the total cost estimate was reduced from \$4516K as proposed in the plan to \$4057K by means of ATU task reductions and some lowering of direct costs.

To accommodate an anticipated Fort Hood project budget ceiling in FY 79, Case 2 was prepared with a 15-month schedule and approximately \$600K additional cost but with only \$1748K required during FY 79. Purchase orders for major long lead items would be delayed under Case 2 until FY 80, but procurement of an initial collector array segment (1560 ft^2) was provided in FY 79 to expedite the selection of that critical design component.

SUMMARY OF RECOMMENDATIONS FOR DEFINITIVE DESIGN PHASE

- TWO OPTIONS PREPARED FOR DOE/ALO CONSIDERATION
  - CASE 1: 10 MONTHS, $4057K TOTAL COST (ALL IN FY 79)
  - CASE 2: 15 MONTHS, $4653K TOTAL COST ($1748K IN FY 79)
- INCREASE DESIGN REVIEWS FROM TWO TO THREE (CASE 1)
- DELETE LIFE CYCLE COST ANALYSES AND INTEGRATED LOGISTIC SUPPORT PLANNING TASKS
- REVISE ATU TASK DESCRIPTIONS AND MANPOWER ALLOCATIONS
- ADD PROCUREMENT OF PARTIAL COLLECTOR ARRAY IN FY 79 FOR CASE 2 ($100K COST)

Chart 6-8

CONSTRUCTION PHASE COST ESTIMATES

Following the procedure for technical review of the system design, various portions of the detailed cost estimates for construction were assigned to different members of the Review Committee. The seven categories are listed in Chart 6-9.

During the time the committee was convened, a number of questions relating to missing or incomplete cost information were relayed to ATU which was very prompt in responding with the needed data.

The full review by Aerospace of Construction Phase task descriptions, manpower allocations, construction management fees, and the construction schedule did not occur during the report period, and are not included in this report.

CONSTRUCTION PHASE COST ESTIMATE CATEGORIES

- SITE PREPARATION
- SOLAR COLLECTOR SUBSYSTEM
- THERMAL STORAGE SUBSYSTEM
- POWER CONVERSION SUBSYSTEM
- HEATING/CHILLING AND DOMESTIC HOT WATER SUBSYSTEM
- STES BUILDING
- OVERALL INSTRUMENTATION AND CONTROL SUBSYSTEM

REVIEW OF CONSTRUCTION COST ESTIMATE

A summary of major discrepancies noted by the Review Committee in the detailed cost estimate for plant construction is given in Chart 6-10.

As pointed out by committee members from Sandia Laboratories familiar with component selection difficulties when dealing with hot oil pumping systems and balancing of hot oil flow in a collector field, many of the items priced indicated a lack of appreciation for the stringent requirements on fluid handling components in those applications.

REVIEW OF CONSTRUCTION COST ESTIMATE

ITEM	
COLLECTOR FIELD FOOTINGS	$56,400 LOW
FLOW CONTROL VALVES - COLLECTOR STRINGS	28,000 LOW
COLLECTOR FLUID DRAINAGE VALVES	58,000 LOW
INSULATION FOR THERMAL STORAGE TANKS	30,000 LOW
HEATING/CHILLING AND DOMESTIC HOT WATER SUBSYSTEM	6,800 LOW
PUMPS AND VALVES IN THERMAL STORAGE SUBSYSTEM	LOW[a]
3-WAY VALVES AND GATE VALVE (FIELD CONTROL)	LOW[a]
TURBINE GENERATOR	LOW[b]
LABOR COSTS	LOW[c]

[a] Prices given do not correspond to the quality of item needed.

[b] Performance and detailed analytic modeling data not included.

[c] Labor overhead and management costs not included.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

7.0 REFERENCES

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

REFERENCES

1. "Preliminary Modeling and Collector Sizing Analysis, Fort Hood Solar Total Energy Project," R. J. Waldron, Jr., 5 April 1978, Aerospace Report No. ATR-78(7733)-1.

2. "Oil Overtemperature Versus Effective Defocusing Rate," R. G. DeBiase, 24 October 1978, Aerospace Report No. ATM-79(7743)-1.

3. "An Assessment of the Accuracy of Energy Load Measurements at Fort Hood," David H. Ross, July 1978, Aerospace Report No. ATR-78(7743)-1.

4. "Environmental Impact Assessment, Fort Hood Solar Total Energy Project," (Draft), 31 August 1978, American Technological University.

5. "Equipment Specification for Parabolic Trough Solar Collector," (Draft), Westinghouse AESD, 6 September 1978, Westinghouse Document No. E-677542.

6. "Fort Hood STE-LSE Turbine Generator Specification," Westinghouse AESD, 20 October 1978, Westinghouse Document No. E-677563.

7. "Value of Energy Within STE-LSE," J. A. Christenson and B. S. Preble, 19 May 1978, Westinghouse Data Release Memorandum No. DA-0553.

8. "Fort Hood Solar Total Energy Project" - Preliminary Draft Final Report, October 1978, American Technological University. Vol. I: Executive Summary (ALO/4231/09-1), Vol. II: Preliminary Design (ALO/4231/09-2), Vol. III: Engineering Drawings (ALO/4231/09-3), Vol. IV: Management Plan (ALO/4231/09-4).

9. "Review of Preliminary Design, Fort Hood Solar Total Energy Project," The Aerospace Corporation, November 1978.

10. "Fort Hood Solar Total Energy Project, Project Plan, Definitive Design and Construction Phases," October 1978, American Technological University.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-640-258-1514