310
2/15/80

DR.680

DOE/CS/40046-1(Vol.1)

# TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT

Final Report for Phase-I System Design for June 6, 1978—February 28, 1979

MASTER

By
William M. Marcy
Richard A. Dudek

March 30, 1979

Work Performed Under Contract No. ET-78-C-04-4269

College of Engineering
Texas Tech University
Lubbock, Texas

## U.S. Department of Energy



Solar Energy

## DISCLAIMER

# DISCLAIMER

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

Price: Paper Copy $10.75
Microfiche $3.00

DOE/CS/40046-1(Vol.1)
Distribution Category UC-63c

# TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT

FINAL REPORT FOR PHASE-I SYSTEM DESIGN

FOR THE PERIOD

6 JUNE 1978 - 28 FEBRUARY 1979

WILLIAM M. MARCY

RICHARD A. DUDEK



30 MARCH 1979

WORK PERFORMED UNDER CONTRACT

ET-78-C-04-4269

TEXAS TECH UNIVERSITY
COLLEGE OF ENGINEERING
DEPARTMENT OF SYSTEMS
BOX 4200
LUBBOCK, TEXAS 79409

TABLE OF CONTENTS VOL. 1


| | | Page |
|---|---|---|
| CHAPTER I | FINAL REPORT TASK TEAM-1 EXECUTIVE SUMMARY | I-1 |
| | ABSTRACT | I-1 |
| | INTRODUCTION | I-2 |
| | APPLICATION LOAD AND UTILITY INTERFACE | I-3 |
| | SYSTEM DESIGN | I-4 |
| | SYSTEMS ANALYSIS | I-11 |
| | ENVIRONMENTAL INPACT | I-16 |
| | DATA COLLECTION | I-17 |
| CHAPTER II | FINAL REPORT TASK TEAM-2 SOLAR/GRID INTEGRATION | II-1 |
| | ON-SITE WIRING | II-1 |
| | SOLAR UTILITY INTERFACE | II-1 |
| | LIGHTNING PROTECTION | II-2 |
| CHAPTER III | FINAL REPORT TASK TEAM-3 SOLAR PVC SYSTEM ENGINEERING | III-1-1 |
| | SECTION-i INTRODUCTION | III-1-1 |
| | SECTION ii PROGRAM SUMMARY | III-2-1 |
| | SECTION iii BASELINE DESIGN | III-3-1 |
| | SECTION iv COMPONENT SPECIFICATIONS | III-4-1 |
| | SECTION v ORIGINAL DESIGN CONCEPT | III-5-1 |
| | SECTION vi SUPPORTING ANALYSES | III-6-1 |
| | SECTION vii PHASE-II DETAIL | III-7-1 |
| | SECTION viii PHASE-III CONCEPTS | III-8-1 |

| | | Page |
|---|---|---|
| CHAPTER IV | FINAL REPORT TASK TEAM-4 THERMAL ENERGY REJECTION. | IV-1 |
| | THERMAL REJECTION SYSTEM DESIGN TRADEOFFS. | IV-1 |
| | PERFORMANCE PREDICTIONS FOR THE EVAPORATION ASSISTED AIR COOLER. | IV-5 |
| | FIELD PIPING ARRAY DESIGN. | IV-9 |
| | REFERENCES | IV-16 |
| CHAPTER V | FINAL REPORT TASK TEAM-5 CONSTRUCTION. | V-1 |
| | PROJECT SUMMARY. | V-1 |
| | ATTACHMENT-1 SOIL TESTING. | V-3 |
| | ATTACHMENT-2 FINAL PIER DESIGN | V-11 |
| | ATTACHMENT-3 COST COMPARISON OF CONCRETE VS STEEL PILE | V-16 |
| | ATTACHMENT-4 TRANS-PECOS EXPERIMENT BUILDING SPECIFICATIONS. | V-17 |
| | ATTACHMENT-5 SITE RESTORATION TRADEOFF STUDY | V-22 |
| | ATTACHMENT-6 ENVIRONMENTAL ASSESSMENT. | V-24 |
| | ATTACHMENT-7 STRUCTURAL TESTS. | V-29 |
| CHAPTER VI | FINAL REPORT TASK TEAM-6 DATA COLLECTION AND ANALYSIS. | VI-1 |
| | DATA COLLECTION REQUIREMENTS | VI-5 |
| | DATA COLLECTION SPECIFICATIONS. | VI-7 |
| CHAPTER VII | FINAL REPORT TASK TEAM-7 TECHNOLOGY ASSESSMENT. | VII-1 |
| | PURPOSE. | VII-1 |
| | METHOD | VII-2 |
| | RESULTS. | VII-4 |
| | TECHNOLOGY ASSESSMENT MODEL. | VII-8 |
| | AFFECTED PARTIES | VII-9 |
| | CAUSAL DIAGRAM | VII-15 |

Page

CHAPTER VIII FINAL REPORT TASK TEAM-8 SITE LOCATION AND ANALYSIS . . . . . . . . . . . . . . . . . . . . . . VIII-1

CHAPTER IX FINAL REPORT TASK TEAM-9 SYSTEMS ANALYSIS. . . . . . IX-1

INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . IX-1

RESULTS. . . . . . . . . . . . . . . . . . . . . . . . . IX-2

REFERENCES . . . . . . . . . . . . . . . . . . . . . . . IX-4

CHAPTER X FINAL REPORT TASK TEAM-10 IRRIGATION AND AGRICULTURE. . . . . . . . . . . . . . . . . . . . . X-1

INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . X-1

OBJECTIVES . . . . . . . . . . . . . . . . . . . . . . . X-2

FINDINGS . . . . . . . . . . . . . . . . . . . . . . . . X-8

SUMMARY AND LIMITATIONS. . . . . . . . . . . . . . . . . X-14

CHAPTER XI FINAL REPORT TASK TEAM-11 SURVIVABILITY, SAFETY AND MAINTENENCE. . . . . . . . . . . . . . . . XI-1

FAILURE MODE AND HAZARD ANALYSIS . . . . . . . . . . . XI-1

CLEANING SYSTEM. . . . . . . . . . . . . . . . . . . . . XI-2

OPERATION AND EVALUATION PLAN. . . . . . . . . . . . . . XI-8

SAFETY. . . . . . . . . . . . . . . . . . . . . . . . . XI-9

CONTENTS OF APPENDICES VOL. 2


| | | Page |
|---|---|---|
| APPENDIX A | BASELINE DESIGN DETAIL. . . . . . . . . . . . . | A-1 |
| APPENDIX B | ORIGINAL CONCEPT DETAIL . . . . . . . . . . . . | B-1 |
| APPENDIX C | OCLI FINAL REPORT (not available) . . . . . . . . . | C-1 |
| APPENDIX D | EVAPORATIVE ASSISTED HEAT EXCHANGER SIMULATION SUBROUTINE AIRHEX . . . . . . . . . . . . . . . . | D-1 |
| APPENDIX E | PHOTOVOLTAIC CONCENTRATOR MODEL. . . . . . . . . . . | E-1 |
| APPENDIX F | SOLAR ECONOMIC COST ACCOUNTING COMPUTER PROGRAM. . . | F-1 |
| APPENDIX G | SENSITIVITY STUDIES OF THE ERDA/JPL ECONOMIC MODEL. . | G-1 |
| APPENDIX H | A GASP-IV SIMULATION MODEL OF THE CONCENTRATING PHOTOVOLTAIC SOLAR ENERGY SYSTEM. . . . . . . . | H-1 |
| APPENDIX I | SURVIVABILITY, SAFETY, AND MAINTENANCE . . . . . . . | I-1 |

CHAPTER I

FINAL REPORT OF TASK TEAM-1

MANAGEMENT AND COORDINATION

# TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT

**(Executive Summary)**

**Submitted To:**

U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Pennsylvania and H Street
Kirtland Air Force Base East
Albuquerque, NM 87185

**Prepared By:**

Dr. William M. Marcy (Department of Systems)
Dr. Richard A. Dudek (Department of Industrial Engineering)
College of Engineering
Texas Tech University
Lubbock, Texas 79409

# CHAPTER I

## FINAL REPORT OF TASK TEAM-1 EXECUTIVE SUMMARY MANAGEMENT AND COORDINATION TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT

William M. Marcy and R.A. Dudek

## ABSTRACT

The Trans-Pecos Photovoltaic Concentrating Experiment is the design of a 200 kWe peak photovoltaic concentrating system applied to deep well irrigation in the Trans-Pecos region of Texas. The site selected is typical of deep well irrigation in arid regions of Texas, New Mexico, and Arizona. The existing well utilizes a 200 horse power, three phase, 480 volt industion motor to lift water 540 feet to irrigate 380 acres.

The Trans-Pecos Photovoltaic Concentratinc (PVC) system employs a two axis (azimuth-elevation) tracking parabolic concentrator module that focuses sunlight at 38X concentration on two strings of actively cooled silicon solar cells. The direct current from a field of 102 collector modules is converted by a maximum power point electric power conditioning system to three phase alternating current. The power from the power conditioning system is connected through appropriate switchgear in parallel with the utility grid to the well's induction motor.

The operational philosophy of the experiment is to displace daytime utility power with solar generated electric power. The solar system is sized to provide approximately 50 per cent of the 24 hour energy demand of the motor. This requires an energy exchange with the utility since peak solar power (200 kWe) generated exceeds the peak motor demand (149.2 kWe). The solar system daily generation together with the seasonal irrigation demand are such that the installation of the

solar system would provide peak shaving for the utility during the summer months.

The solar PVC system provides a net electric peak AC power of 200.0 kWe at solar noon on March 10, the mid-point of the spring pre-planting irrigation season. The annual energy production is projected to be 511 Mwh using El Paso, Texas solar TMY data. System electrical power production efficiency is projected to be 7.4 percent at the design point, and 7.0 percent on an annual electrical energy production basis. The system is projected to provide 37.8 percent of the 24 hour energy demand of the motor at the design point of March 10, excluding energy delivered to the grid in excess of motor demand. The total energy produced is projected to be 49.0 percent of the 24 hour energy demand of the motor at the design point of March 10.

## INTRODUCTION

The baseline system is composed of selected components and subsystems functionally designed and specified for production of AC electric power. Requirements for electric power were that the net AC output from the electric power conditioning system (1) be of sufficient quantity to significantly service the application load demand on an annual basis, (2) supply 100 percent of the application load demand at the specified design point, and (3) be of sufficient quality to permit interconnection with the existing utility grid distribution network.

The mechanical, thermal, and electrical implementation concepts developed for the Trans-Pecos experiment are detailed in chapters II,III,IV, and V of this report as accomplished by the task teams. The system design is based upon the use of photovoltaic generated electrical energy to displace load induced demand upon utility supplied energy. The most significant benefit resulting from direct utility interconnection is the operational buffering from trnasients that typically characterize both the solar photovoltaically generated energy and the daily and seasonal load variations.

Finally, the PVC system design is mechanized to provide positive protection from both short- and long-term environmental threats. The Trans-Pecos region of Texas is subject to sudden and often severe thunderstorm activity producing frequent lightning strikes, sizeable hail, and strong gusting winds. The solar PVC system is designed to survive such conditions and will be installed with protection systems instrumented for data collection. Details concerning survivability, safety, and maintenance may be found in Chapter XI of this report.

## APPLICATION LOAD AND UTILITY INTERFACE

The Community Public Service Company of Pecos, Texas provides power to the site selected on the Garvin G. Passmore Farm, 14 miles south of Pecos, Texas through a three phase 24.9 Kv, shielded, distribution line with primary KwH and peak demand metering. The utility short-circuit capacity is 8,895 amperes. At the solar site, the 24.9 Kv power is transformed to 480 volts using three 7 KVA transformers connected in a Y-delta bank. The 480 volt secondary is connected through a Delta™ Switchboard Company combination part-winding starter to the 200 horse power motor. Short circuit and overcurrent protection are provided by 200 ampere time delay fuses. The motor nominal starting current is 1000 amperes.

The output of the solar field DC to AC power conditioning inverter is connected to the 480 volt transformer bank through a 400 ampere fused disconnect. An undervoltage relay connected at this point automatically disconnects the solar system from the utility in the event of loss of utility grid power. Under weather threat conditions, should utility power be interrupted, the solar system central controller will start a standby diesel generator to supply sufficient power to stow the collectors in a protected configuration.

## SYSTEM DESIGN

**Components and interconnections required to install the solar PVC system in the presence of the existing utility grid and the existing application load are shown in figure 1.**

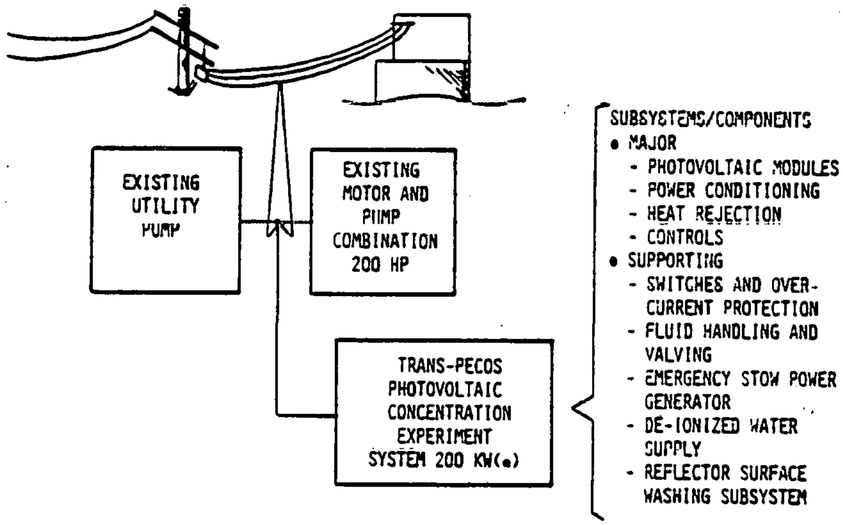



Fig.1 Major System Interconnections

The power production system is composed of four major subsystems and related components. The major subsystems are: (1) the two-axis tracking photovoltaic collector modules, (2) the electric power conditioning subsystem, (3) the heat rejection subsystem, and (4) the control subsystem. Related supporting components include : field wiring, switch gear, overcurrent protection, field plumbing, field valving, emergency stow generator, and the collector washing equipment.

Photovoltaic Concentrator Modules- The base line system is composed of 102 photovoltaic concentrator modules which produce a gross electrical power output of 252 KW at the design point of March 10, solar noon. Each PVC module as shown in

Figure 2 is a two-axis tracking elevation over azimuth mechanization attached to a single center pedastal.

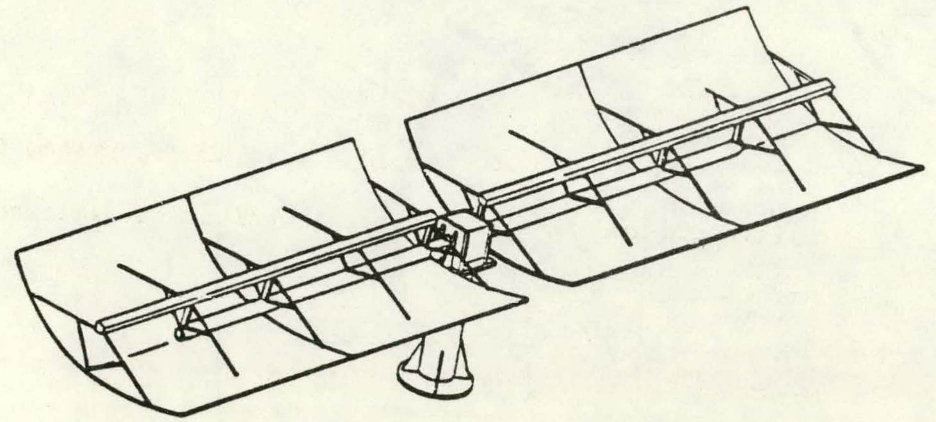


Fig. 2 Photovoltaic Concentrator Module

The module pedastal is secured to a reinforced concrete foundation. Alternating current induction motors power the elevation and azimuth motions through high torque, anti-backlash gear reducers.

Each of the photovoltaic collectors mounted on a module is composed of a concentrating parabolic reflector and a photovoltaic receiver. The reflectors are parabolic with a 24 inch focal length and have a 90 degree rim angle. The resultant aperture is 8 feet 2 inches wide by 18 feet long and produces a 45:1 geometric concentration ratio at the receiver. Each reflector is constructed of four, half-parabolic aluminum honeycomb-cored panels of bonded construction. The reflective surface is an integral part of the reflector panel's construction and consists of a 0.0200 inch thick sheet of KINGLUX$^{tm}$ aluminum sheet.

The photovoltaic receiver utilizes an aluminum extrusion that serves simultaneously as a photovoltaic cell mounting surface, thermal heat sink, coolant channel, wiring conduit, and self-supporting beam. Figure 3 Illustrates the photovoltaic receiver.

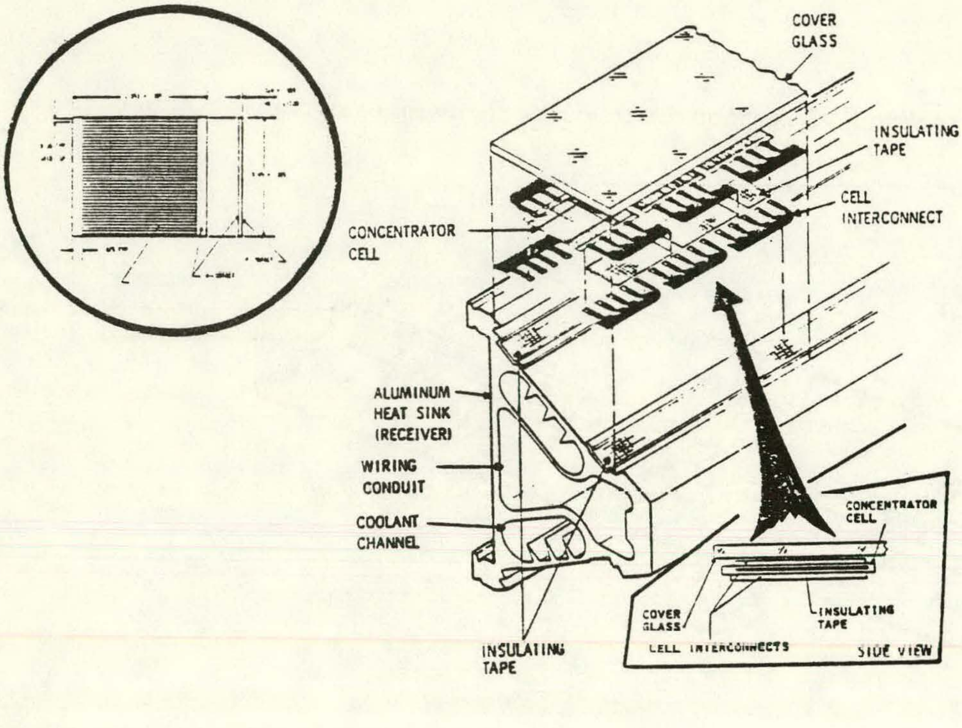



Fig. 3 Collector Module Photovoltaic Receiver

Power Conditioning Subsystem- The power conditioning subsystem is composed of twin-paralleded solid state DC to AC inverters designed upon current-fed, line commutated technology. Each inverter is nominally rated at 125 KW AC output and is controlled at all times by a built-in dedicated control subsystem. A photovoltaic electrical interface network is provided on the input of each inverter to match impedence characteristics of the DC generating field. Maximum power point tracking circuitry and control algorithms are employed to achieve maximum power production from the solar collector field. An isolation transformer provides the required interface of the inverter output to the utility interconnection.

An added measure of safety is afforded the overall system in that a line commutated inverter will cease operation in the event that a fault on the utility line pulls the line voltage down, even in the event that the undervoltage relay should fail to operate. Protection of line crews working to clear faults or to perform maintenance is a principal concern to utilities when secondary generating systems are connected to the utility grid network. Figure 4 illustrates the power conditioning subsystem.

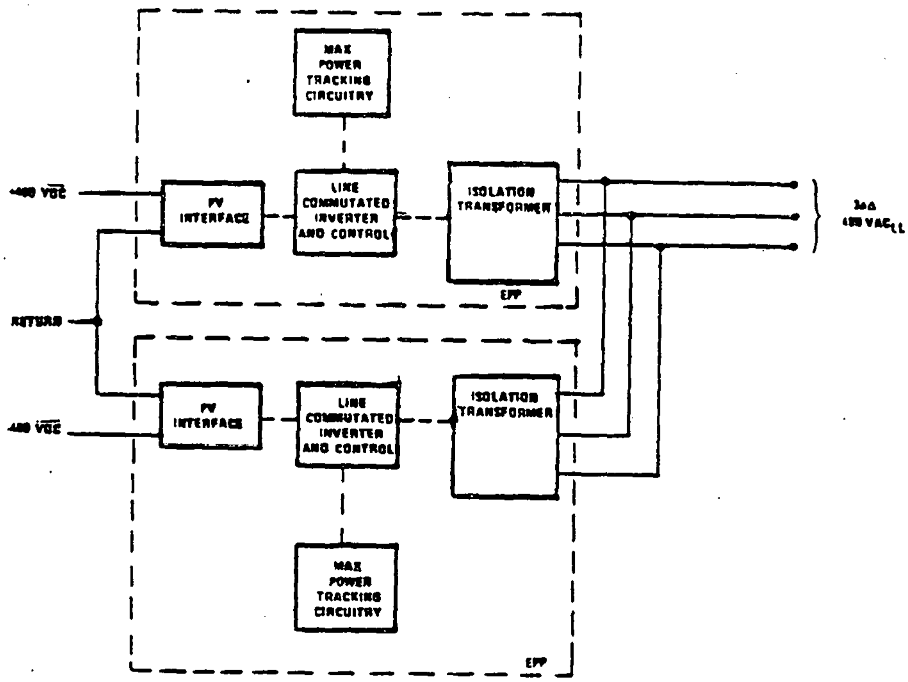



Fig. 4 The Power Conditioning Subsystem

Heat Rejection Subsystem- The heat rejection subsystem is a standard commercially available wet surface air cooler designed to take advantage of the low ambient wet-bulb temperatures typical of arid regions. The exchange media in the cooler will be operated in a contiuuously flooded manner to ensure positive removal of mineral matter that would otherwise be deposited in the media. Cooling performance is maintained by a fan-forced convection that is controlled by the cooling subsystem controller.

Plumbing and valving in the coolant transport loop is designed for both system and environmental protection. Electrically operated row isolation valves controlled by the central control system ensure that plumbing failures in any row do not result in significant spills of the ethylene glycol-water cooling solution. Flow balancing and shut-off valves at each module allow adjustment for peak field performance and provide for maintenance of individual modules with disruption of field operation.

Figure 5 illustrates the field row plumbing and valving.

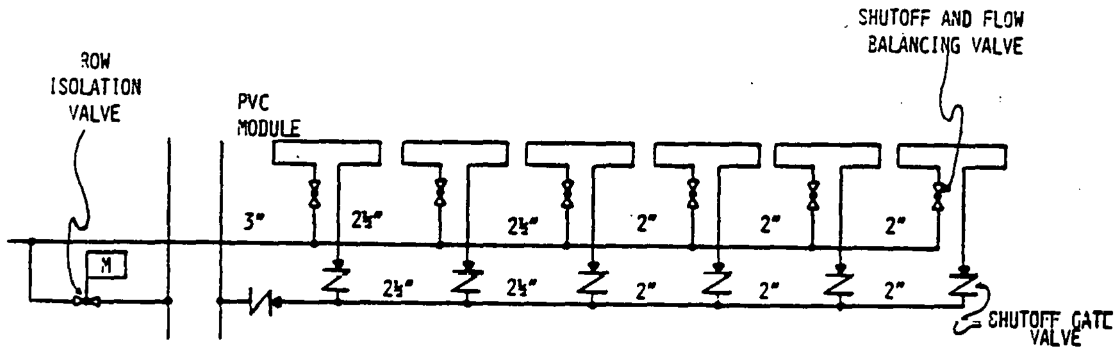



Fig. 5 Field Row Plumbing and Valving

<u>Control Subsystems</u>- Control for the solar PVC system is implemented by means of a directive central controller which commands active module-level controllers distributed one to each photovoltaic module. The central controller has overall operational responsibility, and in addition to the 102 module level controllers, also controls the essential PVC system thermal, electrical, and mechanical functions. The central and module controllers are microprocessor based systems that communicate with each other via multi-plexed data links. The central controller is powered by a dedicated battery/AC power supply ensuring continuous status monitoring of essential functions and provides the capability to institute protective measures during a utility outage.

The module level controller provides orientation control and self-protection functions. Communication with the central controller allows the module controller to receive commands and to provide current status for operator review. Data acquisition permits the module controller to measure collector cell string voltages, collector position, and to sense abnormal conditions. Outputs from the module controller actuate relays to drive positioning motors and to allow open circuit cell string voltage measurements to be made. Figure 6 depicts the solar system control states.

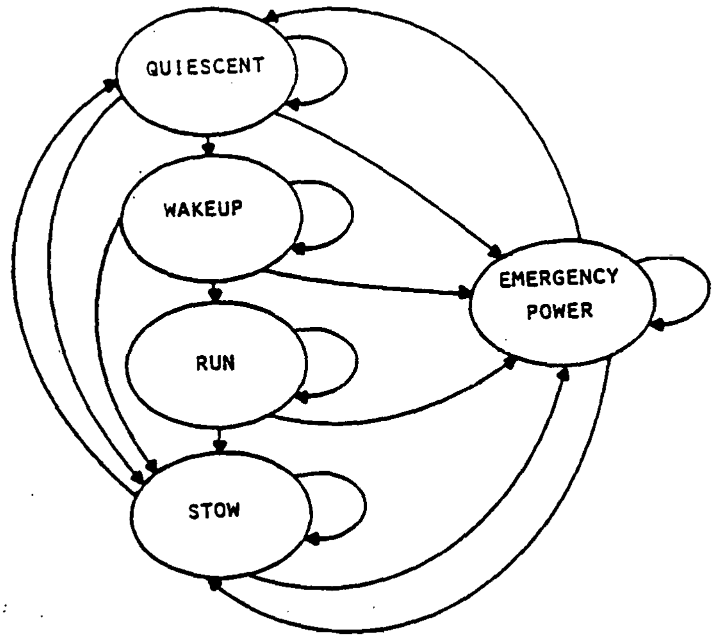



Fig. 6 Solar PVC System Control States

The module controller may operate in either a manual or an automatic mode. In the manual mode an operator can position the module via a manual control panel. The microprocessor continues to update module status and responds to the central controller communications, but cannot actuate the positioning motors. The automatic mode disables manual positioning and allows the microprocessor to execute its active solar tracking functions, it so commanded by the central controller.

Abnormal conditions which threaten the module such as coolant over-temperature, loss of coolant flow, coolant pressure out-of-balance, photovoltaic leakage current, and elevation-azimuth over travels are identified by the central controller to protect the solar field and to position the affected module to eliminate the threatening condition.

Accurate tracking under normal conditions is accomplished by the central controller providing synthetic solar position data to the module level controller to enable sun acquisition and then enabling each module level controller to lock onto the concentrated solar flux by means of photosensitive cells on the photovoltaic receiver.

Emergency Stow Power Subsystem-An industrially standard, commercially available diesel powered electric generator is included in the system design. Its function is to provide emergency electric power during utility outages to ensure that the field can be placed in a stowed position in the event of a weather threat. Wind velocity and lightning sensor inputs to the central controller are used to signal the existence of a weather threat.

Field Wiring, Switching, and OverCurrent Protection- Two complete electric power systems are required for field operation. On is an AC electric power system that serves three functions:(1) It connects the electric power conditioning system to the utility grid interface, (2) it distributes the AC parasitic power to the field to operate all field systems, (3) it transfers and distributes emergency stow power in the event of a simultansous grid outage and weather threat.

The AC electrical system is designed with a distribution feed main bus running north-south through the center of the solar field. Switching and over current circuit breakers are provided for each branch bus from the main bus serving each half row.

The other electrical power system required for field operation is the DC electrical system. This DC electrical system collects the photovoltaic receiver electrical power production from each module in the field and brings the power to the input terminals of the electric power conditioning system. A three wire main bus is run through the center of the field and alon each half row branch circuit and is equipped with switching and over current protection similarly to the AC electric power system.

For personnel protection a shorting and grounding circuit breaker controlled from the face of the module controller is provided and interlocked with the DC branch bus circuit breaker to ensure isolated operation whenever module maintenance is required.

Reflector Surface Washing Equipment-A washing system for the reflector surfaces is included in the system to ensure maintainability of the field performance through use of controlled experimental cleaning proceedures. A truck mounted, high pressure spray pumping system using deionized water has been designed for flexible use in the solar field. Detergent solutions followed by a clear rinse are sprayed from truck mounted nozzles as the vehicle drives slowly along a row in the east-west direction. Pumped handlines are also provided to clean trouble areas. The cleaning system has sufficient capacity to completely clean the solar field in one eight hour day.

## SYSTEMS ANALYSIS

Comprehensive technical analyses were performed to define details of performance, component size, and interface requirements. Chapters III and IX of this report provide further detail on the systems analysis performed. A fundamental question was sizing the overall system. Measurements of the deep well pump motor power consumption over several years showed very little cariance from season to season, typically within 6 kWe of the 147 kWe recorded average. A total of 596.8 Mwh of electrical energy is consumed during the irrigation season of 5-1/2 months of 24 hour per day pumping. Based upon these load demand factors and the design philosophy stated previously, a baseline 200 kWe peak power level was chosen. This size system will satisfy the design philosophy and provide on a yearly basis sufficient energy to offset 83 to 87 percent of the annual energy demand imposed on the utility by the application load.

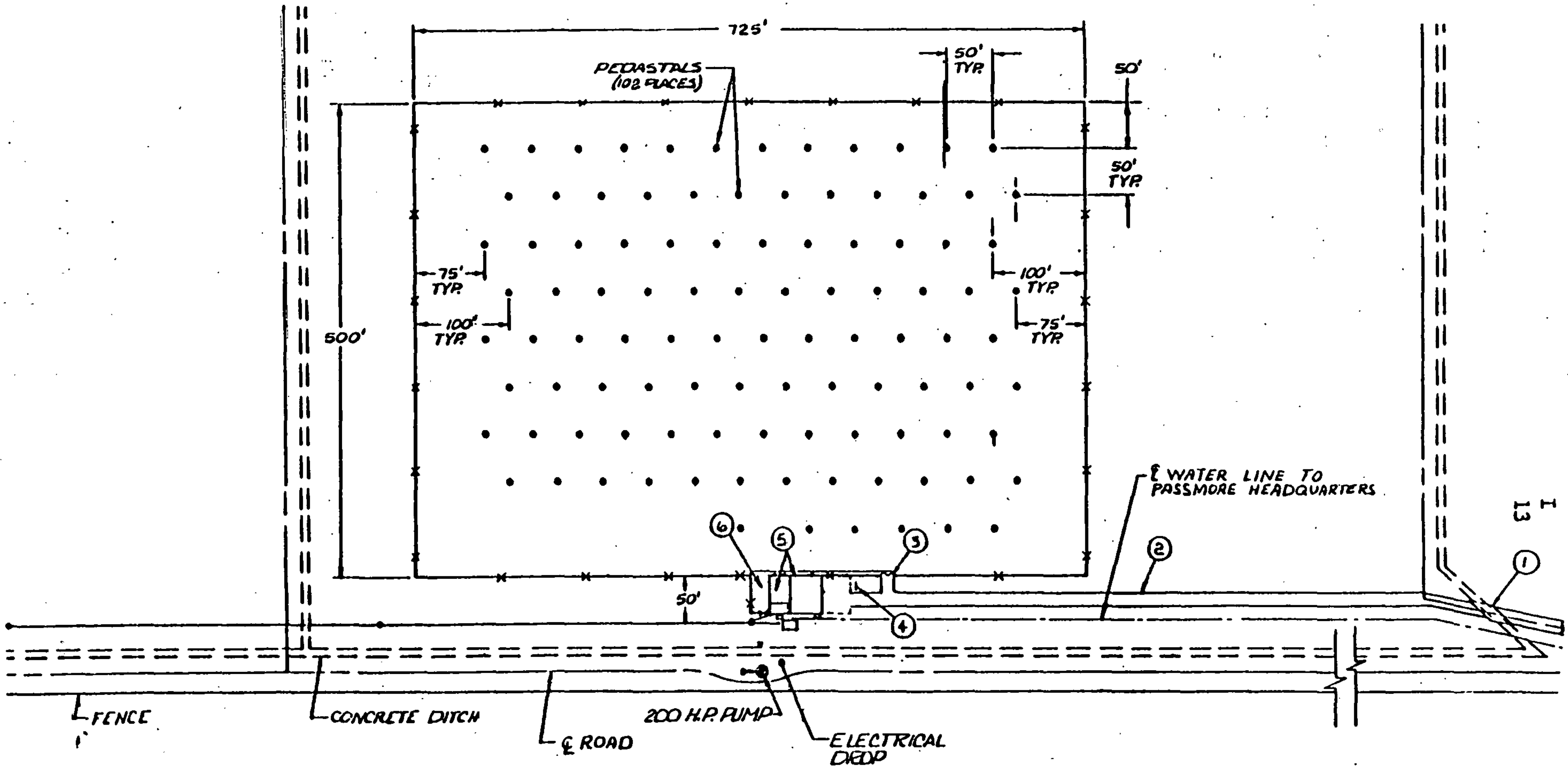
Meteorlolgical Data- Two weather data banks were utilized in the analysis, the March 10 design point weather data and the annual weather data. Weather data from cities in a 200 mile radius of Pecos, Texas was assembled. Data tapes for NOAA, SOLMET, and TMY data were also obtained. Comparisons showed that the Albuquerque 1962 SOLMET data, the Albuquerque TMY data, and the El Paso TMY data were suitable for performance predictions. Data collected locally in Pecos, Texas and obtained from Wink, Texas flight service station were also examined. Finally, Midland-Odessa NOAA weather tapes were used to define the March 10 solar noon design point data as summarized below:

Design Point Weather

| | |
|---|---|
| DAY | March 10 |
| TIME | Solar Noon |
| DNI | 316 $BTU/HR/FT^2$ |
| DRY BULB | 62.5 F |
| WET BULB | 47.7 F |
| WIND | 18.33 FT/SEC |

Component Simulation Models- Three major simulation models were used in the analysis: (1) a reflectance code to aid in the selection of candidate surfaces and to generate performance predictions, (2) a ray trace code to analyze the optical concentrator errors and energy budget, and (3) a system performance code to generate annual and design time-point system performance estimates.

Reflective Material Choice- The reflectivity code was used to analyze four candidate reflective materials: an Optical Coatings Laboratory (OCLI) experimental product; KINGLUX[tm]; ALZAK[tm]; and FEK-244 (3M). The best reflectivity was obtained




1. Irrigation canal
2. Access Road
3. Field Entrance Gate
4. Entrance Sign
5. Site Office and Data Acquisition System
6. Cooling Tower

Fig. 7 Trans Pecos Site Plan

from the OCLI product, but was rejected due to its non-production status. FEK-244(3M) has the next best reflectivity, but was rejected due to high installation costs. ALZAK[tm] had third best reflectivity but was rejected due to high materials cost and a tendency to degrade under environmental conditions expected in the Trans-Pecos region. KINGLUX[tm] exhibited fourth best reflectivity, however it also exibited the lowest installed cost and shows no long-term degradation and was therefore selected as the reflective material. Additional details of this analysis are found in Chapter III of this report.

Field Spacing- Two field layout designs were analyzed, one with modules in a rectilinear array, and the other with every east-west row staggered from the rows directly north-south. The staggered field was shown to be consistantly as good as or better than the rectilinear field on an annual energy basis and was chosen for the field layout as shown in figure 7, the project site plan. A design spacing of 50 feet north-south by 50 feet east-west has been selected.

Field Piping and Flow Rate Analysis- Two piping arrangements were investigated: (1) piping every module in parallel and (2) piping the modules in series groups of three. The system simulation model was used to evaluate a variety of field flow rates for both field designs to determine optimal flow rates. A field flow rate of 3.5 feet/second was found to be optimal and used to perform an economic evaluation of both layouts. High electric power production costs for this experimental system gives the parallel piping approach an annualized cost advantage, therefore the parallel piping method was chasen. It should be noted that as future systems are built and electrical production costs go down, the series field will have a cost advantage.

Cooling Tower Sizing-A study was performed to determine size, performance, and cost trade-offs for the cooling tower. While increasing the size of the tower improves thermal performance of the entire field, this also results in high parasitice power requirements. Best annual performance for the PVC system is obtained with a cooling tower designed for a 95 degrees F inlet temperature and an 86.5 degree F outlet temperature at an ambient wet bulb temperature of 65 degrees F. Decreasing exit temperature to 83 degrees F results in an annual energy increase of only 0.4 per cent due to the doubling of the cooling tower parasitic power demand and doubles the cost of the cooling tower.

System Performance Summary-Net annual electrical energy production has been estimated for two locations closest to Pecos, Texas that have TMY and/or SOLMET data characterizations available. Figure 8 shows the net annual electrical energy production estimates assuming the application site locations of El Paso, Texas and Albuquerque, New Mexico.

| SITE | METEROLOGICAL DATA BASE | NET ANNUAL ELECTRICAL OUTPUT (kWh) |
|---|---|---|
| El Paso, Texas | TMY | $5.114 \times 10^5$ |
| Albuquerque, NM | TMY | $5.002 \times 10^5$ |
| Albuquerque, NM | SOLMET(1962) | $5.219 \times 10^5$ |

Fig. 8 System Performance Summary

The El Paso, Texas TMY data is selected as representative since it is nearly the average of the other two estimates. Based on this choice, Figure 9 illustrates the solar system annual efficiency stairstep.

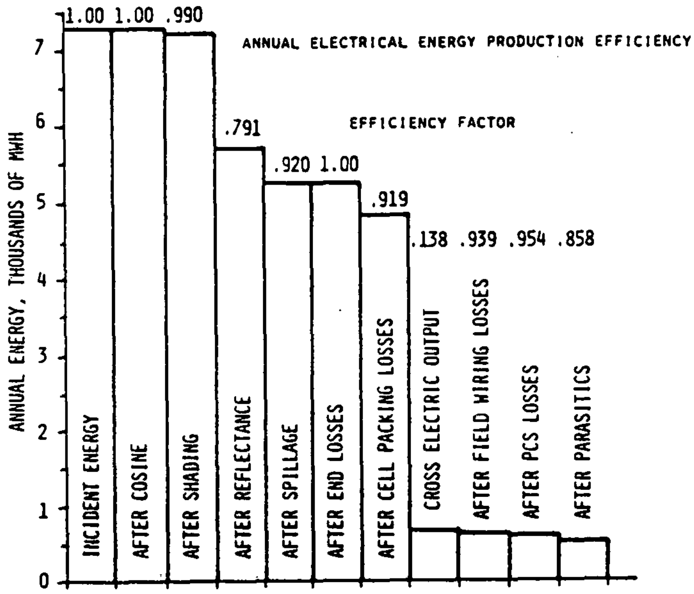



Fig.9 System Annual Efficiency Stairstep

## ENVIRONMENTAL IMPACT

The operation of the Trans-Pecos PVC system will not result in concentrated solar flux outside the PVC modules. Access to the site is controlled and the site in enclosed in a security fence. There are no residences closer than one-half mile from the site.

The cooling system is designed as a closed loop with automatic valving incorporated to isolate parts of the system if a plumbing failure occurs. Broken coolant lines would release less than 500 gallons of 30% ethylene glycol-water solution to the environment. If necessary, the entire cooling system can be drained into a fiberglass holding tank during maintenance without loss of coolant.

Air quality will not be changed by the site facility. Improvements to the access road will minimize dust during construction. Construction will utilize local contractors and will have a beneficial impact on the local economy. Some conversion (11 acres) of land from farming will occur. The site selected is currently not farmed due to the high costs of energy for irrigation. The project will restore 380 acres of farm land to production. The solar field will have no marked effect on animal or bird life in the area. Plant life at the site has been eliminated through agricultural operations and will not be affected. There are no known archaeological or historical resources within the site area.

Other locations for the Trans-Pecos experiment are viable possibilities; however, they would have similar environmental impacts. The site selected is on land set aside by the owner for this specific application and is representative of sites suitable for installation of solar PVC systems.

## DATA COLLECTION

Transducer Data Collection- Transducer data will be collected during the experiment from a row of six collector modules located nearest the on-site data acquisition system. These six modules are representative of the field and participate fully in all electrical, thermal and control systems. Additionally, these modules have been configured to allow easy modification of transducers, and to allow numerous experiments to be conducted to investigate the long-term reliability, survivability of solar PVC systems.

Experimental Data Collection- Experiments have been designed to investigate the following areas: (1) Support structure verification, (2) cleaning methods for large solar fields, (3) hail storm survivability, (4) lightning survivability, (5) reliability and maintainability, (6) thermal system nominal performance, (7) thermal system configuration, (8) thermal system coolant channel design, (9) utility interface economics, (10) utility interface dynamics, (11) site restoration, (12) storm detection and stowing.

Technology Assessment-A technology assessment has been designed whereby the results of evaluating the Trans-Pecos PVC experiment can be fully integrated. These types of data are used in a class of studies intended to anticipate and to explore the consequences of the introduction of a new hechnology, no only on the direct participants but also in terms of the full range of parties that may become involved.

# CHAPTER II

# FINAL REPORT OF TASK TEAM-2
# SOLAR/GRID SYSTEM INTEGRATION

Submitted To:
Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:
Dr. John P. Craig
Department of Electrical Engineering
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER II

## TASK TEAM-2

## SOLAR/GRID SYSTEM INTEGRATION

Team 2 is concerned with the interface between the solar system and the electric utility, lightning protection and the electrical wiring and equipment to be installed on-site. Team 3 is concerned with the electrical wiring on the solar modules, the power conditioning equipment and the emergency generator and its automatic switchover apparatus.

### On-site Wiring

The wiring interconnecting the modules, the power conditioning equipment and the central controller are part of the on-site wiring, and is shown in drawing PVC0027. The wiring for the office/ equipment, maintenance and control building is shown in drawing PVC0020.

### Solar/Utility Interface

The electric utility (Community Public Service Company) has shown a great deal of interest in this solar project and are very cooperative. Their service to the Passmore farm is through a 3-phase, 24.9 kV, shielded, distribution line with primary kW-hr and peak demand metering approximately 1½ miles from the solar system site where the 250 hp irrigation well moter is located. The utility system short circuit capacity at that point is 8,895 amps.

Lightning Protection

The solar array must be protected from lightning, particularly due to the high cost of the solar cells. In addition, the power conditioning equipment, particularly the solid state inverter, must be protected from lightning pulses which may travel in on the 24.9 kV distribution lines.

The protection of the array is similar to the way outdoor substations and switchyards are protected. That is, by an overhead grounded grid system of shield wires. This grid is shown in drawing PVC0008 The shielding is further enhanced by the support conductors for the strings of solar cells. The overhead wires shield out direct strikes and the support conductors shield out the induced fields from the voltages and currents in the overhead lines.

The lightning pulses coming in on the distribution line are reduced in number and magnitude by the grounded shield wire over the distribution line. They are further attenuated by lightning arresters on the primary of the 3-phase transformer bank. The remaining pulse is attenuated further by the transformer itself. Finally a low voltage arrester is placed at the inverter-transformer in the equipment building.

The sectionalizer on the line serving the Passmore wells operated 180 times in 1977, but locked out only 4 times. This was an unusually high number of operations due to work being done in that area. In 1978 to date, there have been 26 operations with only 1 lock out. In addition, there has been one lateral fuse blown in 1978. Actual data concerning the time periods that the power was off due to the lockouts and fuse opening are not available, however, typical times are on the order of 2 hours. The 1978 data can be considered to be a typical year.

The blowing of the fuse occurred when one of the wells was damaged by lightning.

Passmores' 24.9 kV, shielded distribution line extends the 1½ miles to the solar site where it ends. Two 150 hp well motors are connected through separate transformer banks to this line between the metering and the solar site.

At the solar site, the 24.9 kV is transformed to 480 volts with three 75 kVA transformers connected in a 3-phase Y-delta bank. The delta is not grounded.

The 480 V secondary is connected to the 200 hp well motor through a delta Switchboard Company combination part winding starter. Short circuit and over-current protection are provided by 200 A time delay fuses. The starting current is on the order of 1000 amps.

The solar system is to be connected to the 480 volt transformer bank through a 400 amp fused disconnect. An undervoltage relay connected at this point will automatically disconnect the solar system from the utility, and start and connect an emergency generator to supply sufficient power to stow the solar field. Hence, the solar system will shut down anytime utility power is not available. Of course, it will also be shut down by the solar system controller when solar incidence falls below a given level.

The above is a description of the physical interconnection between the solar system, well motor and the electric utility. The areas of concern as a result of the interconnection are:

1. Protection of the electric utility system from faults occurring in the solar system.
2. The introduction of harmonic currents into the power system due to solar system power conditioning equipment.
3. Preventing the solar system from energizing the power system when the power system is down for maintainance.
4. The effect on the utility load factor of the combined well motor load and the solar generation system.

A brief discussion of these four concerns follows:

1. Protecting the power supply system from faults in the solar system is essentially no different than protecting the supply systems from faults in any other connected apparatus. Hence, the proper, routine application of the fused disconnect will solve this concern.
2. The harmonics introduced into the power system by the solar power conditioning equipment are essentially no different than those introduced by SCR controlled rectifiers which are routinely connected to utility systems throughout the world. Occasionally, some communication system interference requires some added filtering (which is routine and inexpensive).
3. The under voltage relay will disconnect the solar generator from the power system when the voltage falls below a preset per centage of rated voltage. However, there is a possible mode of operation such that this would not be sufficient

protection. That is, if the total load on the 24.9 kV line (including andy of the three well motors and any load between the wells and the sectionalizer) is less than or equal to the available solar electric power. Under these conditions, if part of the load were motors, the solar system could hold up the system voltage even though the sectionalizer were open. This possibility can be eliminated by slaving the solar system contactor to the sectionalizer opening signal. Or, a non-automatic solution would simply be an operating procedure such as tagging the sectionalizer and having the maintenance crew to check that the solar system was definitely off-line before performing any maintenance. In either case, the standard procedure of applying ground straps to the phase conductors should be adhered to.

4. The effect on the utility load factor is of no significance for the experimental unit. However, if the use of such systems becomes widespread, studies will be required to determine the combined effect for the particular utilities load curve and the distribution of the solar systems over the power system. This study is one of those proposed for phase 3. It is believed that the solar systems can be operated in such a way as to have a positive effect on the power system load factor.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CHAPTER III

FINAL REPORT OF TASK TEAM-3

SOLAR PVC SYSTEM ENGINEERING

Submitted To

Texas Tech University

Department of Systems

College of Engineering

Lubbock, Texas 79409

Prepared by

Honeywell Incorporated

Energy Resources Center

2600 Ridgway Parkway N.E.,

Minneapolis, Minnesota 55413

22 February 1979

Texas Tech University Subcontract Number: HYI-78-001

Department of Energy Prime Contract Number: ET-78-C-04-4269

# TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| I | INTRODUCTION | 1-1 |
| II | PROGRAM SUMMARY | 2-1 |
| III | BASELINE DESIGN | 3-1 |
| IV | COMPONENT SPECIFICATIONS | 4-1 |
| V | ORIGINAL DESIGN CONCEPT | 5-1 |
| VI | SUPPORTING ANALYSES | 6-1 |
| VII | PHASE II DETAIL | 7-1 |
| VIII | PHASE III CONCEPTS | 8-1 |
| APPENDIX A. | BASELINE DESIGN DETAIL | A-1 |
| APPENDIX B. | ORIGINAL CONCEPT DETAIL | B-1 |
| APPENDIX C. | OCLI FINAL REPORT | C-1 |

# SECTION I
# INTRODUCTION

This Final Report was prepared by Honeywell Incorporated and submitted to Texas Tech University in partial fulfillment of Phase I System Design requirements for the Trans-Pecos Photovoltaic Concentration Experiment. Presented in this report are the project objectives, engineering activities, and resultant conclusions and design detail generated by Task Team 3, Solar PV-C System Engineering.

Honeywell participated in the Phase I program as a major subcontractor to Texas Tech University, one of seventeen PRDA-35 prime contractors. The PRDA-35 program series, titled Photovoltaic Concentrator Application Experiments, was originated by the U.S. Department of Energy, Division of Solar Technology, Photovoltaic Programs Branch and was administered by the DOE Albuquerque Operations Office. Sandia Laboratories was the DOE-designated Technical Monitor for the program.

The overall objective of the Trans-Pecos Photovoltaic Concentration Experiment Phase I program was to design a 200 kW(e)-peak, photovoltaically powered, deepwell irrigation application experiment. In fulfillment of its Task Team 3 Solar PV-C System Engineering subcontract responsibilities, Honeywell's Phase I program objective was to design a photovoltaic concentrator system which could be installed and operated in the Trans-Pecos region of Texas upon completion of Phase II activities. The resultant experimental system described in this document was designed to provide technical, operational, and performance data for solar concentrating systems employed in on-site power generation applications and additionally to obtain information on identifiable non-technical related issues.

Award of the Phase I contract for System Design to Texas Tech University was announced by DOE on March 2, 1978. A total of seventeen Phase I contract awards were announced on that date. Proposals for the Phase I program were solicited by DOE and resulted in receipt of a total of 77 responses by the January 13, 1978 deadline.

In addition to the Phase I program for System Design, two more phases are presently planned to complete the overall program series. Phase II, System Fabrication and Installation, is anticipated to begin in June, 1979 and require twelve months to complete. This phase is devoted to procurement of system components, application site preparation, assembly and installation of all required components into a functional system, and verification of system operability through a limited period of performance testing which concludes the Phase II program.

The concluding segment of the presently planned overall program is Phase III, System Operation and Evaluation. Scheduled to begin in mid-1980, this phase may be of optional length up to two years. Both technical and non-technical assessments of system placement, application, operation, performance and interfacing will be evaluated and recorded for continuing analyses.

Upon termination of Phase III activities, present plans require complete removal of the entire system installation and return of the application site to its original condition.

This document is the Phase I, System Design, Final Report of engineering activities and resultant design detail and conclusions reached by Task Team 3, Solar PV-C System Engineering. Principal team members were the Energy Resources Center of Honeywell Incorporated and the Photoelectronics Division of OCLI. The effective contract start date for the Phase I program was June 1, 1978. Phase I effort concluded February 28, 1979.

This report is organized into eight principal sections, this being Section I, Introduction. Included for completeness are three appendices providing backup technical detail.

Section II, Program Summary, presents a description of Phase I program activities, highlights the resultant system design features, and summarizes overall system performance.

Section III, Baseline Design, describes in detail the system design from the photovoltaic module to the completed field installation of all major support subsystems.

Section IV, Component Specifications, references the detailed drawings and specifications prepared during Phase I and discusses component availability and potential sources for supply.

Section V, Original Design Concept, briefly traces the evolution of the design concept from the original Phase I proposal to the present resultant baseline design.

Section VI, Supporting Analyses, presents results of detailed tradeoff analyses performed during the Phase I program. Data are presented encompassing all aspects of the technical design characterization from reflective surface efficiency to annual system efficiency.

Section VII, Phase II Detail, documents the plan for accomplishing the Phase II program for System Fabrication and Installation. Included is a description of the envisioned procurement plan, quality control plan, and the suggested detailed statement of work.

Section VIII, Phase III Concepts, highlights features of the Operation and Evaluation concluding phase of the overall applications program. Of particular importance are the descriptions of planned experiments.

Appendix A, Baseline Design Detail, contains a collection of independent detail providing insight to technical aspects of the baseline design. The format of this section is as-written or as-acquired.

Appendix B, Original Concept Detail, is similar in content and format to that described above for Appendix A but presents information applicable to the earlier versions of the design concept.

Appendix C, OCLI Final Report, contains the entire report as submitted by OCLI to Honeywell.

# SECTION II
# PROGRAM SUMMARY

The Phase I program is summarized in this section in terms of (1) Program Activities, (2) System Design and (3) System Performance. Detailed descriptions of program activities documenting dates of meetings, purposes for meetings, agendas, information exchanged, lists of action items assigned, and results of meetings are not presented in this report but are available in program files maintained at Honeywell. The system design description presented here in summary is fully detailed in Section III, Baseline Design. Similarly, system performance presented briefly in this section is detailed in Section VI, Supporting Analyses.

## Program Activities

Phase I program activities began officially on June 7, 1978 at a program kick-off meeting held at Texas Tech. Team organization was confirmed and preliminary program assignments made initiating engineering activities.

Throughout the duration of the program, written monthly technical progress reports were submitted to Texas Tech summarizing principal engineering activities and decisions made affecting the overall program. Included in these reports were plans for the next reporting period and a statement of resource expenditure incurred to date of report.

Program coordination meetings between Honeywell and Texas Tech were held at approximately monthly intervals. Designed to assure efficient and accurate communications these meetings also served to disseminate information among all Task Teams and provided a common data base for program information and perspective. Early detection of principal issues and identification of system component interface incompatibilities were enhanced by this process.

A Mid-Program Technical Review was presented to the Technical Monitors at Sandia Laboratories, Albuquerque, New Mexico, on October 23, 1978. This was a major milestone during Phase I which served, in general, to terminate formulation of design options. Subsequent activity was devoted to firming the design approach as a system of controlled interfaces documented in terms of specifications and drawings.

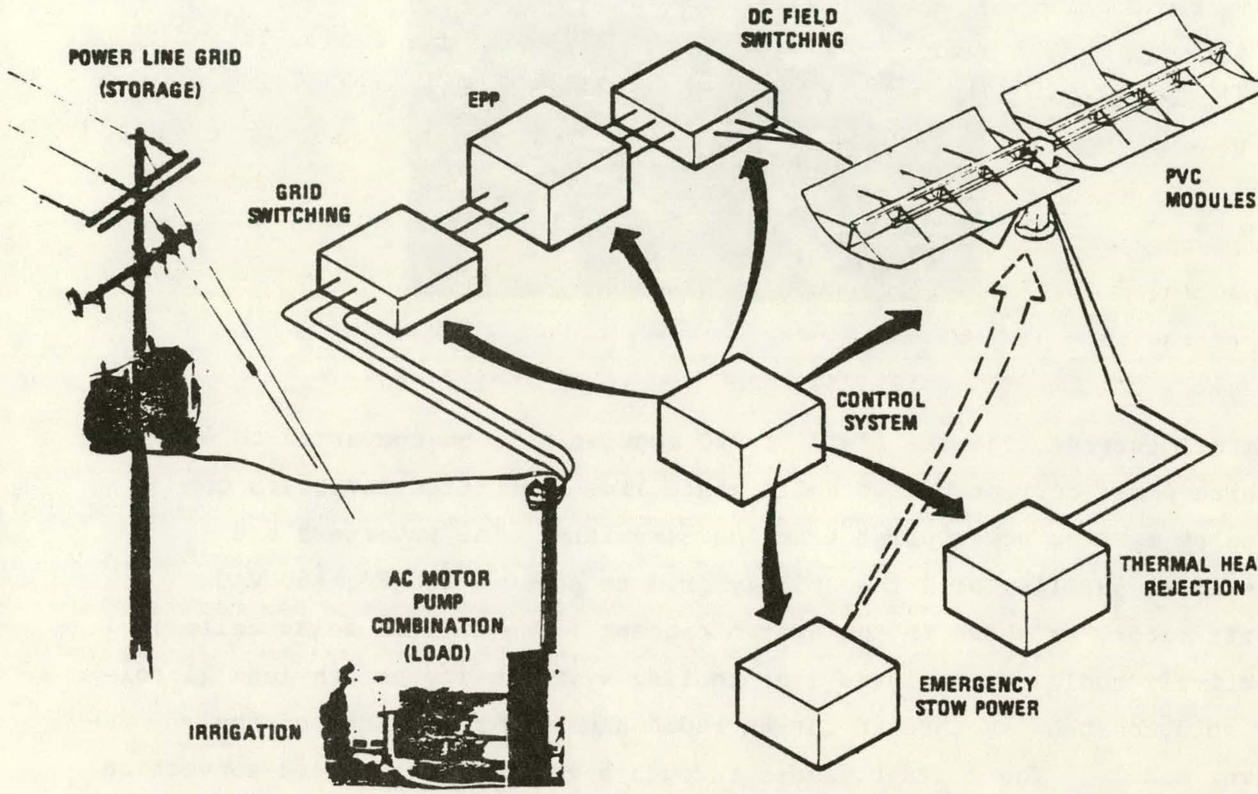
Principal documentation submissions during this program included a Baseline System Technical and Management Proposal for Phases II and III, a Cost Proposal for Phase II System Fabrication and Installation, a Cost Proposal for Phase III System Operation and Evaluation, and a corresponding set of similar documents detailing an optional system scaled downward to reduce program costs. Among the most important of documents prepared during Phase I was the technical data package, submitted as the Appendix to the technical and management proposal, which contained the system and major component specifications and detailed drawings.

A major activity performed during the Phase I program by Honeywell at no cost to the program was the development and fabrication of an operational prototype module. Internally funded by Honeywell, this engineering activity represented a significant cost sharing contribution which was dedicated to advancing the technical state-of-the-art of photovoltaic module design and fabrication.

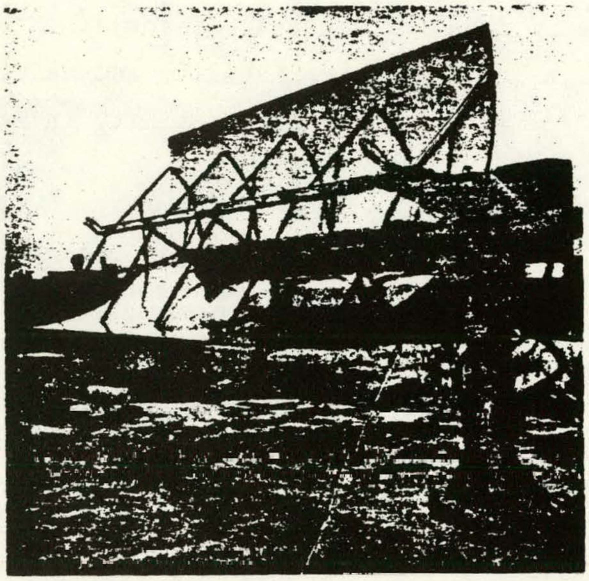
## System Design

The Trans-Pecos Photovoltaic Concentration Experiment is designed to provide solar-derived electric power to an existing 200 HP motor and to operate in parallel with an existing utility grid. The baseline system is sized to generate 200 kW(e)-peak three-phase AC power at solar noon on March 10, the midpoint of the pre-irrigation season. The design philosophy required that (1) the full 150 kW demand of the motor be supplied for several hours each day, (2) 50 percent of the 24-hour demand of the motor be supplied, and

(3) a margin of power in excess of motor peak demand be produced so that an energy interchange with the utility can occur on both a daily and a seasonal basis. By so doing, the experiment will provide information on the economics of solar photovoltaic irrigation, on the reliability and maintainability of the PVC system, and on the dynamics of the solar-utility interface on a daily basis.




The baseline solar electric energy system is shown above and consists of 102 two-axis (azimuth-elevation) tracking photovoltaic concentrator (PVC) modules. A photo of the production prototype model of this module is shown on the following page.

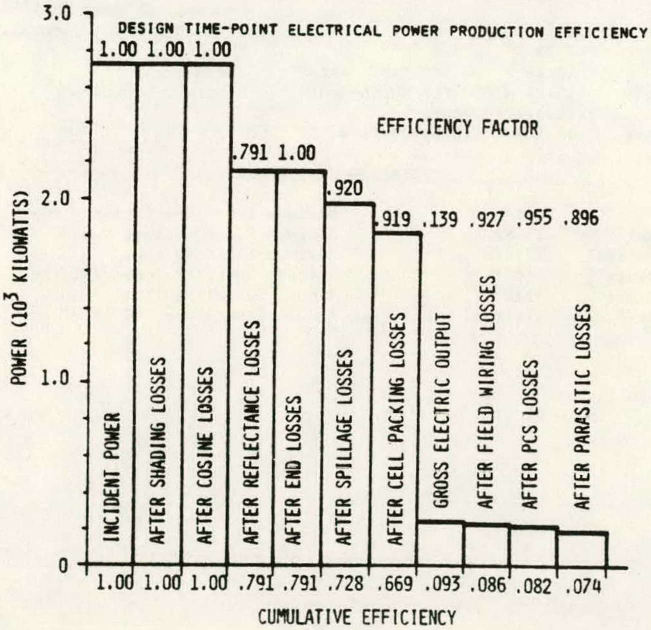


The direct current from the field of PVC modules will be converted to 480 VAC three-phase current by two solid state line-commutated inverters controlled by maximum power point tracking circuitry. The inverters are connected in parallel with the utility grid to power a 200 HP, 460 VAC electric motor, as shown in the system concept. The silicon solar cells are actively cooled by a closed-loop cooling system using an ethylene glycol-water solution passing through the extruded aluminum heat sinks of the receiver module. The coolant passes through a wet-surface, forced-convection heat exchanger which rejects waste heat to the atmosphere (taking advantage of the low wet-bulb temperatures present in the Trans-Pecos region).

A central supervisory controller provides field control and system monitoring using microprocessor-based control systems. Module controllers provide active solar tracking and monitoring of each PVC module's operation. The system control employs five operational modes: quiescent, wakeup, run, stow and emergency stow. The system in the quiescent state is stowed in a position to minimize weather threats. The wakeup mode positions the field for sun acquisition and monitors the available solar power. When available solar power exceeds system parasitic demand, the system comes on line and enters the run mode. The stow mode returns the field to the quiescent state using utility power. The emergency stow mode involves a simultaneous wather threat and loss of grid power. This activates a standby generator to provide sufficient power to stow the field.

System Performance

The solar PVC system will provide a net electric peak AC power of 200 kW(e) at solar noon on March 10. The annual energy produced is projected to be 511 Mwh using El Paso-TMY weather data. System electrical power production efficiency is projected to be 7.4 percent at the design time-point, as shown in the efficiency plot, and annual electrical energy production efficiency is 7.0 percent.




The system is projected to power 37.8 percent of the 24-hour duty cycle of the motor excluding energy delivered to the grid in excess of motor demand. Total energy produced is projected to be 49 percent of the 24-hour motor demand.

Modifications to the present irrigation cycle emphasizing pre-irrigation extends the irrigation cycle to 11 months. The extended cycle is projected to utilize 70 to 80 percent of the system's annual energy production for irrigation and approximates the present annual energy demand of the existing irrigation cycle.

The following summary of parameters describes the module, the field, the operating conditions and projected performance:

| PHYSICAL CHARACTERISTICS | | PERFORMANCE CHARACTERISTICS | |
|---|---|---|---|
| **Module** | | **Module** | |
| Description | Az-El Tracking Parabolic Trough First Surface Kinglux™ | Gross power Output (Design Point) | |
| | | Electric | 2.47 kW(e) |
| | | Thermal | 11.64 kW(t) |
| Aperture Area | 26.76 $m^2$ (288 $ft^2$) | **System** | |
| Total Length | 12.2 m (38 ft 9 in) | Gross Power Output (Design Point) | 252 kW(e) |
| Total Height (Stowed) | 2.42 m (7 ft 8 in) | Net Power Output (Design Point) | |
| Total Width (Stowed) | 2.63 m (8 ft 4 in) | Electric | 200 kW(e) |
| | | Thermal | 1074 kW(t) |
| | | Electric Efficiency | 0.074 |
| **Field** | | Gross Energy Output | |
| | | (Annual, El Paso-TMY) | $6.69 \times 10^5$ kWh(e) |
| Number of Modules | 102 | Net Energy Output (Annual, El Paso-TMY) | |
| Total Aperture Area | 2729 $m^2$ (29376 $ft^2$) | Electric | $5.11 \times 10^5$ kWh(e) |
| Field Spacing | 15.24 m (50 ft) East-West 15.24 m (50 ft) North-South Staggered Rows. | Thermal | $3.03 \times 10^6$ kWh(t) |
| | | Electric Efficiency | 0.070 |
| Module-Occupied Land Area | 25,084 $m^2$ (270,000 $ft^2$) | | |

OPERATING CONDITIONS

| | | | |
|---|---|---|---|
| Field Flow Rate | 664.4 GPM | Maximum Stow Time (Standby Power) | 9 min. |
| Stow Windspeed (Freestream) | 25 MPH | Minimum Field Voltage | 371 VDC |
| Survival Windspeed (Freestream) | 77 MPH | Maximum Field Voltage | 412 VDC |
| Minimum Operating Temperature | -10°F | Average Inverter Input Voltage | 400 VDC |
| Maximum Operating Temperature | +110°F | Annual Operating Time | 3467 hours |
| Maximum Stow Time (Utility Power) | 2.1 min. | Annual Time Above 150 kw(e) | 2214 hours |

# SECTION III
# BASELINE DESIGN

The baseline system design for the Trans-Pecos Photovoltaic Concentration Experiment installation proposed for Phases II and III evolved following a planned and controlled series of Phase I engineering tasks. System and component design development began with concept formulation, proceeded with technical tradeoffs based upon detailed analytical evaluations of performance, sizing and interface compatibility and has concluded with fabrication and test of a full-scale photovoltaic module (Figure 2-1) and preparation of detailed procurement specifications submitted for quotation.

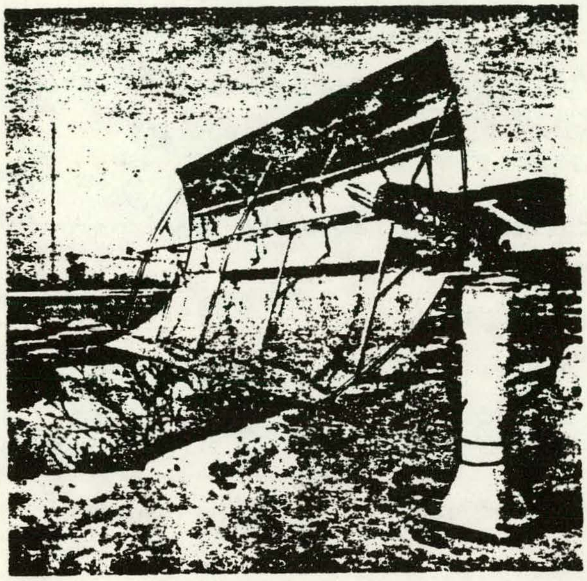


Figure 3-1. Prototype Module Developed During Phase I and Tested at Honeywell/Minneapolis.

The baseline system is composed of selected components and subsystems functionally designed and specified to effectively produce electrical power. Requirements delineating effective power were that the net AC output from the inverter subsystem (1) be of sufficient quantity to significantly service the application load demand on an annual basis, (2) supply 100 percent of the application load demand at the specified design time--point and (3) be of sufficient quality to permit parallel interconnection with existing utility distribution grid networks.

The mechanical, thermal and electrical implementation concepts developed for the Trans-Pecos system design are based upon use of the photovoltaic generated electrical energy to displace load-induced demand upon utility-supplied energy. In addition to the obvious advantage afforded by use of existing grid network distribution lines and power handling equipment for energy transport, protection and control, the most significant benefit resulting from direct utility interconnection is the effective operational buffering provided between transients that typically characterize both the solar photovoltaically generated energy and the daily/seasonal load demand variations associated with nearly every application load.

For Phase III operation and evaluation experiments this system design approach provides that no application load-induced faults can propagate into the photovoltaic system to interrupt either system operation or ongoing experiments, nor can system-induced faults propagate to disturb the application load. This feature not only maximizes total Phase III experiment data return but also represents solar photovoltaic installations most likely typifying those interfacing sizeable loads in near-term applications where both flexibility of system intergration and reliability of operation are required.

Finally, the system design is mechanized to provide positive protection from both short- and long-term environmental threats. The Trans-Pecos area of Texas is subject to sudden and often severe thunderstorm activity producing frequent lightning strikes, sizeable hail and strong gusting winds. The Phase II and III system is designed to survive such conditions and will be installed with protection systems instrumented for data acquisition.

Results of the Phase I system design and analysis effort are summarized in the following table:

PHYSICAL CHARACTERISTICS

| | |
|---|---|
| **Module** | |
| Description | Az-El Tracking Parabolic Trough First Surface Kinglux™ |
| Aperture Area | 26.76 $m^2$ (288 $ft^2$) |
| Total Length | 12.2 m (38 ft 9 in) |
| Total Height (Stowed) | 2.42 m (7 ft 8 in) |
| Total Width (Stowed) | 2.63 m (8 ft 4 in) |
| **Field** | |
| Number of Modules | 102 |
| Total Aperture Area | 2729 $m^2$ (29376 $ft^2$) |
| Field Spacing | 15.24 m (50 ft) East-West<br>15.24 m (50 ft) North-South<br>Staggered Rows. |
| Module-Occupied Land Area | 25,084 $m^2$ (270,000 $ft^2$) |

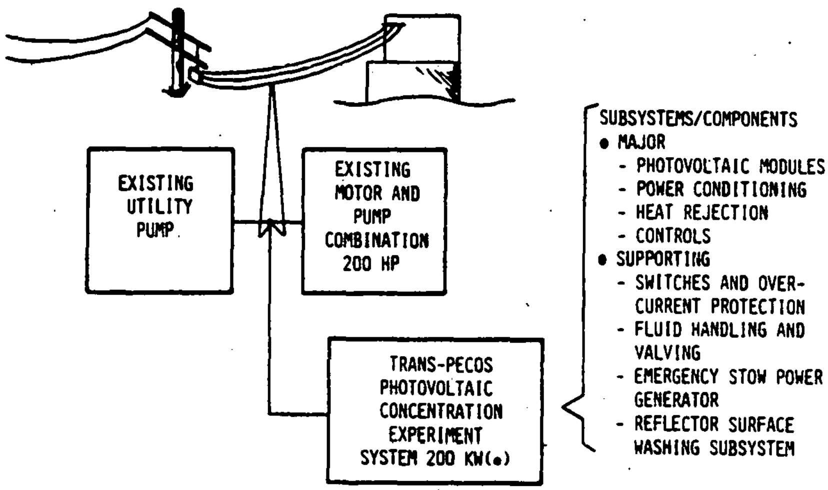
PERFORMANCE CHARACTERISTICS

| | |
|---|---|
| **Module** | |
| Gross power Output (Design Point) | |
| Electric | 2.47 kW(e) |
| Thermal | 11.64 kW(t) |
| **System** | |
| Gross Power Output (Design Point) | 252 kW(e) |
| Net Power Output (Design Point) | |
| Electric | 200 kW(e) |
| Thermal | 1074 kW(t) |
| Electric Efficiency | 0.074 |
| Gross Energy Output (Annual, El Paso-TMY) | $6.69 \times 10^5$ kWh(e) |
| Net Energy Output (Annual, El Paso-TMY) | |
| Electric | $5.11 \times 10^5$ kWh(e) |
| Thermal | $3.03 \times 10^6$ kWh(t) |
| Electric Efficiency | 0.070 |

OPERATING CONDITIONS

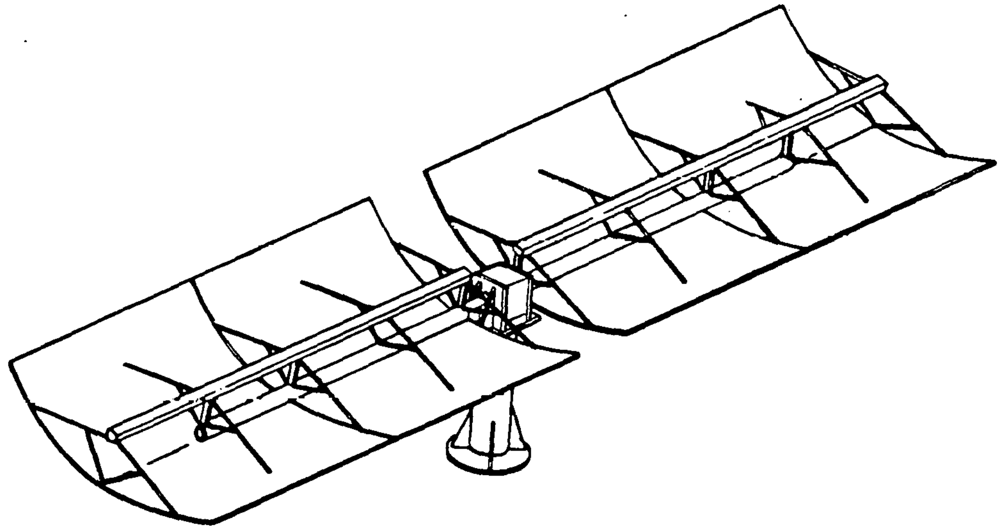
| | | | |
|---|---|---|---|
| Field Flow Rate | 664.4 GPM | Maximum Stow Time (Standby Power) | 9 min. |
| Stow Windspeed (Freestream) | 25 MPH | Minimum Field Voltage | 371 VDC |
| Survival Windspeed (Freestream) | 77 MPH | Maximum Field Voltage | 412 VDC |
| Minimum Operating Temperature | -10°F | Average Inverter Input Voltage | 400 VDC |
| Maximum Operating Temperature | +110°F | Annual Operating Time | 3467 hours |
| Maximum Stow Time (Utility Power) | 2.1 min. | Annual Time Above 150 kw(e) | 2214 hours |

System Description—The concept of energy displacement is a fundamental feature of the baseline system design. The major system components and the interconnections required to install the system in the presence of the existing utility grid and the existing application load on the Garvin G. Passmore farm in the Trans-Pecos region of Texas are illustrated in the block diagram below.



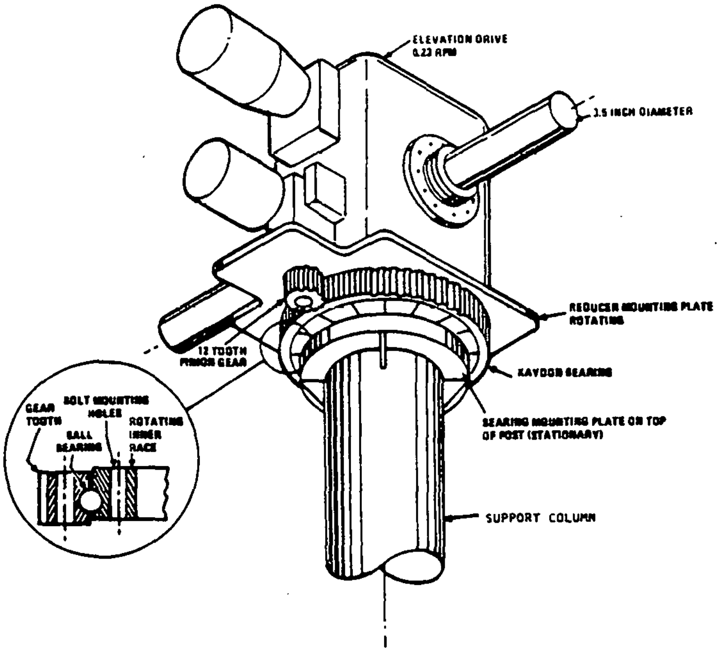

The power production system is composed of four major subsystems and several supporting subsystems and components. The major subsystems are: (1) Photovoltaic Modules, (2) Power Conditioning Subsyste, (3) Heat Rejection Subsystem and (4) Control Subsystem. Supporting subsystems and components include: Field wiring, switching and over-current protection components; field plumbing and valving components; emergency stow power generator subsystem; and the reflector surface washing subsystem.

Photovoltaic Modules—The baseline system is composed of 102 photovoltaic modules which produce a gross electrical power output of 252 kw at the design time-point chosen as solar noon March 10. Each module (see figure below) is two-axis tracking through an elevation-over-azimuth mechanization attached to a single center pedestal. The pedestal is secured to a reinforced concrete foundation designed to provide the required support in the deep sandy brown clay of the application site. Site soil composition and load bearing characteristics were determined early in the Phase I program by analysis of test borings made at the site.



The drives which power the elevation and azimuth axis motions utilize AC induction motors and high torque, anti-backlash gear reducers (see figure below). Two collectors are mounted on each module and are directly supported on the output shaft extensions of the elevation gear reducer. Total angular travel of the elevation-axis is approximately 180 degrees upward from the elevation stow position which is vertically downward and is limited by the positioning of overtravel limit switches. Maximum slew rate is approximately 83 degrees per minute. The elevation gear reducer has a gear ratio of 7500:1 and is powered by a 1/2-horsepower, three-phase, 460-volt electric motor.

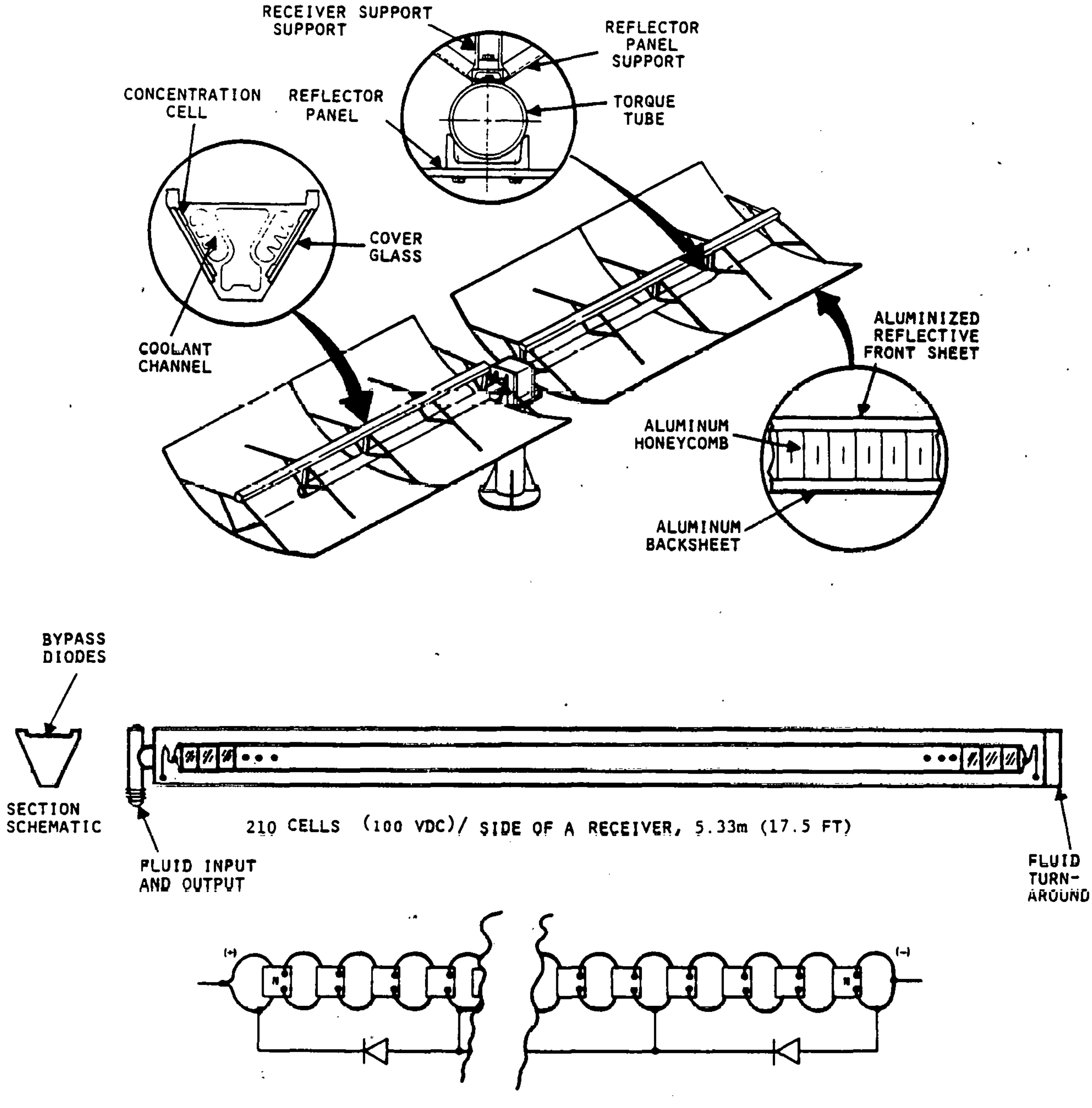
The elevation axis gear reducer is attached through a bearing plate to the inner race of a ring gear bearing which provides the azimuth axis motion. The outer race of the bearing ring contains external gear teeth and is attached to the pedestal column. The azimuth axis motion is produced with a gear reducer mounted on the elevation axis bearing plate which drives against the fixed external ring gear through a pinion gear. Total angular travel of the azimuth axis is approximately 220 degrees split equally about the solar noon position and is limited by the positioning of overtravel limit switches. Maximum slew rate is approximately 23 degrees per minute. The azimuth gear reducer has a gear ratio of 25200:1 and is powered by a 1/4-horsepower, three-phase, 460-volt electric motor.




Each of the two collectors mounted on a module is composed of a concentrating reflector and a photovoltaic receiver. Each reflector is gemetrically a parabolic trough having a two-foot focal length and a 90-degree rim angle. The resultant aperture is approximately 8 feet 2 inches wide by 18 feet long and produces a 45:1 geometric concentration ratio at the receiver plane near the focal point line. Each reflector is constructed of four half-parabola aluminum honeycomb-cored panels approximately 9 feet long (see figure below). The panels are attached to a cantilevered torque tube supported by the elevation gear reducer shaft extension. Each panel is nominally 3/8-inch thick and incorporates 0.020-inch thick Kinglux™ reflective aluminum sheet as the intergrally bonded front skin. Commercial grade 5052 aluminum sheet, 0.020-inch thick, is the bonded back skin of the panel.

The photovoltaic receiver (see next page) features an integrated-function aluminum extrusion as the basic structure. In addition to being a self-supporting beam, the extrusion also serves as the photovoltaic cell mounting surface, thermal heat sink, coolant channel and wiring conduit.

III
3-6

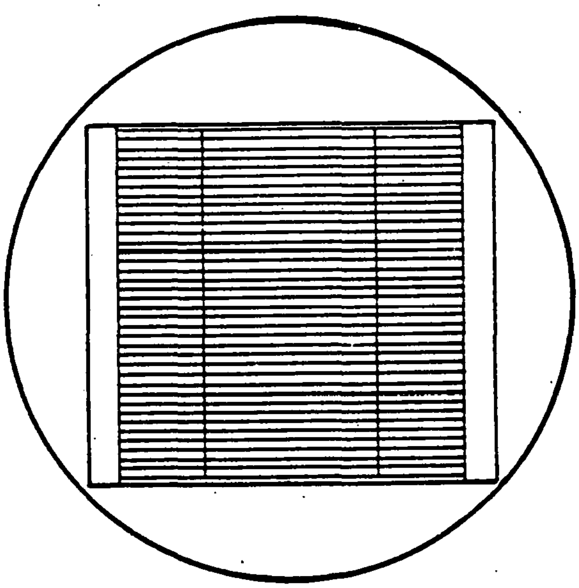


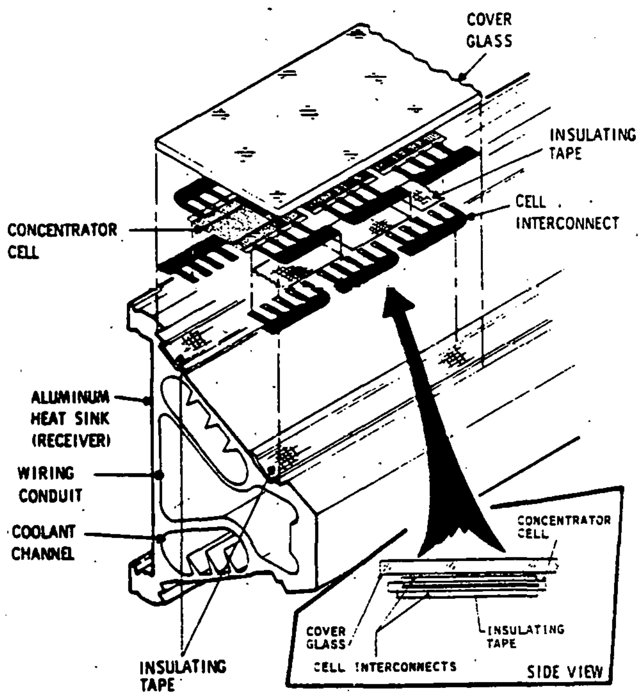

Elevation and azimuth axis positioning input is provided through use of solar image tracking by photosensors integrated into the receiver extrusion assembly. Four sensors are used for the elevation axis and two for the azimuth axis and are placed to measure the degree to which the concentrated receiver flux is optically centered in each of the two axes. A net bias signal is supplied to the module controller for independent tracking control of each axis.

The actively cooled receiver has silicon photovoltaic cells bonded to it with a filled-RTV adhesive which enhances the heat transfer effectiveness of the assembly. The illustration below shows the cell configuration developed by OCLI during Phase I that has been performance tested at both OCLI and Honeywell. Test results confirm an average cell efficiency of 17.4 percent at 28½C and 40 suns.

Overall, the photovoltaic module design is predicated upon fielding the greatest aperture area with the least foundation, structural support and drive expense possible while maximizing annual energy collection potential.

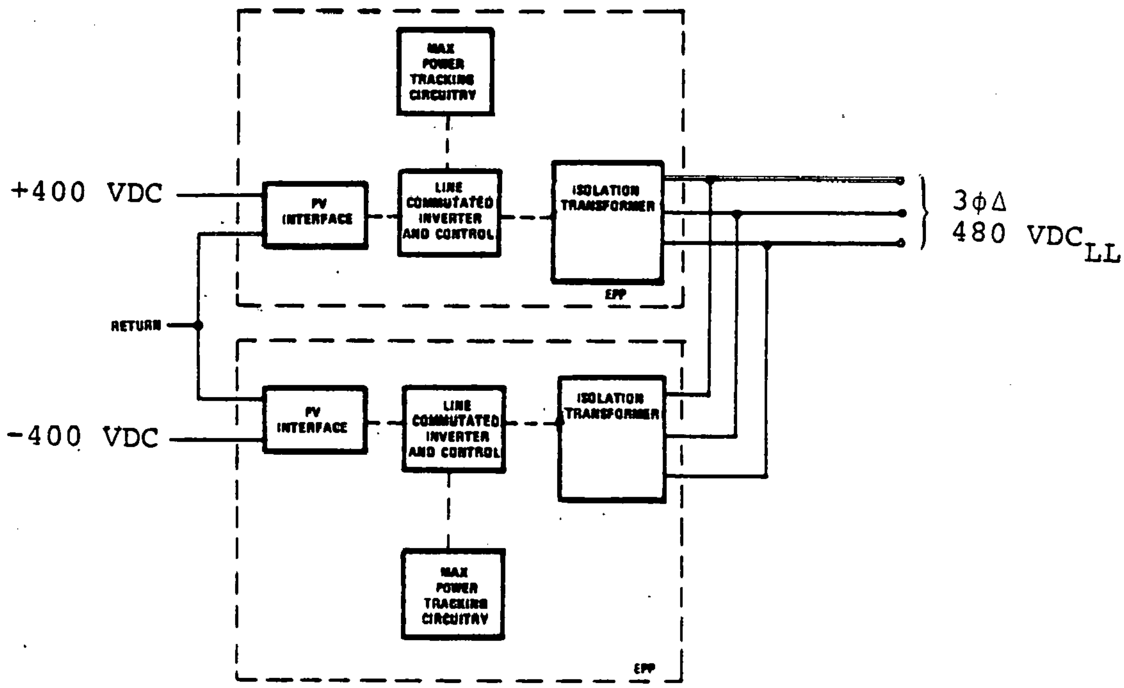
Power Conditioning Subsystem--The baseline power conditioning subsystem is composed of twin-paralleled solid state DC to AC inverters designed based upon proven basic current-fed, line-commutated conversion technology (see figure below). Each inverter is nominally rated at 125 kw AC output and is controlled at all times by a built-in dedicated control subsystem. Included at the input side of each inverter is a photovoltaic interface electrical network designed to match impedance characteristics of the DC generating network in the field to the inverter circuitry. Maximum power point tracking circuitry and control algorithms are employed to achieve maximum





power production at the overall field level. Isolation transformers provide the required interface of inverter output to the utility interconnection.

Based upon technical, reliability and economic considerations, only two candidate inverter technologies appear feasible for successful integration with a photovoltaic system: (1) a current-fed, line-commutated inverter. Industry experience and technology improvement forecasts confirm that the current-fed, line-commutated inverter is not only the best short-term approach, but also the best long-term approach, based upon the following considerations:




- The line-commutated inverter is significantly less expensive than an equivalent force-commutated inverter and will remain so independent of any technical or cost improvements in force-commutated inverter state-of-the-art development.
- The line-commutated inverter is, and is evaluated to remain, far more efficient than a force-commutated inverter for both full and partial-load operation.

- The line-commutated inverter is inherently more reliable than a force-commutated inverter and is signficantly more efficient and cost effective when evaluated based upon the same power semiconducter failure rates.
- The line-commutated inverter places no operational restrictions on power generation for the proposed application.

An added measure of safety is afforded the overall system in that a line-commutated inverter will cease operation when the interconnected utility goes down. Protection of line crews working to clear faults or perform line maintenance is a principal concern to utilities when secondary generating systems are connected in the grid network.

Heat Rejection Subsystem--The baseline heat rejection subsystem is a standard, commercially available wet surface forced convection heat exchanger designed to take advantage of the low ambient wet-bulb temperatures typical of the Trans-Pecos region. The exchange media in the cooler will be operated in a continuously flooded condition to ensure positive removal of mineral matter that would otherwise by deposited in the media. This is important in that the water supply will be the wellwater pumped for irrigation application. Cooling performance is maintained by a fan-forced convection that is controlled by the cooling subsystem controller.

During Phase III operation the thermal energy derived from active cooling of the photovoltaic receiver will be rejected to the atmosphere as waste heat. This will be accomplished in the most economical way practicable so as to minimize Phase II capital costs and Phase III parasitic power consumption to the lowest achievable levels. In a nonexperimental application it is desireable to supply this thermal energy to some compatible process and thereby to derive an economic benefit, or--at a minimum--to not incure capital and/or operating expenses characteristic of heat rejection processes.

Control Subsystem--The baseline system control subsystem is composed of a directive central controller which commands active module controllers distributed one to each photovoltaic module. The central controller has overall system operation responsibility and, in addition to the 102 module controllers, also controls other essential system thermal, electrical and mechanical functions. The central and module controllers are microprocessor-based systems that communicate via multiplexed data links. The central controller is powered by a dedicated battery-power supply ensuring continuous status monitoring of essential functions and provides the capability to institute protective measures during a utility outage. The control subsystem is presented in greater detail at the end of this section.

Several supporting subsystems and components provide essential functions to overall system operation and are briefly described as follows:

Field Wiring, Switching and Over-Current Protection Components—Two complete electrical power-conducting systems are required for field operation. One is an AC electrical system that serves three functions: (1) connects the power conditioning output to the utility grid interface, (2) distributes the grid-derived parasitic power required for system operation, and (3) transfers and distributes the emergency stow power generator output to the field bus when a utility outage occurs.

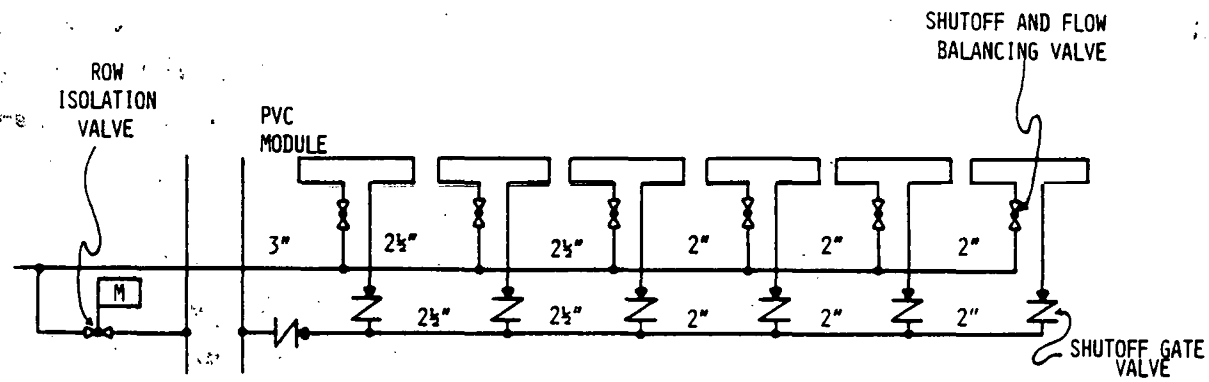
The AC electrical system is designed with a distribution feed main bus running north-south through the center of the photovoltaic module field. Switching and over-current protection breakers are provided for each branch bus from the main bus serving each half row. Switching and over-current protection breakers are provided at each module and are placed at readily accessible locations on the assembly. Field electrical power distributed to each module is 480-volt, three-phase and powers the elevation and azimuth drive motors at that voltage. Power for the module controller is transformed down to the required voltage at each module. Additionally, an outlet is included in the pedestal J-Box of each module which makes this field electrical power available for any necessary maintenance function required during the lifetime of the system.

The other electrical system required for field operation is the DC electrical system. This DC electrical system collects the photovoltaic receiver electrical output from each module in the field and conducts the power to the input terminals of the power conditioning subsystem. A three-wire DC bus is run through the center of the field and along each half-row branch circuit and is equipped with switching and over-current protection breakers distributed similarly as in the AC description above. In addition to the disconnect breaker provided at each module, a breaker which, when tripped, shorts and grounds the photovoltaic receiver DC electrical leads is provided for maximum personnel safety during module maintenance activities. The shorting and grounding breaker is controlled from the face of the module controller

J-box and is interlocked with the DC branch bus breaker to ensure isolated operation. The three-wire DC electrical bus is employed to permit use of the highest DC voltages practicable in the field power collection network. One side operates at minus 400 volts relative to the neutral return while the other side operates at plus 400 volts. Field wiring-related power losses are minimized while photovoltaic cell-to-receiver structure isolation-related breakdown voltage requirements are increased. The approach and voltage levels chosen for the baseline system design are achievable and result in the most cost-effective DC power generation and field transport supported by state-of-the-art technology.

In both the AC and DC electrical bus systems, switching and over-current protection of all equipment at critical interfaces is provided and controlled through the central control system. The system uses industrial standard components for operation reliability and both personnel and equipment safety.

Field Plumbing and Valving Components--Plumbing and valving (see figure below) in the coolant transport loop are designed for both system and environmental protection. Electrically operated row isolation valves controlled by the central control system ensure that plumbing failures in any row to not result in sizable coolant spills. Flow balancing and shutoff valves at each module allow adjustment for peak field performance and provide for maintainability of individual modules without disruption of field operation.



Emergency Stow Power Generator Subsystem--An industrially standard, commercially available, diesel engine-driven generator is included in the system. Its purpose is to provide emergency electrical power during utility outages to ensure field placement in the stowed position.

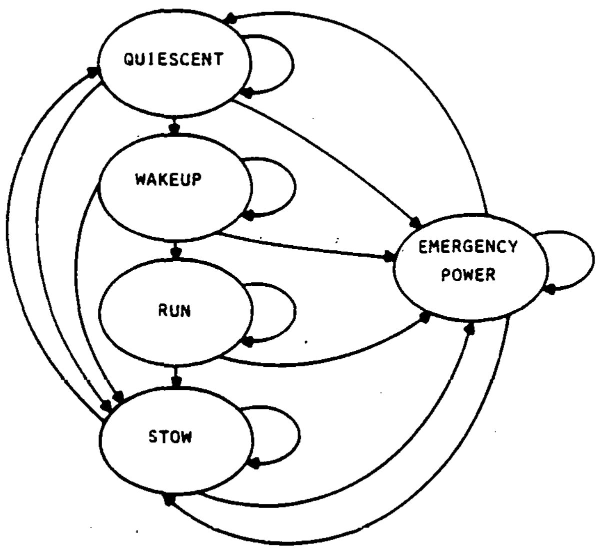
Reflector Surface Washing Subsystem--A washing system for the reflector surfaces is included in the system to ensure maintainability of field performance through use of controlled experimental cleaning procedures. A truck-mounted, high-pressure spray pumping system uses deionized water processed at the site. Detergent solutions followed by a clear rinse are sprayed from truck-mounted nozzles as the vehicle drives slowly along a row of modules. Pumped hand lines are also available on the truck if particularly troublesome cleaning problems are encountered. The replenishment rate of the deionized water supply is sufficient to permit cleaning of the entire field in one day.

System Operating Modes--Photovoltaically generated electrical energy distribution can be viewed relative to the application load in four principal ways. First, the PV-generated energy can be said to be powering the load directly assuming available PV-derived energy matches the real-time load demand. In this instance the PV system would be performing a 100-percent offset function where no load-induced demand is imposed on the utility grid. Second, in instances where the PV-generated energy is more than sufficient to satisfy the load demand, the excess energy is supplied directly into the grid for distribution to grid-connected loads other than the application load. Third, at times when the PV-generated energy is sufficient to only partially satisfy the application load demand, the grid interconnection is used to supply the deficit. Fourth, at any time the application load is off-line and not consuming energy, the PV-generated energy is supplied directly in its entirety to the grid, and the PV system acts as a secondary generating source in the overall grid network. Of course, if the PV system is itself off-line, induced demand from the application load is satisfied 100 percent by the utility grid, which is the only way the motor and pump combination presently operates.

Because the PV system is parallel interconnected with the utility grid and therefore functions as a displacing or net generating energy source, there is only one basic operating mode from the PV system viewpoint. Where the net produced electrical energy goes in real time is not known to the PV system nor does the PV system require, monitor or receive such information that in any way affects system operation.

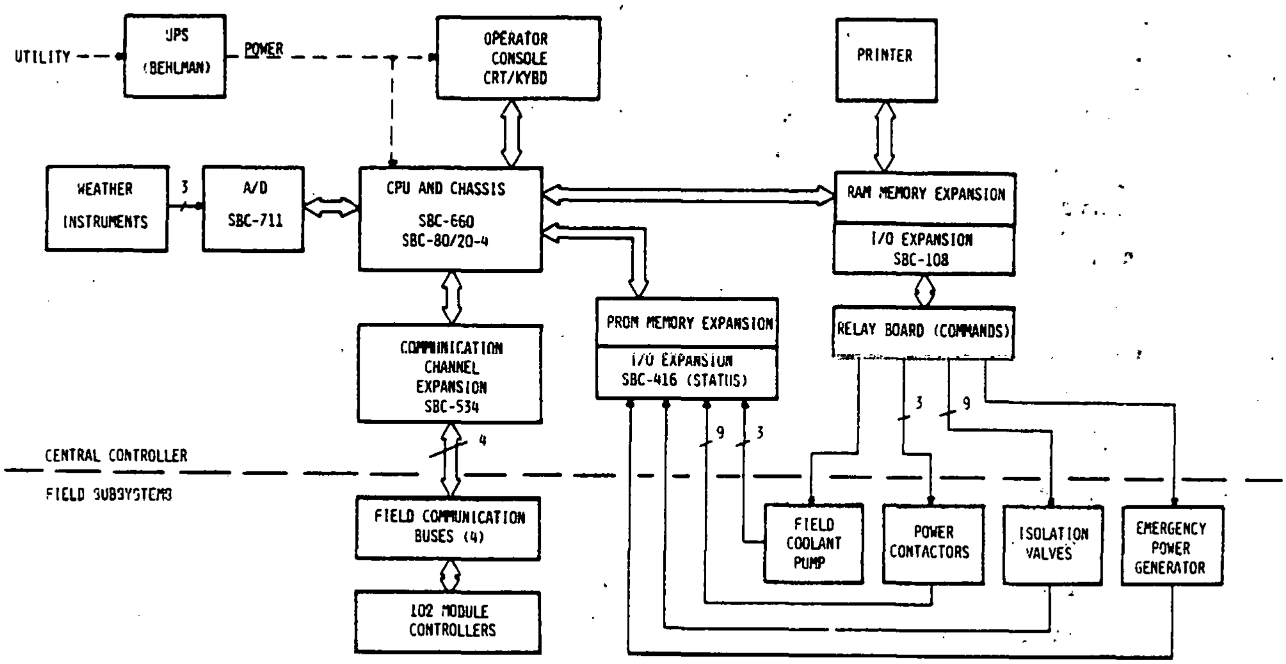
The only requirements of the grid interconnection are (1) that the utility be actively present so the line-commutated inverter can derive power frequency data re- required for control of the DC power inversion and (2) that the utility supply field parasitic power until sufficient inverter output is established.

From a control system perspective, there are five system operational modes (see figure below). First, the Quiescent Mode is the basic nonactive or rest mode for the system. The central controller is alert and monitoring time-of-day, insolation presence and level, and any ambient conditions that may pose a threat to the systems. Second, the Wakeup Mode is a transitional mode used to initiate and stage sequences of activities required preparatory to solar acquisition and power generation. Third, the Run Mode is the principal steady-state mode used for power production. Fourth, the Stow Mode is a transitional mode used to position the array in protective attitudes. Fifth, Emergency Stow Power Mode, is active at any time a utility outage exists and the field array is not stowed.




Control System Detail--A distributed control system approach has been selected for the Trans-Pecos PV experiment. A microcomputer and associated peripheral equipment provides central supervisory control to the 102 module controllers and other subsystems. The figure below is a detailed block diagram of the central controller and associated field interfaces. The central controller transmits commands to the module controllers and receives status information from them over dedicated communication buses. The module controllers are microprocessor-based and provide local self-protection and solar tracking to each module and status data to the central controller.

For control and communication purposes, the 102 module controllers are arranged in groups of up to 26. Each group of controllers has its own dedicated communication bus. This 4-bus arrangement provides individual addressing and control of each module. In addition, the 4-bus scheme provides greater field reliability since failure of a single bus will leave approximately 75 percent of the field in operation.



<u>Central Controller Function</u>--The central controller is responsible for total system supervisory control. Internal algorithms are structured to provide automatic field operation, self-protection, PV power control and servicing of operator manual controls.

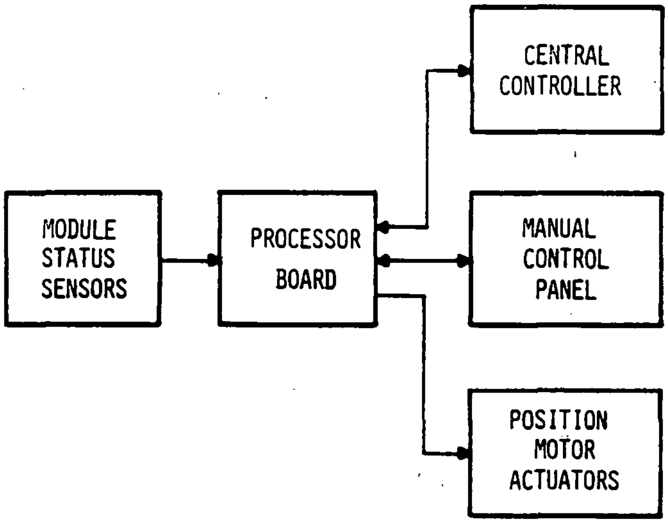
Automatic field operation includes: starting of the field coolant pump, waking up the module controllers, providing solar acquisition orientation commands, monitoring module controller status for malfunction or abnormal operation and stowing the field of modules at sunset or in the event of weather threats. Self-protection functions include:

- Monitoring status of all module controllers and commanding corrective action.
- Providing module orientation commands (implemented by module controllers) to reduce possibility of weather damage.
- Isolation of thermal rows upon coolant leak detection.
- Start/stop commands to the emergency power system to provide backup field stow power in the event of utility outage.
- Monitoring of wind speed and direction to detect wind threat.
- Monitoring of field coolant for positive flow before solar tracking is initiated.

The central controller controls PV field power by controlling the contactor which connects the PV field power to the system inverters and by controlling contactors which connect inverter AC output to the utility. The central controller also controls the emergency power system (EPS) generating equipment by means of an interlock on an automatic transfer switch associated with the EPS.

The central controller provides an operator interface, CRT and keyboard to allow entry of manual commands to the module controllers and all other subsystems. The operator interface also provides a means of displaying the status of the process variables associated with each module as well as other major subsystems. A printer is also provided for hard-copy data logging.

<u>Module Controller Functions</u>--The module controller is a microprocessor-based unit that provides orientation control and self-protect functions. Below is a block diagram of the module controller. Communication with the central controller allows the module controller to receive commands and provide present status for operator

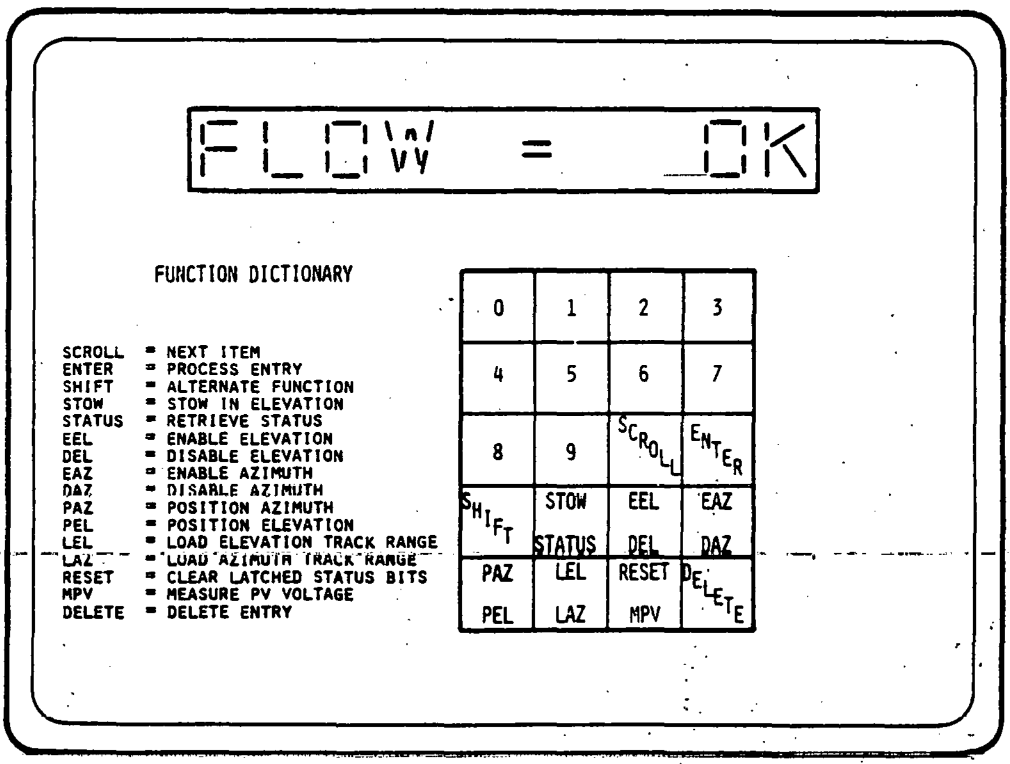



review. Data acquisition permits the module controller to measure collector voltage, read positional indicators and sense abnormal conditions. Outputs from the module controller actuate relays to drive positioning motors and allow an open-circuit DC voltage measurement to be made.

The module controller may operate in either a manual or an automatic mode. In the manual mode an operator can position the module via the manual control panel. The microprocessor continues to update module status and respond to the central controller, but cannot actuate positioning motors. Selecting the automatic mode disables manual positioning and allows the microprocessor to execute its tracking functions, if instructed to by the central controller. Abnormal conditions such as coolant over-temperature, loss of coolant flow, coolant pressure out of balance, photovoltaic current leakage, and elevation or azimuth overtravels are immediately identified by the controller. If the condition threatens, the module is rotated to the stow position. An operator will detect the error condition after the central controller has requested module status and reported the incident. Accurate tracking is accomplished by the central controller providing computed position data to the module controllers and each module controller employing photosensors to lock onto the reflected concentrated flux.

The microprocessor was chosen to minimize the overall parts count and allow flexibility in the control scheme. The microprocessor and associated circuitry are housed within a separate metal enclosure to eliminate electromechanical interference from the high voltage control mechanisms. This enclosure and the high voltage control circuitry are mounted in a weatherproof enclosure on each module.

Test Instrument--The test instrument is a compact, microprocessor-based unit that is used to exercise individual module controllers by an operator situated in the field. An entry keyboard and visual display allow an operator to issue commands identical to those of the central controller. The test instrument utilizes existing communication interfaces between the module controller and the central controller. Test instrument output appears identical as though issued by the central controller. The purpose of test instrument is to verify module operation during initial installation and to diagnose module errors at any time. The following sketch of the test instrument control panel illustrates the command entry keyboard, status indicator display and available function options.



THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# SECTION IV
# COMPONENT SPECIFICATIONS

Detailed specifications for major subsystems and components were prepared, released for quotation, and are discussed in this section. The discussion is segmented according to application to either the photovoltaic array, power conditioning, storage or thermal subsystems.

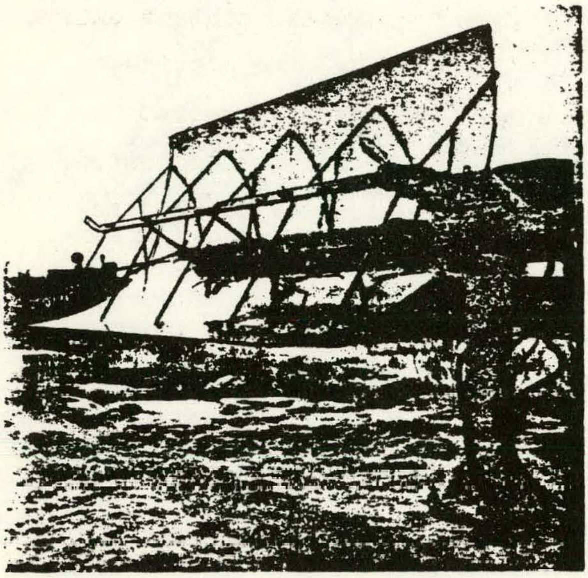
The detailed specifications and drawings prepared during the Phase I program are contained in the Technical Data Package appendix to the Baseline System Technical and Management Proposal for Phases II and III.

## PHOTOVOLTAIC ARRAY

The photovoltaic array is singularly the most important assembly of technically integrated components contained in the overall system. The extent of components defining the array includes all photovoltaic modules; all field-level AC, DC and control wiring and related switching and over-current protection breakers; and all field-level plumbing and valving. Excluded from this definition of the array are the module control subsystems included in system control specifications.

There are 102 photovoltaic modules in the baseline system photovoltaic array. The modules are positioned 12 to a row, spaced 50 feet apart in an east-west direction. Eight complete rows of modules are spaced 50 feet apart in the north-south direction. A ninth, incomplete row contains six modules that occupy the eastward half of the row. Row and module relative spacings are identical to those of the complete rows. The main electrical AC and DC buses and the main coolant headers run north-south through the center of the array. AC and DC electrical circuits branch from the main buses at each row and are separately switched and over-current protected to service each half row. Control wiring utilizes four main buses distributed throughout the array.

Coolant loop plumbing branches from the main supply and return headers at each row. Each row's supply branch main feed is serviced by an electrically operated



motorized valve controlled by the central control subsystem. Each row return branch connection to the return header includes a check valve.

Each module in the array is serviced by switching and over-current protection breakers for the AC and DC electrical circuits and by a flow-balancing and shutoff valve on the supply side and by a shutoff valve on the return side of the coolant loop plumbing.

Each module in the array is composed of a reinforced concrete foundation, a supporting pedestal, elevation and azimuth gear drives and electric motors, and two photovoltaic collectors. Each photovoltaic collector is cantilevered from opposing elevation axis gear drive shaft extensions.

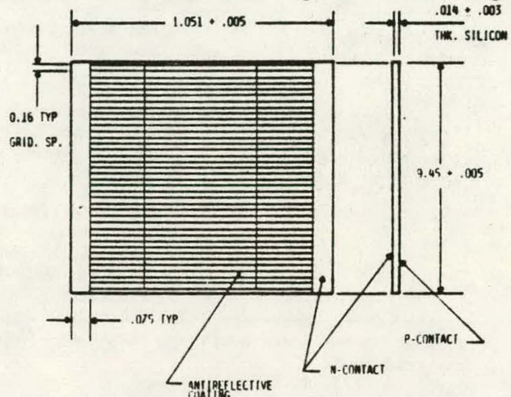
Each photovoltaic collector is composed of a concentrating reflector and a photovoltaic receiver. The concentrating reflector is fabricated from four parabolic trough-shaped, aluminum-skinned, aluminum honeycomb-cored panels assembled two to each side of a torque tube. The front skin of each reflector panel is a highly polished, coated, high purity aluminum sheet integrally bonded as a principal structural element during panel fabrication.

Closed-cell foam sheet material is bonded to the back surface of each concentrating reflector following field assembly and installation. This foam-based technique is employed to minimize hail-caused damage to the reflector panels comprising the large aperture area contained in the field. Tests have demonstrated that damage is virtually eliminated for all but the largest and highest velocity hail, the characterization of which is dependent upon the thickness and density of foam sheet applied.

Each photovoltaic receiver is assembled utilizing a multifunction aluminum extrusion. In addition to serving as a self-supporting structural beam, the extrusion provides mounting for the silicon photovoltaic cells and protective coverglass segments; provides finned coolant flow channels; provides conduit space for electrical wiring; provides mounting space for the cell protection diodes, coolant entry, exit, and turnaround fittings and receiver electrical junction box; and provides attachment mounting space for the module control tracking system photosensors.

The solar cell, developed by OCLI during Phase I, has been performance tested. An average of the I-V curves from four individual cells yields the following data for conditions of 40X solar irradiance and a cell junction temperature of 28°C (82.4°F):

$V_m$ = 0.568 VDC
$I_m$ = 6.73 ADC
$V_{oc}$ = 0.676 VDC
$I_{sc}$ = 7.12 ADC
$\eta_m$ = 17.4 %




The temperature coefficient for voltage is approximately $-2.0 \times 10^{-3}$ VDC/C°. The temperature coefficient for current is approximately +0.5 %/C°. Extrapolation of cell performance data to module-level estimates must include effects of cell-to-cell mismatch and interconnect losses.

The cell coverglasses will be longer than one cell and will correspond to the dioded length of cells. Honeywell and OCLI have reviewed the PRDA-35 Newsnote No. 6 by Sandia Laboratories. OCLI's consultant, Dr. S.I. Soclof, Professor, Electrical Engineering, California State University, Los Angeles, has concluded that a diode should be placed around every four solar cells. Experiments will be performed by OCLI to determine whether this number of cells per diode may be increased, but for now it is proposed to use one diode per each four solar cells.

The solar cell curves analyzed confirm an average efficiency of 17.4 percent at 28°C (82.4°F) and r0 suns. The cell module specification requires an efficiency of 16 percent minimum at 28°C (82.4°F), 40X (AM1).

A test section of the cell module has been temperature cycled at OCLI during Phase I. Results of 50 cycles from ambient to -40°C to ambient to +90°C to ambient showed no observable degradation nor any indication of coverglass delamination or bond discoloration. However, the prototype cell module installed outdoors at Honeywell has exhibited some observable changes. Continuing test and analysis is required to characterize the nature of these observations.

The following summary of parameters describes the array and its projected performance.

| PHYSICAL CHARACTERISTICS | | PERFORMANCE CHARACTERISTICS | |
|---|---|---|---|
| **Module** | | **Module** | |
| Description | Az-El Tracking Parabolic Trough First Surface Kinglux™ | Gross power Output (Design Point) | |
| | | Electric | 2.47 kW(e) |
| | | Thermal | 11.64 kW(t) |
| Aperture Area | 26.76 $m^2$ (288 $ft^2$) | **System** | |
| Total Length | 12.2 m (38 ft 9 in) | Gross Power Output (Design Point) | 252 kW(e) |
| Total Height (Stowed) | 2.42 m (7 ft 8 in) | Net Power Output (Design Point) | |
| Total Width (Stowed) | 2.63 m (8 ft 4 in) | Electric | 200 kW(e) |
| | | Thermal | 1074 kW(t) |
| | | Electric Efficiency | 0.074 |
| **Field** | | Gross Energy Output (Annual, El Paso-TMY) | $6.69 \times 10^5$ kWh(e) |
| Number of Modules | 102 | Net Energy Output (Annual, El Paso-TMY) | |
| Total Aperture Area | 2729 $m^2$ (29376 $ft^2$) | Electric | $5.11 \times 10^5$ kWh(e) |
| Field Spacing | 15.24 m (50 ft) East-West 15.24 m (50 ft) North-South Staggered Rows. | Thermal | $3.03 \times 10^6$ kWh(t) |
| | | Electric Efficiency | 0.070 |
| Module-Occupied Land Area | 25,084 $m^2$ (270,000 $ft^2$) | | |

OPERATING CONDITIONS

| | | | |
|---|---|---|---|
| Field Flow Rate | 664.4 GPM | Maximum Stow Time (Standby Power) | 9 min. |
| Stow Windspeed (Freestream) | 25 MPH | Minimum Field Voltage | 371 VDC |
| Survival Windspeed (Freestream) | 77 MPH | Maximum Field Voltage | 412 VDC |
| Minimum Operating Temperature | -10°F | Average Inverter Input Voltage | 400 VDC |
| Maximum Operating Temperature | +110°F | Annual Operating Time | 3467 hours |
| Maximum Stow Time (Utility Power) | 2.1 min. | Annual Time Above 150 kw(e) | 2214 hours |

The following list tabulates specifications, copies of which are included in the appendix, that apply to major components of the photovoltaic array:

Specification Listing for Module

| Specification No. | Title |
|---|---|
| I0078-BAO-1 | Metal Finish |
| I0078-BAO-2 | A Worm Gear Reducer (Elevation Drive) |
| I0078-BAO-3 | A Worm Gear Reducer (Azimuth Drive) |
| I0078-RWJ-4 | A Concentrator Silicon Solar Cell Module |
| I0078-JRW-5 | A Diesel Engine-Generator Set |
| I0078-JRW-6 | A Power Inverter System |

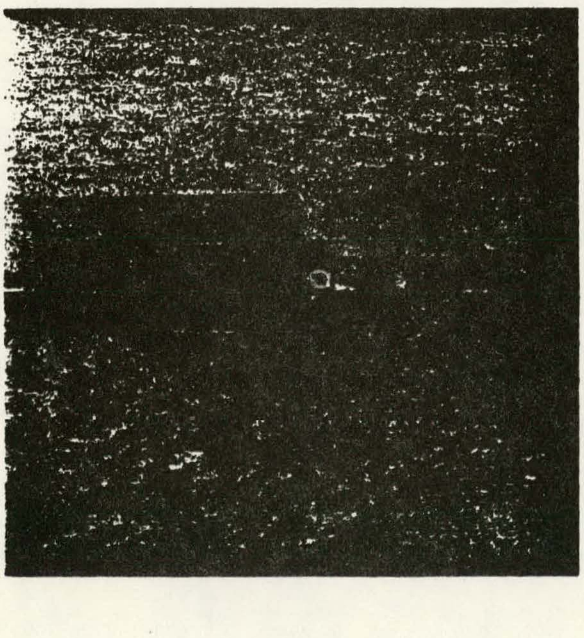
| | |
|---|---|
| I0078-RCP-7 | Aluminum, Parabolic-Shaped Concentrating Reflector for a Photovoltaic Concentrator System and Related Services and Hardware |
| I0078-RCP-8 | Optical Properties for Reflecting Aluminum Sheet |

Drawings, tabulated in Section IV and included in the appendix, also describe the major and minor components of the photovoltaic array and document assemby and installation details.

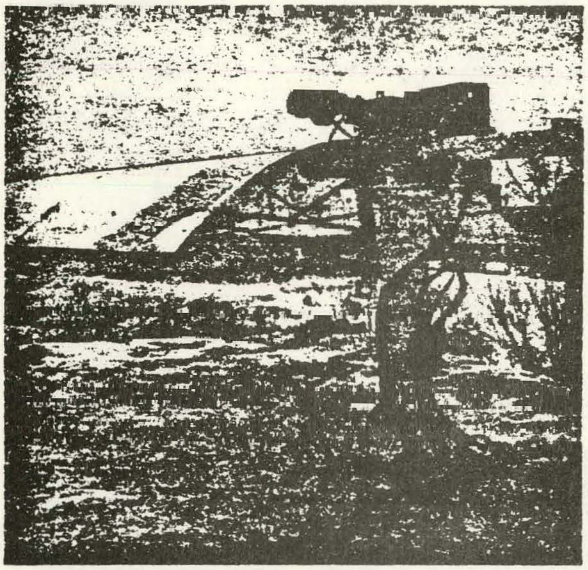
As can be observed from the referenced drawings and specifications, the majority of the components employ industrially standard materials and fabrication techniques, require industrially standard installation procedures, and/or are commercially procurable parts or assemblies from numbered stock inventories.

Exceptions to the above that involve higher levels of technical or manufacturing specialty are the silicon solar cell, the silicon solar cell module, and the parabolic reflector panel.

The development status of standard materials and fabrication techniques, industrial installation procedures, and commercially available parts is such that use of these in Phase II installation presents no identifiable risk or uncertainty to successful accomplishment.



To ascertain and advance the development status of the remaining higher technology solar specialty components, prototype versions were procured, installed and subjected to test and analysis. One nearly complete module was installed by Honeywell in Minneapolis, Minnesota, at the Energy Resources Center solar laboratory. Of two photovoltaic collectors required for each module, only one was built and installed on the prototype module at Honeywell. In addition, the drive enclosure cover on top of the pedestal assembly was omitted for ease of access. The installed foundation is peculiar to the soil characteristics at the laboratory site, but in construction detail, it is similar to that specified for the Trans-Pecos experiment site. The iron work and concrete were prepared and installed by local suppliers. The pedestal was cut and welded by local steel fabricators and delivered to Honeywell's dock for completion of finishing detail, including painting. The ring gear bearing was ordered from a catalog by stock number and was delivered to Honeywell's dock for incorporation of interface detail. The elevation and azimuth gear drivers are standard Winsmith assemblies ordered by catalog number. Specials on the order included low viscosity oil to ensure operation in the cold Minnesota environment and a solid steel, through-the-bore, extended shaft on the elevation gear reducer in lieu of the normally supplied gear case-flush tubing. The electric motors powering the drive are standard 208-volt, three-phase models ordered by catalog number.



The torque tubes were prepared by Honeywell technicians using standard steel tubing. The reflector panels were custom fabricated by Parson's of California in Stockton, California. The Kinglux™ reflective surface, integrally bonded as the front skin of the reflector panel structural assembly, was procured as commercially available material from Kingston Industries, New York, New York.

The aluminum extrusion for the photovoltaic receiver was pushed by Temroc Incorporated, Minneapolis, Minnesota, using a custom design die set. The extrusion was finish machined by Honeywell and shipped to OCLI, City of Industry, California. The silicon photovoltaic cells were custom fabricated by OCLI at its City of Industry facility according to Honeywell specifications. The cells were attached to the receiver extrusion by OCLI and were environmentally protected with SUNADEX™ glass covers over each cell. The finished assembly was shipped to Honeywell in Minneapolis.

Honeywell technicians assembled the prototype module under direction of the program engineering staff. Numerous small detailed changes were noted and incorporated into the drawings and specifications referenced above and included in the appendix.

Results obtained during Phase I testing show the design implementation to be functionally compatible with specified requirements and able to operate in the harsh Minnesota winter environment.

The following table presents a list of expected sources and the delivery (availability) schedule for major module components. The balance of the photovoltaic array

EXPECTED SOURCES AND DELIVERABILITY (AVAILABILITY) SCHEDULE
OF MAJOR MODULE COMPONENTS

| DESCRIPTION | EXPECTED SOURCE | DELIVERY ARO |
|---|---|---|
| GEAR REDUCER | • WINSMITH | 12-14 WEEKS |
| | • HUB CITY | |
| | • MORSE DIV., BORG-WARNER | |
| MOTORS | • G.E. | 8-10 WEEKS |
| | • BODINE | |
| | • HUSKY-LING | |
| TURNTABLE BEARING | • KAYDON BEARING | 8-10 WEEKS |
| REFLECTOR PANELS | • PARSONS | 18-20 WEEKS |
| | • HEXCEL | |
| | • HEATH-TECHNA | |
| RECEIVER ASSYS | • OCLI | 16-18 WEEKS |
| SUPPORT PEDESTALS | TRANS-PECOS AREA FABRICATORS | 8-10 WEEKS |
| | • CBS MACH. & ENGR. CO. | |
| | • TARGET ENTERPRISES CO. | |
| | • METAL SPECIALTIES CO. | |
| | • DUNCAN ERRECTORS AND FABRICATORS | |
| TORQUE TUBES | TRANS-PECOS AREA FABRICATORS | 8-10 WEEKS |
| | • CBS MACH. & ENGR. CO. | |
| | • TARGET ENTERPRISES CO. | |
| | • METAL SPECIALTIES CO. | |
| | • DUNCAN ERECTORS AND FABRICATORS | |
| MISCELLANEOUS ASSEMBLY MATERIAL | TRANS-PECOS AREA FABRICATORS | 8-10 WEEKS |
| | • TARGET ENTERPRISES CO. | |
| | • METAL SPECIALTIES CO. | |
| | • DUNCAN ERECTORS AND FABRICATORS | |
| MISCELLANEOUS ASSEMBLY HARDWARE | • COMMERICAL OFF-SHELF | 6-8 WEEKS |

detail will be installed at the experiment site by contractors at the time of site preparation. (Reference the Detailed System Fabrication and Installation Plan PERT chart in Section IV for component identification and construction/installation schedule.)

Calculations of the projected annual efficiency of the array were performed using El Paso, Texas, TMY meteorological data in the system performance simulation model that integrates hourly energy balance calculations on an annual basis. Results of these calculations project the annual efficiency of the array to be 8.54 percent, where array annual efficiency is defined as the array net annual energy production divided by the annual direct solar energy available. The array net annual energy produced includes module energy produced minus drive power consumed and minus field wiring losses. By comparison, the annual efficiency of the total system installation is projected to be 7.0 percent.

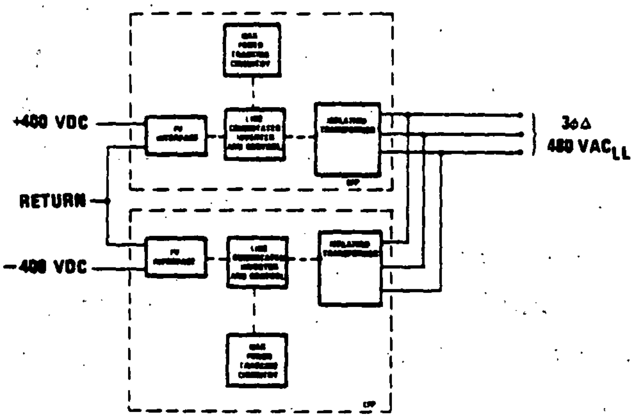
Module material costs are estimated to be $228.77 per square meter of aperture area based upon data in PRDA-35 documentation. Based upon Honeywell experience, steel gears cost closer to $7.00 per pound than $4.00 per pound, and steel gear boxes cost closer to $2.73 per pound than $4.00 per pound. Based upon these changed data elements, Honeywell estimates module materials costs to be $206.94 per square meter of aperture area. For the special purpose of these calculations, a module includes all structural components but does not include foundation, controls, wiring and plumbing. Data supporting the above calculations are contained in the following table:

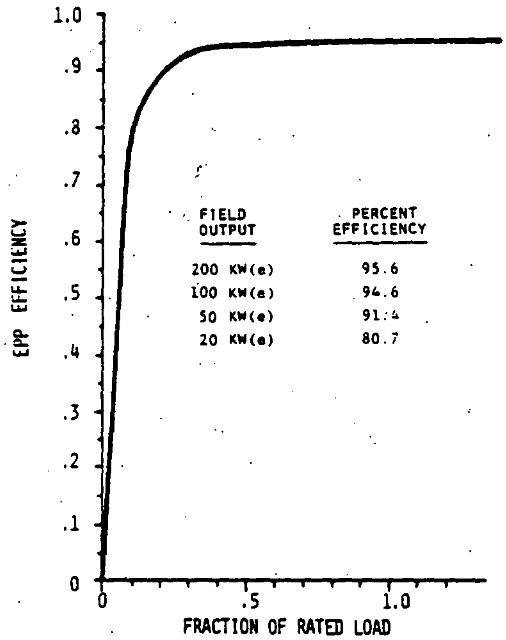
MODULE MATERIAL COST CALCULATION

| Material | Quantity | DOE Provided | Honeywell Change |
|---|---|---|---|
| Aluminum | | | |
| Extruded | 112 Pounds | $ 0.85/Pound | — |
| Sheet 5052 | 192 Pounds | $ 1.10/Pound | — |
| Honeycomb | 120 Pounds | $ 11.00/Pound | — |
| Structural | 65 Pounds | $ 1.05/Pound | — |
| Steel | | | |
| Structural | 15 Pounds | $ 0.38/Pound | — |
| Sheet (Plate) | 206 Pounds | $ 0.25/Pound | — |
| Gears | 50 Pounds | $ 4.00/Pound | $7.00/Pound |
| Gear Boxes | 578 Pounds | $ 4.00/Pound | $2.73/Pound |
| Misc. Steel Plates | 827 Pounds | $ 0.50/Pound | — |
| Motors | 40 Pounds | $ 3.00/Pound | — |
| Silicon Cells and Interconnections | 5382 $cm^2$* | $ 0.25/$cm^2$ | — |

*This is actual cell area of which 4614 $cm^2$ is active.

POWER CONDITIONING, MAJOR SWITCHGEAR AND SYSTEM CONTROLS




Power Conditioning--The power conditioning subsystem is composed of twin paralleled, solid state, current-fed, line commutated inverters. A photovoltaic system interface provided at the input to each inverter to best match the impedance characteristics of the DC field to the inverter circuitry. Input voltages will nominally be +400 VDC to one inverter and -400 VDC to the other. Each inverter is nominally rated at 125 kw(e) AC output and is controlled at all times by a built-in dedicated control subsystem. Maximum power point tracking circuitry and control algorithms are employed to achieve maximum power production at the overall field level. An isolation transformer provides the required interface of each inverter output to the utility interconnection.

Specification I0078-JRW-6, Power Inverter System, documents the details of the inverter and power conditioning subsystem. A copy of this specification is included in the appendix. Drawings, included in the appendix, detail the power conditioning subsystem installation.

The power conditioning subsystem is a custom fabricated standard industrial electrical component. Large numbers of these units in capacity ranges varying from watts to megawatts are operating in industries and utilities worldwide.

The power conditioning subsystem supplied for the Phase II installation is expected to be produced by Windworks, Incorporated, Mukwonago, Wisconsin. The delivery (availability) schedule is estimated to be 8 to 10 weeks ARO, based upon past performance.

Major Switchgear--Switchgear equipment providing switching and over-current protection is entirely electrical industry standard. Switchgear equipment sets will be supplied by the site electrical contractor and installed according to the PERT chart schedule included in Section IV, Detailed System Fabrication and Installation Plan.

System Control--System control functions are provided by: (1) a central controller and (2) module controllers distributed one on each module. Additionally, a test instrument is employed to individually exercise modules through simulation of central controller-issued commands.

Central Controller--The central controller is structured about the Intel SBC-80/20-4. This single-board computer is housed in an SBC-660 card cage together with analog-to-digital conversion cards, memory expansion cards, digital input/output expansion cards and RS-232 communication expansion cards. A CRT and keyboard provide for manual operator control and system status display. Specification I0078-KLC-9 describes the central controller configuration in detail. Table 3-2 shows the availability, manufacturer and schedule for the major central controller components.

| ITEM | MANUFACTURER/ SUPPLIER | MODEL | DELIVERY (AVAILABILITY) WEEKS ARO |
|---|---|---|---|
| 1. MICROCOMPUTER SYSTEM | INTEL | | |
| CPU | | SBC-80/20-4 | 8 |
| CHASSIS | | SBC-660 | 4 |
| RS-232 EXPANSION | | SBC-534 | 8 |
| A/D BOARD | | SBC-711 | 4 |
| PROM EXPANSION | | SBC-416 | 6 |
| I/O MEM. EXPANSION | | SBC-108 | 8 |
| 2. CABINET | BUD | E-2019 | 3 |
| FAN RACK | | B-234 | 3 |
| CASTERS | | RC-7758 | 3 |
| SHELF | | SA-1720 | 3 |
| 3. WEATHER INSTRUMENTS | WEATHER MEASURE | | |
| WIND INDICATING STATION | | W-221 | 2 |
| PYRANOMETER | | R-414 | 2 |
| 4. PRINTER | HONEYWELL | VIPS-7200 | 7 |
| 5. CRT/KEYBOARD | HAZELTINE | 1500 | 7 |
| 6. SOLID STATE RELAYS | CRAMER | SIGMA-223A-1-5D | 2 |
| 7. UNINTERRUPTIBLE POWER SUPPLY | BEHLMAN | 350VA | 8 |
| 8. RELAY CARD AND WEATHER STATION INTERFACE | HONEYWELL | CUSTOM FABRICATED | 2 |

An Intel MDS-230 or MDS-800 development system will be used to develop software for the Trans-Pecos PV Concentration Experiment central controller. This development system will be provided by Honeywell for system development work only and will not be included in the equipment complement of the deliverable control system.

The central controller will utilize the Intel RMX/80 Real-Time Operating System to provide real-time, multi-tasking software execution. This operating system is presently used in Honeywell internal development projects and has been shown to be efficient and easy to use. Central controller software will be written in PL/M, a high-level language that will greatly facilitate software development operations. Software support for PL/M and RMX/80 is provided by Intel Corporation on a continuing basis.

All components of the central controller are standard off-the-shelf products readily available from manufacturers within a 6- to 8-week timeframe. The central controller will be housed in a standard equipment cabinet. Cabling provisions will be made within the cabinet to interface the central controller to the various experiment subsystems via a terminal junction box at the control building.

The central controller components have been selected based upon demonstrated performance in Honeywell internal development programs. Current controller software development tools, programming language and the multi-tasking real-time operating system have been chosen for their ease of use, demonstrated performance and supplier support.

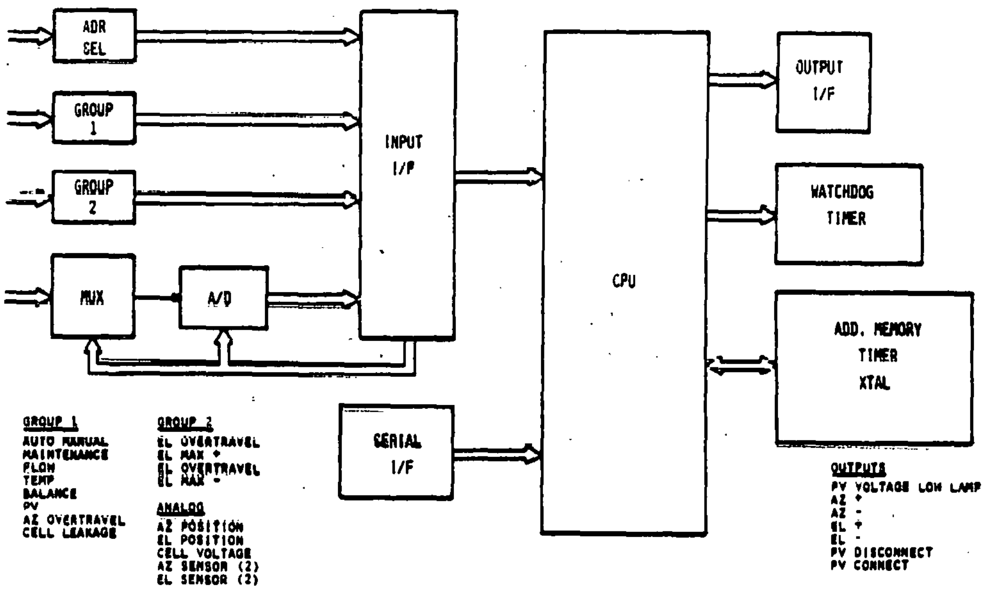
A Weather Measure W-221 Remote Wind Indicating system and an R-414 pyranometer are included with the central controller equipment. Wind speed and direction measurements made by the W-221 provide data to the central controller so that wakeup and stow command decisions can be made ensuring safe system operation. The R-414 pyranometer data is used by the central controller to determine when sufficient solar energy is available for net positive power production. The R-414 information will be used to wakeup and stow the field.

The central controller will also include an uninterruptible power supply (UPS) system to ensure availability of power for the central controller. The UPS is sized to provide only the power required to prevent loss of vital information stored in the central controller memory and to provide enough power to control the emergency power generator interlock circuit.

The central controller will be composed entirely of available industry standard products.

MODULE CONTROLLER

The module controller consists of the processor board and the controller assembly. Specification I0078-DLY-10 describes the module controller in detail. Component relationships are shown on the following page. The processor board is designed around a microprocessor, either an Intel 8048 or a Motorola 6801. A host of support circuits to interface with the external process is included with either part. These parts are chosen for their availability, manufacturer support and use in previous projects similar to the module control board. Use of the microprocessor and erase-able, programmable memory allow modifications to be made easily. The module operation can be modified on site during initial installation, if necessary. The module control board has twenty-four digital inputs for sensing switch positions, an analog-to-digital



onverter to read analog inputs, and eight digital outputs to drive solid state relays and switches. The microprocessor and related circuitry are situated on a ten- by twelve-inch printed-circuit board. This board is mounted in a metal enclosure to guard against the electromagnetic interference generated by the components in the controller assembly. The controller assembly consists of motor starters, circuit breakers, relays and associated circuitry. All components are standard and have been chosen to provide safe operation. The controller assembly is mounted in a 24-inch by 30-inch by 8-inch NEMA 12 weatherproof electrical equipment enclosure. Mounted on the inside of the NEMA box door is the metal enclosure containing the processor board. The controller assembly is scheduled for completion on December 1, 1979.

TEST INSTRUMENT

Specification I0078-DLY-11 describes the test instrument configuration in detail. The test instrument takes advantage of the present microprocessor technology, minimizing the parts count and providing greater flexibility compared to discrete logic devices. Typical microprocessor parts are an Intel 8048 or a Motorola 6801. These parts have also been chosen because of previous Honeywell experience in developing similar microprocessor products. Associated hardware used to interface the microprocessor to the display, keyboard and module controller is also standard. The communications scheme used between the test instrument and a module controller employs industry-standard FSK-MODEM for serial communication in noisy environments.

The test instrument has been designed with the operator in mind. Prompting, queueing and reporting to the operator are accomplished in easily understandable statement displays. All interactions with the test instrument are via an alpanumeric display and a keypad, which are standard, readily-available parts. The test instrument is packaged in a weatherproof metal enclosure with a twenty-five foot cable for hand use in the field. Delivery of the complete test instrument is scheduled for December 1, 1979.

STORAGE

The baseline system employs no storage subsystems as such. However, system-related dynamic operating characteristics normally associated with storage subsystems are experienced by the baseline system, but in a limited extent. This is true due to (1) the parallel interconnection with the utility and (2) the inclusion of a standby power source for emergency use.

From this perspective, the parallel utility interconnection affords a pathway useable in realtime where excess photovoltaically-generated electrical energy not required by the application load can be channeled. This duplicates a function typically performed by a storage subsystem. Similarly, excess application load-induced demand not able to be satisfied by the PV system is derived from the utility. This deficit supply function is also typical of storage subsystem operation.

The use of a standby power source in the baseline system also duplicates storage functioning, though in only one context--supply of energy on demand. In this instance, however, the source of energy (hydrocarbon fuel) is converted to useful power (by an engine-generator) but cannot be recharged or resupplied by the system deriving the benefit.

Emergency Stow Power Generator Subsystem - A standby emergency use electrical power generator is included in the baseline system and is composed of a diesel engine-driven generator and a line transfer switch. This emergency-use-only subsystem is controlled by the central control subsystem and is utilized to stow the array of modules when utility power is not available.

Specification I0078-JRW-5 documents the details of the diesel engine-generator set. Wiring interfaces for the generator and line transfer switch are included in the drawings included in the appendix.

The development status of the diesel engine-generator set and line transfer switch is that they are commercially available, industrial standard equipment sets ordered by part number. Optional specials are readily available to interface installation-specific applications. Potential suppliers include Allis-Chalmers, Caterpillar, Cummins, Detroit Diesel Allison, and Onan. Delivery (availability) is 8 to 10 weeks ARO.

THERMAL SUBSYSTEM

Field coolant consisting of a 30 percent ethylene glycol water solution will be cooled from a nominal 97°F to 85°F using a wet surface, forced-convection heat exchanger. Two sources of these exchangers are: Niagara Blower Company, 405 Lexington Avenue, New York, NY 10017 and Ecodyne MRM, Division of Chase, Inc., P.O. Box 45246, Tulsa, Oklahoma 74145. The unit having lowest projected cost and parasitic power demand is the Niagara Aero Heat Exchanger, Model 44021. The unit will cool 665 gpm of 30 percent ethylene glycol-70 percent water from 97°F to 80°F with a worst case parasitic power demand of 18 kW(e). Specification PVC00017 documents the cooling tower and is included in the appendix.

Associated with the cooling unit is a 5800-gallon holding tank and a field circulation pump. The holding tank provides surge protection and has sufficient capacity to drain the field coolant plumbing. The field pump and motor have a capacity of 665 gpm at 19 psi using 7.5 HP. Specification PVC00010 documents the field surge tank, and specification PVC00014 documents the main delivery pump and motor combination. Both documents are included in the appendix.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# SECTION V
## ORIGINAL DESIGN CONCEPT

The baseline design for the concentrating photovoltaic module developed during Phase I and proposed for Phase II differs substantially from that originally presented in the Phase I proposal document.

That original design concept is illustrated in Figure V-1 just as it was presented in the Phase I proposal. Three features account for the pertinent characteristics of the design. First, the mechanization of the two-axis motion was unusual at best. Designed to produce polar mount tracking capabilities, the proposed mount actually had limited solar acquisition and tracking ability whenever the sun position was north of the east-west plane. In addition, the use of the relatively large and tall north post posed shadowing problems for adjacent modules in the array. Second, the design employed 70-degree rim angle, 3-foot focal length parabolas covered with a 3M plastic reflective film material. Support for the parabolas was to be provided by ribs attached to back surface of each parabola. And third, the photovoltaic receiver was shown as assembled from two independent segments with counterflow coolant circulation through each segment (see Figure V-2).

By the time work on the Phase I contract actually began, the design concept had been significantly altered in an attempt to reduce component costs, to decrease numbers of parts and assemblies, and to improve the functional performance effectiveness of the concentrating photovoltaic module. The design shown in Figure V-3 became the starting point for Phase I engineering effort. Note first that the two-axis tracking polar mount motion remained including the limited northward solar acquisition capability. The prominent change was in the attendant mechanization wherein the old two-post design had been changed to use of a single south-end post, resulting in a cantilevered configuration strongly suggesting highly stressed components. While

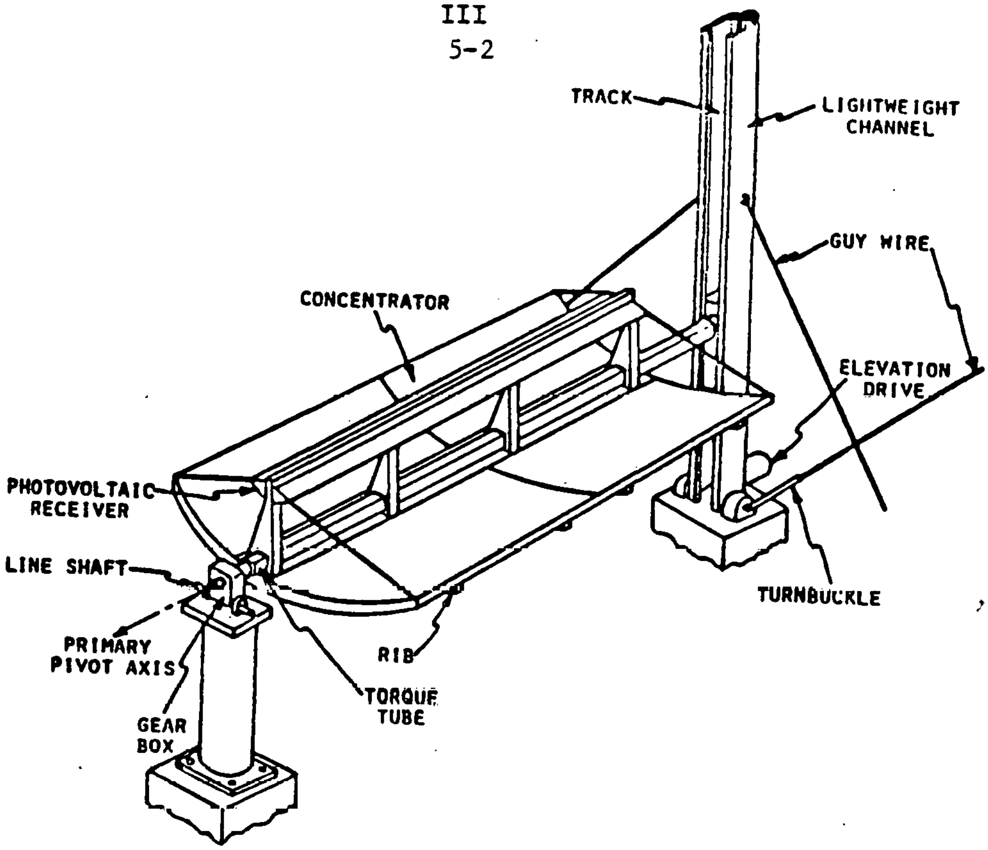



Figure V-1. Original Proposed Module Concept

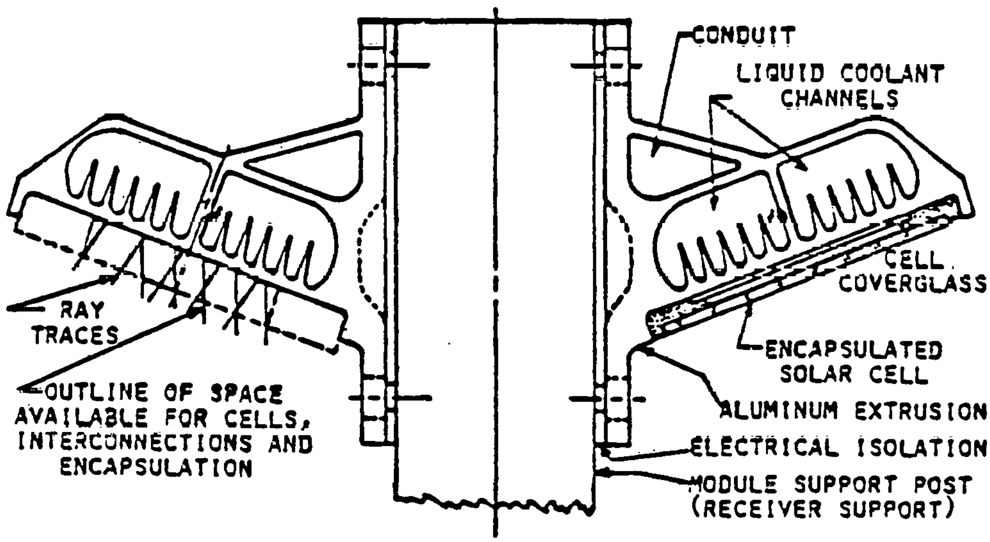



Figure V-2. Original Proposed Receiver Concept

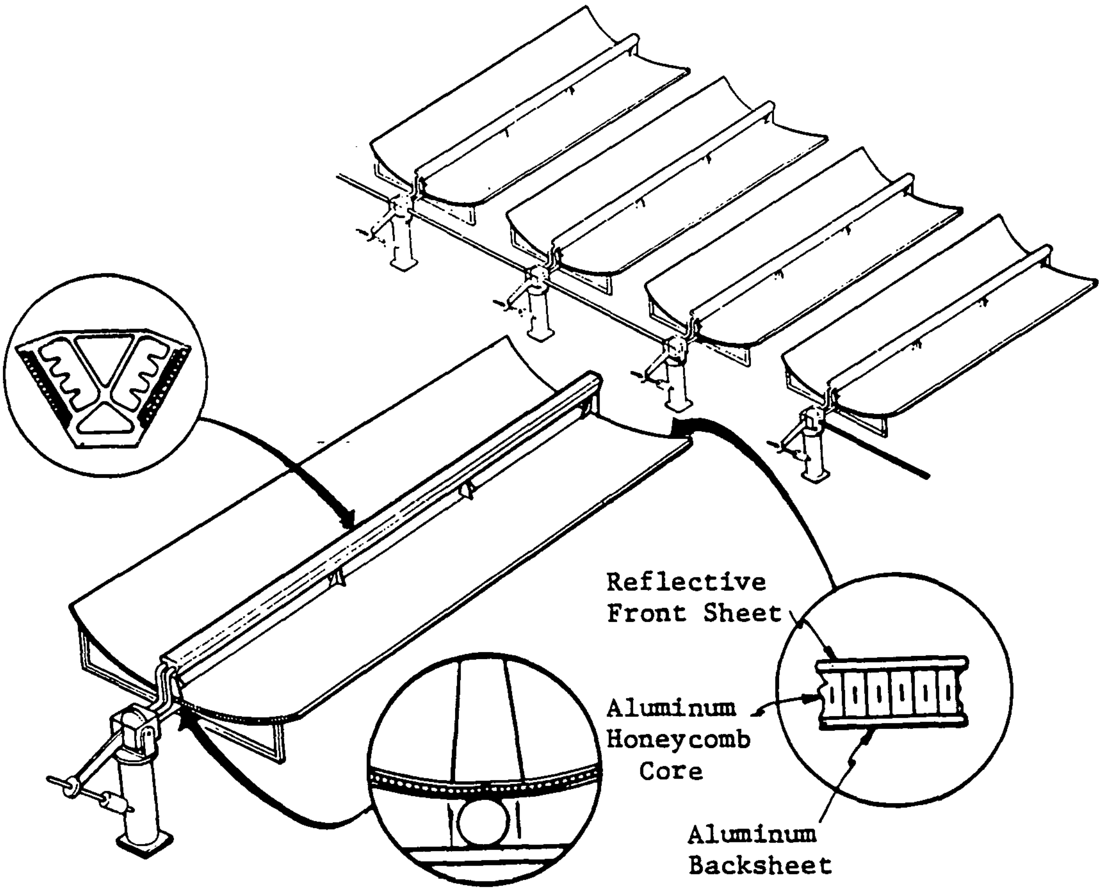



Figure V-3. Revised Concept at Start of Phase I

obviously true that high strength components were required to implement construction of the new design mechanization, it turned out that such strength was already characteristic of standardly available components and materials. Overall the new design approach actually represented a decreased cost to fabricate and install while maintaining required performance and survival features demanded by the application.

Secondly, the parabolic shape had been changed to a 90-degree rim angle, 2-foot focal length offering reduced path lengths and improved concentrated image controlability. Additionally, the use of plastic reflective film was eliminated and replaced by reflective aluminum sheet integrally bonded to the parabolic panel assembly as the front skin. And thirdly, the photovoltaic receiver assembly was markedly changed to a one-piece extrusion providing a more compact, lighter weight, and cheaper assembly.

Finally, mid-way through the Phase I program, a decision was made to take full advantage of the capability of the structural strength of the foundation and support pedestal components by maximizing the supported collector aperture area. This resulted in the design of the present Phase I baseline module featuring azimuth-elevation two-axis tracking (see Figure V-4). In addition to reducing the foundation and support pedestal assemblies by a factor of two, the resultant az-el mount was the lowest possible mount in terms of height above terrain for reduced wind-induced loads effects and provided complete positioning ability for solar acquisition and tracking.

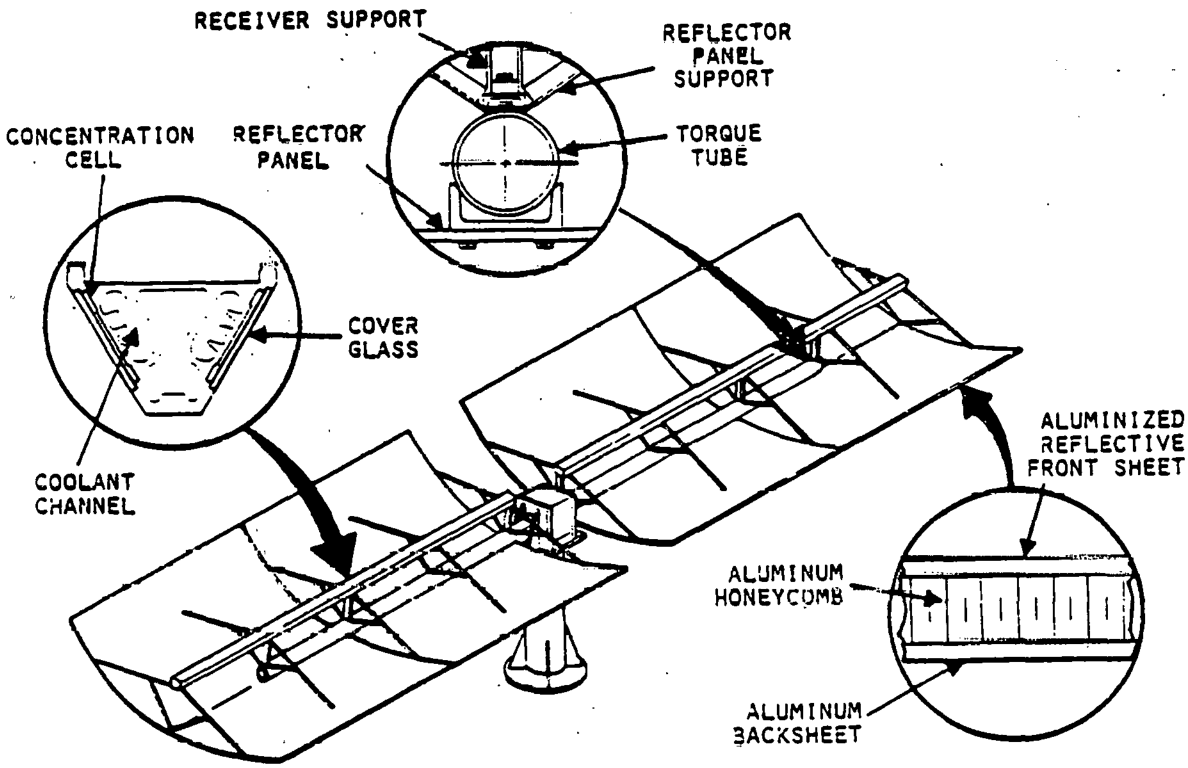



Figure V-4. Baseline Concept Resulting from Phase I

Design-related details characterizing engineering assessments of the cantilevered polar mount configuration are provided in Appendix B, Original Concept Detail.

Design-related details supporting the engineering aspects of the az-el mount configuration are provided in appendix A, Baseline Design Detail.

# SECTION VI
# SUPPORTING ANALYSES

Comprehensive technical analyses were performed during the Phase I program engineering tasks to define details of performance, component size and interface requirements.

A fundamental question was sizing of the overall system. Measurements of the deep well pump motor power consumption performed over a number of years showed very little variance from season to season, typically within 6 kw(e) of the 147 kw(e) recorded average. A total of 596,800 kwh of electrical energy is consumed during a typical irrigation season (5-1/2 months of active pumping).

Based upon these facts and the additional considerations that follow, a baseline system of 200 kw(e) capacity was selected. This system size will produce energy sufficient to offset an estimated 83 to 87 percent of the annual energy demand imposed on the utility grid by the application load.

Installation of the baseline 200 kw(e) system offers distinct advantages important to the quality of Phase III data return. To enable production of a significantly large percentage of the annual energy requirement, the peak production capability must be compatibly large. The resultant system size enables the system to carry the entire load demand for extended time periods and provides experimental data acquisition opportunities. In addition to enabling energy exchanges with the utility on a seasonal basis, the opportunity exists to backfeed the utility in real time while under full load demand conditions. System dynamic response and stability in the full load transient operating environment are essential data re-required for complete system performance characterization.

Detailed Analyses--

Meteorological Data--A major input to the systems analysis task is the baseline weather data. Two baseline weather data banks were selected for our analysis - the design point weather data and the annual weather data.

The table below compares long-term weather data for cities within 200 miles of Pecos, Texas, and the average weather data for this region of the country. Also shown is the Albuquerque, New Mexico, long-term weather data. Two choices can be made of weather data used to determine annual system performance: standard NOAA weather tapes from the city nearest the site can be used and the solar insolation data generated via the ASHRAE methodology, or a SOLMET data tape that includes solar insolation measurements can be used. The city nearest the site for which NOAA tapes are available is Midland-Odessa, Texas, whereas SOLMET tapes are available for Albuquerque, New Mexico, and El Paso, Texas. Since the weather data for all the cities listed is similar, it is likely the errors generated by use of generated solar data would be greater than the errors caused by use of SOLMET data from a city further from our site. Since we had the Albuquerque 1962 data available, it was selected as the initial data base for our system optimization. Since that time we have acquired the TMY data base, and final annual performance predictions have been made using the Albuquerque 1962 SOLMET tapes, the Albuquerque TMY tape and the El Paso TMY tape.

| SITE | AVERAGE MAXIMUM TEMPERATURE | AVERAGE MINIMUM TEMPERATURE | AVERAGE ANNUAL TEMPERATURE | MEAN CLOUD COVER | CLEAR DAYS | PARTLY CLOUDY DAYS | CLOUDY DAYS | PERCENTAGE SUNSHINE | SOLMET DNI ($kwh/m^2$/DAY) |
|---|---|---|---|---|---|---|---|---|---|
| ROSWELL, NM | 76.8 | 41.8 | 59.1 | 4.1 | 173 | 118 | 74 | 81 | -- |
| EL PASO, TX | 77.2 | 49.5 | 63.4 | 3.8 | 193 | 101 | 71 | 83 | 7.25 |
| MIDLAND-OD, TX | 77.2 | 50.1 | 63.9 | 4.5 | 166 | 99 | 100 | -- | -- |
| LUBBOCK, TX | 73.6 | 45.8 | 59.7 | 4.5 | 163 | 104 | 98 | 76 | -- |
| SAN ANGELO, TX | 78.7 | 53.6 | 66.2 | 4.8 | 157 | 96 | 112 | -- | -- |
| WINK, TX | 79.5 | 50.1 | 64.9 | -- | -- | -- | -- | 76 | -- |
| AVERAGE | 77.2 | 48.5 | 62.8 | 4.3 | 170 | 104 | 91 | 79 | -- |
| ALBUQUERQUE, NM | 70.0 | 43.5 | 56.8 | 4.2 | 174 | 108 | 83 | 77 | 7.13 |

THE ABOVE DATA IS BASED ON LONG TERM NOAA WEATHER DATA, WITH THE EXCEPTION OF WINK, TX WHICH IS BASED ON U.S. DEPARTMENT OF COMMERCE DATA.

Data from Midland-Odessa was used to determine the design point weather conditions. March 10 solar noon was selected as the design point data because it represents the peak of the spring irrigation season. DNI was computed at this time by the ASHRAE clear air methodology. Dry-bulb temperature was computed from long-term March temperature data and the ASHRAE method of determining daily temperature variations. Wet-bulb temperature was estimated using the dry-bulb temperature and the

March average noon relative humidity. Windspeed was based on long-term Midland-Odessa data. These design point conditions are summarized below.

Design Point Weather Condition

| | | |
|---|---|---|
| Day | - | March 10 |
| Time | - | Solar Noon |
| DNI | - | 316 $Btu/hour\text{-}ft^2$ |
| Dry Bulb | - | $62.5^oF$ |
| Wet Bulb | - | $48.7^oF$ |
| Windspeed | - | 18.33 ft/sec |

Component Simulation Models--Three major simulation models were used in the analyses: (1) a reflectance code to aid in the selection of candidate surfaces and to generate performance predictions for each candidate optical reflective surface based upon input test measurement data, (2) a ray trace code to analyze the optical concentrator error budget effects and (3) a system performance code to generate annual and time-point system performance estimates.

Reflectivity Code--The reflectivity data quoted by manufacturers may not be meaningful for solar photovoltaic applications unless the wavelengths associated with reflectance measurements are also specified. A typical solar cell is responsive to spectral wavelengths between 0.41 and 1.15 microns. Other wavelengths incident on the cell and absorbed by the cell produce no power but do heat the cell. The computer code calculates total thermal reflectivity and reflectivity over the solar spectrum for any material for which reflectivity as a function of wavelength is available.

The total reflectivity of the material is calculated from the equation:

$$TOT = \frac{\int_0^\infty \rho_{(\tau)} h(\tau) d\tau}{\int_0^\infty h(\tau) \, d\tau}$$

Where:

$\rho_{TOT}$ = total reflectivity

$h(\tau)$ = solar spectrum intensity (from tables)

$(\tau)$ = measured reflectivity as a function of $\tau$

$\rho\tau$ = wavelength

The effective reflectivity seen by the solar cell is computed as:

$$\text{cell} = \frac{\int_0^{\infty} \rho(\tau) h(\tau) r(\tau) d\tau}{\int_0^{\infty} h(\tau)\, r(\tau)\, d\tau}$$

Where:

$\rho_{cell}$ = material overall reflectivity for the solar cell

$r(\tau)$ = response of the solar cell to radiation of wavelength

Ray Trace Model--The ray trace model uses a Monte Carlo technique to determine the optical performance of a parabolic concentrating reflector. Required inputs includes aperture area, focal length, rim angle, receiver size and receiver slant angle. In addition, the standard deviation of the surface normal error, tracking error and reflectance profile must be supplied as input parameters.

The sun is modeled as a disc with a constant intensity profile having a cone angle of 1/2-degree. Rays are drawn unformly over the aperture to the center of the sun. Each ray is then perturbed uniformly over the sun's surface. The normal to the reflector surface at the ray hit point is computed and perturbed by the normal distribution function using the resultant standard deviation of the tracking surface and reflectance profiles. The perturbed sun ray and the perturbed surface normal are then used to compute the reflected ray. Finally, the hit point of the reflected ray in the plane of the receiver is calculated.

System Performance Code--The system performance code is a quasi-steady state analysis of the performance of the photovoltaic system. At every time-point the weather data and solar intensity and position are used to calculate system performance. The system output is integrated over a year to determine annual performance. The model has four major components: the weather and sun model, concentrating reflector optical model, cell performance model, and thermal performance model.

The weather and sun model reads and interpolates the weather data for use in the simulation and calculates the sun's position. Weather data is read either from a NOAA "typical year" weather tape or a SOLMET weather tape. If a non-SOLMET weather tape is used, solar intensity is calculated from cloud cover data using the method of Kimura and Stevens.

The reflector model computes the power incident on the receiver at each timepoint from the equation:

$$P_r = DNI\ A_p\ \eta_s\ \eta_c\ \eta_r\ \eta_e\ \eta_m$$

Where:

$P_r$ = power incident on the receiver
DNI = current direct normal solar intensity
$A_p$ = receiver aperture area
$\eta_s$ = field shading efficiency
$\eta_c$ = cosine efficiency due to the aperture area not being normal to the sun
$\eta_r$ = reflectivity
$\eta_e$ = reflector receiver end losses due to reflected light missing the end of receiver
$\eta_m$ = reflector/receiver spillage losses due to the reflected beam angle being larger than the angle subtended by the receiver.

In the code two different values of $P_r$ are computed, one for thermal power output computation and one for electric power output computations. This is due to the reflector having two different effective reflectances as described under the reflectivity code discussion.

The photovoltaic cell array model computes the output of the solar array as a function of cell temperature, flux intensity on the cells and time of year from the equation:

$$P_\varepsilon = P_r\ \eta_p\ \eta_B\ \eta_c\ \eta_w\ \eta_{DA}$$

Where:

$P_\varepsilon$ = gross electric power output of the field

$P_r$ = power incident on the receiver (based on the solar cell spectrum reflectance)

$\eta_P$ = cell packing factor

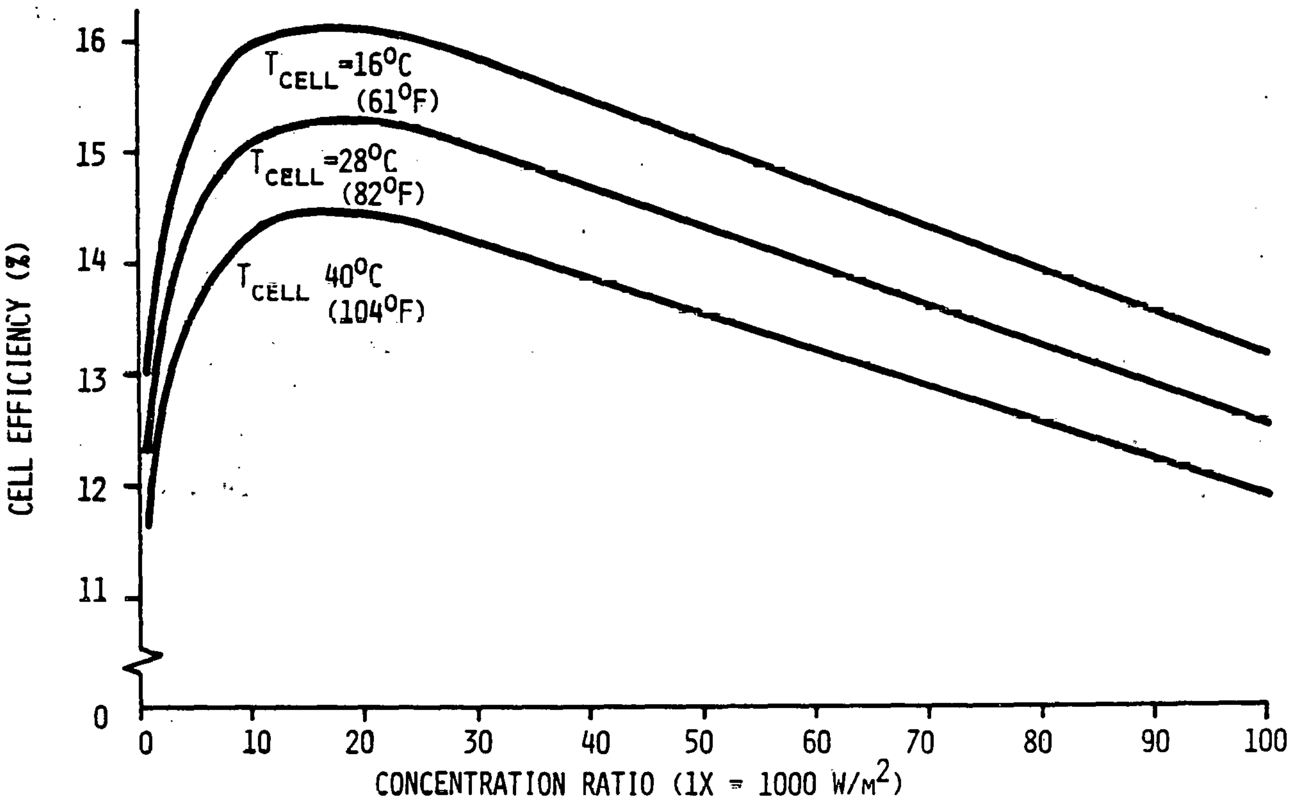
$\eta_B$ = cell blocking efficiency

$\eta_c$ = cell string efficiency

$\eta_w$ = field wiring efficiency

$\eta_{DA}$ = DC to AC conversion efficiency

The model assumes peak power point operation. The figure below shows the estimated efficiency of the cell strings ($\eta_c$) as a function of flux intensity and average cell temperature. The cell packing factor is due to intercellular gaps.



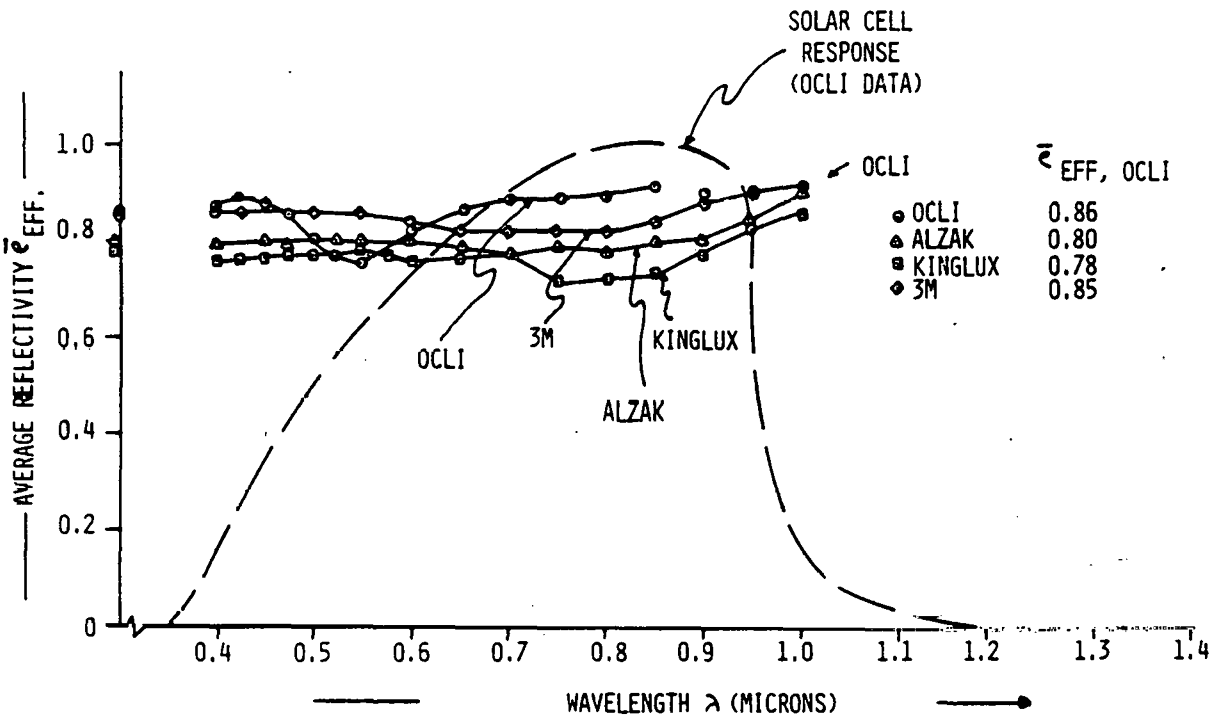
The cell model assumes there are no diodes in the cell string and that the cell string output is limited by the worst cell in the string. The cell blocking efficiency ($\eta_B$) is, therefore, the ratio of the output of the worst cell in the string (due to shading or endloss effects) to the output of the average cell in the string. Comparison of the no diode assumption with the assumption of "perfect" dioding ($\eta_B = 1$) has shown a less than one percent annual performance change at the module spacing for our system, and therefore detailed modeling of the diodes was not attempted.

The field wiring efficiency is computed at every time-point assuming constant field voltage output and variable current output. The DC to AC conversion efficiency is calculated from manufacturers data at every time-point.

The thermal performance model calculates heat balances in the entire field at every time-point by a quasi-steady state analysis which separately considers the cooling tower, the field inlet manifolding, the field outlet manifolding and the receiver cell assembly. In addition, pressure drops are calculated as are pumping power requirements, cooling tower power requirements and tracking/control parasitic power requirements at every time-point. The code assumes a constant field flow rate and the receiver film heat transfer coefficient is calculated at each time-point as a function of flow velocity and current fluid temperature. The cooling tower model is based on a curve fit of manufacturers data for Marley 7733 cooling towers.

System Performance and Sizing Tradeoffs--

Reflective Material Choice--The reflectivity code was used to analyze four candidate reflective materials: an OCLI experimental product, KINGLUX™, ALZAK™, and 3M's FEK-244. Cell response characteristics were based on data from OCLI for concentrating solar cells. The reflectivity data and the cell response data is shown in the following figure.

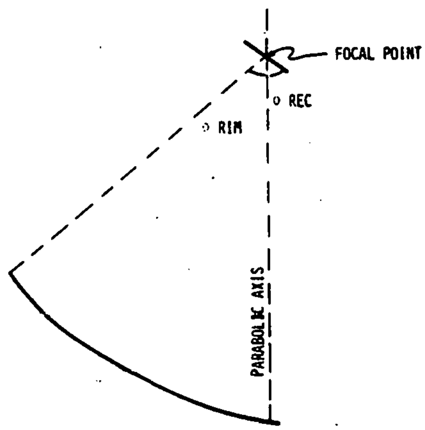



The results of the analysis are shown in the table below along with other data on each reflective material. The best reflectivity was shown by the OCLI product. Unfortunately, this material and processing are experimental developments.

| MATERIAL | STOCK SIZE | COST ($/FT$^2$) SMALL QTY. ~200 FT$^2$ | COST ($/FT$^2$) LARGE QTY. > 10K FT$^2$ | REFLECTIVITY OVERALL | REFLECTIVITY EFFECTIVE | LONGEVITY (EXPOSURE TESTS) |
|---|---|---|---|---|---|---|
| KINGLUX (KINGSTON INDUSTRIES) | 24" x 48" x 0.020"<br>24" x COIL x 0.012"<br>24" x COIL x 0.020"<br>30" x COIL x 0.020" | \$1.95/FT$^2$<br>\$1.75/FT$^2$<br>\$1.50/FT$^2$<br>— | —<br>—<br>—<br>\$1.86/FT$^2$ | 0.811 (LIT. VALUE 0.874) | 0.791 | EMMAQUA TESTS AT DSET SHOWED NO CHANGE IN REFLECTIVITY |
| FEK-244 (3M CO) | 24" x 150 FT (ROLLS) 4 TO 6 MILS FILM THICKNESS | \$1.00/FT$^2$ | — | 0.865 | 0.864 | EEK TESTS SHOWED NO CHANGE IN REFLECTIVITY ($\rho_{EMMAQUA}$ = 0.78) |
| ALZAK | 24" x 72" x 0.020"<br>24" x 72" x 0.025"<br>24" x 72" x 0.032" | \$3.37/FT$^2$ | \$2.43/FT$^2$ | 0.825 | 0.814 | A SLIGHT DECREASE IN REFLECTIVITY ($\rho$ = 0.78) (FROM EEK TESTS) |
| COILZAK | 24" x 96" x 0.020"<br>24" x 96" x 0.025"<br>24" x 96" x 0.032" | \$1.67/FT$^2$ | \$0.72/FT$^2$ | APPROX = (0.75) ($\rho_{ALZAK}$) | | NOT AVAILABLE |
| OCLI (EXP.) | ? | ? | ? | 0.870 | 0.888 | NOT AVAILABLE |

The second best reflectivity was exhibited by the FEK-244 3M product. In addition, it has the lowest material costs. However, unlike the other products, it requires a mounting surface (the other products can be used as the structural front surface of the reflector assembly) and the labor costs for installation are twice that of any other reflective surface. The ALZAK™ product showed the third best reflectivity for solar cells. It is also the costliest material and shows a slight tendency to degrade on exposure to the environment. The KINGLUX™ material exhibited the poorest reflectivity in our tests, although the literature values are higher than our measured values. In addition, the installed cost of the KINGLUX™ material is the lowest of all materials and it shows no degradation in long-term exposure tests. Therefore, KINGLUX™ has been chosen as our baseline reflective material. Recent tests of new samples show the average specular reflectance to be 0.830 measured from 12 samples. The new data ranged from a high of 0.842 to a low of 0.818. The average measured in the perpendicular direction was 0.826.

Reflector Rim Angle and Receiver Tilt Angle--The optical model was used to determine optimal rim angle ($\emptyset_{rim}$) and receiver tilt angle ($\emptyset_{rec}$) as defined in the illustration below.




The geometric concentration ratio was held constant at 48:1 for this early analysis, and the values of 4, 6 and 8 milliradians were used as estimates of the standard deviation of the parabolic surface normal error.

Variation of the rim angle at constant geometric concentration ratio has two effects. Decreasing the rim angle will increase the focal length of the reflector, therefore increasing the size of the image at the focal point from every part of the reflector. However as the rim angle increases the required viewing angle of the receiver increases, increasing the real size of the image on the receiver due to cosine effect. The larger the effective image size, the larger the amount of reflected light which misses the receiver.

The cosine effect between the receiver and the parabolic surface can be minimized by proper selection of the receiver angle. The optimum receiver angle (minimum spillage losses) does not vary with surface normal error and is dependent only on the rim angle. Figure 2-2 shows the optimal receiver angle as a function of rim angle.

Using the optimal receiver tilt angles, spillage factor as a function of rim angle was determined for various values of the surface normal error. These results appear in Figure 2-3.

The tracking error of the module is expected to be at most 1.75 milliradians. The reflector surface normal error is expected to be 4.7 milliradians based on data presented by Pettit and Butler. The reflectance error is set at 4.2 milliradians based on an average of two normal distributions reported for KINGLUX™ by Pettit and Butler. The resultant standard deviation of the surface normal can be found from the equation:

$$\theta^2 = \theta_T^{\ 2} + \theta_N^{\ 2} + (\theta_r/2)^2$$

Where:

$\theta$ = effective surface normal error

$\theta_T$ = tracking error

$\theta_N$ = surface normal slope error

$\theta_r$ = reflectance error

The effective surface normal error for the reflector design is 5.44 milliradians. From Figure 2-3 the optimal rim angle is near 90 degrees while the optimal receiver angle is near 30 degrees (Figure 2-2). The spillage efficiency of the collector is estimated to be 0.92.

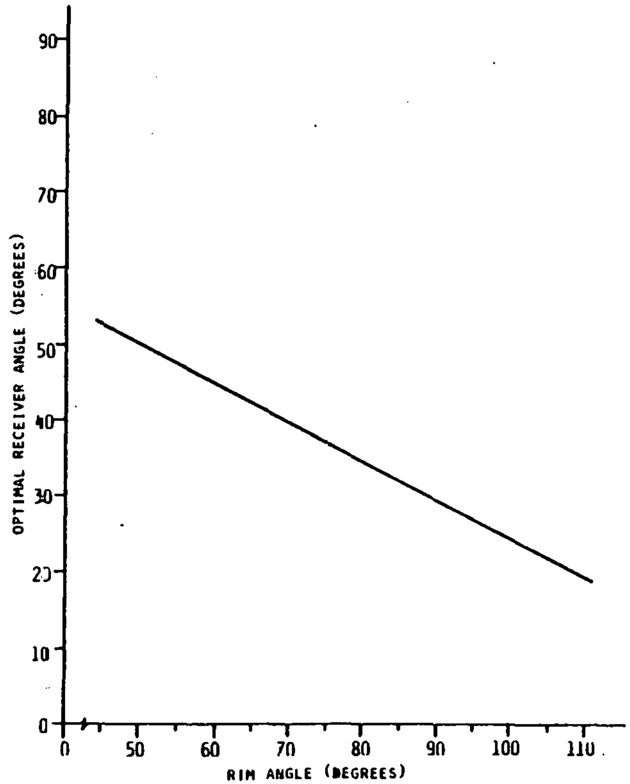



Figure 6-2. Optical Receiver Angle As a Function of Collector Rim Angle

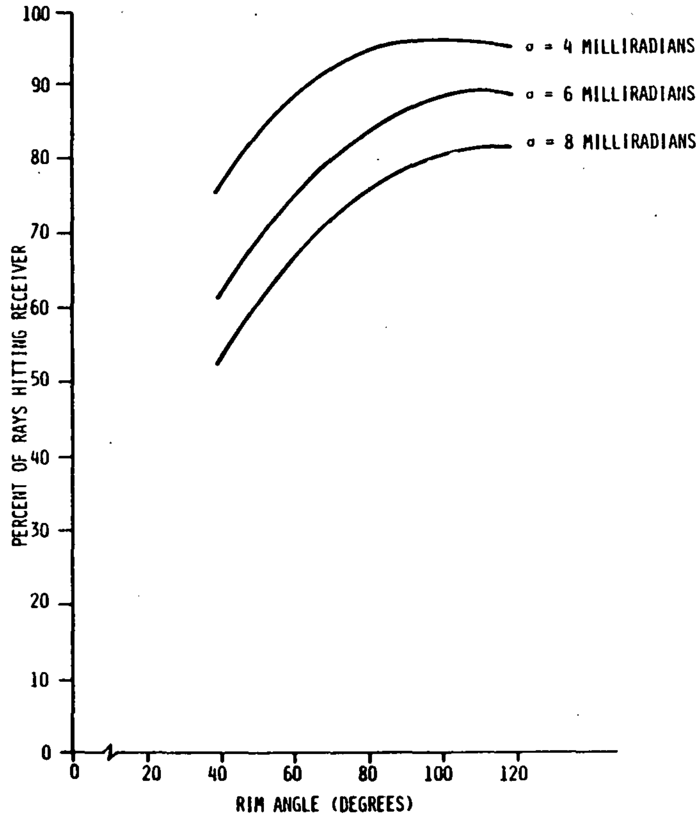



Figure 6-3. Percent of Receiver Hits versus Rim Angle for Three Surface Normal Slope Errors

Field Spacing Tradeoff--Two field layout designs were analyzed, one with the modules placed in a rectilinear array and a second with every east-west row staggered from the rows directly north and south. For both designs annual net electric output was determined as a function of north-south and east-west module spacing.

Figures 2-4 and 2-5 exhibit the results. The numbers given in the figures are the net percentage changes in annual electric output relative to the reference case, 40 feet north-south by 40 feet east-west staggered module spacing. The staggered module array is consistently as good as or better than the rectilinear array, and has been selected as the baseline design array configuration. Because the piping and wiring costs are a small part of the total system costs, the life-cycle cost optimum module spacing will be very near the annual energy optimum, but will be slightly smaller. A design spacing of 50 feet north-south by 50 feet east-west has been selected as module spacing for the baseline system.

Adhesive Selection--A principal technical problem posed by concentrating photovoltaic systems is efficient cooling of the photovoltaic cells. Cells operate best at low temperature and require low thermal resistance adhesive bonds to the receiver. Further complicating the problem is the requirement that the cells be connected in series to generate high output voltages to minimize field-level $I^2R$ losses and electrical wire sizes. The resultant conflicting set of thermal and electrical re-requirements imposed on the function of the adhesive layer make this a very difficult problem. Simultaneously the adhesive must have high electrical resistance and low thermal resistance.

Three adhesives were investigated for use on the receiver module: RTV, Eccosil 4952 and Berlon. All three have similar electrical properties. A thickness of 0.005-inch was chosen for all of the adhesives for evaluation purposes. The following table summarizes the design point system performance using each of the adhesives:

| Adhesive | Net Electric Output (kw) | Average Cell Temperature (°C) | Average Cell Efficiency | Cells-to-Coolant Differential Temperature (°C) |
|---|---|---|---|---|
| RTV | 197.2 | 47.9 | 0.131 | 15.5 |
| Eccosil | 204.1 | 40.8 | 0.135 | 8.3 |
| Berlon | 205.6 | 39.2 | 0.137 | 6.7 |

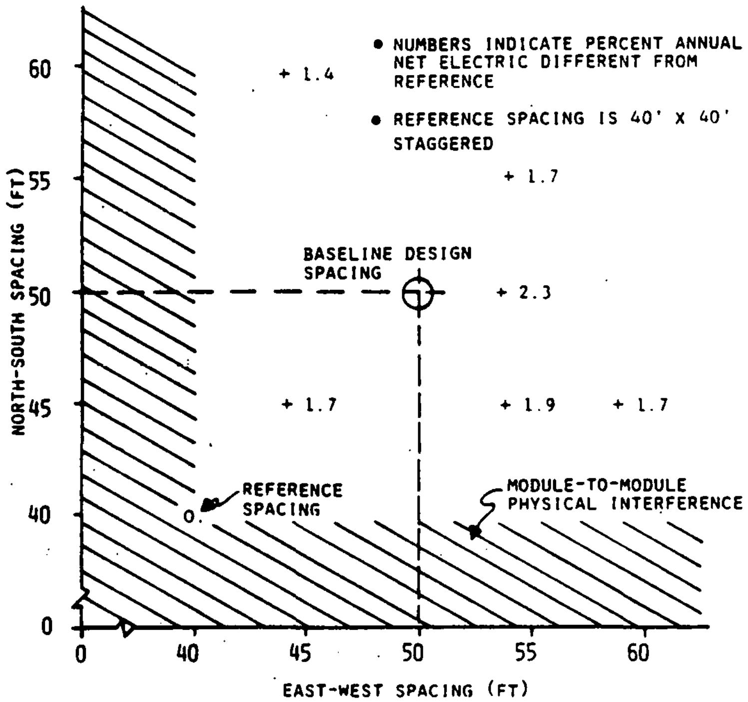



Figure 6-4. Module Spacing versus Net Electric Output, Staggered Field

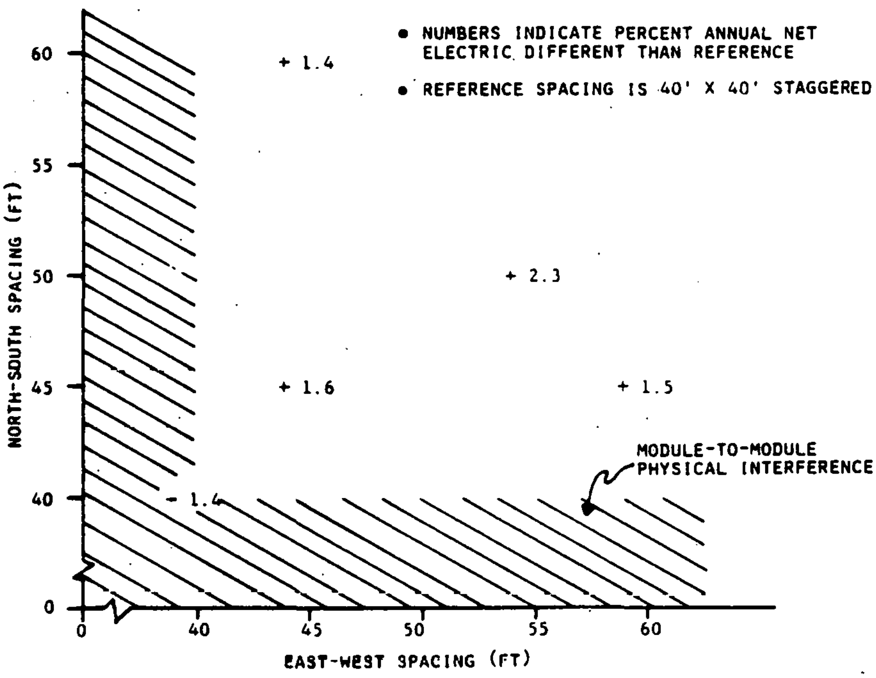



Figure 6-5. Module Spacing versus Net Electric Output, Nonstaggered Field

Use of Eccosil adhesive results in a net electric output improvement of 3.5 percent over the RTV, and the Berlon adhesive shows an additional improvement of 0.74 percent over the Eccosil. However, there are possible health hazards associated with the use of Berlon. Therefore, Eccosil has been selected as the adhesive for the baseline cell module design.

Field Piping and Flow Rate Analysis--Two piping arranagements were investigated: piping every module in parallel and piping the modules in series groups of three. A field layout was chosen consisting of 102 collectors in a rectangular array with a 50-foot east-west by 50-foot north-south spacing. Two Marley 7733 cooling towers were used in the system. Preliminary pipe sizes were selected based on a flow velocity of two feet per second through the delivery pipes and four feet per second through the receiver.

The system simulation model was then used to evaluate a variety of flow rates for both field designs to determine the optimal performance. At low flow rates, the low Reynolds number in the receiver results in high fluid film heat transfer coefficients and yields high cell temperatures. The resultant low cell efficiency reduces the field electric output. At high flow rates, the pressure dop in the field becomes large requiring increased pumping power resulting in reduction of the net electric output of the field.

Analysis results for the two field designs show an optimal field flow rate of 2.5 to 3.5 feet per second (Figure 2-6). Because 3.5 feet per second flow rate is nearer the turbulent regime desired for optimal heat transfer, it was chosen for further analysis. This flow rate was used to perform an economic analysis on the piping systems in both fields and to define optimal pipe sizes and pumping power requirements. The resultant pumping power, field piping capital costs, and the difference in field gross electric output between the series and parallel fields were combined to determine the difference in life-cycle costs. Final results of the analyses assuming two levels of system electric power production costs, are summarized below.

High electric power production costs (typical of the first system) show the parallel field to have an annualized cost advantage. However, lower electric power production costs (typical of future systems), show the series field to have only a slight cost advantage. The parallel piping approach was selected for the baseline field design.

Annual Cooling Performance Summary (k = $0.30/kwh)

| | | Parallel | Series |
|---|---|---|---|
| Annual Gross Output | | 608500 kwh | 593000 kwh |
| Annual Pumping Power | | -26179 kwh | -15824 kwh |
| Net Annual Output | | 582321 kwh | 577176 kwh |
| Delta Parallel | = | + 5153 kwh | |
| at $0.30/kwh | = | + $1546 | |
| Delta Parallel Capital Cost | = | - $8358 | |
| Annualized Capital Cost | = | - $1672 | (20%) |
| Net Annual Cost Difference | | | |
| (Series Cheaper than Parallel) | = | - $126 | |

Annual Cooling Performance Summary (k = $0.60/kwh)

| | | Parallel | Series |
|---|---|---|---|
| Annual Gross Output | | 608500 kwh | 593000 kwh |
| Annual Pumping Power | | -18839 kwh | -12018 kwh |
| Net Annual Output | | 589661 kwh | 580982 kwh |
| Delta Parallel | = | + 8679 kwh | |
| at $0.60/kwh | = | + $5207 | |
| Delta Parallel Capital Cost | = | - $8495 | |
| Annualized Capital Cost | = | - $1699 | (20%) |
| Net Annual Cost Difference | | | |
| (Series More Expensive than Parallel) | = | + $3508 | |

Cooling Tower Sizing--A study was performed to determine the best size and performance of the cooling tower system for this application. Manufacturer's data was used to estimate cooling tower thermal performance and parasitic power requirements. Better thermal performance is obtained by increasing the size of the tower, but this results in higher parasitic power requirements.

The results of this analysis are shown in Figure 2-7. At an ambient air wet-bulb temperature of 65°F and a coolant inlet temperature of 95°F, best annual performance is obtained with a cooling tower designed for an 86.5°F exit temperature. Decreasing the exit temperature to 83°F results in a net annual electric output decrease of only 0.4 percent, but does double the power consumption of the cooling tower as well as increasing capital costs.

Transient Performance--Two types of transient effects occur in this system: normally expected transient effects due to clouds, solar variability, and weather variability, and abnormal (system failure related) transients due to loss of coolant, pump failure, or failure of electrical components.

Failure of the cooling system, either by a loss of flow or a reduction in flow rate, will cause an increase in cell temperature unless the modules are quickly defocused. A study was performed to estimate resultant maximum cell temperatures and field outlet temperatures under a variety of conditions to determine limit points for emergency shutdown temperature and flow rate sensors. Normal module flow rate is 6.5 gpm. Maximum resultant coolant and cell temperatures are as follows:

| System Status | Outlet Temperature (°F) | Cell Temperature (°F) |
|---|---|---|
| Normal operation | 110.6 | 124.4 |
| Coolant flow reduced to 3.25 gpm | 127.9 | 206.8 |
| Loss of electric output | 118.0 | 133.2 |
| Loss of electric output and coolant flow reduced to 3.25 gpm | 137.0 | 212.6 |

Based on this data, a temperature cutoff of 150°F and flow rate cutoff of 3.25 gpm should protect the cells from exceeding 300°F without risking losses of useful energy output.

During normal system operation, thermal transients have little effect on system output. A change in average cell temperature will result in a change in peak power point voltage, and the inverters will automatically adjust to maintain peak power

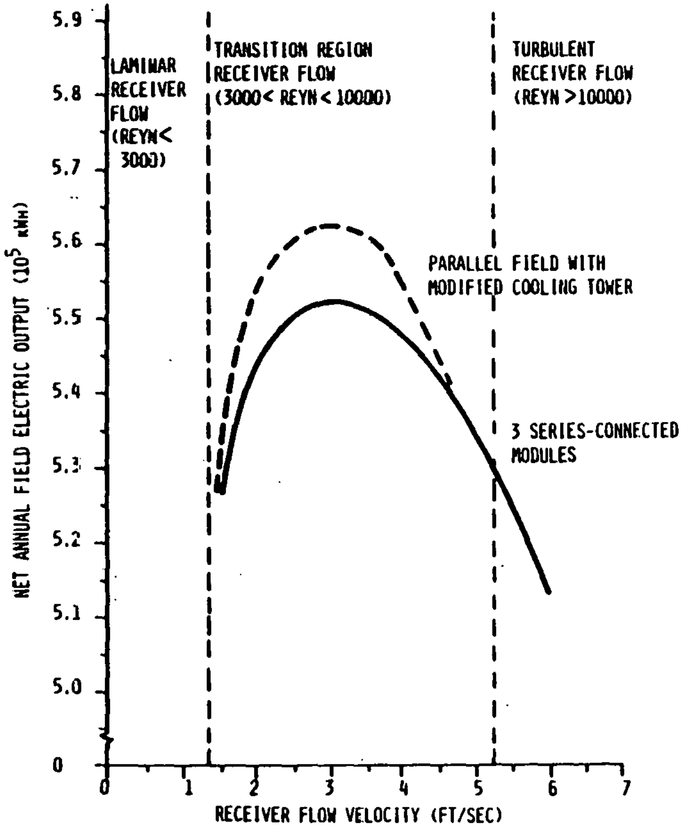



Figure 6-6. Net Annual System Electric Output as a Function of Receiver Flowrate for Two Different Field Designs

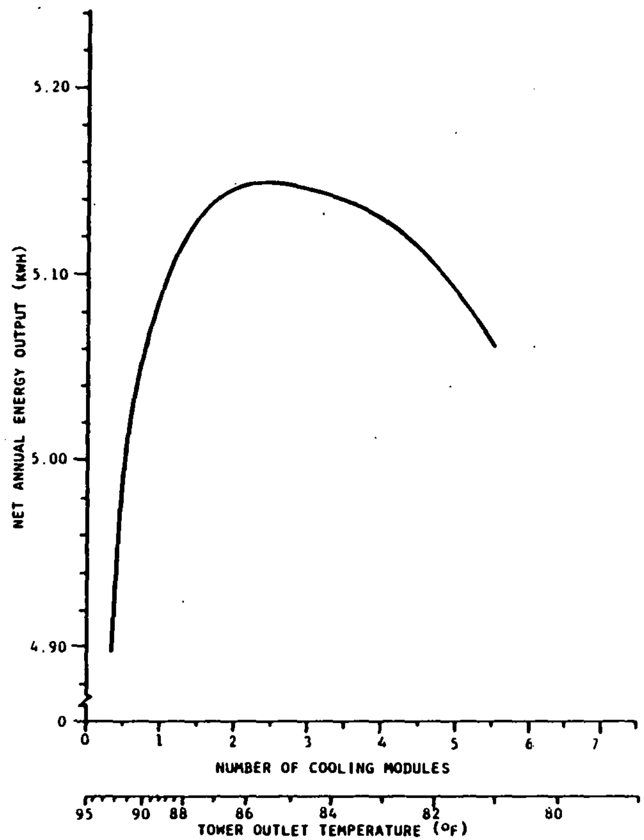


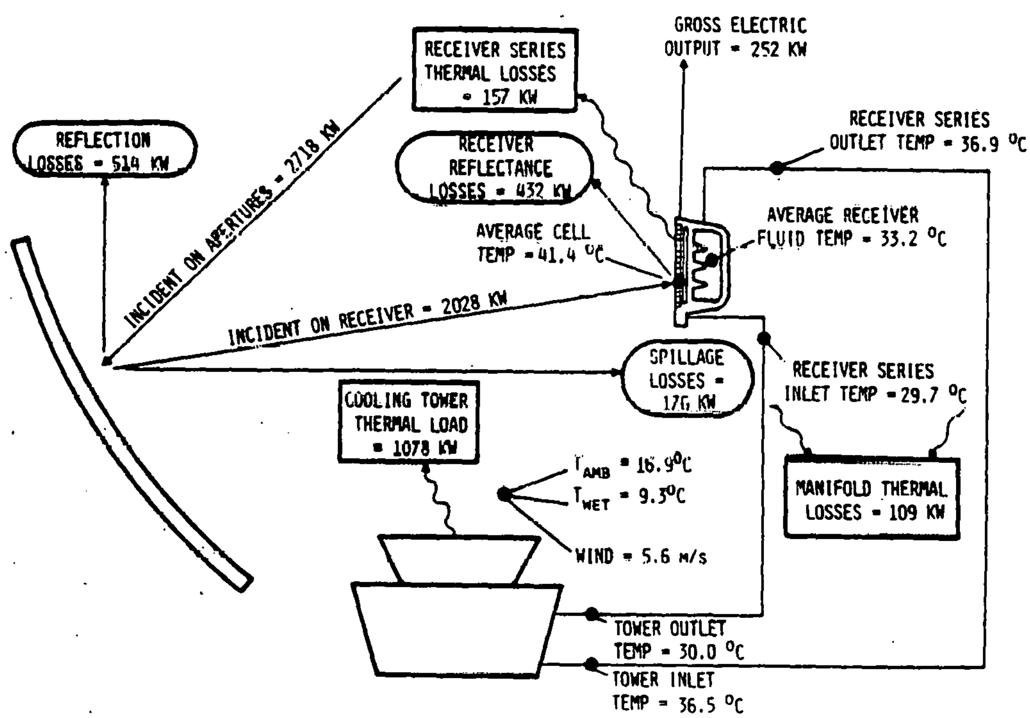

Figure 6-7. Net Annual System Electric Output versus Number of Cooling Modules and Tower Outlet Temperature (Inlet Tower Temperature of 95°F, Wet Bulb Temperature of 65°F)

point tracking. Failure of electric components will increase the temperature of the solar cells, but not enough to cause permanent damage.

System Performance Summary--Overall system performance is a location-dependent function of meteorological conditions experienced at any given application site. Net annual electrical energy production has been estimated for two locations closest to the Trans-Pecos region that have TMY and/or SOLMET data characterizations available. Shown below are net annual electrical energy production estimates assuming application site location of El Paso, Texas, and Albuquerque, New Mexico.

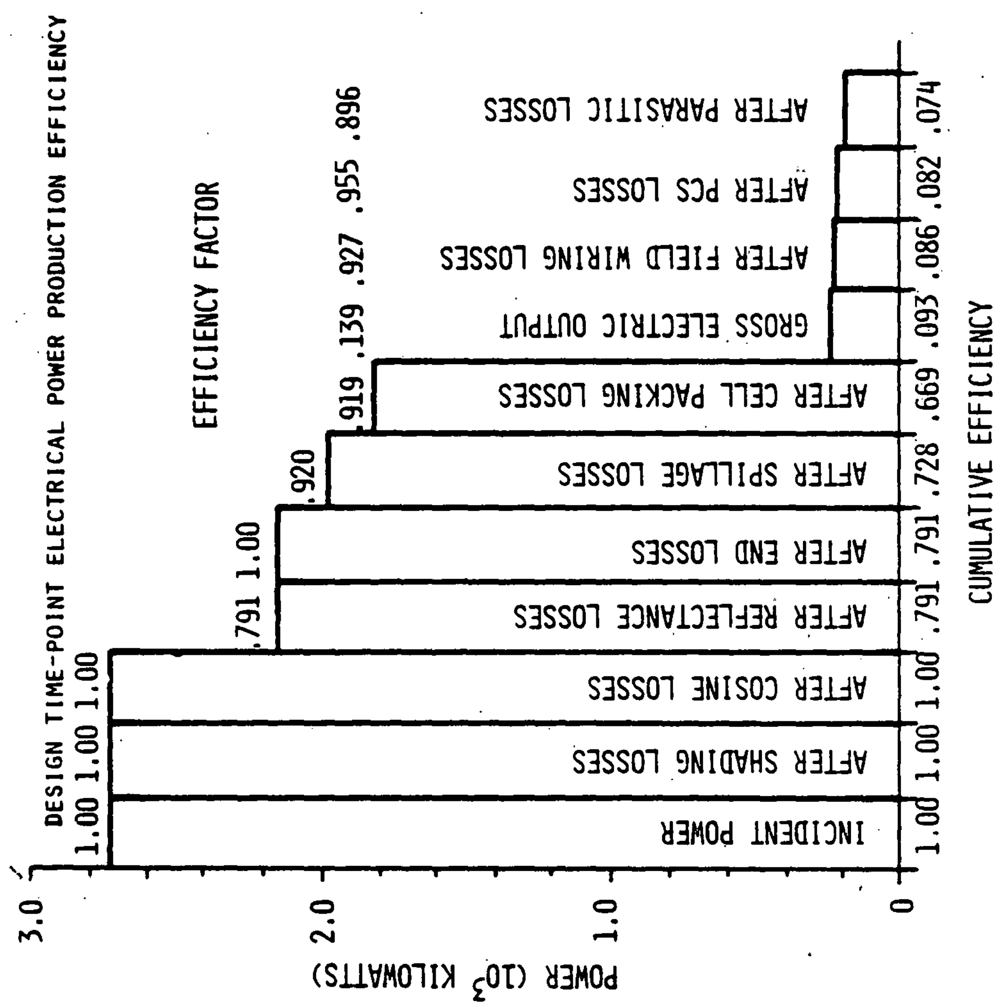
| Site | Meteorological Data Base | Net Annual Electrical Output (kwh) |
|---|---|---|
| El Paso, TX | TMY | $5.114 \times 10^5$ |
| Albuquerque, NM | TMY | $5.002 \times 10^5$ |
| Albuquerque, NM | SOLMET (1962) | $5.219 \times 10^5$ |

The variation in estimated net annual electrical energy produced is relatively small, but El Paso-TMY will be selected as representative in that it is nearly the average of the three estimates and will serve as the data base for the data presented below.

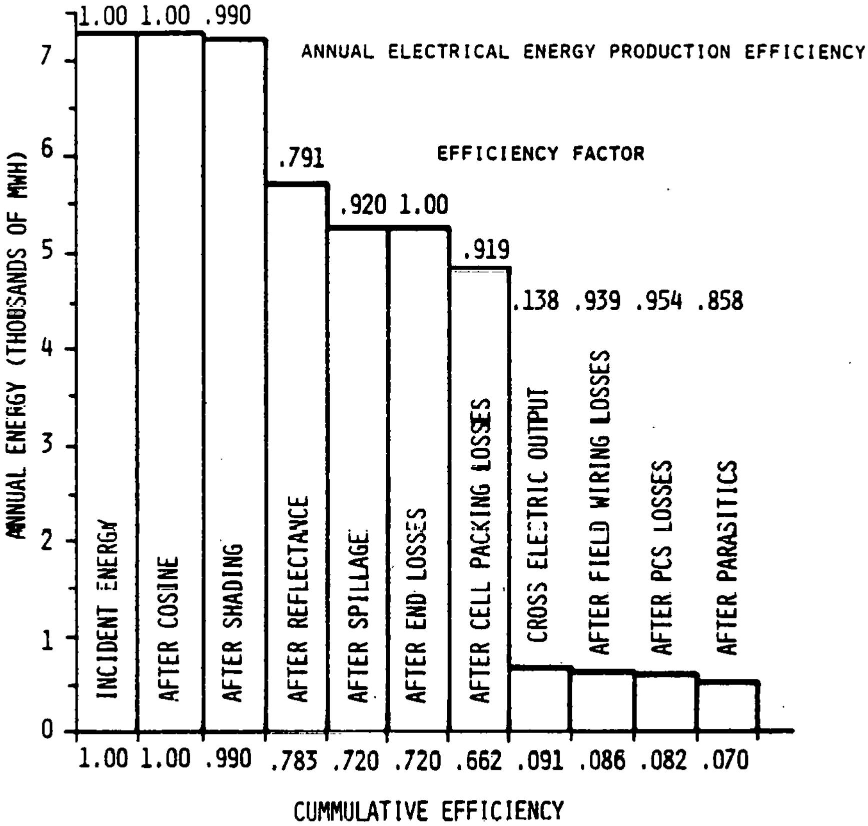


A heat balance diagram is shown defining detailed thermal process conditions for the baseline system at the March 10, solar noon design time-point.

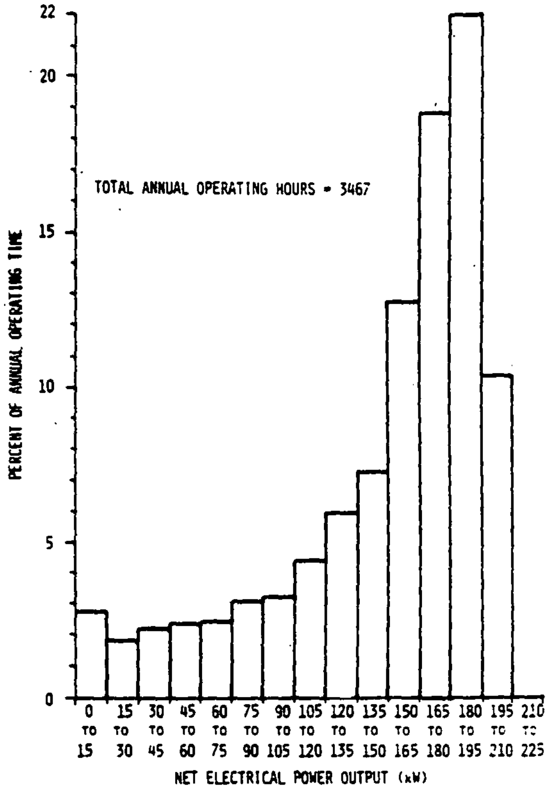
Also shown in the following figure is a detailed accounting of electrical power production efficiency at the same time-point.



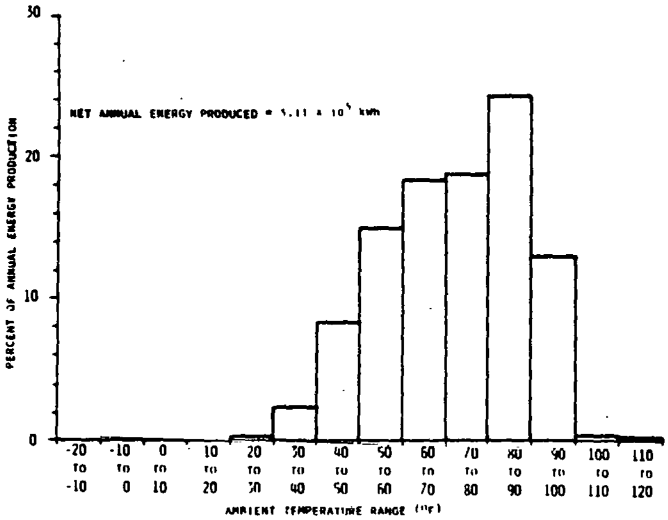
Similarly shown below is a detailed accounting of annual electrical energy production efficiency.




The following figure displays the annual percent of annual operating time spent at various net output power levels. Note that 64 percent of the annual operating time is at an output of 150 kw(e) or greater.




Finally, the following figure summarizes the percent of net annual energy generated in discrete ambient temperature ranges.



THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# SECTION VII
# PHASE II DETAIL

The work tasks comprising the total Phase II effort are outlined in the Statement of Work (SOW) attached at the end of this section. This SOW, modified as required by DOE, would be included as part of the prime contract with Texas Tech University (TTU). The University would subcontract with Honeywell Inc. for those A&E functions (tasks), within the SOW, to be delegated to Honeywell.

A Program and Evaluation Review Technique (PERT) chart detailing the interaction of the SOW tasks and showing the flow of the procurement, site preparation, site assembly, site installation and the resulting checkout/starting/verification is provided within the SOW.

## PROCUREMENT PLAN

A procurement procedure has been established for selecting suppliers for all site preparation, components and subsystems necessary to assemble and install the entire Trans-Pecos PVC Experiment. This procedure is an extension of existing Honeywell procedures used in the past by ERC for Government and privately funded solar projects and of those used by the Honeywell Avionics Purchasing Group.

The procedure details the use of Request for Procurement forms for competitive bidding on all material and labor. Suppliers shall be selected on the basis of quality, delivery and price. Except for solar unique components the Trans-Pecos area small business manufacturers and suppliers shall be given preference where they are cost competitive.

Purchase orders (P.O.s) shall be issued for all material and labor based on the supplier selected by this competitive bidding. The purchase order shall include the quoted price, the scheduled site delivery dates and the standard procurement terms and conditions. Solar unique components P.O.s shall include a Statement of Work and a specification to define, measure, and control the performance and quality of the particular component.

An outline for a material control procedure has been established and shall be used to control all materials, components and subsystems received at the assembly and installation site.

Outlines of the Procurement Procedure and Material Control Procedure are provided at the end of this section.

QUALITY CONTROL PLAN

A Quality Control Plan has been established for this experiment which incorporates source inspection for solar unique components and a site receiving inspection plan for all components at the experiment site.

The source inspection plan is outlined in the appropriate procurement specification for the solar unique components, and that plan shall be included in the Statement of Work for these specified components.

All solar unique components shall be subject to a first-run acceptance test at the supplier's manufacturing site. Quality assurance (QA) spot checks of this production run will be accomplished according to the QA plan defined in the appropriate procurement specification. Failure to meet the QA requirement at any point in the production run shall warrant shutdown of the run until appropriate corrective action is taken. Subsequent startup production runs shall also be scheduled so that an experiment representative, including the government technical monitor, shall be able to recheck the quality of the component and stop further production until corrective action is taken.

All material arriving at the experiment site shall be inspected for shipment damage, conformance to the appropriate prints and a physical parts count. An outline of the procedures to be used in checking the components at the site and segregating hold or rejected components for corrective action by the supplier is part of the present procedure for Honeywell's purchasing and quality control functions. A copy of this Quality Control Procedure outline is provided at the conclusion of this section.

PHASE II INFORMATION

From the first day of the Phase II contract, a log will be maintained of all problems, issues and experiences encountered during the program. This information will be recorded on a daily basis on the form shown on the next page. This form will be filled out at each of the five (5) major locations associated with this program--Texas Tech University program management and purchasing offices, Honeywell program management and purchasing offices and Honeywell site contruction management office. OCLI will also use this form, as needed, to record the same type of information on their experiences. This data will cover, but not be limited to, specific functional categories such as purchasing, fabrication, receiving, storage, security, labor, assembly, installation and startup, along with the soft science issues, environmental, institutional and social. The impact of this data will be given a relative rating of minor, major, or critical. The corrective action, if any, will also be recorded on this form.

This information will be submitted to the Texas Tech University program office on a weekly basis. The data will be summarized monthly by that office and submitted to DOE as part of the Monthly Progress Report. This same data will also be transmitted to all program offices.

SYSTEM DESIGN DRAWING PACKAGE

The drawing package generated during Phase I covers all aspects of the fabrication and installation of the Phase II and Phase III experiment at the Passmore Farm. Bids were solicited from small business suppliers both in the Trans-Pecos area and throughout the country. Those bids were used in preparing the cost quotation for Phases II and III.

The drawing package, with only slight differences, was used to fabricate, assemble, and install the prototype Photovoltaic Array module shown in the following photo. Information gathered while building this demonstration hardware has been incorporated into the drawing package.

# T-P PVC EXPERIMENT
# PHASE II
## Program History Data

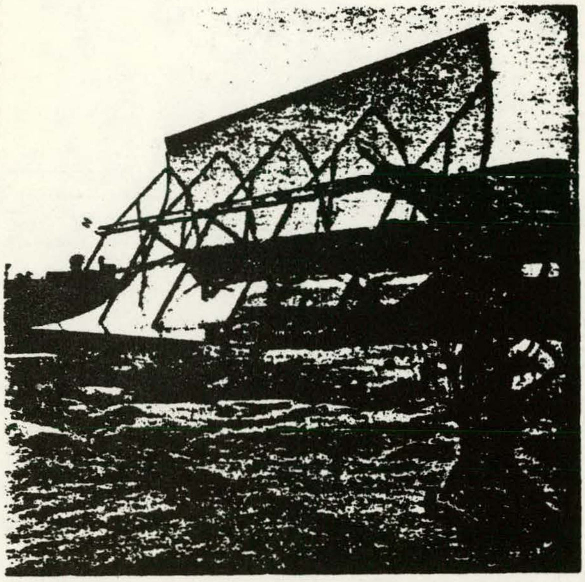
DATE ____________

LOCATION ____________

RECORDER ____________

| CATEGORY | DETAILS | IMPACT | RECOMMENDED CORRECTIVE ACTION |
|---|---|---|---|
| | | | |

TTU FORM T-P 101
DATED 1-15-79



A listing of the drawing package is provided below and has been arranged by site and related support hardware drawings, a top-down assembly drawing list of the module, specification listings for the site hardware and specification listings for the module.

SITE AND RELATED EXPERIMENT SUPPORT HARDWARE DRAWING LIST

| DRAWING NO. | TITLE |
|---|---|
| PVC00000 | Site Access |
| PVC00001 | Site Plan |
| PVC00002 | Culvert Bridge |
| PVC00003 | Entrance Sign |
| PVC00023 | Foundations, Buildings |
| PVC00005 | Pedestal |
| PVC00030 | Cement Slabs |
| PVC00006 | Field Fence |
| PVC00007 | Field Pipe Layout |
| PVC00022 | Field Electrical Layout |
| PVC00024 | Trenches, Raceways |
| PVC00025 | Site Drywells |
| PVC00026 | Site Sumps |
| PVC00029 | Dry Well Junction Box, Electrical |
| PVC00028 | Pedestal Junction Box, Electrical |
| PVC00004 | Site Headquarters, Building Layout |
| PVC00018 | Plumbing, Building |
| PVC00027 | Equipment Room Electrical Wiring |
| PVC00020 | Electrical Lights, Outlets Building |
| PVC00021 | Data Acquisition Wiring |
| PVC00008 | Site Lightning Protection |
| PVC00015 | Wash Vehicle |
| PVC00016 | Wash Equipment |

SITE AND RELATED EXPERIMENT SUPPORT HARDWARE SPECIFICATION LIST

| SPECIFICATION NO. | TITLE |
|---|---|
| PVC00019 | Warning Signs |
| PVC00012 | Fire Suppression Equipment |
| PVC00018 | Plumbing Building |
| PVC00011 | Water Deionization Unit |
| PVC00009 | Deionization Water Tank |
| PVC00013 | Water Re-Pressurization Unit |
| PVC00017 | Cooling Tower |
| PVC00014 | Pump, Main Delivery |
| PVC00010 | Field Surge Tank |
| PVC00031 | Motorized Valves |
| PVC00032 | Ball & Check Valves at Solar Collectors |

TOP-DOWN ASSEMBLY DRAWING LIST FOR MODULE

| DRAWING NO. | TITLE |
|---|---|
| 23000430-102 | Collector Module Assembly |
| 23000441-102 | Concentrator Assembly |
| 23000442-101 | Plate, Backup |
| 23000399-101 | Channel, Support-Long |
| 23000435-101 | Reflector, Parabolic |
| 23000398-102 | Channel, Support-Intermediate |
| 23000406-102 | Bar, Mounting |
| 23000408-101 | Insulator, Large |
| 23000402-102 | Strap |
| 23000411-102 | Receiver, Assembly |
| 23000418-101 | Bracket, Sensor |
| 23000060-102 | Sensor Assembly |
| 23000417-101 | Holder, Sensor |
| D805611 | Module Assembly Honeywell |
| 23000445-101 | Receiver J-Box Assembly |
| 23000444-101 | J-Box |
| 23000047-101 | Voltage Limiter Assembly |
| 23000046-101 | Block, Voltage Limiter |
| 23000437-101 | Receiver, Machining |
| 23000343-101 | Receiver, Extrusion |
| 23000438-101 | Cap, End-Casting |
| 23000439-101 | Connection, Hose-Casting |
| 23000439-102 | Connection, Hose-Casting |
| 23000409-101 | Insulator, Small |
| 2300390-102 | Torque Tube |

| | |
|---|---|
| 23000424-101 | Actuator, Switch |
| 23000408-105 | Insulator, Large |
| 23000441-101 | Concentrator Assembly |
| 23000442-101 | Plate, Backup |
| 23000397-101 | Channel, Support-Long |
| 23000399-101 | Channel, Support-Short |
| 23000435-101 | Reflector, Parabolic |
| 23000398-102 | Channel, Support-Intermediate |
| 23000406-102 | Bar, Mounting |
| 23000408-101 | Insulator, Large |
| 23000411-103 | Receiver Assembly |
| 23000418-101 | Bracket Sensor |
| 23000060-102 | Sensor Assembly |
| 23000417-101 | Holder, Sensor |
| D805611 | Module Assembly Honeywell |
| 23000445-102 | Receiver J-Box Assembly |
| 23000444-102 | J-Box |
| 23000047-101 | Voltage Limiter Assembly |
| 23000046-101 | Block, Voltage Limiter |
| 23000437-101 | Receiver, Machining |
| 23000343-101 | Receiver, Extrusion |
| 23000438-101 | Cap, End-Casting |
| 23000439-101 | Connection, Hose-Casting |
| 23000439-102 | Connection, Hose-Casting |
| 23000409-101 | Insulator, Small |
| 23000424-101 | Actuator, Switch |
| 23000402-102 | Strap |
| 23000390-102 | Torque Tube |
| 23000408-105 | Insulator Large |
| 23000416-102 | Pedestal Assembly |
| 23000391-101 | Column, Support |
| 23000426-101 | Channel, Actuator |
| 23000420-102 | Drive Assembly |
| 23000425-101 | Plate, Switch |
| 23000414-101 | Worm Gear Reducer |
| 23000427-101 | Gear Reducer |
| 23000421-102 | Plate, Mounting-Elevation Switch |
| 23000393-101 | Plate, Mounting-Reducer |
| 23000421-103 | Plate, Mounting-Elevation Switch |
| 23000392-101 | Gear, Pinion |
| 23000436-101 | Bearing, Turntable |
| 23000423-102 | Bracket, Switch |
| 23000433-101 | Bar, Spacer |
| 23000432-101 | Spacer |
| 23000431-101 | Bracket, Pot |
| 23000443-101 | Local Control Assembly |
| 23000446-101 | Brace, Angle |
| 23000447-101 | Cover, Front |

| | |
|---|---|
| 23000448-101 | Cover, Rear |
| 23000449-101 | Guard, Gear |
| 23000450-101 | Channel, Mounting |
| 23000451-101 | Frame, Mounting |

SPECIFICATION LISTING FOR MODULE

| Specification No. | Title |
|---|---|
| I0078-BAO-1 | Metal Finish |
| I0078-BAO-2 | A Worm Gear Reducer (Elevation Drive) |
| I0078-BAO-3 | A Worm Gear Reducer (Azimuth Drive) |
| I0078-RWJ-4 | A Concentrator Silicon Solar Cell Module |
| I0078-JRW-5 | Diesel Engine-Generator Set |
| I0078-JRW-6 | A Power Inverter System |
| I0078-RCP-7 | Aluminum, Parabolic-Sahped Concentrating Reflector for a Photovoltaic Concentrator System and Related Services and Hardware |
| I0078-RCP-8 | Optical Properties for Reflecting Aluminum Sheet |
| I0078-KLC-9 | Central Supervisory Controller (Central Controller) |
| I0078-DLY-10 | Module Controller Processor Board |
| I0078-DLY-11 | Module Controller Tester/Central Controller Simulator |

## PROCUREMENT PROCEDURE OUTLINE

### 1.0 GENERAL APPLICATION

This document covers the procedure to be used to purchase material and labor for the fabrication, assembly and installation of solar systems.

### 2.0 SCOPE

This procedure establishes the method for selecting suppliers for the material and labor required for site preparation, components, subsystems, assembly and installation for the Trans-Pecos Photovoltaic Concentration Experiment.

### 3.0 MATERIAL ACQUISITION

3.1.1 Request for Procurement (RFP) forms will be used for competitive bidding on all materials and labor.

3.1.2 Bid packages will be provided for each component, subassembly and the site preparation materials. The package will contain the necessary quote letters, prints and specifications for each item.

3.1.3 Suppliers will be selected on the basis of quality, delivery and price. Except for special items that may be purchased in an expertise area, Trans-Pecos small business suppliers will be given preference where they are cost competitive.

3.1.4 Purchase orders will be generated for all material and will be expedited to meet schedule commitments.

3.1.5 Statement of Work (SOW) will be used for purchase of critical components and subassemblies.

### 4.0 SITE PREPARATION, ASSEMBLY, AND INSTALLATION

4.1.1 RFP forms will be used to solicit construction or mechanical contractor firms to bid on the site preparation, assembly and installation of the complete experiment.

4.1.2 Bid packages containing all necessary technical data, bills of material and schedules will be provided.

4.1.3 The Trans-Pecos area small business firms will be solicited to bid on the site preparation, assembly and installation labor.

4.1.4 Concentrating firms will be selected on the basis of quality, price and ability to meet schedule commitments. Trans-Pecos area small business firms will be given preference where they are cost competitive.

4.1.5 Honeywell, with Texas Tech University approval, will be responsible for selection of the subcontractor to prepare the site and assemble and install the complete experiment.

4.1.6 Statement of Work (SOW) will be used to control the performance of work to be accomplished by the supplier on the site preparation, assembly and installation of the complete experiment.

# MATERIAL CONTROL PROCEDURE

## 1.0 GENERAL APPLICATION

This document covers the procedure to be used to control all material at the installation site.

## 2.0 SCOPE

This procedure establishes the detailed method for acceptance, storage and accountability of all material to be used in the Trans-Pecos Photovoltaic Concentration Experiment.

## 3.0 ACCEPTANCE

3.1.1 All material delivered to the installation site shall be received by the controlling authority (Site Construction Manager).

3.1.2 Material shall be inspected per the required prints and appropriately tagged as accepted, hold or reject.

3.1.3 Packing slips, properly signed and dated, will be filed to provide receiving record control.

3.1.4 Standard forms will be used to log quantities and identification of received material.

## 4.0 STORAGE

4.1.1 All material shall be stored in a secured area, and will be identified by part number or subassembly number.

4.1.2 Security may be accomplished by fencing, temporary buildings, or visual security.

4.1.3 Hold and rejected material will be stored separately so that disposition may be expedited by the appropriate authority.

5.0 ACCOUNTABILITY

5.1.1 An updated Bill of Material will be the document for controlling inventory.

5.1.2 Standard forms will be used to log material in and out of storage.

# QUALITY CONTROL PROCEDURE OUTLINE

## 1.0 GENERAL APPLICATION

This document covers the procedure for controlling material, site preparation, subassemblies, assembly and installation at the experiment site.

## 2.0 SCOPE

This procedure establishes the methods that will be used to assure the quality of material, site preparation, subassemblies, assembly and site installation for the Trans-Pecos Photvoltaic Concentration Experiment.

## 3.0 SITE PREPARATION

3.1.1 Inspection of mounting pads (support column footings) will be made to assure compliance with appropriate drawing and field spacing requirements.

3.1.2 Wiring, fencing, building, etc., installation will be monitored to assure compliance with appropriate drawings and specifications.

## 4.0 MATERIAL AND SUBASSEMBLIES

4.1.1 Components and subassemblies that have critical performance standards (solar unique) will be subject to source inspection per the appropriate procurement specifications.

4.1.2 Detailed prints and purchase orders will be used for material and subassemblies that are standard (nonsolar unique).

4.1.3 All material and components will be subject to a general receiving inspection check for damage during shipment and compliance with appropriate specifications and drawings.

4.1.4 Standard quality control records will be used to record inspection data.

5.0 ASSEMBLY AND INSTALLATION

5.1.1 Assembly and installation will be monitored to assure compliance with appropriate specifications and drawings.

Issue Date ______________

Revision Date ______________

# THE TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT

## SYSTEM FABRICATION

## PHASE II

## STATEMENT OF WORK

(Preliminary Draft)

Contract No.

Approved by: ______________________
Program Manager

Prepared for:

Sandia Laboratories
Albuquerque, NM 87115

Prepared by:

Department of Industrial Engineering
and
Department of Systems
College of Engineering
Texas Tech University
Lubbock, Texas
79409

# STATEMENT OF WORK FOR THE SYSTEM FABRICATION (PHASE II) OF THE TRANS-PECOS PHOTOVOLTAIC CONCENTRATION EXPERIMENT
(Preliminary Draft)

## 1.0 OBJECTIVE

The objective of this Statement of Work (SOW) is to define and outline a detailed System Fabrication program for the Phase II effort on the Trans-Pecos Photovoltaic Concentration Experiment.

## 2.0 SCOPE

This SOW covers the entire Phase II (System Fabrication) program, which includes: procurement, component fabrication, site preparation, subsystem assembly, system installation, system checkout and startup, program management and data. Twelve (12) months are required to complete this program scope. The system will be installed on the Passmore Farm, located approximately 14 miles south of Pecos, Texas, in compliance with the tech data package developed in Phase I of this experiment. This system is defined within the system requirements specification RCP-12 for the Trans-Pecos Photovoltaic Concentration Experiment. Figure SOW-1 is a Program and Evaluation Review Technique (PERT) chart detailing the interaction of the procurement, fabrication and installation elements of the experiment. Figure SOW-2 is a Work Breakdown structure for this phase of the program.

## 3.0 PROGRAM PLAN SCHEDULE

The schedule for this entire program is shown in Figure SOW-1.

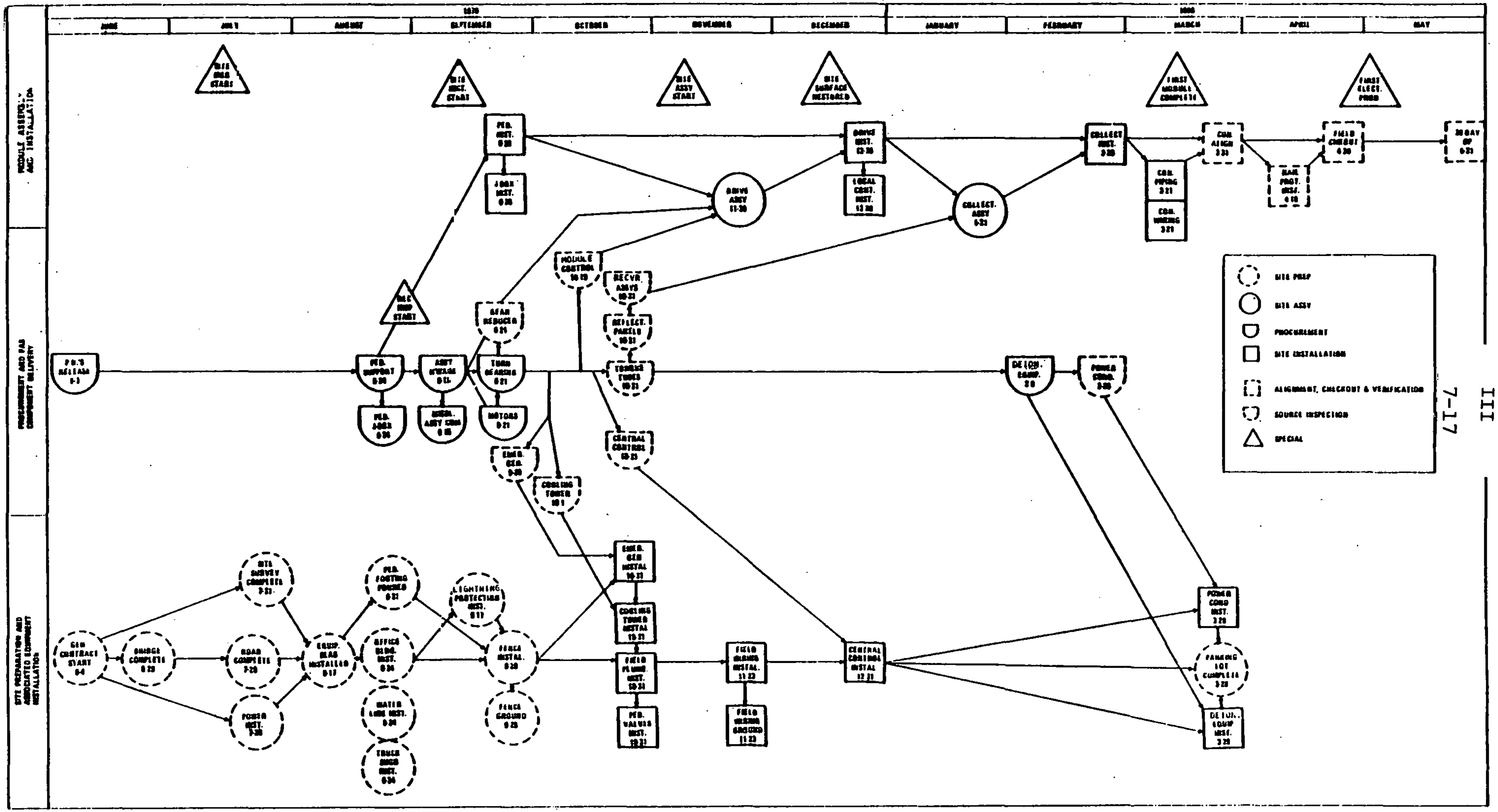
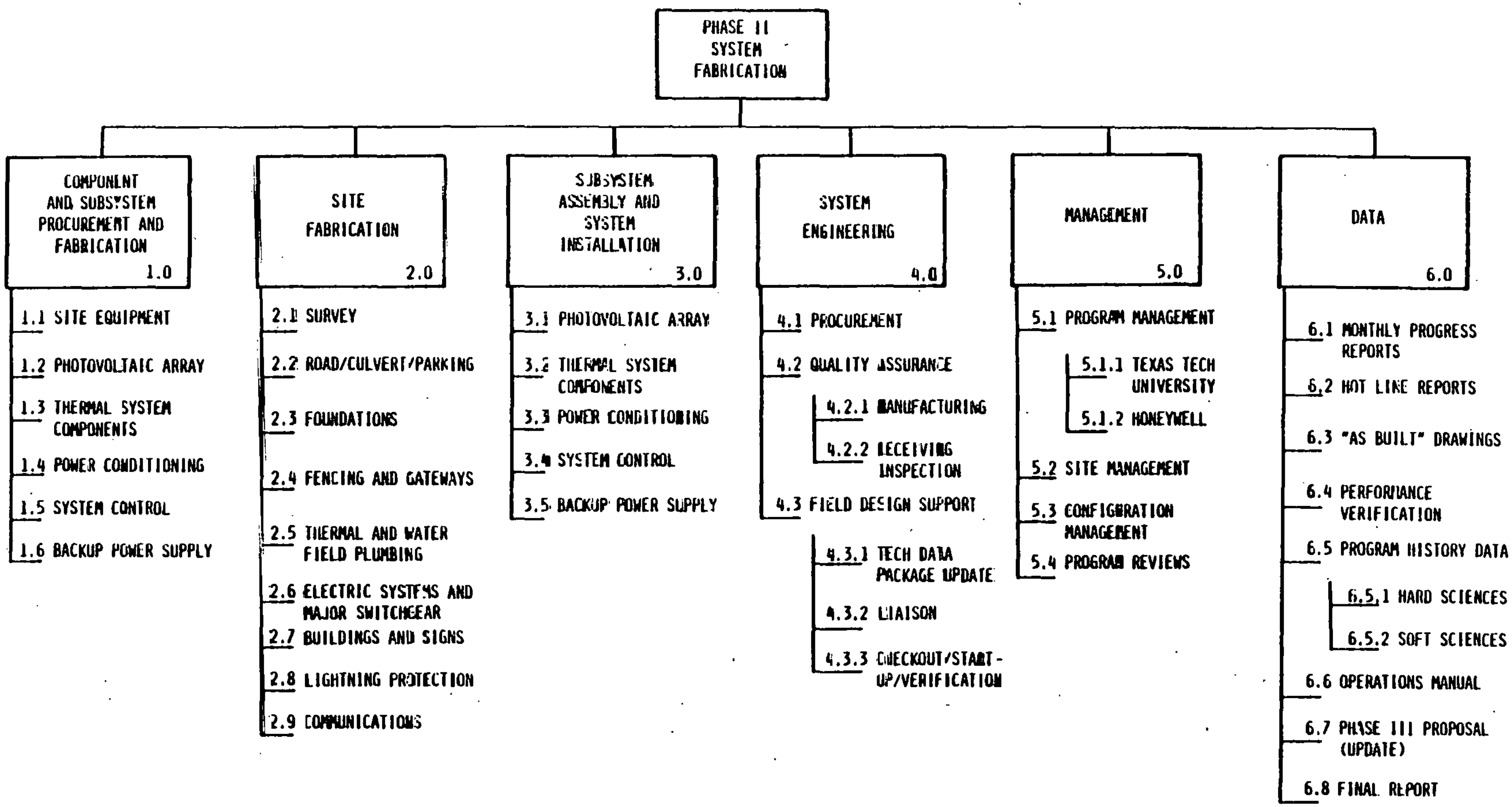



Figure SOW-1. PERT Chart


PHASE II SYSTEM FABRICATION
COMPONENT AND SUBSYSTEM PROCUREMENT AND FABRICATION 1.0
1.1 SITE EQUIPMENT
1.2 PHOTOVOLTAIC ARRAY
1.3 THERMAL SYSTEM COMPONENTS
1.4 POWER CONDITIONING
1.5 SYSTEM CONTROL
1.6 BACKUP POWER SUPPLY
SITE FABRICATION 2.0
2.1 SURVEY
2.2 ROAD/CULVERT/PARKING
2.3 FOUNDATIONS
2.4 FENCING AND GATEWAYS
2.5 THERMAL AND WATER FIELD PLUMBING
2.6 ELECTRIC SYSTEMS AND MAJOR SWITCHGEAR
2.7 BUILDINGS AND SIGNS
2.8 LIGHTNING PROTECTION
2.9 COMMUNICATIONS
SUBSYSTEM ASSEMBLY AND SYSTEM INSTALLATION 3.0
3.1 PHOTOVOLTAIC ARRAY
3.2 THERMAL SYSTEM COMPONENTS
3.3 POWER CONDITIONING
3.4 SYSTEM CONTROL
3.5 BACKUP POWER SUPPLY
SYSTEM ENGINEERING 4.0
4.1 PROCUREMENT
4.2 QUALITY ASSURANCE
4.2.1 MANUFACTURING
4.2.2 RECEIVING INSPECTION
4.3 FIELD DESIGN SUPPORT
4.3.1 TECH DATA PACKAGE UPDATE
4.3.2 LIAISON
4.3.3 CHECKOUT/START-UP/VERIFICATION
MANAGEMENT 5.0
5.1 PROGRAM MANAGEMENT
5.1.1 TEXAS TECH UNIVERSITY
5.1.2 HONEYWELL
5.2 SITE MANAGEMENT
5.3 CONFIGURATION MANAGEMENT
5.4 PROGRAM REVIEWS
DATA 6.0
6.1 MONTHLY PROGRESS REPORTS
6.2 HOT LINE REPORTS
6.3 "AS BUILT" DRAWINGS
6.4 PERFORMANCE VERIFICATION
6.5 PROGRAM HISTORY DATA
6.5.1 HARD SCIENCES
6.5.2 SOFT SCIENCES
6.6 OPERATIONS MANUAL
6.7 PHASE III PROPOSAL (UPDATE)
6.8 FINAL REPORT

4.0 PROGRAM WORK BREAKDOWN STRUCTURE

Figure SOW-2 (WBS) outlines the work packages into which this entire program has been divided. These work packages, discussed in the following paragraphs, allow for assignment of definable, measureable tasks that can be used to plan and control total program effort.

Task 1.0 - Component and Subsystem Procurement and Fabrication--The contractor shall procure, fabricate, assemble and deliver to the Passmore Farm all piece-parts, components, subsystems and equipment required for this experiment. The system engineering effort required to perform the related factory inspection and acceptance function shall also be accomplished. All materials required in preparing the site for this harare are listed under Task 2.0, Site Preparation.

1.1 Site Equipment--The permanent site equipment to support the maintenance and cleaning of the overall system shall be procured. The wash vehicle and wash equipment are defined in drawings, PVC00015 and PVC00016, respectively.

1.2 Photovoltaic Array--The hardware required for assembly and installation of the complete photovoltaic array module, i.e., pedestal, turntable bearing, drive motors and gear boxes, torque tubes, parabolic reflectors, receiver assemblies and related support structure, shall be procured. The only hardware item not procured under this subtask, the local controller (which is physically attached to this module), is procured under Subtask 1.5, System Control.

1.3 Thermal System Components--All components required for the assembly and installation of the complete heat rejection system defined in specification PVC00017, Cooling Tower, shall be procured. This subtask does not include the related field plumbing and valving, which is procured under Subtask 2.5, Thermal and Water Field Plumbing.

1.4 Power Conditioning--All components required to assemble and install the complete power conditioning subsystem equipment defined in requirements specification I0078-JRW-6, Power Inverter System, shall be procured.

1.5 System Control--The contractor shall procure all components (less field wiring) required to assemble and install the complete control system, which consists of a central controller, central control panel, local controllers, a test instrument and the weather station as defined in design specifications I0078-KLC-9, Central Supervisory Controller; I0078-DLY-10, Local Controller Processor Board; and I0078-DLY-11, Local Controller Tester/Central Controller Simulator.

1.6 Backup Power Supply--All components required for the assembly and installation of the complete backup power supply, as defined in requirements specification I0078-JRW-5, Diesel Engine-Generator Set, shall be procured.

Task 2.0 - Site Preparation--Procurement, delivery, assembly, and installation at the Passmore Farm of all piece parts, components, subsystems and equipment required in preparing the site for the assembly and installation of the components and subsystems associated with Task 1.0, Component and Subsystem Procurement and Fabrication, shall be accomplished. System engineering required to perform the related site inspection and acceptance functions shall also be performed. It is assumed all GFM data acquisition hardware could be installed concurrent with this site preparation to minimize installation costs.

2.1 Survey--All materials and labor required to survey the complete site for location of buildings, fencing, pedestals, trenching, construction, etc., shall be procured, and the survey shall be performed.

2.2 Road/Culvert/Parking--All materials and labor required to construct and install the culvert bridge, road and parking area defined in drawings PVC00001, Site Plan and PVC00002, Culvert Bridge, shall be procured.

2.3 Foundations--All materials and labor required to install the photovoltaic array module and building foundations, to the requirements of Drawings PVC00005, Pedestal; PVC00030, Cement Slabs; and PVC00023, Foundations, Buildings shall be procured.

2.4 Fencing and Gateways--All materials and labor required to install the fencing defined in drawing PVC00006, Field Fence, shall be procured.

2.5 Thermal and Water Field Plumbing--All materials and labor required to extend the existing water line at the farm house to the site and to install the field related thermal plumbing and valving shall be procured. This installation shall be accomplished to the requirements of drawings and specifications of

PVC00007, Field Pipe Layout; PVC00024, Trenches, Raceways; PVC00025, Site Drywells; PVC00026, Site Sumps; PVC00031, Motorized Valves; and PVC00032, Ball and Check Valves at Solar Collectors.

2.6 Electric Systems and Major Switchgear--All materials and labor required to install all field wiring (AC, DC and control) and related switchgear, along with the wiring and switchgear required to connect the experiment site to the existing grid network, shall be procured. This installation will be accomplished to the requirements of drawings PVC00021, Data Acquisition Wiring; PVC00022, Field Electrical Layout; PVC00024, Trenches, Raceways; PVC00028, Pedestal Junction Box, Electric; PVC00029, Drywell Junction Box, Electric; and PVC00031, Motorized Valves.

2.7 Building and Signs--All materials and labor required to construct and install all buildings and signs associated with the site shall be procured. This construction and installation shall be in conformance with drawings and specifications PVC00003, Entrance Sign; PVC00004, Site Headquarters, Building Layout; PVC00009, Deionization Water Tank; PVC00010, Field Storage Tank; PVC00011, Water Deionization Unit; PVC00012, Fire Suppression Equipment; PVC00013, Water Re-Pressurization Unit; PVC00018, Plumbing, Building; PVC00020, Electrical Lights, Outlets, Building; and PVC00027, Equipment Room Electrical Wiring.

2.8 Lightning Protection--All materials and labor required to install a field lightning protection system to the requirements of drawing PVC00008, Site Lightning Protection, shall be procured.

2.9 Communications--All materials and labor required to install a mobile or line communication system to an existing telephone system shall be procured.

Task 3.0 - Subsystem Assembly and System Installation--The contractor shall unpack, assemble and install the components and subsystems fabricated in Task 1.0, Component and Subsystem Procurement and Fabrication. This task includes the system engineering effort required to perform the related site acceptance, stores, security and checkout functions.

3.1 Photovoltaic Array--The contractor shall assemble, install and align the photovoltaic array modules, which include the local controller, in compliance with the requirements of drawing 23000430, Collector Module Assembly. The electrical and thermal connections of each module shall be completed.

3.2 Thermal System Components--The contractor shall assemble and install the heat rejection system in compliance with the requirements of specification PVC00017, Cooling Tower. The electrical and thermal connections of this system shall be completed.

3.3 Power Conditioning--The contractor shall assemble and install the power conditioning equipment in compliance with the requirements of specification I0078-JRW-6, Power Inverter System, including completion of the power conditioning electrical connections.

3.4 System Control--The contractor shall assemble and install the central controller, central control panel and weather station in compliance with the requirements of specifications I0078-KLC-9, Central Supervisory Controller; I0078-DLY-10, Local Controller Processor Board; and I0078-DLY-11, Local Controller Tester/Central Controller Simulator. This includes connecting this control system to the field electrical and communication wiring.

3.5 Backup Power Supply--The contractor shall assemble and install the back-up power supply equipment in compliance with the requirements of specification I0078-JRW-5, Diesel Engine-Generator Set, including completion of electrical connections.

Task 4.0 - System Engineering--System engineering support required for procurement, inspection, acceptance, checkout and startup of this experiment shall be performed.

4.1 Procurement--System engineering support required for the procurement activities of Task 1.0, Component and Subsystem Procurement and Fabrication, and Task 2.0, Site Preparation, shall be performed. This support activity will consist of, but not be limited to, review of change order, waiver and deviation requests. This activity is charged directly into the appropriate sub-tasks under Tasks 1.0 and 2.0.

4.2 Quality Assurance--System engineering support required at the various component and subsystem fabrication points and at the experiment site to inspect, accept, store and functionally check out the subsystems and the system shall be provided. This activity is charged directly into the appropriate subtasks under Tasks 1.0, 2.0 and 3.0.

4.3 Field Design Support--System engineering support required to review change orders, waivers and deviations resulting from the site preparation, assembly and installation construction, maintenance of the "as-built" engineering drawings, and the checkout and startup of the complete system shall be provided. This subtask shall also include the system performance evaluation to be accomplished in the last month of the program. The equipment required for this performance evaluation is considered as part of the GFM Data Acquisition hardware and is not procured within this SOW.

Task 5.0 - Management--The contractor shall perform all coordination, supervision and management efforts required to schedule, direct and control the entire program.

5.1 Program Management--The prime contractor (Texas Tech University) and the major subcontractor (Honeywell Inc.) shall provide all program management efforts required in the implementation of overall program schedules, cost management, construction schedules, liaison efforts between team members and data management.

5.2 Site Management--The contractor shall perform those activities required to manage all site activities. These include, but are not limited to, the following functions: receiving, storage, stores, security, assembly, installation checkout and startup of the system.

5.3 Configuration Management--The contractor shall perform those activities required to approve, control and document the implementation and effectivity of each change order, waiver and deviation.

5.4 Program Reviews--The contractor shall perform those activites required to support one mid-program and review and one final program oral review.

Task 6.0 - Data--The contractor shall provide those efforts required to prepare the reports, drawings, data documents, manuals and proposals required during the program.

6.1 Monthly Progress Reports--The contractor shall prepare and submit concise narrative reports once each month summarizing the previous month's accomplishments and problems and an estimate of the next month's activities.

6.2 Hot-Line Reports--The contractor shall prepare and submit Hot-Line Reports as required during the contract.

6.3 "As-Built" Drawings--The contractor shall modify the construction drawings to reflect the "as-built" configuration of the site.

6.4 Performance Verification--The contractor shall perform those activities necessary to perform and document the system performance evaluation scheduled during the last month of the program.

6.5 Program History Data--The contractor shall perform those activities rerequired to gather (on a daily basis), evaluate and document a history file of all problems, experiences and issues occurring during Phase II.

6.6 Operations Manual--The contractor shall generate and submit for approval an operations manual for the systems.

6.7 Phase III Proposal (Up-Date)--The contractor shall perform those efforts required to update the Phase III proposal which may result from the Phase II program.

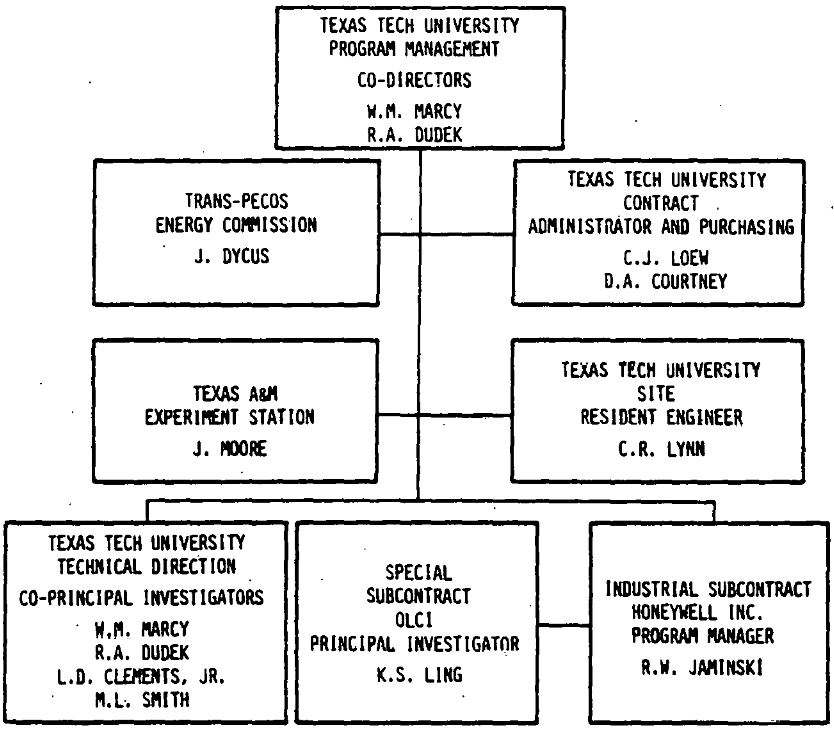
6.8 Final Report--The contractor shall provide a comprehensive description of all activities associated with the Phase II program. This report shall be provided in draft form to the cognizant Technical Monitor for review and approval prior to submittal in final form.

# SECTION VIII
# PHASE III CONCEPTS

## ORGANIZATION

The team organized to conduct the Phase I (System Design) effort on the Trans-Pecos Photovoltaic Concentration Experiment is shown in the chart below. In this organization, Texas Tech University--the prime contractor--interacted with industry through a major subcontract with Honeywell Inc. to accomplish all tasks of the program. Honeywell in turn subcontracted with the Optical Coating Laboratory, Inc. for the necessary engineering services and materials required by the program in the silicon solar cell technology area. Because this team proved so successful on Phase I, Texas Tech University proposes the same teaming arrangement for Phase II (System Fabrication) with only minor organizational changes, which are required to match the Phase II program task requirements.

PHASE I ORGANIZATION



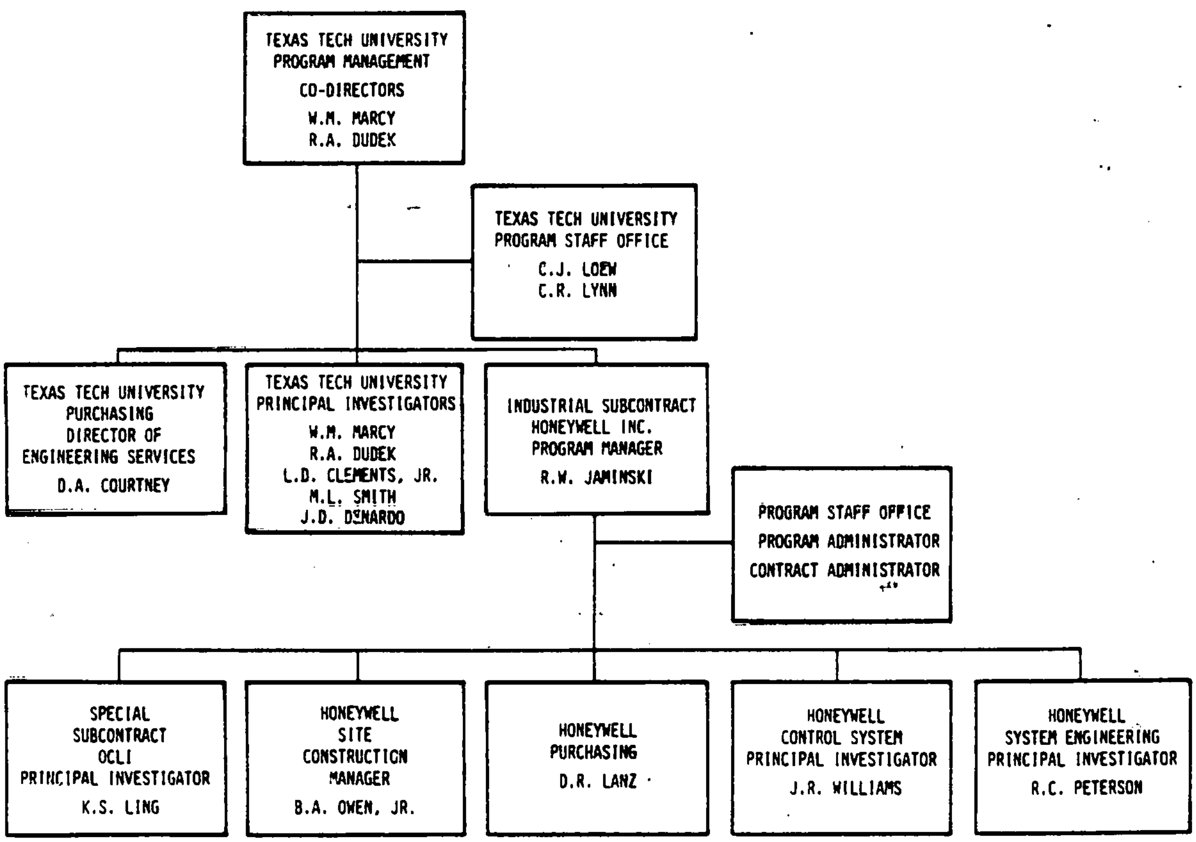
This Phase II organization, shown in the chart below, maximizes the use of each team member's capabilities, minimizes total program costs and assures efficient use of all program resources.

MANAGEMENT

Texas Tech University proposes a program manager organization, providing a single point of authority with clear lines of subordination and responsibility. Texas Tech University and Honeywell program managers will have simple, direct lines of communication, assuring rapid response to either DOE and/or team member-initiated action items.

In this organization, the Texas Tech University program managers are solely responsible to DOE for successful execution of all technical, schedule and cost

PHASE II ORGANIZATION



requirements of the contract. The Honeywell program manager will be directly accessible to DOE on technical and site related issues. The Texas Tech program managers formulate and coordinate all work schedules and define tasks with their staff in accordance with the program schedules, and they are responsible for monitoring technical progress. A system of internal documentation and periodic status reviews allow tracking performance and progress against schedule requirements and cost goals.

A program staff supports the program managers in cost, schedule and subcontractor management. The baseline cost schedule establishment and maintenance are determined by the contract administrator in communication with the program managers. The basic instruments used for planning and budgeting are the Statement of Work and the Program and Evaluation Review Technique chart, which provides a budget for all costs by task and a schedule of accomplishments. This will ensure proper allocation of costs for scheduled tasks and requirements. In addition to the contract administrator, program staff support includes the procurement administrator. Together they handle all contractual and subcontractual matters with agreement of the program managers. The contract administrator is the direct interface with the contracting officer. Flowdown requirements to subcontractors are coordinated with the procurement administrator, who handles major subcontract management.

Texas Tech University, under the co-direction of Dr. William M. Marcy and Dr. Richard A. Dudek, as in Phase I, will have overall Phase II program responsibility. In this position Texas Tech University will assume the Owner's role in the site construction and system installation activities. All program direction, major subsystem procurement, cost accounting, coordination and system engineering support (in the soft sciences) will be provided by Texas Tech.

Honeywell, in a major subcontract with Texas Tech University, will perform the A&E role during Phase II. Responsibilities will include, but not be limited to, maintaining a technical interface with OCLI, managing of the construction site, system engineering, supplying the control subsystem and procuring the majority of the services and materials required in preparing the site. The Honeywell program effort will be under the direction of Mr. Richard Jaminski, who also directed Honeywell's Phase I effort. Site construction management will be under the direction of Mr. Basil Owen, one of the Phase I engineers responsible for the competitive procurement activities already initiated. He has successfully completed supervising the assembly of approximately 35,000 square feet of parabolic collectors used in three solar thermal demonstration programs. This experience and his related production engineering background provide the team with a very knowledgeable and capable site construction manager. All procurement, site preparation, subsystem assembly performed at the site and system installation schedules will be coordinated through the site construction manager.

CHAPTER IV

# FINAL REPORT OF TASK TEAM-4

# THERMAL ENERGY REJECTION

Submitted To:

Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:

Dr. L. Davis Clements
Department of Chemical Engineering
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER IV

## TASK TEAM IV

## Thermal Rejection System: Design Trade-Offs and Specification

This section is divided into two parts: a) the sequence of design trade-offs which lead to the specified thermal rejection system, and; b) the development of the field and collector piping system. The route to thermal rejection system choice will be described using the framework of a formal design trade-off study, while the piping layout will be described on the basis of simple comparisons. The appropriate choice of the thermal rejection for the Trans-Pecos Concentrating Photovoltaic Project is critical to the overall system not because of any new technology to be developed, but because of the large parasitic power requirement represented by the system.

### A. Thermal Rejection System Design Trade-Offs

There were a number of design requirements imposed upon the thermal rejection system. Most important among these were:

a) operable whether irrigating or not,

b) operable over a wide range of ambient temperatures (-20 to +40°C)

c) able to maintain the photovoltaic cells close to the desired operating temperature of 50°C.

This set of requirements was compared with several possible thermal rejection options, shown in Table I. Two of the candidate systems were rejected immediately for the reasons shown. The remaining three concepts all showed promise for this application.

Once the use of a passive cooling system was rejected, it was necessary to choose a suitable coolant fluid for the active system. A mixture of

Table I. Candidate Thermal Rejection Systems for the Trans-Pecos Concentrating Photovoltaic Project

Passive Cooling*

Rejection to Irrigation Water**

Conventional Wet Cooling Tower

Cooling Pond-Air Cooler Hybrid

Air Cooler with Evaporative Assist

Reasons for rejection:

* Rejected because of high ambient temperatures. Calculations indicated that to maintain an average cell temperature of 82°C, with an ambient temperature of 27°C and a 24 kmph wind requires 25 $m^2$ of extended heat transfer surface for every 1 $m^2$ of photovoltaic cells.

** Rejected initially because it does not allow for operation when not irrigating. An additional problem, which is site specific, is the high (24-30°C) temperature of the irrigation water from the well. Return of a coolant to the photovoltaic field at 27°C would be difficult to assure.

30 percent ethylene glycol-70 percent water was chosen. This mixture is usable over the wide range of temperatures expected without freezing or boiling, and with a minimal increase in pumping horsepower or loss of heat transfer effectiveness. Under nominal operation the coolant will be circulating at a rate of 1200 liters per minute with a field inlet temperature of 30°C and a return temperature of 36.5°C. The total duty on the heat rejection system is, then 1078 kw thermal. It is important that the heat rejection system not contaminate or degrade the coolant fluid, as well as for the system to operate reliably under a wide range of conditions.

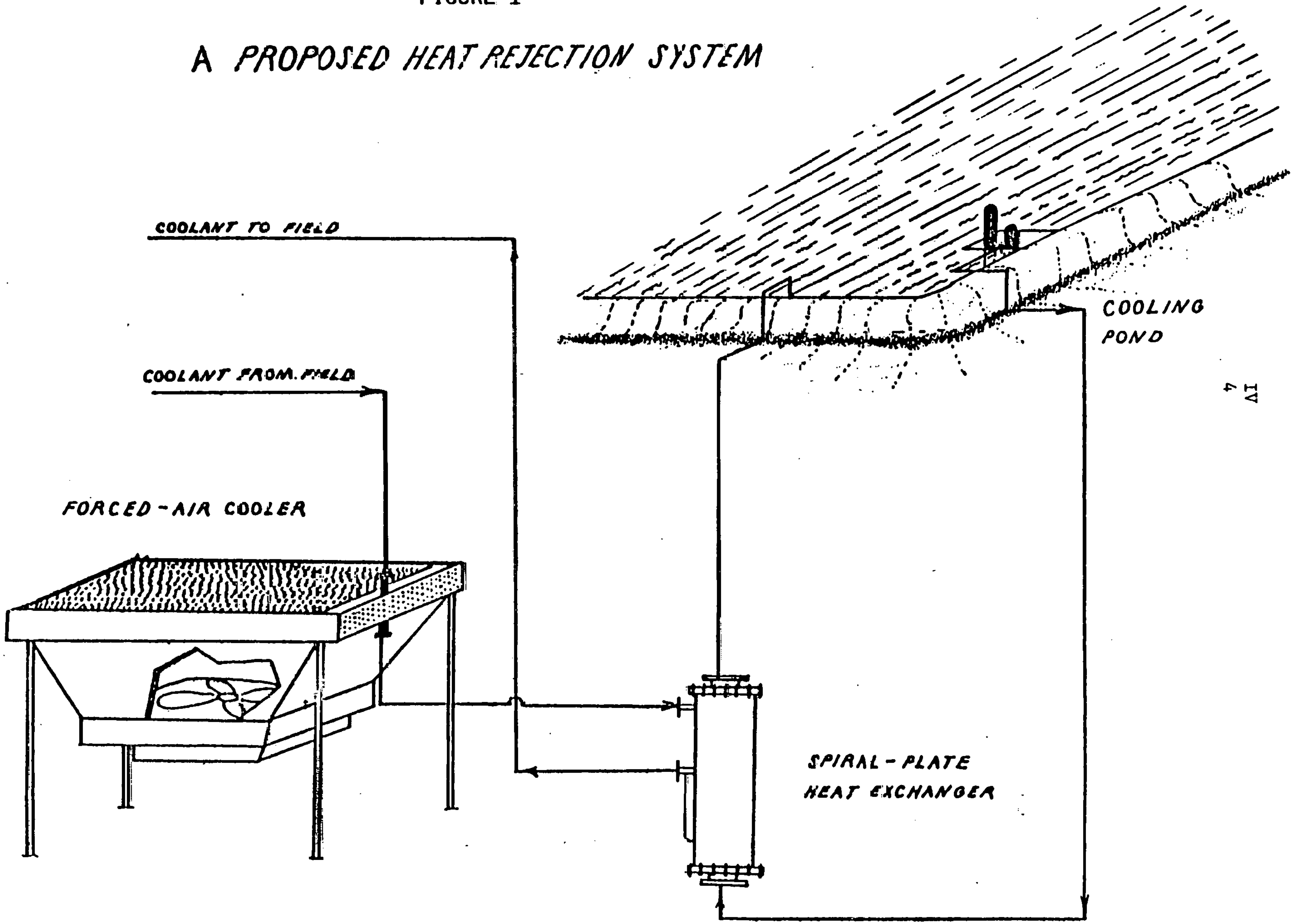
In view of the specific application and the requirements of the proposed location, it is useful to discuss the three candidate systems further. Each will be described and its advantages and disadvantages discussed.

Conventional Wet Cooling Tower - This heat rejection device is commonly used throughout the industry. The wet cooling tower circulates a water stream which is chilled by evaporation of part of the water through one side of a heat exchanger, cooling down the hot-side fluid. This type system has the advantage of a high heat transfer efficiency and good reliability. However, because the chilled water is used in a heat exchanger, it is critical that a low level of dissolved solids and oxygen be maintained in the coolant loop to prevent fouling. For this reason there is a requirement for removing a substantial amount of water as blowdown, to match the increase in dissolved solids caused by evaporation. Based on the stated operating requirements it was estimated that a wet cooling tower operating under summertime conditions at Pecos would require a make-up flowrate of about 80 liters per minute based on the nomograph in (1). This high water requirement (all of which must be treated) coupled with the unusually bad quality water available (Total Dissolved Solids = 2607 ppm and Hardness = 1227 ppm) is a definite drawback to this approach.

Cooling Pond-Air Cooler Hybrid - This system, shown in Figure 1, employs a pond which is approximately 1130 $m^2$ by 1.2 m deep as a source of cool water, to be combined with an air cooler and a shell-and-tube heat exchanger. The pond was sized using the method suggested by Langhaar (2) and the air cooler was rated using the program described in Appendix I. When the air temperature is low enough, heat may be rejected directly to the surroundings, or the heat may be used to keep the pond warm. During periods of fairly high ambient temperature, cool (about 21°C) water from the pond is used to supplement the air cooler. This concept offers the attractive possibility of gaining some use from the rejected heat by keeping a pond for raising fish warm during the

FIGURE 1

A PROPOSED HEAT REJECTION SYSTEM



winter. However, this concept involves a number of interlinked components and considerable land area.

Air Cooler with Evaporative Assist - As shown in Figure 2, this heat rejection concept combines many of the best features of the previous two as suggested in the article by Maze (3). When air temperatures are adequately low, the system acts as a simple fin-fan air cooler. Above a critical temperature, set by the amount of exchange area available and the desired coolant outlet temperature, additional cooling is obtained by evaporating water directly into the air stream, lowering its temperature to near the wet bulb temperature. The air cooler with evaporative assist provides for operation over a wide range of ambient temperatures. However, the system does not require the high purity water for make-up like a wet cooling tower does. Make-up water requirements for this system are on the order of 14 liters per minute of untreated water. A distinct disadvantage of this system is the parasitic power requirement is high because of moving very large volumes of air over the heat exchange surface. The large volume of air is required because of the relatively low efficiency of the air-to-liquid heat exchange process.

The three candidate systems were all designed to meet the thermal load requirements of the photovoltaic array. The designs were compared on the basis of the trade parameters listed in Table II and the results of this comparison are given in Table III. It is evident that the choice of the evaporative assisted air cooler is primarily on the basis of its consistency in ratings. The fact that the wet cooling tower option has a significantly lower power parasitic shown is somewhat misleading. Not included in the figure are estimates for the approximately 80 liters per minute of make-up water. At $10,000 per installed kilowatt, the parasitic requirements for option C are the equivalent of about 11 kw for a constant total construction cost, thus the statement B=C. The rest of the notations in Table III are based to a large extent on experience.

## Performance Predictions for the Evaporation Assisted Air Cooler

The expected performance of the evaporation assisted air cooler system as a part of the overall photovoltaic field has been estimated using the AIRHEX simulator described in Appendix D. In order to estimate the size of

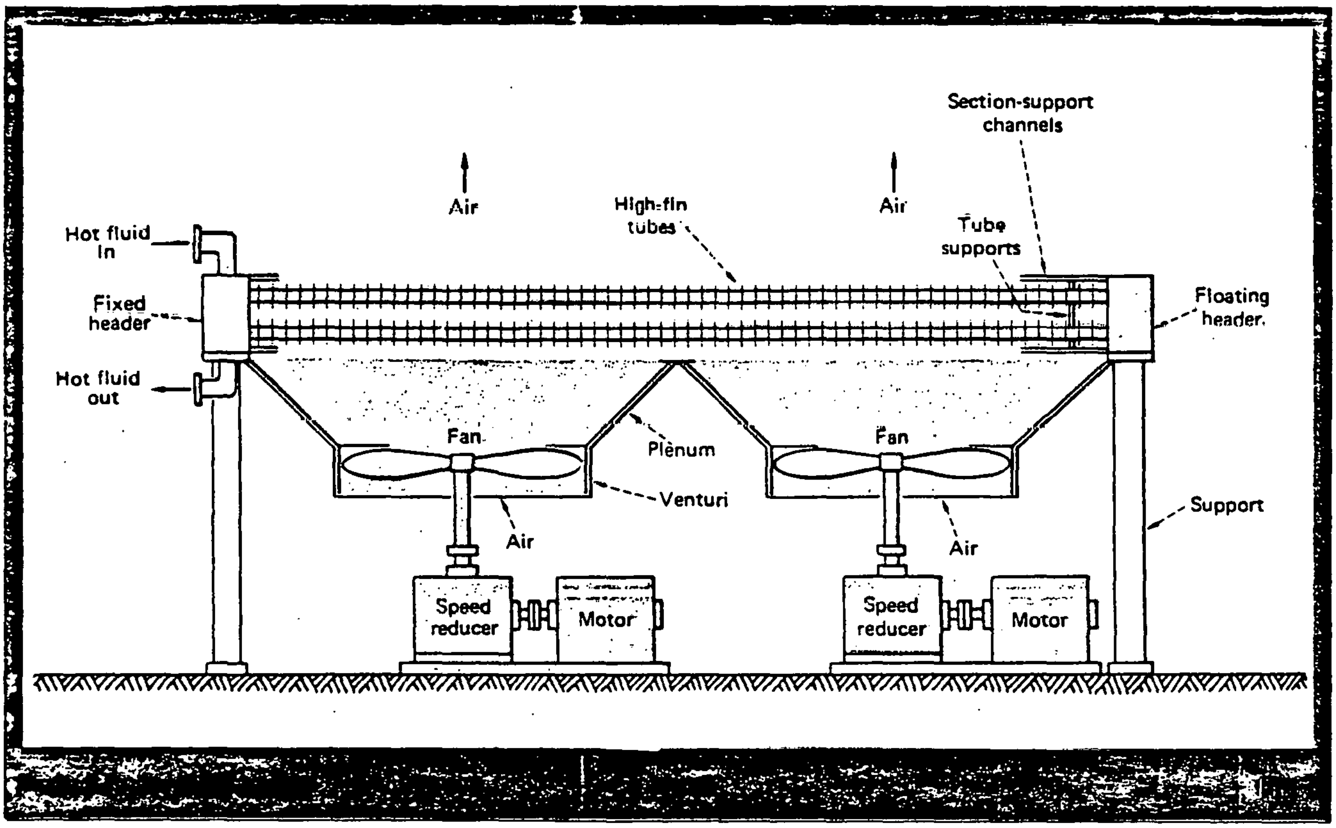



Figure 2. Forced Draft Air-Fin Cooler (does not show the evaporative assist feature).

Table II. Trade Parameters for the Thermal Rejection System Concepts

Parasitic power requirements - normal operation.

Initial cost - installed at site.

Operating cost - other than power parasitics.

Reliability - number and types of maintainable items.

Simplicity - remote sites and unsophisticated labor.

Maintenance requirements - frequency and complexity.

Load matching capability.

Uses for reject heat.

Corrosion, pollutants, residues - types and magnitude.

Table III. Formal Design Trade-Off Comparison for the Candidate Heat Rejection Systems

| Trade Parameter | Wet Cooling Tower (A) | Air Cooler-Pond Hybrid (B) | Air Cooler-Evaporator (C) | Selection |
|---|---|---|---|---|
| Parasitic Requirements, kw (est) | 5.9 (not counting make up water) | 9.9 | 13.1 | A,B=C |
| Initial cost, $ (est) | 85K | 81K | 60K | C,A=B |
| Operating Cost | Very High (water treatment) | Low Moderate (sump pump) | Low-Moderate (Make-up water) | B=C,A |
| Reliability | Good | Moderate | Good | A=C,B |
| Simplicity | Low | Moderate | Good | C,B,A |
| Maintenance | Moderate-High | Moderate | Low-Moderate | C,B,A |
| Load Matching | Moderate | Good | Good | B=C,A |
| Use for Reject Heat | None | Possible | None | B,C=A |
| Corrosion, etc. | High (Large blow-down stream) | Low (Fouling in exchanger) | Moderate (Small blow-down stream) | B,C,A |
| | | | Trade Selection | C |

heat exchanger required, the simulator was first run in a mode where the coolant inlet and outlet temperatures are fixed and the required heat exchanger area was calculated at full field flow rate (1200 liters per minute). The results of this calculation are shown in Figure 3. The saw-tooth appearance is a result of adding the evaporative assist option when the ambient temperature is within 8°C of the desired coolant exit temperature. It is evident from the figure than an exchanger area of about 190 $m^2$ will be satisfactory for all but the highest ambient temperatures.

The next step in the air cooler evaluation was to fix the area at 190 $m^2$, the coolant inlet temperature at 36°C and calculate the outlet temperature as a function of the ambient temperature. The results of this study are shown in Figure 4. It should be noted that the estimated parasitic power required is fairly constant at 13 kw. An actual unit specified by one bidder calls for two 7.5 hp fan motors and a 2 hp pump for a total parasitic requirement of 16 hp (11.9 kw).

In this section we see that the evaporation-assisted air cooler system offers the most promising means of heat rejection from the photovoltaic array. The rather high parasitic requirements for operation of the system are more than offset by its lower initial cost (worth about 2 kw in parasitic) and much cheaper and more simple operation. The system specified is expected to be both highly reliable and easily maintained.

B. Field Piping Array Design

The primary objective in developing the field piping array was a system which would involve the lowest pressure loss throughout, consistent with maintaining heat transfer integrity between the photo cells and the fluid.

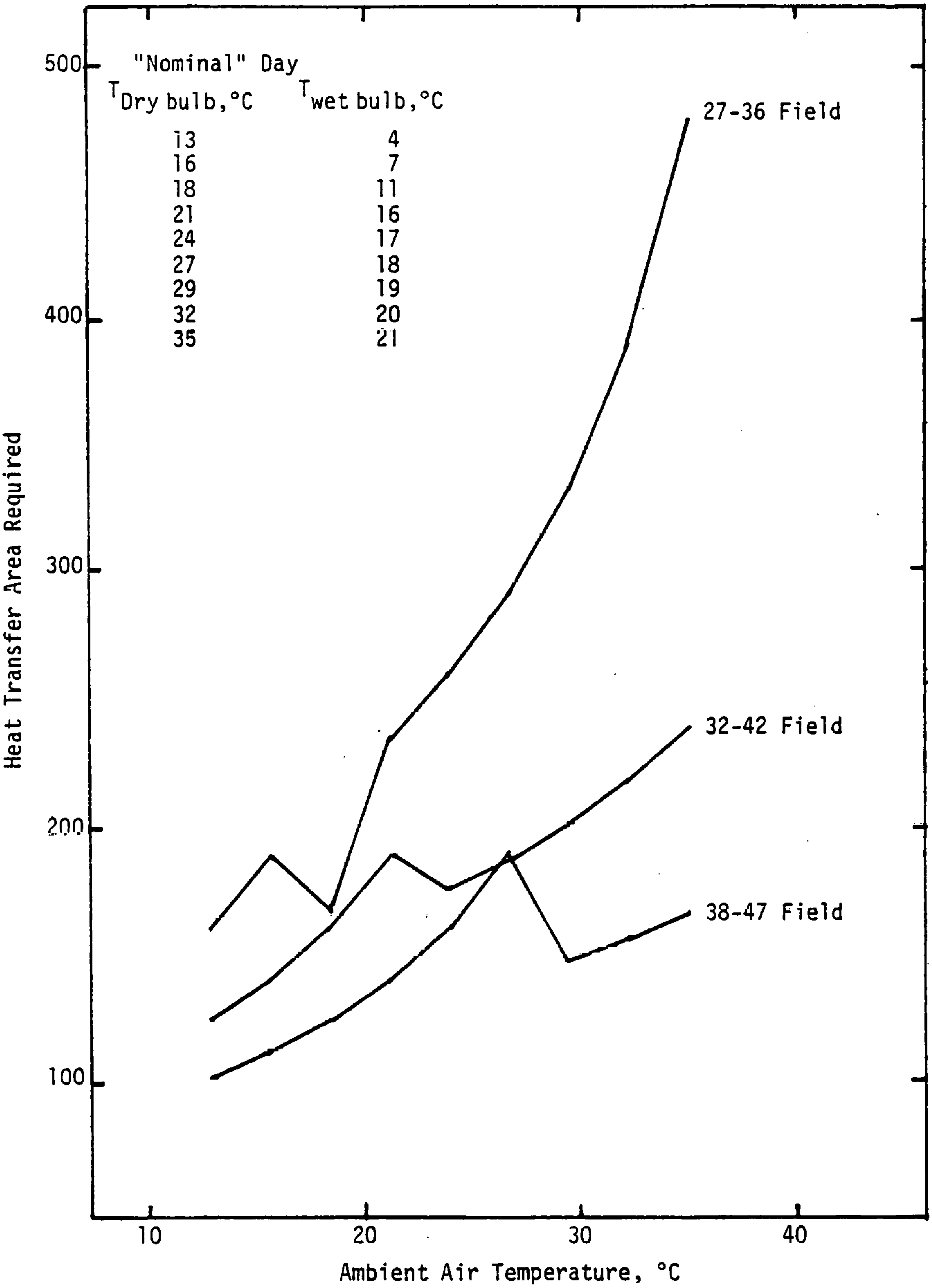
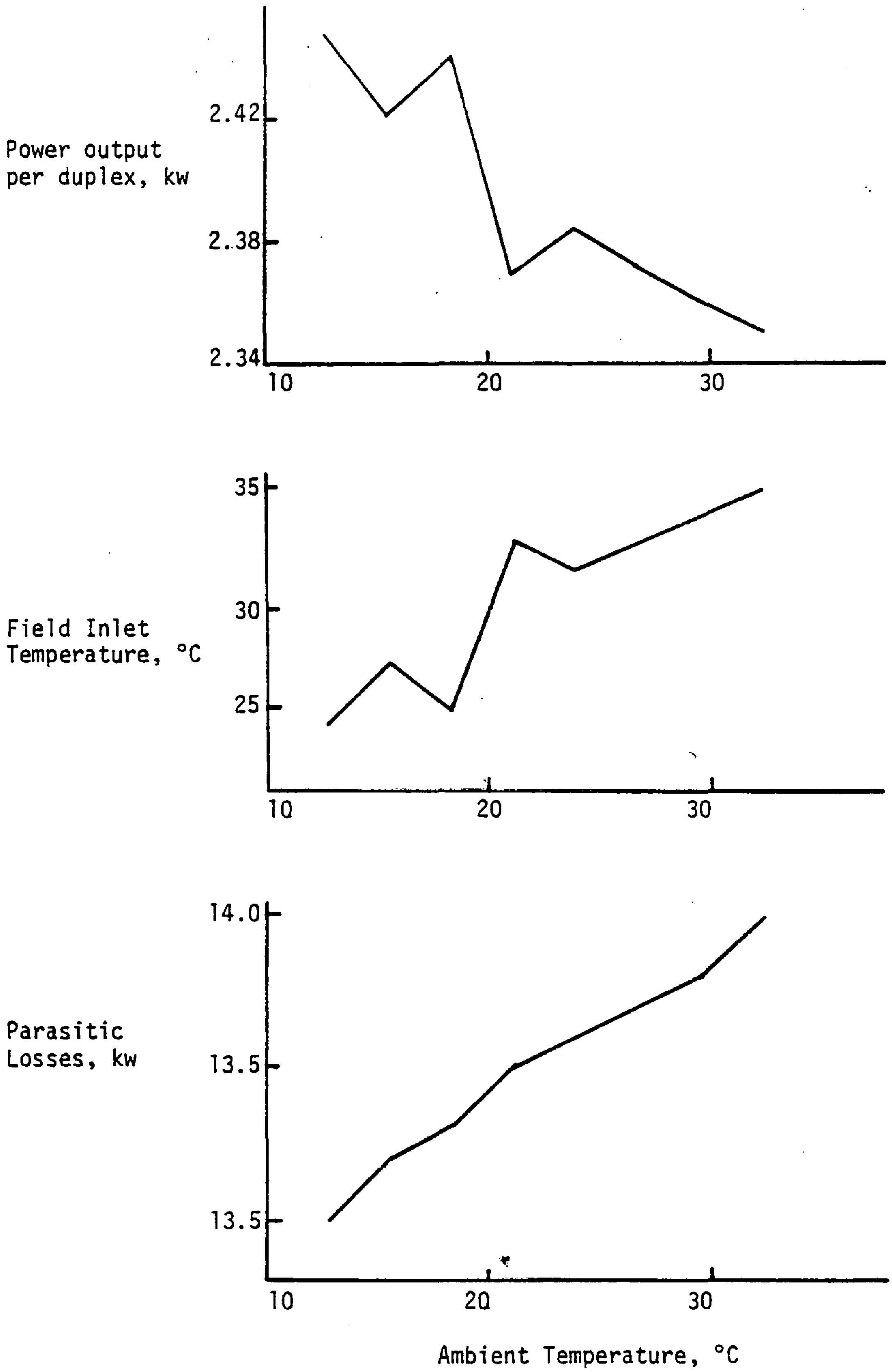



Figure 3: Effect of Ambient Temperature on Air Cooler Exchange Area Required for Set Coolant Inlet-Outlet Temperatures

Figure 4. Field Performance with a 190 $m^2$ Evaporative Assist Air Cooler as a Function of Ambient Temperature



A subpart of the field piping design was to determine the optimal coolant flow path within and between collectors. Several arrangements, shown in Figure 5, were tried. Performance predictions using the calculation technique given in Appendix E indicated that the coolant flow path within a collector, or number of collectors in series has a minimal effect on field output. At this point, the flow geometry shown in Figure 5a was chosen because of its simplicity, and because it required the fewest control valves.

The overall field layout was dictated by the need for a capability to isolate groups of collectors and the requirement to minimize the number of motorized control valves. The arrangement finally chosen is shown in Figure 6. Other piping geometries would result in smaller lengths of pipe, but would require far more valving and active control for the collector field.

The final collector field array was divided into sections depending on the required flow rate through that section, and the piping sized. The expression used to estimate optimum diameters was (4)

$$D_{i,opt} = q_f^{0.448}\ \rho^{0.132}\ \mu_c^{0.025} \left[\frac{0.88k(1+J)H_y}{(1+F)\ X\ E\ k_f}\right]^{0.158} \qquad (1)$$

where $D_{i,opt}$ = optimum pipe diameter, inches

$q_f$ = fluid flow rate, $ft^3/sec$

$\rho$ = fluid density, $lb/ft^3$

$\mu_c$ = viscosity, cp

$k$ = cost of electrical energy, \$/kwhr

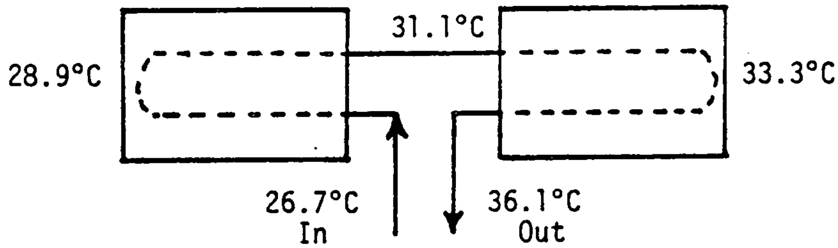
$J$ = fitting losses as a percent of tube losses

$H_y$ = operating hours per year, hr

$X$ = purchase price of pipe, \$/ft

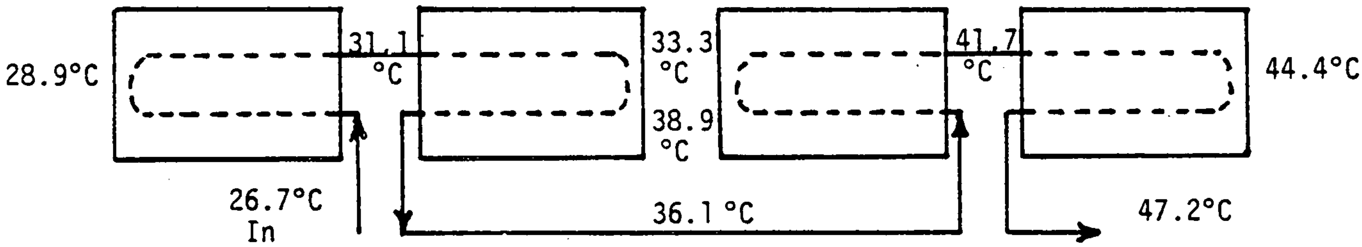
Figure 5: Duplex Piping Arrangements Considered

a) Single Duplex



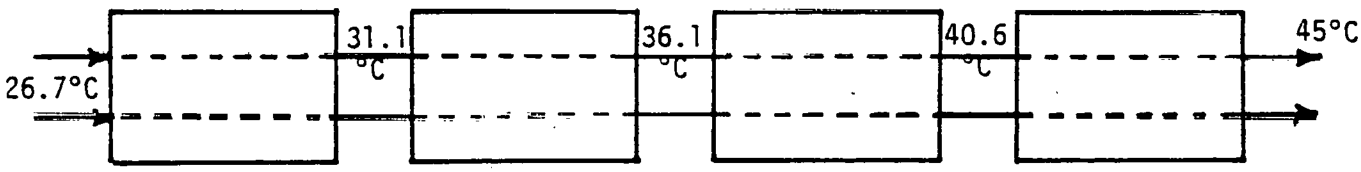

Coolant Flow: 1477 kg/hr Duplex output: 2.4237 kw

b) Two Serial Duplexes




Coolant Flow = 739 kg/hr Duplex output: 2.3922 kw

c) Two Parallel Duplexes



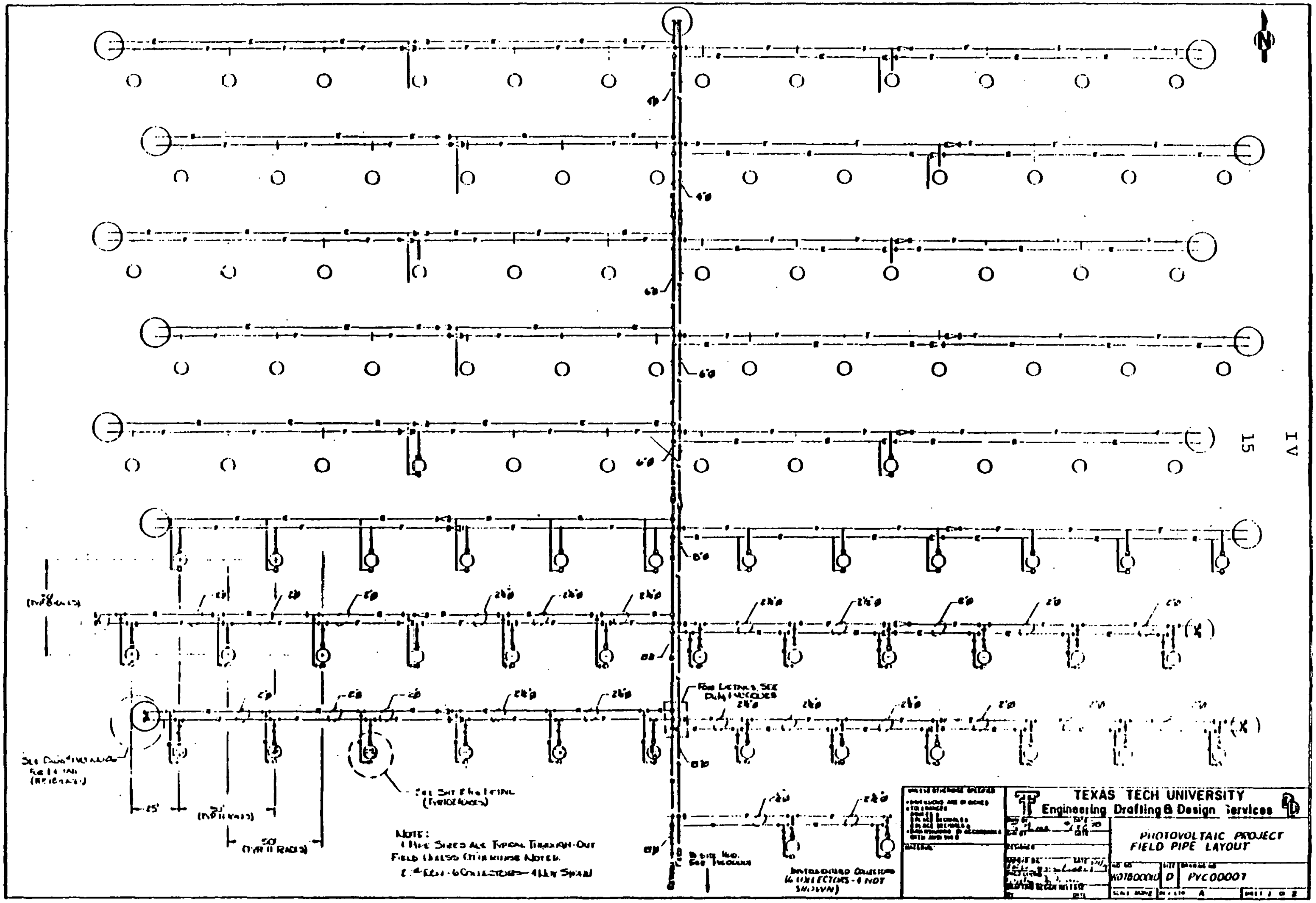

Coolant Flow: 1477 kg/hr Duplex output: 2.4451 kw

$E$ = motor/pump efficiency

$k_f$ = fixed charges as fraction of initial cost

$F$ = fittings cost as fraction of pipe cost

This empirical expression results in a trade-off between pressure drop and pumping costs and pipe diameter and initial costs which minimizes the overall system cost. The diameters calculated from Equation (1) were then rounded to the nearest standard pipe size and are shown in Figure 6.



NOTE:
25'
TEXAS TECH UNIVERSITY
Engineering Drafting & Design Services
PHOTOVOLTAIC PROJECT
FIELD PIPE LAYOUT
D
PVC00007
A


15

IV

## References

1. Caplan, F., "Quick Calculation of Cooling Tower Blowdown and Makeup," Chem. Engr., July 7, 1975, p. 110.

2. Langhaar, J. W., "Cooling Pond May Answer Your Water Cooling Problem," Chem. Engr., August, 1953, pp. 194-198.

3. Maze, R. W., "Air Cooler or Water Tower - Which for Heat Disposal?," Chem. Engr., January 6, 1975, pp. 106-114.

4. Peters, M. S. and K. D. Timmerhaus, Plant Design and Economics for Chemical Engineers, pp. 302-308, McGraw Hill Book Company, New York, 1968.

CHAPTER V

FINAL REPORT OF TASK TEAM-5

CONSTRUCTION

Submitted To:

Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:

Dr. C. E. Teske
Department of Engineering Technology
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER V
# FINAL REPORT OF
# TEAM 5 - PROJECT SUMMARY

1. Initial site survey began on June 21, 1978 when the site was surveyed with a level. The land was found to be generally flat with a very gentle slope from north to south, i.e. one tenth of a foot in 150 feet. A definite slope exists from west to east, i.e. 2 feet in 700 feet. These grades are continuous since the field has been used for ditch irrigation. Soil boring locations were located and staked during the survey.
2. Soil investigation was completed by July 26, 1978. Soil boring information is contained in Attachment 1. The soil is classified as a brown sandy clay material.
3. Pier design is based upon these load conditions:

   Twisting 9833.33 ft. lb.
   Overturning 2740 lb at 6' above ground level
   Vertical Load 3400 lb.

   Soil Data:

   Soil: Silty Clay
   Ave. Unconfined Strength 3000 psf
   Allowable Skin Friction 1000 psf
   Safety Factor 3
   Design Based Upon Broms Analysis

   Design calculations are contained in Attachment 2, with the selected design shown on page 3. Also construction details are shown in the structural sheets. Pier cost comparison of concrete pier vs steel pile is shown in Attachment 3. Concrete pier are found to be more economical.
4. Office building pier placement; site layout and pier construction details are found in site layout and foundation construction sheets. The office building complex was considered to be built of Bulter buildings or Portable relocatable buildings. It was found that portable relocatable structures were cheaper in initial cost ($\$30/ft.^2$ vs $\$35/ft.^2$) and would have the advantage of being a good resale item at the completion of the project. Drawings and specifications (Attachment 4) were developed for portable structures.
5. Site restoration considered four options, i.e. 1) contract removal, 2) sell to farmer, 3) sell material/equipment with removal, 4) abandon. The study, Attachment 5, shows that option 3 would be most economical.

6. An environmental impact study was performed and is summarized in Attachment 6.
7. Proposed research efforts during and at the completion of the project are presented in Attachment 7.

ATTACHMENT-1 V
3

SOIL MECHANICS
SUB-SURFACE EXPLORATION
CONCRETE
AGGREGATES
WELDING
BITUMINOUS MATERIALS
MASONRY PRODUCTS

# AMARILLO TESTING LABORATORY

Phone 374-2756 — 508 South Bowie
AMARILLO, TEXAS 79106

MEMBER OF
AMERICAN SOCIETY FOR
TESTING MATERIALS

26 July 1978

Texas Tech University
Department of Civil Engineering
P. O. Box 4089
Lubbock, Texas 79409

Attn: Dr. C.E. Teske

Subject: Soil Investigation in Pecos, Texas

Dear Dr. Teske:

In accordance with your instructions in your letter dated 6 July 1978, Amarillo Testing Laboratory has completed drilling, logging, and testing for the subject soil investigation for the Trans-Pecos Concentrating Photovoltaic Applications Experiment in Pecos, Texas. The drill work was performed in the presence of Dr. C.V. Girija Vallabhan of Texas Tech University.

The enclosed logs present both the field and laboratory test data with a figure depicting the location of each boring.

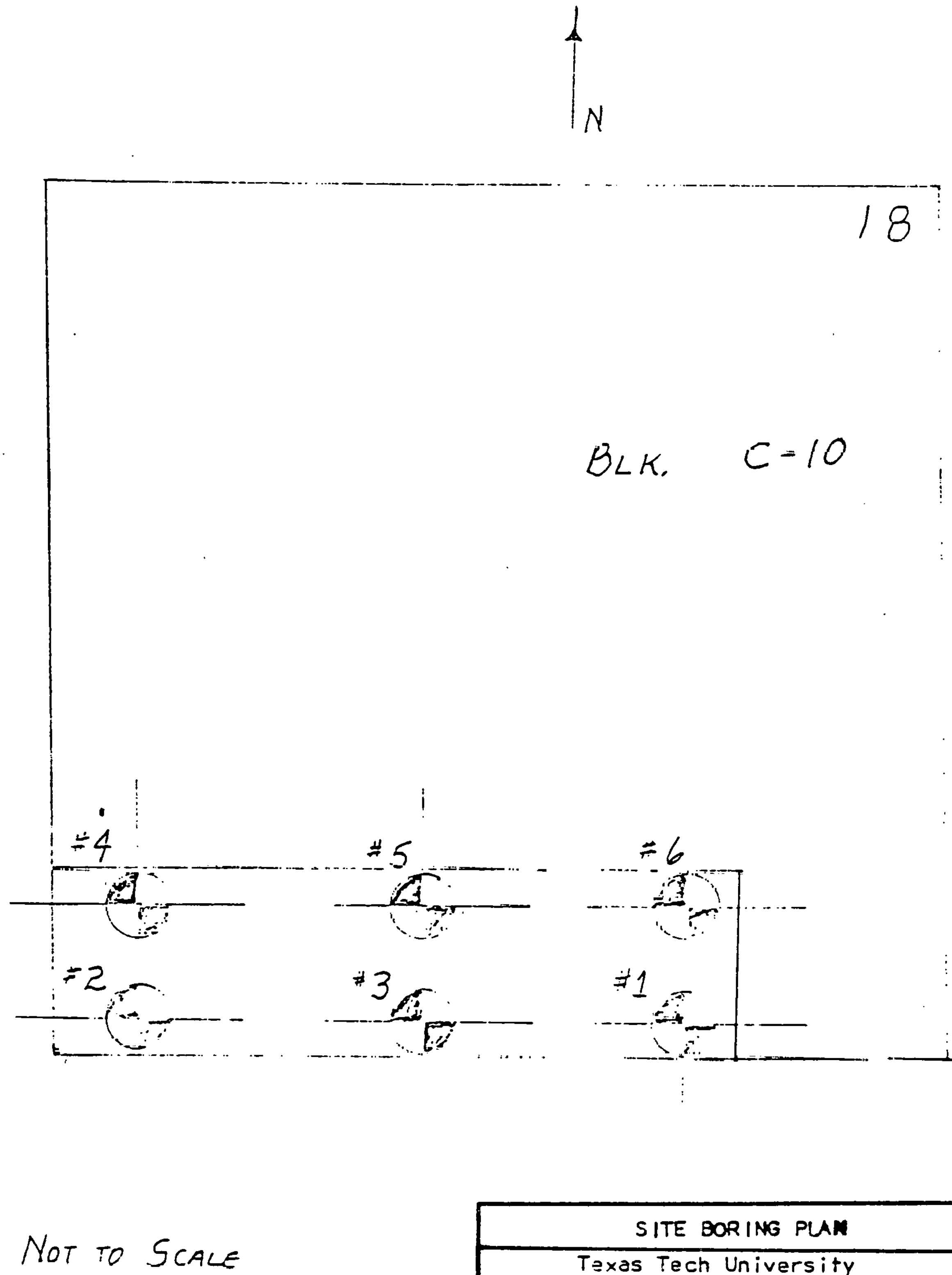
We appreciate this opportunity to provide this service to you and welcome your consideration on future projects.

Very Respectfully,

Bernard Ray Tillery

Bernard Ray Tillery P.E.
Amarillo Testing Laboratory

BRT/mt
Enclosures




SITE BORING PLAN

Texas Tech University
Proposed Trans-Pecos Concentrating
Photovoltaic Applications Experiment
Pecos, Texas

AMARILLO TESTING LABORATORY

Date: 26 July 1978 Drawing No.:

ATTACHMENT-1



# LOG OF BORING
HOLE NO. 1

CLIENT Texas Tech University

DATE DRILLED 21 July 1978

PROJECT Trans-Pecos Concentrating Photo-voltaic Applications Experiment

BORING METHOD Hollow Auger

LOCATION Pecos, Texas

SURFACE ELEV.

JOB NO. S-78432

HOLE DIAM. 8"

REPORT DATE 26 July 1978

DEPTH OF HOLE 15 ft.

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS | | | DEPTH OF PENE. VALUE | NO. OF BLOWS | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LL | PL | PI | | 1st 6" | 2nd 6" | Percent Finer than #200 Sieve |
| | Topsoil-Brown Sandy Clay | CL | 3% | 27 | 17 | 10 | | | | 85% |
| | | | | Linear Shrinkage= | | | | | | 3.8% |
| 2-3 | Brown Sandy Clay | CL | 13% | | | | | 6 | 9 | 87% |
| 5 | Brown Sandy Clay | CL | 12% | | | | | 7 | 7 | 89% |
| 10 | Brown Sandy Clay mixed with gravel | GC | 14% | | | | | 7 | 8 | 40% |
| 15 | Brown Sandy Clay | CL | 17% | 29 | 15 | 14 | | 7 | 8 | 92% |

AMARILLO TESTING LABORATORY

ATTACHMENT-1

V
6

LOG OF BORING
HOLE NO. 2

CLIENT Texas Tech University
PROJECT (Continued)
LOCATION
JOB NO.
REPORT DATE

DATE DRILLED
BORING METHOD
SURFACE ELEV.
HOLE DIAM.
DEPTH OF HOLE 10 ft.

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS LL | PL | PI | DEPTH OF PENE. VALUE | NO. OF BLOWS 1st 6" | 2nd 6" | REMARKS Percent Finer than #200 Sieve |
|---|---|---|---|---|---|---|---|---|---|---|
| 2-3 | Brown Sandy Clay | CL | 11% | | | | | 9 | 13 | 87% |
| 5 | Brown Sandy Clay | CL | 11% | | | | | 10 | 9 | 97% |
| 10 | Brown Sandy Clay | CL | 20% | 46 | 26 | 20 | | 10 | 14 | 89% |

AMARILLO TESTING LABORATORY

ATTACHMENT-1

V

7

LOG OF BORING
HOLE NO. 3

CLIENT Texas Tech University

PROJECT (Continued)

LOCATION

JOB NO.

REPORT DATE

DATE DRILLED

BORING METHOD

SURFACE ELEV.

HOLE DIAM.

DEPTH OF HOLE 10 ft.

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS | | | DEPTH OF PENE. VALUE | NO. OF BLOWS | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LL | PL | PI | | 1st 6" | 2nd 6" | Percent Finer than #200 Sieve |
| 2-3 | Brown Sandy Clay | CL | 14% | | | | | 5 | 7 | 87% |
| 5 | Brown Sandy Clay | CL | 14% | | | | | 8 | 9 | 91% |
| 10 | Brown Sandy Clay | CL | 16% | | | | | 8 | 8 | 97% |

AMARILLO TESTING LABORATORY

ATTACHMENT-1

V
8

LOG OF BORING
HOLE NO. 4

CLIENT Texas Tech University
PROJECT (Continued)
LOCATION
JOB NO.
REPORT DATE
DATE DRILLED
BORING METHOD
SURFACE ELEV.
HOLE DIAM.
DEPTH OF HOLE 15 ft.

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS LL | PL | PI | DEPTH OF PENE. VALUE | NO. OF BLOWS 1st 6" | 2nd 6" | REMARKS Percent finer than #200 Sieve |
|---|---|---|---|---|---|---|---|---|---|---|
| 2-3 | Brown Sandy Clay | CL | 10% | 31 | 16 | 15 | | 13 | 13 | 81% |
| | Linear Shrinkage = 3.8% | | | | | | | | | |
| 5 | Brown Sandy Clay | CL | 13% | | | | | 10 | 11 | 90% |
| 10 | Brown Sandy Clay | CL | 20% | | | | | 9 | 3 | 93% |
| | Some Gravel @ 13 ft. down | | | | | | | | | |
| 15 | Brown Sandy Clay mixed with gravel | GC | 13% | | | | | 5 | 5 | 56% |

AMARILLO TESTING LABORATORY

ATTACHMENT-1

V
9

LOG OF BORING
HOLE NO. 5

CLIENT Texas Tech University

PROJECT (Continued)

LOCATION

JOB NO.

REPORT DATE

DATE DRILLED

BORING METHOD

SURFACE ELEV.

HOLE DIAM.

DEPTH OF HOLE 10 ft.

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS LL | PL | PI | DEPTH OF PENE. VALUE | NO. OF BLOWS 1st 6" | 2nd 6" | REMARKS Percent Finer then #200 sieve |
|---|---|---|---|---|---|---|---|---|---|---|
| 2-3 | Brown Sandy Clay | CL | 10% | | | | | 9 | 5 | 92% |
| 5 | Brown Sandy Clay | CL | 13% | | | | | 5 | 5 | 89% |
| 10 | Brown Sandy Clay | CL | 9% | | | | | 11 | 13 | 72% |

AMARILLO TESTING LABORATORY

LOG OF BORING
HOLE NO. 6

CLIENT Texas Tech. University
PROJECT (Continued)
LOCATION
JOB NO.
REPORT DATE
DATE DRILLED
BORING METHOD
SURFACE ELEV.
HOLE DIAM.
DEPTH OF HOLE 10 ft

| DEPTH IN FEET | DESCRIPTION OF SOIL | USC | NATURAL MOISTURE | ATTERBERG LIMITS | | | DEPTH OF PENE. VALUE | NO. OF BLOWS | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LL | PL | PI | | 1st 6" | 2nd 6" | Percent Finer than #200 sieve |
| 2-3 | Brown Sandy Clay | CL | 12% | | | | | 8 | 9 | 89% |
| 5 | Brown Sandy Clay | CL | 12% | 32 | 17 | 15 | | 12 | 13 | 92% |
| 10 | Brown Sandy Clay | CL | 17% | | | | | 8 | 10 | 91% |

AMARILLO TESTING LABORATORY

# FINAL PIER DESIGN

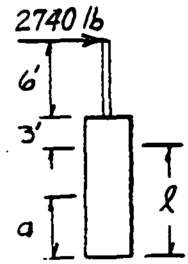
**Loading:**

Twisting = 9833.33 ft.#
Overturning = 2740lb @ 6' above ground
Vertical = 3400 lb

**Soil Data:** Silty Clay

q = est av. unconf str = 3000psf
allowable skin friction = 1000psf
Use Broms Analysis
Max Lat. Resist/F = 9(3)(2) = 54 $^k/_{ft}$
Use safety factor =3
$\therefore$ Allowable Lat. Resist = 18 $^k/_{ft}$

TRY 24" Diameter
Neglect top 1.5 Dia. or 3'




$\Sigma F_H = 0$

$2.75^k + 18\,a = 18(\ell - a)$

$a = \ell/2 - .076$

$\Sigma M$@ Bottom

$2.75\,(9 + \ell) + 18\,\frac{a^2}{2} = 18(\ell - a)\left(\frac{\ell + a}{2}\right)$

$24.75 + 2.75\ell + 9a^2 = 9(\ell^2 - a^2) = 9\ell^2 - 9a^2$

$9\ell^2 - 18a^2 - 2.75\ell - 24.75 = 0$

$9\ell^2 - 18(\ell/2 - .076)^2 - 2.75\ell - 24.75 = 0$

$-18(\ell^2/4 + .00576 - .076\ell)$

$4.5\,\ell^2 - 1.38\ell - 24.85 = 0$

$\ell^2 - .31\ell - 5.52 = 0$

$\ell^2 - .31\ell = 5.52$

$(\ell - .153)^2 = 5.52 + .0235$

$(\ell - .153)^2 = 5.5435$

$\ell - .153 = 2.3545'$

$\ell = 2.5075'$ or $2.5'$

Overturning Total Length = 2.5 + 3 = 5.5'

**Rotation:**

Resist Mrot = $2\pi L(1000)$
Rotation Moment = 9834 ft#

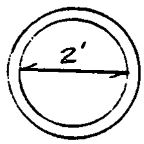
$9834 = 2\pi(1000)L$

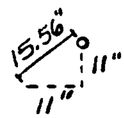
$L = 1.57' < 2.5'$ $\therefore$ OK

Vertical:

Vertical Load = 3.40 k
Allow Bearing = 1.5q = 4.5ksf

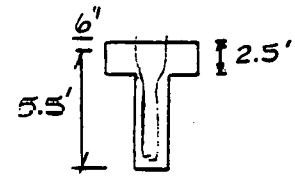
Bearing Stress = $\frac{3.40}{\pi(1)^2}$ = 1.08ksf < 4.5ksf ∴ OK




15.56 + 1" + 3" = 18.56" radius
Dia. = 37.12" or 38"

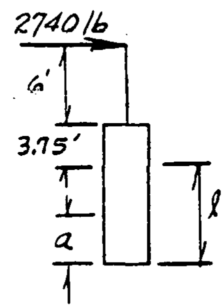
$$\frac{\pi\left(\frac{38}{12}\right)^2}{4}(2.5) = 19.69$$




$$\frac{\pi(2)^2}{4}(3) = \frac{9.42}{29.11 ft^3} = 1.08\ yd^3$$

W/O Top Blk: $\frac{\pi(2)^2}{4}$ (6') = 18.8 ft³ or .7 yd³

Try 2.5' Pier (30")
1.5 (2.5) = 3.75' Top Neurtal Zone




Max Lat Resist = 9(3)(2.5) = 67.5
Safety Factor = 3
Allow Lat Resis = 22.5

$a = \ell/2 - .0611$

ΣM@BOTT

$2.75\,(9.75 + \ell) + 22.5\,a^2/2 = 22.5\,(\ell - a)(\ell + a/2)$

$26.81 + 2.75\ell + 11.25a^2 = 11.25(\ell^2 - a^2)$

$11.25\ell^2 - 22.5\,(\ell/2 - .0611)^2 - 2.75\ell - 26.81 = 0$

$11.25\ell^2 - 22.5(\ell^2/4 + .000373 - .0611\ell)$

$5.63\ell^2 - 1.38\ell - 26.82 = 0$

$\ell^2 - .244\ell - 4.764 = 0$

$(\ell - .122)^2 - 4.764 + .015$

$= 4.779$

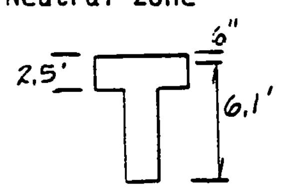
$= 2.186$

$\ell = 2.308$

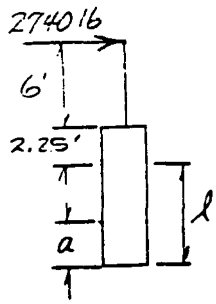
Total Length = 2.3 + 3.75 = 6.06'   Longer due to 3.75' top Neutral zone

Volume: Top 19.69 ft³

$$\frac{\pi(2.5)^2}{4}\ 4.1 = \frac{20.13}{39.82\ ft^3} = 1.47\ yd^3$$



Try 18" Pier




1.5(1.5) = 2.25' or 27"

Mal Lat Resist = 9(3)(1.5) = 55.5

Safety Factor = 3

Allow Lat Resist = 18.5

$a = \ell/2 - .0743$

ΣM@BOTT

$$2.75\,(8.25 + \ell) + 18.5\,a^2/2 = 18.5(\ell - a)(\ell + a/2)$$

$$22.69 + 2.75\ell + 9.25\,a^2 = 9.25\,(\ell^2 - a^2)$$

$$9.25\ell^2 - 18.5\,(\ell^2/2 - .0743)^2 - 2.75\ell - 22.69 = 0$$

$$-\,18.5(\ell^2/4 + .0055 - .0743\ell)$$

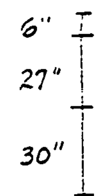
$$4.63\ell^2 - 1.38\ell - 22.79 = 0$$

$$\ell^2 - .30\ell = 4.92$$

$$(\ell^2 - .15)^2 = 4.92 + .023$$

$$\ell - .15 = 2.223$$

$\ell$ = 2.373' or 28.5" use 30"



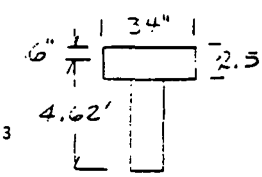

Total Length = 2.37 + 2.25 = 4.62'

30 + 27 = 57"

Top = 19.69 $ft^3$

$\frac{\pi(1.5)^2}{4}$ (2.62) = 4.63 or .9$yd^3$

24.32 $ft^3$




W/O Top Block: 4.62 + .5 = 5.12 $ft^3$

$\frac{\pi(1.5)^2}{4}$ (5.12) = 9.05 $ft^3$ or .34 $yd^3$

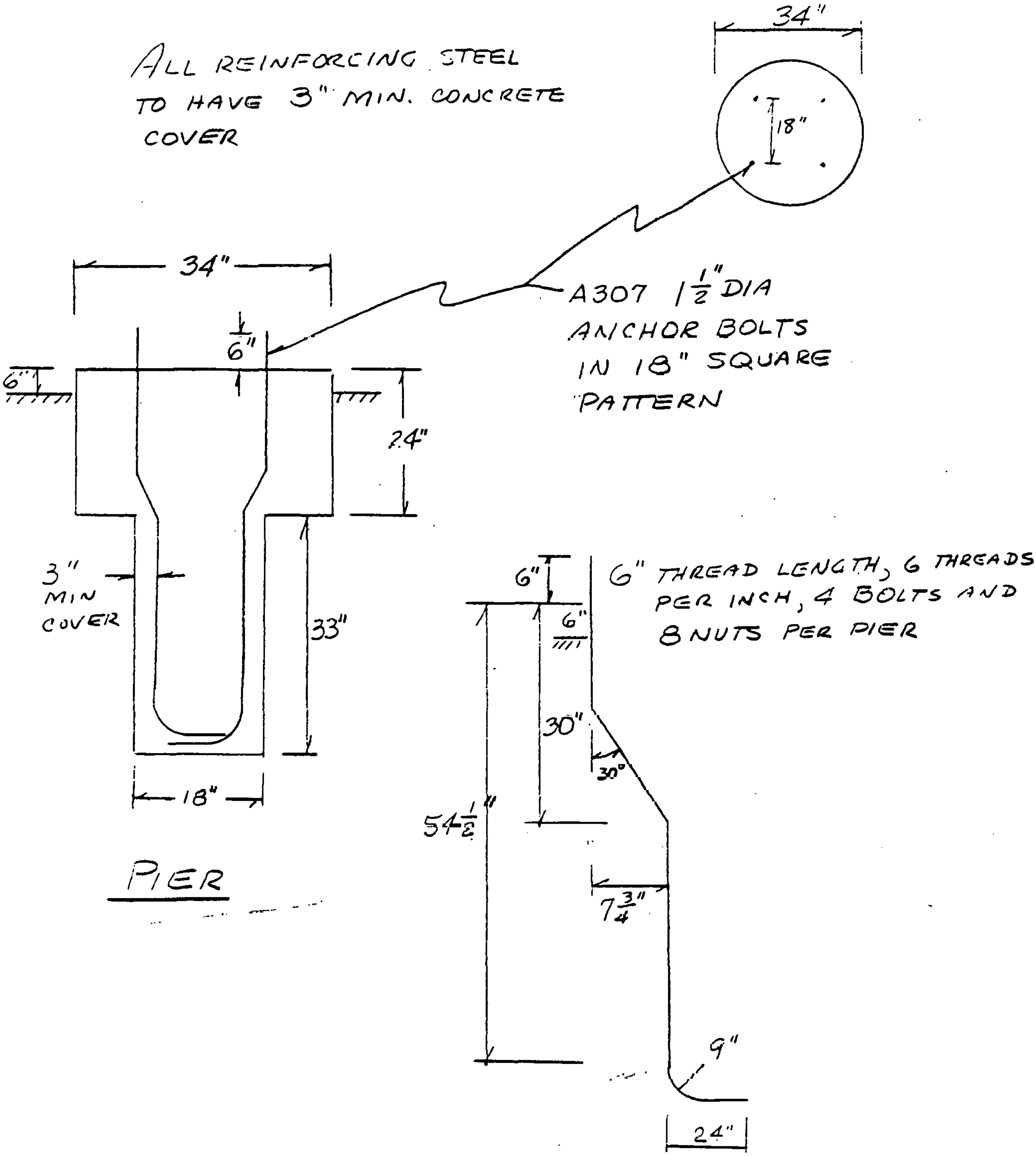
Rot M = $2\pi L(1000)$

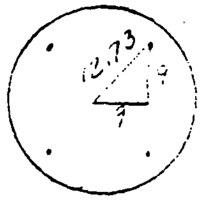
9834 = $2\pi L(1000)$

L = 1.57' < 2.37' ∴ OK

Vertical Load:

$$\frac{3.4^k}{\frac{\pi(1.5)^2}{4}} = 1.92 \text{ ksi} < 4.5\text{ksf} \quad \therefore \text{OK}$$


ALL REINFORCING STEEL TO HAVE 3" MIN. CONCRETE COVER
34"
18"
34"
6"
6"
24"
A307 1 1/2" DIA ANCHOR BOLTS IN 18" SQUARE PATTERN
3" MIN COVER
33"
18"
PIER
6"
6" THREAD LENGTH, 6 THREADS PER INCH, 4 BOLTS AND 8 NUTS PER PIER
6"
30"
30°
54 1/2"
7 3/4"
9"
24"



d = 18 - 6 - 1.5 = 10.5"

Neglect Concrete

$\bar{x}$ = cos 45(10.5) = 7.42"

Overturning Moment: 2740lb (6) = 16440 ft#

$M_{OV}$ = As · $\bar{x}$ (σAll.)

16440(12) = As 7.42" (36000)

As = .74 in²

Assume overturn with one bolt $\bar{x}$ = 10.5

Mov = As $\bar{x}$ σAll.

16440(12) = As 10.5 (36000)

As = .52 in² < .74 in² previous

1 1/2" Dia less threads, say 1" clear

Area 1"φ = $\frac{\pi(1)^2}{4}$ = .79 in² > .52 required

Rotational Shear:

$$\tau = \frac{9834(12)}{4(.79)(10.5)} = 3557\text{psi or } 3.6 \text{ ksi} \therefore \text{OK}$$

Use 11/2" Dia A 307 Anchor Bolts (on previous page) with #3 ties @ 6" c-c.

Max allowable = 160 psi 1/2 of that allowable for deformed bar.

2πr or πd = perimeter

π(1.5) = 4.71 inches perimeter

Overturn Moment = 16440 ft#

$$\frac{16443(12)}{12.73} = 15500 \text{ \# pull}$$

Pull = σAll. (area) = σAll. (4.71) (24+23)

15500 = σreq. (4.71) (47)

15500 = σreq. (221.37)

σreq = 70 psi < allowable of 90 of 2000 psi concrete, ref. CRSI Handbook pg. 32. This neglects hooks.

Texas Tech University
BOX 4089 / LUBBOCK, TEXAS 79409 / (806) 742-3523
DEPARTMENT OF CIVIL ENGINEERING

MEMORANDUM

TO: W.M. Marcy

FROM: C.E. Teske

SUBJECT: Cost Comparison of Concrete Pier vs. Steel Pile

DATE: October 13, 1978

Assume: That Both type foundation has a steel base plate anchored to the foundation to which the collector support structure is mounted. Hence only the cost of material and labor below this base plate is considered.

Loading: 5K vertical, 5K horizontal, 6 ft above ground level.

Concrete Pier: Using Broms Method of Analysis, a 2' diameter pier 6.5' deep will support the loading

| | |
|---|---|
| Steel including labor | $ 66 |
| Drilling hole | 23 |
| Concrete in place | 38 |
| Total cost per pier | 127 |

Piling: (Using the same depth as concrete pier which is much less than what would be required for a 12 inch diameter pile)

| | |
|---|---|
| 12" diameter pipe delivered | $ 92 |
| Hole drilling (Assume 6" diameter) | 3 |
| Driving pile | 98 |
| Total cost per pile | 193* |

*This cost does not include cutting off top of pile after driving; nor spoilage of cutting lengths from standard lengths of 40, 50, 60 ft material; nor the true length required of a 12 inch diameter pile.

It can be seen that a concrete pier is more cost effective. Another factor worth mentioning is that pile driving contractors are difficult to find in Texas. The cost information came from a contractor in El Paso. The only other pile driving contractors are in Houston.

Salvage value of pipe of this short length would be very little if at all. Most work requires the use of much longer pile.

TRANS-PECOS PHOTOVOLTAIC CONCENTRATING COLLECTOR EXPERIMENT

SPECIFICATIONS

## BUILDING SPECIFICATIONS

### FLOOR SYSTEMS

Floor framing system shall be built on pressure-creosoted 3 x 6 rough sawn skids with a certified retention of 8 lbs. per cubic ft. Four additional 3" x 12" boards 8 feet long shall be provided for use by others.

All floor joists shall be treated with pentacholorcpenol preservative for protection against termite decay. The joists in the office building shall be 2 x 6's 16" o.c. The joists of the storage/garage shall be 2 x 8's at 8" o.c. Each floor joist will be attached to the skid with 1) 40D spike and (1) power driven 12D cement coated nail at each connection. The spike shall alternate in direction along the connection points at the skid. In addition, TECC CL & CR framing anchors shall be installed at 8' o.c. along each skid. Framing anchors all to be installed with (11) 1½" barb nails.

The side bands shall also be treated in pentacholorophenol preservative. They shall be 2 x 6 Southern Yellow Pine as the joists. The side band will connect to the joist with 3 power driven 12D cement nails at each connection.

All sub-flooring shall be 5/8" exterior glued American Plywood Association Grade marked plywood, which is plugged and touch sanded. The flooring shall be installed with the face grain running perpendicular to the floor joists, with solid blocking at all unsupported plywood joints. The floor shall be attached to joists, side bands, and solid blocking with power driven 12D cement coated nails at approximately 6" o.c. at all perimeter plywood edges, and approximately 8" o.c. on intermediate spacing.

The storage/garage subfloor shall receive a second floor covering like the subfloor.

### WALL SYSTEMS

All framing members shall be 2 x 4 kiln-dried Southern Yellow Pine @ 16" o.c. with double studs at all door openings and triple studs at all corners. All headers shall be sized to meet or exceed the applicable roof and wind loads called for in local code. Wind bracing shall be 1 x 4 and shall be mortised into studs and plates diagonally.

Top and bottom plates shall be attached to each stud with (2) power driven 12D cement coated nails. CR & CH framing anchors shall be spaced at approximately 6' o.c. along the bottom plate at the plate and stud connections.

The bottom plate shall be fastened to the floor along the side bands with power driven 12D cement coated nails at approximately 12" o.c. and bolted with heat-treated 4" lag bolts at approximately 4' o.c. alternating between the joists and side band. Bolts will also be used to tie the intersecting walls together at the corner studs. A minimum of 3 shall be used at each corner.

The diagonal bracing shall be mortised into the stud at the corners of the building and at points along the wall where stress dictates. The bracing shall be attached at each end and at each stud connection with (2) power driven 12D cement coated nails.

The siding shall be heavy-duty, corrosion-resistant aluminum alloy with a twin rib configuration. It shall have a white baked-on enamel finish and carry a 20-year guarantee on the finish. It shall be fastened with triple cadmium plated screws. The siding will be installed so that the ribs run in a vertical manner. It will be in a manner so there are not visible splices in the material.

The office building wall height shall be 8'. The storage/garage wall height shall be 11' high. The storage/garage vehicle access doors shall provide an opening of 10' high and 9' wide with doors opening overhead.

ROOF SYSTEMS

All roofing shall be of heavy timber construction. Roof beams shall be 2 x 6 kiln-dried Southern Yellow Pine sized and spaced to meet requirements for all dead loads plus a live load in excess of 20 lbs. per sq. ft.

Roof beams shall transfer loads directly into load-bearing walls and box beams. The box beams shall be designed to meet the requirements for a live load plus the dead in excess of 20 lbs. PSF.

All roof beams shall be supported by blocking into wall framing or by framing anchors installed with power driven 12D cement coated nails. The box beams shall be finished with paneling to match the interior finish. The exposed beams are to be stained to complement the interior.

Roof material shall be .0210 high strength continuous ribbed natural mill finish aluminum roofing with diamond embossed pattern. The material shall have a yield strength of approximately 33,000 lbs. PSI and conform to specifications prescribed in FHA technical bulletin as applicable. It will be attached to the beam and top plates with 2¼ ring shank aluminum roofing nails with neoprene washers. Nails shall be spaced on alternate ribs at 60 nails per square. All nails will be sealed with butyl caulking. For type of caulking see Insulation and Moisture Protection in these specifications.

INSULATION AND MOISTURE PROTECTION

TRIM (exterior):

All exterior trim shall be 26 gauge electro-galvinized steel with a baked on enamel finish on both sides. Trim color is brown. All edges of all corner and door trim shall be hinged so that no sharp edges are exposed. Care shall be taken to install trim neatly in a workmanlike manner.

Trim shall be installed on gables and eaves, at all corners, around door openings, and at the splice between underpinning and siding material.

FIBER GLASS INSULATION:

All insulation shall be low density continuous rolled fiber glass blanket of moisture resistant, odorless fibers of flame-flown type, bonded with fire-resistant thermalsetting resin. Insulation shall be installed in a manner to prevent hollow areas and voids. It shall be installed in walls and roof area. The roof system shall have no less than an R value of 20 and the wall system no less than R-13.

CAULKING:

Architectural caulking shall be oil-based caulking and shall be applied at all window and door head trim, and other areas as needed. The caulk shall be the type which cures through the solvent release, oxidation process, and the Shore Hardness to exceed 20. Materials shall comply with PS:TTC-598B.

BUTYL CAULKING:

Butyl caulking shall be of the skinning type. Materials shall be of the butyl polymers with inert reinforcing pigments, non-volatile plasticers and polymerizable dryers. Should cure to a tack-free surface in 24 hours.

DOORS

All doors shall be 3068 x 1-3/4" exterior grade solid core doors. The edges shall be finished with two coats of sealer. The doors shall be finished with two coats of exterior grade enamel applied in accordance with paint manufacturers recommendations over one coat of latex primer. The doors shall then be sealed with a urethane finsih. It will be hung with 1½ pair of full butt hinges bolted through the jam and 10 x 1½ wood screws end to leaf. The doors will have installed a chain spring.

Key locks will be manufactured by Weiser Lock Company series #501 or equal. Door to include panic hardware. Von Duprin "Series 44" exit devices; 44TP keylock and thumb latch in pull or equal.

FINISHES

The interior wall finish shall be random groove, woodgrain paneling. Material to be attached to framing with painted ring shank paneling nails. Material shall have a flame spread rating of 75-200, according to ASTM E-84 Tunnel Test. The ceiling material shall be prefinished white accoustical type fiber board. The ceiling is to be supported on a system of prefinished white T-bars. The material shall carry a flame spread rating of 75-200, according to ASTM E-84 Tunnel Test. The interior trim shall be manufactured moulding stained to complement interior finish. The tile shall be 1/16" gauge 12" x 12" vinyl asbestos tiles. Material pattern to be embossed and must have a flame spread rating of less than 75 when tested in accordance with ASTM E-84 tunnel test. Floor shall be sanded and filled before tile is installed.

SPECIALTIES

The storage/garage loading will consist of a one ton vehicle with maximum loading of 13,000 pounds.

MECHANICAL

Built in, through the wall, heating and ventilating units shall be installed as indicated on the plan. They have to be sized to adequately heat the structure with A 10 occupancy loading. The unit is to be manufactured by General Electric or equal. It has a self-contained thermostat and is American Gas Association approved.

ELECTRICAL

Each module will be independently wired, with a separate multi-breaker panel. This shall be a flush-mounted, surface opening, UL approved box with a door. The panel shall be capable of containing 2-2 pole NA or 4 NA or 12 NC breakers or combinations, rates at 120/240 VAC, 1 phase, 3 wire. 100 amp max sized for maximum load of module. The panels shall be suitable for copper conductors #104-12-100 manufactured by Federal Pacific Electric Corporation or equal. The service entrance shall be stubbed out through the floor. A pull wire for the on-site electrician to install a ground wire shall be provided from the distribution panel through the bottom palte under the building. All multi-breaker panels shall have enough space left to accommodate a double pole main breaker which shall be installed by purchasers on-site electrician. All wiring shall be accomplished in strict accordance with the National Electric Code and other state and national codes where applicable. All wiring shall be executed with copper romex.

Devices for copper wiring shall be manufactured by Bryant or equal.

Fluorescent lighting shall be provided by twin tube fixtures with 20 gauge die-formed steel housing. The finish shall be white enamel with 89% reflectants. The unit is to be wired in accordance with manufacturers recommendations and shall have pedestal type sockets with spring-loaded, single pin or rotating lock bi-pin, as required. It shall have a UL approved ballast. The unit shall be provided with cool white tubes.

FOUNDATION, ANCHORING AND SITE WORK

A recommended foundation system and plan shall be provided by the bidder. The purchaser will provide the necessary foundation as recommended by the bidder. All required site leveling, earth work, drilling, footings, and electrical connections to the multi-breaker panels shall be performed by the purchaser. Foundation skirting will be provided and installed to grade by the bidder. The skriting will be fabricated from material to match the siding of the building.

WINDOWS

All windows shall be horizontal sliding windows and shall be installed as indicated on the plan. Window frame and sash sections shall be constructed from nominal .062" extruded 6063-T5 aluminum alloy and shall meet or exceed AAMA performance specification for HS-B2-HP. Frame and sash shall be mechanically fastened to provide weather-tight, and structurally sound corners: Fixed sash shall be integral to the frame and shall be inside glazed with rigid vinyl glazing bead. The mitered moving sash shall be easily removable, with wrap-around glazing, providing continuous double weather-stripping: Moving sash shall be mounted on durable nylon sheels which roll freely in the extruded sill track. The vertical sash meeting rails shall be interlocking design. Window sash and frame exposed surfaces shall be standard mill finish, free of surface defects. Windows shall have one pair of manufactured shutters with color to match trim.

ATTACHMENT-5

V
22

Texas Tech University

Department of Engineering Technology

MEMORANDUM

TO: Dr. William M. Marcy, Assoc. Prof. Systems DATE: January 10, 1979

SUBJECT: Team 5, Site Restoration Trade-Off Study

FROM: C. E. Teske CET

Broad elements of the project were taken in evaluating the restoration options. The options considered were: (1) contract removal; (2) sell to farmer; (3) sell material/equipment with removal; (4) abandon. Estimates were made for each option and summarized in the attached table. Positive values indicate a return while negative values would indicate an expenditure of money. It can be concluded from the table that option (3) would be the most economical alternative. If the University had direct use of some of the material or equipment, the study results could change.

Box 4360 / Lubbock, Texas 79409 / (806) 742-3538

Site Restoration
Solutions

| Element | 1 | 2 | 3 | 4 | Selection |
|---|---|---|---|---|---|
| Buildings | $ 0 | $ 0 | $ +20,000 | $ 0 | 3,1=2=4 |
| Roads & Parking Lot | - 2,500 | 0 | 0 | 0 | 2=3=4,1 |
| Fencing | - 2,000 | 0 | + 2,000 | 0 | 3,2=4,1 |
| Underground Piping, Wiring (Etc.) | -20,000 | + 1,000 | + 7,500 | 0 | 3,2,4,1 |
| Collectors | - 2,000 | + 1,000 | 0 | 0 | 2,3=4,1 |
| Piers | - 4,000 | + 1,000 | - 4,000 | 0 | 4,2,3=1 |
| Electrical Lighting Arestors | - 500 | 0 | 0 | 0 | 2=3=4,1 |

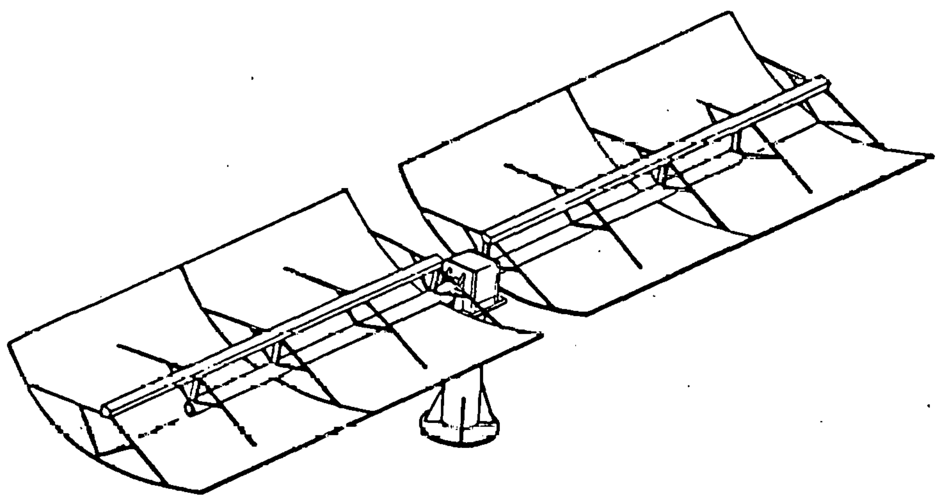
Solutions:

1. Contract Removal
2. Sell to Farmer
3. Sell Material/Equipment with Removal
4. Abandon

ENVIRONMENTAL ASSESSMENT

DESCRIPTION OF PROPOSED ACTION

The proposed action is DOE continued funding of the Trans-Pecos Photovoltaic Concentration (PVC) Experiment. Funding for Phase II of the project will allow design completion, material purchase, and construction of the proposed system, a 200 kw(e) solar Photovoltaic Concentrator operating in parallel with electric utility power to supply an existing deep well irrigation motor. The project site will be located 14 miles south of Pecos, Texas in Reeves County. The project will require the installation of 102 PVC modules each having two solar receivers 18 ft. long and 8 ft. wide. Each PVC module will be mounted on a single concrete pier. The units rotate and tilt to follow the sun. A cooling system provides temperature control of the photovoltaic solar cells. The figure below shows the appearance of one of the PVC modules.



Drawings PVC000001 and PVC000004 in the appendix show field layout and arrangement of major system components.

During Phase I of this project, the general design, economic and technical issues, and fabrication requirements relative to operation of this system have been investigated. Phase II will construct the facility. Phase III will provide for operation of the facility to collect technical and economic data, as well as maintainability and reliability data.

SITE LOCATION AND DESCRIPTION OF ENVIRONMENT

The proposed location of the Trans-Pecos PVC Experiment is shown in drawing PVC000000 included in the appendix. The site is approximately 14 miles south of the city of Pecos in Reeves County, Texas. The property is owned by Mr. Garvin G. Passmore and is located in the southwest part of Section 18, Block C-10. The site is a rectangle 830 feet east-west and 600 feet north-south being 11.43 acres. Adjacent to the site, on the south, is the existing well powered by a 200 hp AC induction motor that will utilize electricity produced by the Solar PVC system.

The site area has been under cultivation for several years. The surface soil is brown sandy clay about five feet thick. Below the surface layer small quantities of gravel are present. The surface layer contains about 85% material finer than a number 200 sieve. The general slope of the surface is west to east, but very flat. Immediately south of the site are several sections of land that remain in a natural state.

Previous farming activities have eliminated any natural vegetation on the site. The wildlife in the area consists primarily of small animals and birds, none use the site as habitat. Coyote, rabbit, field mice, crane, hawks, meadowlarks, and sparrows are all present in the area. The bald eagle is the only threatened species in the general area.

The site is located on the Stockton Plateau lying North of the Davis Mountains. The general elevation is 2,800 feet above mean sea level. The annual rainfall of 10 to 12 inches is not enough for profitable farming operations. Raising irrigated cotton and alfalfa was the staple farm operation until fuel cost for irrigation made such farming operations uneconomic. The mean temperature is 64°F with extremes of 112°F and -9°F. The ground water is plentiful, but deep. The well at the site currently pumps from a depth of 540 ft. Recharge of the wells occurs at a slow rate and has been observed since fuel cost reduced irrigation.

POTENTIAL ENVIRONMENTAL IMPACT

The operation of the Trans-Pecos PVC Experiment will not result in reflected solar energy outside the PVC modules. Access to the site will be controlled and a security fence will enclose the area. There are no residences closer than one-half mile from the site.

The cooling system circulates a water ethylene glycol solution through each of the PVC modules. The heat removed is dissipated into the atmosphere by a wet surface air cooler. The exhaust air under most extreme conditions will be 130°F, that being when ambient temperatures reach 100°F. This airflow is upward and will dissipate rapidly. Under normal conditions exhaust air remains within 20°F of ambient air.

The cooling system is designed as a closed loop. Automatic valving is incorporated to isolate parts of the system so that broken lines will release less than 500 gallons of cooling solution under worse conditions. The entire system can be drained into a fiberglass holding tank without loss of cooling solution.

Washing the reflector surfaces will be required at a time interval determined by operational considerations. The wash operation will be done with pure water and a detergent. The detergent will be a biodegradable type without phosphorus, such as "cut scum" by Fisher Scientific. Much of the wash water will be lost on the ground surface, but because of its nature should not degrade the ground water.

De-ionized water that will be required for some operations will be produced at the site. Residue from the de-ionization unit will be drained into an eight feet by twelve feet by three feet deep evaporating pond. The pond will be lined with a plastic sheet to prevent intrusion into the ground water. Accumulated solids will be transported away from the site and disposed of in an acceptable manner.

Disposal of effluent from the bathroom in the site facility will be by septic tank as is the accepted practice in the Trans-Pecos site area.

Air quality will not be changed by the construction of the project. Improvement of the road to the site will minimize dust during construction.

Construction will utilize local contractors to fabricate and install the solar modules. This will provide a limited increase in the local economy.

Some conversion of land from farm activity will occur. The site selected is not presently farmed due to high energy costs for irrigation. Much larger quantities of land will cease to be used as farm land unless lower energy costs for irrigation are found. The solar field should have no marked effect on animal or bird life in the area. There are no known archaeological or historical resources within the area.

## COORDINATION WITH STATE, LOCAL, AND REGIONAL PLANS

No long range plans for the site area have been formulated; however, agriculture and supportive use seems to be the only reasonable plan. Consultation with the Trans-Pecos Energy Commission, the State AffairsOffice of the Governor of Texas, and the Permian Basin Regional Planning Commission have been made and comment solicited. Either none, or positive comments have been received.

## ALTERNATIVES

The alternatives to the proposed action would be:

1. Build at another location
2. Delay construction

3. Abandon the project.

To abandon the project in light of current energy concerns and considering the benefits to be derived from the project seem illogical. This area has in the past and is capable of producing a large amount of food and fiber if a reasonable source of energy for irrigation can be found. Delaying construction would not change any environmental consequences and would only delay our understanding of the benefits of this research.

Other locations for the Trans-Pecos PVC experiment are viable possibilities; however, they would have similar environmental impacts. The site selected is on land set aside by the land owner for this application and is representative of sites suitable for installation of these systems.

ABSTRACT: STRUCTURAL TESTS

Structural and electrical performance of the solar system as a result of the solar support structure is examined. Strain gages and/or accelerometeres are used to measure the structural response of the collection support structure to the effects of steady state and gusting winds. The vertical column, horizontal structural arms and parabolic concentrator vibrations are correlated with wind velocity, vertical wind profile and resulting effect on system efficiency. The effect of wind vibration on the focal width on the photovoltaic strip are studied for cost savings. The vertical wind profile and resulting change in distribution as the collector field is traversed is examined. Vortex sheding is determined with anometers. Short pier stability testing is conducted on abandoned piers . Experiments of rotation and overturning resistance are compared to predicted values.

Objective: The structural experiments can be categorized into three broad areas. These are solar structural response to the environment, wind profile response to the collector field, and pier stability.

The support structure of a pair of collectors consists of a vertical column and a horizontal arm which rotates about the mid-point and vertically about its longitudinal axis. The structural response to environmental factors (rain, wind and snow) will be studied. Response factors will include stress or strain, vibration frequency and magnitude, and deflections. Correlation will be made between environmental factors and the resulting structural response and the resulting effect upon the efficiency of the system (collector) in producing power. Correlation would include effect of vertical, horizontal deformations of the horizontal arm and the dynamic response in its relation to fatigue failure. The effect of the environmental factors on the reflector (concentrator) will be studied independently and in conjunction with the vertical and horizontal structural support elements. A cost analysis will be made between structural response of the support structure and the cost of the photovoltaic material. That is, an optimum structure design will be found which minimizes structure cost and cost of the photovoltaic cells.

The wind profile before, mid-point and after the collector field will be studied to determine the change and redistribution of wind velocity and direction. Included would be the particulate distribution with the wind profile.

Pier tests will be examined for resistance to rotation about their vertical verticle axis and overturning resistance. Test results will be used to verify or develop methods of predicting their response.

General Approach: The general approach will be to record the structural response to the environment during the Winter and Spring when winds are usually the greatest in velocity and change. Strain gages, accelerometers and/or geophones will be used to record the strains, vibration ~~amplitude~~ amplitude and frequency. Gages will be placed at $90^{o}$ to each other on the vertical support column at two locations, at or near the base where it is attached to the pier and at the top of the column near the connection to the horizontal arms. Similar gages will be attached on orthogonal axes on the horizontal arm near to the connection to the vertical column, mid-length of one arm, and at the end of the arm. The concentrator panel vibration, frequency , and total deflections of the outer edge and quarter points of the curved surface will be recorded. The results will be correlated to structure stress, fatigue failure, and distribution of the focal plane.

Anometers at one foot intervals on a vertical structure will record the wind profile. Profiles will be recorded at three locations, one 25 feet to the south of the collector field, one in the center of the collector field, and the third 25 feet to the north of the collector field. Collection of particulate matter, dust and debris, would be accomplished on the vertical structures with the anometers. Provisions would also be made to record the abrasion profile from the particulate matter.

Little experimental data exists on pier stability. Abandoned piers would be used to perform rotation and overturning failure tests. Rotation tests would be accomplished by attaching a lever arm to the pier and recording the force ( twisting moment) required to cause failure. Similarly, a lever arm extending vertically would be pulled to determine the failure overturning moment. Other piers that have been connected could serve as anchorage for the pulling operations.

TIMING:

The structure response testing and wind profile, dust and abrasion testing should be conducted during the winter - fall season for an approximate 4 month season. Data collection should start on 15 January 1981 and continue through 15 May 1981. The pier stability tests would be performed when the solar ~~pier stability tests would be performed when the~~ collectors and support structures are removed. At that time, approximately 2 weeks would be necessary to complete tests.

BUDGET ESTIMATE:

Structure & Winds Experiments:

| | |
|---|---|
| Gages | $2,000 |
| Recorders (wiring) | 5,000 |
| Structures (3 each) | 4,000 |
| Installation | 25,000 |
| Personnel (½ time-6 months) | 11,000 |
| Grad. Student (½ time) | 4,000 |
| Clerical | 500 |
| | $51,500 |

Pier Tests

| | |
|---|---|
| Material | $ 1,000 |
| Performance test | 30,000 |
| Personnel (½time-4 months) | 6,000 |
| 2 Grad. Students | 8,000 |
| Clerical | 500 |
| | $45,500 |

# CHAPTER VI
# FINAL REPORT OF TASK TEAM-6
# DATA COLLECTION AND ANALYSIS

Submitted To:
Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:
Dr. Donald L. Gustafson
Department of Electrical Engineering
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER VI

## FINAL REPORT TEAM 6

## DATA COLLECTION AND ANALYSIS

Enclosure 1: Data Collection Requirements
Enclosure 2: Data Collection Specifications

Team 6, the data collection and analysis team, split its efforts between determining data acquisition requirements and specifying a system to meet the requirements on a 75-25% basis.

The data acquisition requirements were determined through the integrating of the Department of Energy requirements and those specified "in house" by the other teams. These data collection requirements are spelled out in Enclosure 1 which was transmitted in September, 1978 to Sandia Laboratories.

These data requirements were analyzed as to type of sensor, data sampling rate, and conversion accuracy required. Information from Honeywell, Inc. as to their sensor deployment for system control was obtained to eliminate unnecessary duplication yet assure the separation of costs for realistic economic analysis.

Once the data requirements were determined, the system to acquire the data was designed. Since the Department of Energy is to furnish the data scanning and recording equipment, the system design concentrated on transducer type, cost, signal conditioning, and signal transmission to the trailer housing the data collection equipment. The consolidated data collection and instrumentation specifications are included as Enclosure 2.

A decision was reached to instrument a set of three of our concentrators closest to the instrumentation trailer. This will minimize instrumentation cable lengths, required data signal conditions, and thus minimize costs yet be located such as to give typical values for the complete array.

The required inputs were determined for the system fabrication proposal and incorporated in that document.

III. Triplex structural Properties

A. Accelerometer

Piezotronics 308A $195.

B. Strain gage

Transducer Inc. Model 42 $200.

IV. Heat Rejection System Properties

A/B. Field inlet/Field outlet temp.

Omega T-150F2-12-30455
Omega SH 1-14-T-12 $10.00
Omega NSA2 $20.00

C. Differential pressure drop

Serta Systems 239E $500
Output 0-5V

D. Fan power consumed

Ohio Semitronics VFC $225.00

V. Power Conditioning System

A. Inverter output volts

Ohio Semitronics VT4RV $148.60
Output 0 to 10V

B. Inverter output current

Ohio Semitronics CT600L $51.50
Ohio Semitronics CTA-112 $152.50
Output 4 to 20 MA

C. Inverter input current

Ohio Semitronics CTP-2 $51.50
Ohio Semitronics CTA-112 $152.00

D. Inverter input volt

Ohio Semitronics VT1018 $463.00
Output 0 to 10V

ENCLOSURE-1



Texas Tech University
BOX 4200 / LUBBOCK, TEXAS 79409 / (806) 742-3579
DEPARTMENT OF SYSTEMS

September 29, 1978

Mr. Ron Hayenga
Division 2532
Sandia Laboratories
Albuquerque, New Mexico 87185

Dear Mr. Hayenga:

Attached are our first estimates of data collection requirements for the Trans-Pecos Photovoltaic Concentrating Experiment (DOE contract #ET-78-C-04-4269) with Texas Tech as prime contractor.

The requirements are broken down by subsystems. A triplex is a set of three of our concentrators that operate in series thermally and electrically. One system triplex will be fully instrumented for experiments as shown in the attachment.

Some additional weather data has been included that we feel may need to be sampled more frequently than DOE may require in general.

The transducer signal levels are typically in the millivoltrange (mV) range. Sample rates are in the range 1/day to 50/sec. Some data will be collected sporadically, i.e., only while an experiment is in progress. The minimum number of continuous experimental channels is approximately 45. The number of sporadic experimental channels is 27. Obviously not all sporadic data collection will occur simultaneously. However, we estimate that 72 channels would be needed just to carry out basic experiments. Considering the field as a whole, the total number of discrete data inputs could easily be double this figure. Based on our early estimate we would like to have 150 channels available for data collection.

We will be refining our data collection methods to reduce redundancy and simplify signal conditioning. If we can be of any further assistance at this juncture, please call either Dr. Don Gustafson (806-742-3530) or myself, Dr. William M. Marcy (806-742-3578).

Respectfully yours,

William M. Marcy

William M. Marcy
Project Director

Experimental Data Requirements
for Trans-Pecos Concentrating
Photovoltaic Experiment DOE

Contract ET-78-C-04-4269

| Data Requirement | Transducer Signal | Number of Channels | Maximum Sample Rate | C=Data Taken Continuously During Operation S=Sporadic Data Collection |
|---|---|---|---|---|
| I. Triplex Thermal Properties | | | | |
| A. Cell temperatures | thermocouple | 6 | 1/sec. | C |
| B. Inlet coolant temp. | thermocouple | 3 | 1/sec. | C |
| C. Outlet coolant temp. | thermocouple | 3 | 1/sec. | C |
| D. Differential pressure drop | mV range | 1 | 1/sec. | C |
| II. Triplex Electrical Prop. | | | | |
| A. Sample cell short circuit current | ma range | 3 | 1/15 min. | C |
| B. Cell string currents | amp range | 3 | 1/15 min. | C |
| C. Cell string volts. | 300 V range | 3 | 1/15 min. | C |
| D. Load power | KW range | 1 | 1/10 min. | C |
| E. Integrated energy | Kwhr range | 1 | 1/60 min. | C |
| F. Tracking motor currents | amp range | 2 | 1/60 min. | C |
| III. Triplex Structural Properties | | | | |
| A. Accelerometors | mV range | 6 | 50/sec. | S |
| B. Strain gages | mV range | 6 | 50/sec. | S |
| C. Geophones | mV range | 2 | 50/sec. | S |
| D. Extrusion channel corrosion | mV range | 1 | 1/week | S |
| IV. Heat Rejection System Properties | | | | |
| A. Field inlet temp. | thermocouple | 1 | 1/sec. | C |
| B. Field outlet temp. | thermocouple | 1 | 1/sec. | C |
| C. Differential pressure drop | mV range | 1 | 1/sec. | C |
| D. Fan power consumed | KWH | 1 | 1/day | C |
| E. Water chemistry | manual | - | ------ | - |
| F. Make-up water rates | manual | - | ------ | - |
| V. Power Conditioning System | | | | |
| A. Inverter output volt. | mV range | 1 | 1/sec. | C |
| B. Inverter output current | mV range | 1 | 1/sec. | C |

| | | | | | |
|---|---|---|---|---|---|
| | C. Inverter input current | mV range | 1 | 1/sec. | C |
| | D. Inverter input volt. | mV range | 1 | 1/sec. | C |
| | E. Kilowatts produced | mV range | 1 | 1/day | C |
| | F. Power level | mV range | 1 | 1/sec. | C |
| VI. | Cleaning System | | | | |
| | A. Water conductivity | mV range | 1 | 1/hr. | S |
| | B. Water pressure | mV range | 1 | 1/hr. | S |
| VII. | Irrigation System | | | | |
| | A. Flowrate | mV range | 1 | 1/10 min. | C |
| | B. Motor kilowatt hrs. | mV range | 1 | 1/day | C |
| | C. Motor power | mV range | 1 | 1/min. | C |
| VIII. | Additional Weather Measurements* | | | | |
| | A. Wind profile across field | mV range | 9 | 1/min. | S |
| | B. Hail pad | manual | - | ------ | - |
| | C. Direct normal insolation integrated hrly | mV range | 1 | 1/hr. | C |
| | D. Total insolation integrated hourly | mV range | 1 | 1/hr. | C |
| | E. Reference cell short circuit current | ma | 1 | 1/min. | S |
| | F. Barometric press | ±50 mV | 1 | 1/30 min. | C |
| | G. Dry bulb temp. | -40 to +120mV | 1 | 1/30 min. | C |
| | H. Wet bulb temp. | -40 to +120mV | 1 | 1/30 min. | C |
| | I. Precipitation | ------ | 1 | 1/hr. | C |
| | J. Storm detection by aviation stormscope | ------ | - | ------ | - |

Total Continuous Channels = 45
Total Sporadic Channels = 27

Maximum Requirements = 72 channels

* Signals depend on instruments, can be 0-1V, 1-5ma, 4-20ma, 10-50ma, or in BCD.

Team 6 Enclosure 2

I. Triplex Thermal Properties

A. Cell temperature

Omega SH 1-14-T-12 $10.00

B/C. Inlet Coolant/Outlet Coolant Temp.

Omega T-150F2-12-3045S
Omega SH 1-14-T-12 $10.00
Omega NSA2 $20.00

D. Differential pressure drop

Serta Systems 329E $500
Output 0-5V

II. Triplex Electrical Prop

A. Sample cell short circuit current
Ohio Semitronics CTP2 $51.50
Ohio Semitronics CTA112 $152.00

B. Cell string current

Ohio Semitronics CTP-2 $51.50
Ohio Semitronics CTA112 $152.00

C. Cell string voltage

Ohio Semitronics VT1018 $463.00
output 0-10V

D. Load power

Ohio Semitronics PC5-72 $261.80
output 0 to 100 MV

E. Integrated energy

Ohio Semitronics VFL-2 $225.00

F. Tracking motor current

Ohio Semitronics CTP-1 $51.50
Ohio Semitronics CTA112 $152.00

E. Kilowatts produced

Ohio Semitronics PC5-72 $261.80

F. Power level

Ohio Semitronics VFC-2 $255.00

VI. Cleaning System

A. Water pressure

Bourns 2900 series $200

VII. Irrigation System

A. Flowrate

Fisher Porter $1000

B. Motor kilowatt hrs

Ohio Semitronics VFC-2 $225.00

C. Motor power

Ohio Semitronics PC5-72 $261.80
Output 0 - 100MV

# CHAPTER VII
# FINAL REPORT OF TASK TEAM-7
# TECHNOLOGY ASSESSMENT

Submitted To:
Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:
Dr. Richard A. Dudek
Col. Jack D. Denardo
Mr. Abraham Siedman
Department of Industrial Engineering
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

# CHAPTER VII

## FINAL REPORT OF TASK TEAM-7 : TECHNOLOGY ASSESSMENT

### 1. Purpose

In recent years it has become clear that any technological change may lead to non-technical societal consequences favorable or unfavorable. It seems that the best social solution to this problem is the guidance of change, a constant effort to assume that the indirect implications are recognized early and considered by the proper decision making process and the parties affected.

These types of considerations have given rise to the concept of Technology Assessment - a class of studies intended to anticipate and explore the potential consequences of introducing a new technology, not only on the direct participants but in terms of the fall range of parties that may become involved. Therefore, one may anticipate that this type of assessment not only provides inputs to current political decisions but also indicates conditions and actions that need to be monitored so that society will receive early warning and can take appropriate action if future negative effects appear eminent.

This report is concerned with the preliminary assessment of the non-technical consequences and issues involved with deploying PV-C systems for deep-well irrigation in arid lands.

This report will not provide a totally comprehensive treatment of these consequences but rather presents preliminary recognition concerning the potential directions for further studies.

The following projections were made in this study regarding the PV-C irrigation system:

1. System's output....150-200 KWe.
2. Economical life time....20 years.
3. The system will be economically viable when compared with most conventional (alternate) power sources over a 20 year time period.
4. The system will be owned by the individual farmer.

## 2. Method

The principal procedure used during this study was a modified "Delphi Method" developed for this study. The methodology is designed to obtain collective opinions from a group of experts through a series of structured interviews. This approach has been chosen in order to maintain the benefits of group interaction while minimizing most of the problems of committee action.

To establish the scope of the study, it was necessary to explore the areas most likely to be impacted. Therefore, the areas selected for preliminary evaluation were:

1. Agricultural/Economic impacts.
2. Other related technical considerations.

3. Institutional and social considerations.
4. Regulatory aspects.
5. Financial resources, impacts, and considerations.

The panel included a mix of three types of individuals:

a. Experts: Those who have an applicable specialty and relevant experience. This group included the majority of the PV-C project team leaders from Texas Tech University and Honeywell.
b. Affected Parties: Those individuals who represent potential affected parties relevant to our study. This group was comprised of farmers, bankers, and other members of the agribusiness community in the Trans-Pecos area.
c. Facilitators: Those who have the skills in clarifying, synthesizing, and stimulating alternative global (overall) views of the situation. This group included the Technology Assessment team of this project.

The assessment of non-technical consequences places particularly high demands on the ability of the analysts, their imagination and their diligence in pursuing possible chains of causation, interaction of social factors and identifying the range of affected parties. The structured interview of the modified "Delphi Method" was designed to help the analysts in these aspects. The questionnaire used during the structured interviews consisted of two primary sections:

1. Explanation of consequences: Each panelist was asked to estimate future chains of consequences that may be expected as a result of applying the PV-C systems for irrigation in the Trans-Pecos area. Along with each chain of consequences the relevant affected parties and major policy considerations were identified.
2. Future Scenario: Respondents were also asked to provide a narrative sketch of their view of the future within which they had made their projections. They were asked to consider the future aspects of the technical, social, economic, and political subsystems relevant to this study.

The individual interviews were systematically syntherized and the chains of future consequences were detailed and integrated. The synopsis of the major results of this study are listed below. The detailed chains of consequences along with potential affected parties are included as an appendix to this report.

## 3. Results

Some of the major issues used by the PV-C irrigation system are not necessarily unique or new, but in essence may be variants of present issued whose balance must be readjusted in light of the expected technological and social changes. They include possible issues as indicated by the following:

Who will own or control the PV-C systems that will be operated in the agricultural environment? Will they be operated by the individual farmer, or will operattion tend to move into the hands of the utilities or some other new service organization? If this happens, will the changes impact the viability, growth potential and sense of identity of the individual farmer?

Who will own of control the electricity distribution networks necessary to support the PV-C systems? Will access be unrestricted or limited? What requirements will be placed on those wishing to install these systems? Who will set technical standards for the utility interface, if required?

What kind of skills and levels of skill are required to service these systems? Will the small and the less educated farmers exclude themselves or be excluded from using the PV-C systems? Will they suffer thereby?

Will regulatory agencies be able to function effectively in the new environment, to assure judicious regulations of power buy-back and rate structures?

How will present relationships among regulators' power at the local, state and federal levels be altered? What would be the legal status of the individual energy producer?

Would the local financial community be willing and capable to finance these PV-C systems? What would constitute a proper collateral for the given credit? Will the energy producing farmers be eligible for special financial incentives? How will insurance systems be affected?

Will consumer (farmer) interests be protected as they relate to choice of PV-C method, availability of competitive systems to choose from, equity of changes for system service, legal protection with regard to product quality and similar matters?

What kind of social pressure may be placed on the community farmers as a result of their stand for or against the installation of such systems? Will farmers gradually be forced to install such systems rather than as a matter of privilege?

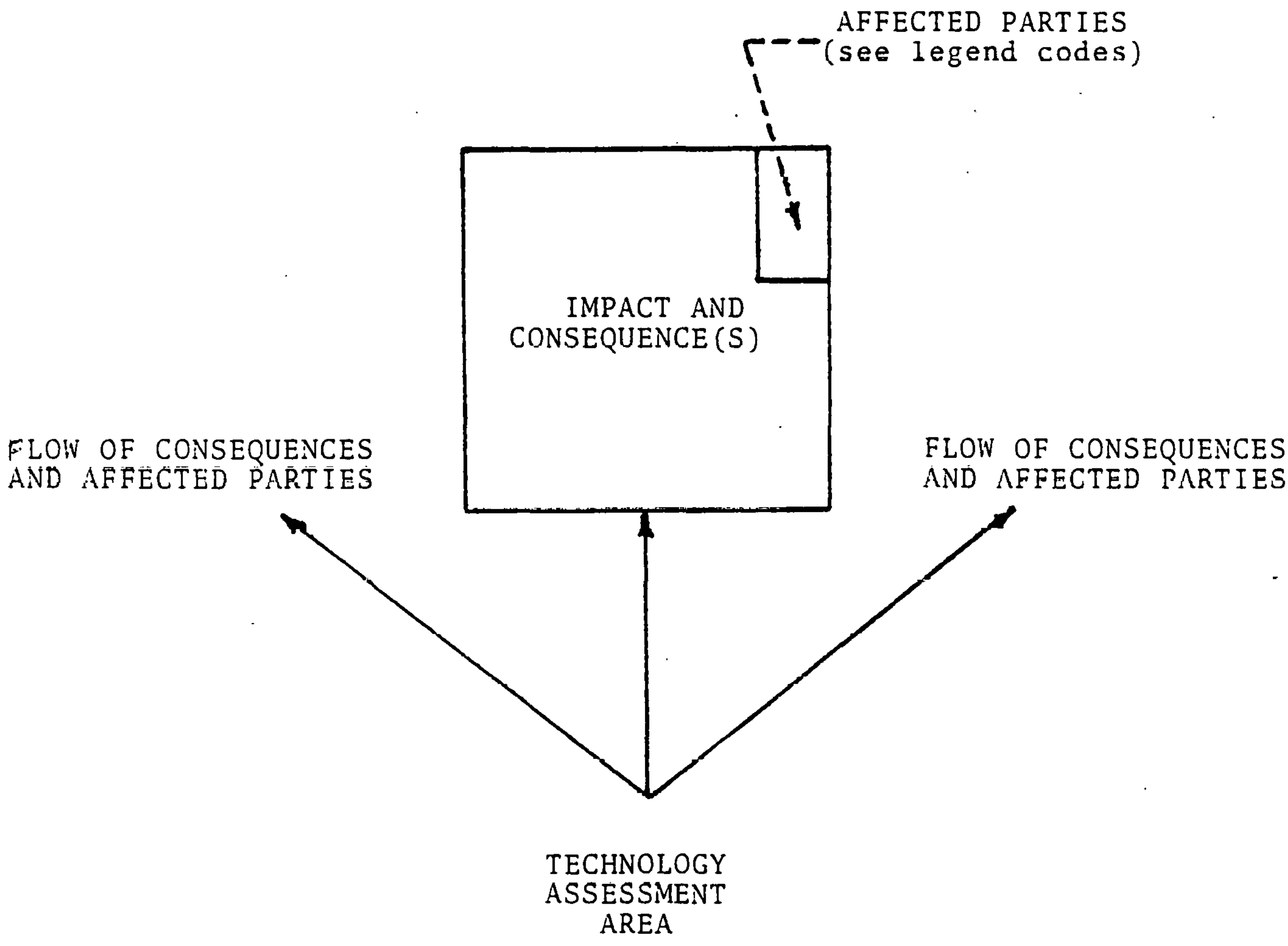
Will the PV-C systems require significant changes in farming practices? What kind of support programs would be necessary for the farmers during any transition period? Would more arid land go into production and how would this affect crop availability and prices?

What kind of restrictions will be placed on the agricultural activities in order to protect the PV-C systems? Will those restrictions result in both operational limitations and unfavorable economical impacts?

Can deployment of PV-C systems significantly change the load factors used by the local electricity utilities? What would be the consequential changes in utilities rate structures? Would those changes be accepted by all affected parties and the local community?

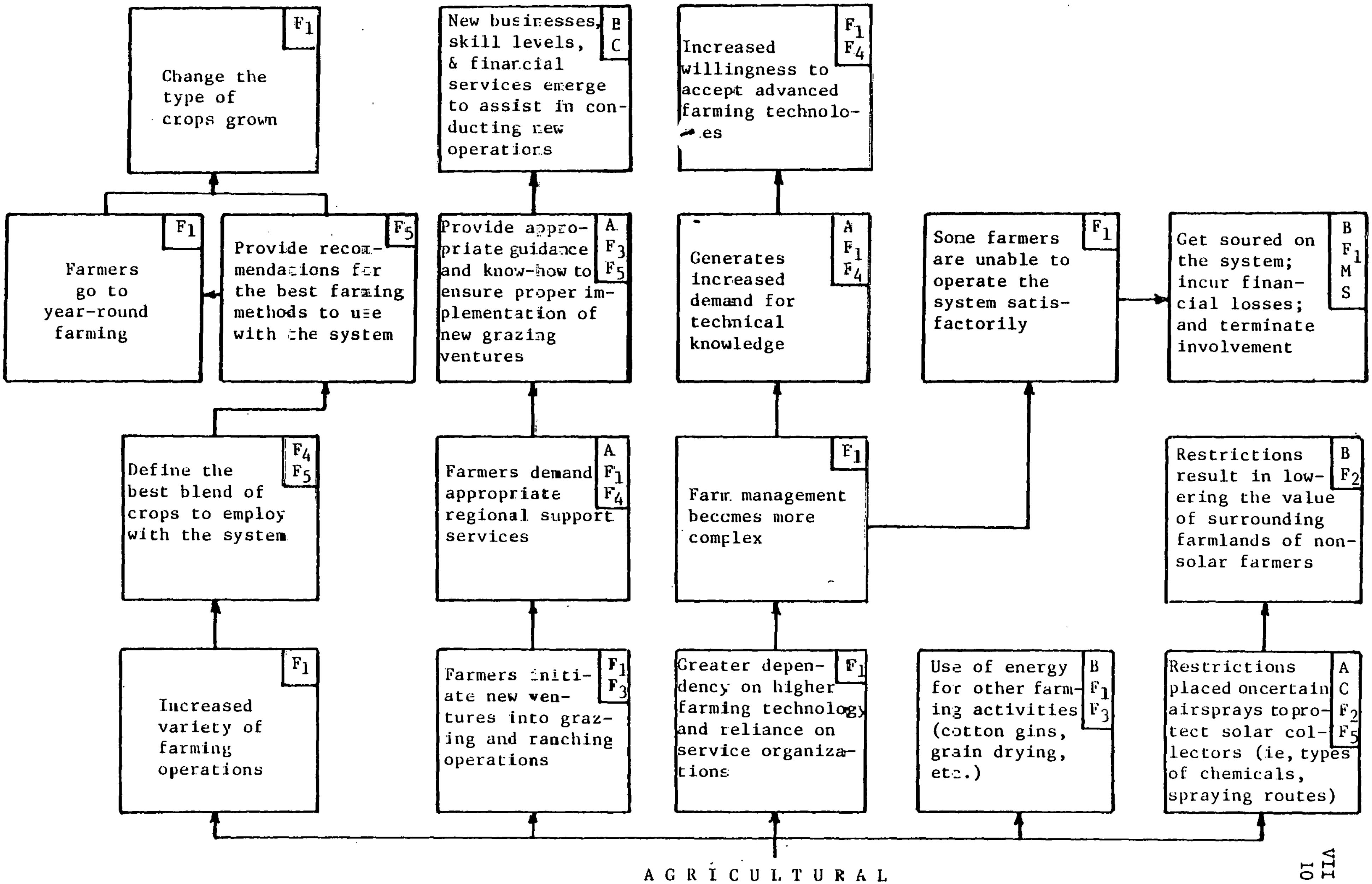
A single, integrated feature of the technology assessment model (see attached appendix) is represented in a final causal diagram of potential consequences resulting from the deployment of agriculture photovoltaic systems. The model is conveniently structured to address the most significant areas from both an internal and external system analysis perspective, and also in terms of specific periodic assessments (i.e., short range, intermediate, and long range) impacts and consequences.

# TECHNOLOGY ASSESSMENT MODEL (PRELIMINARY)

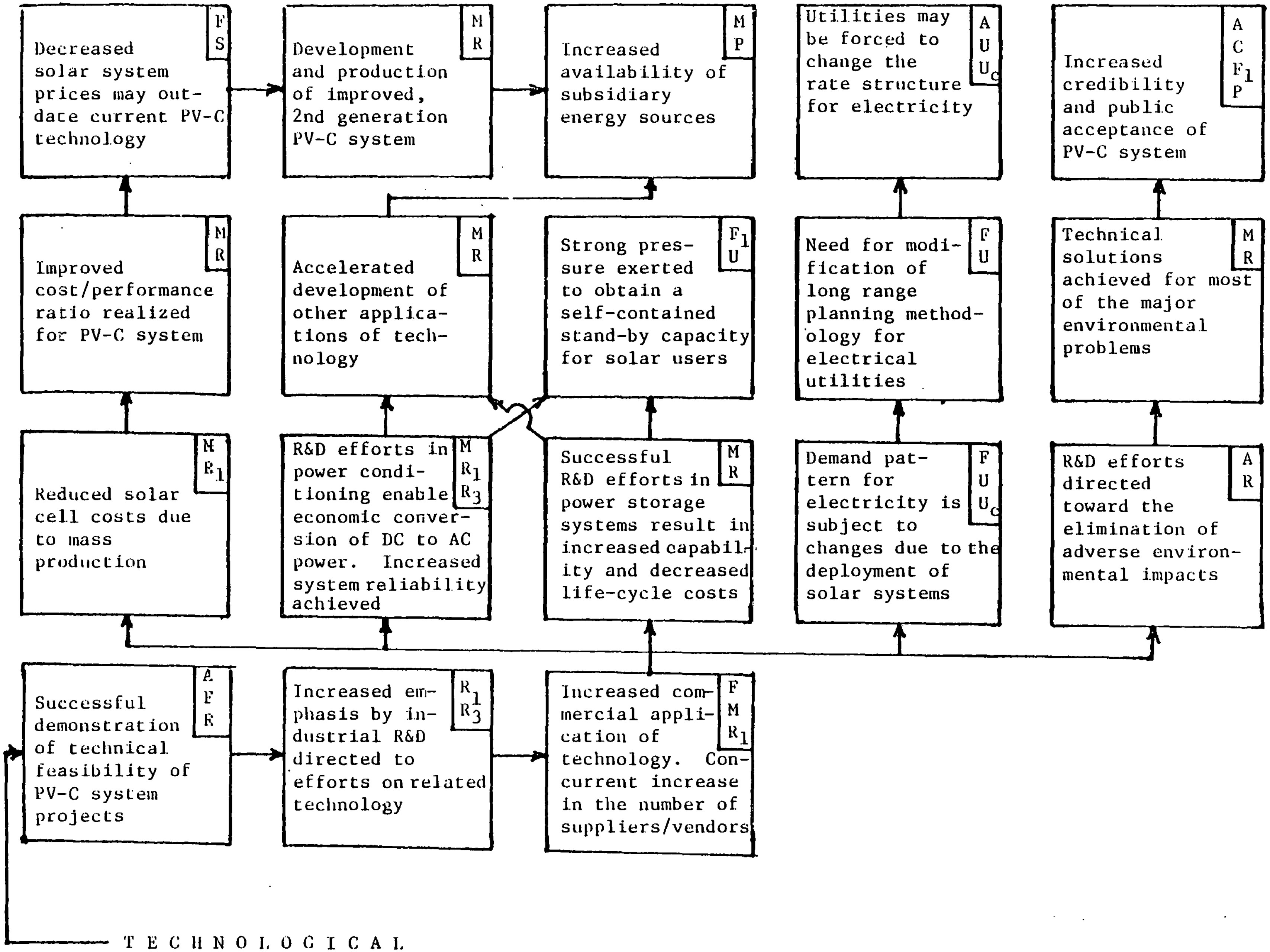


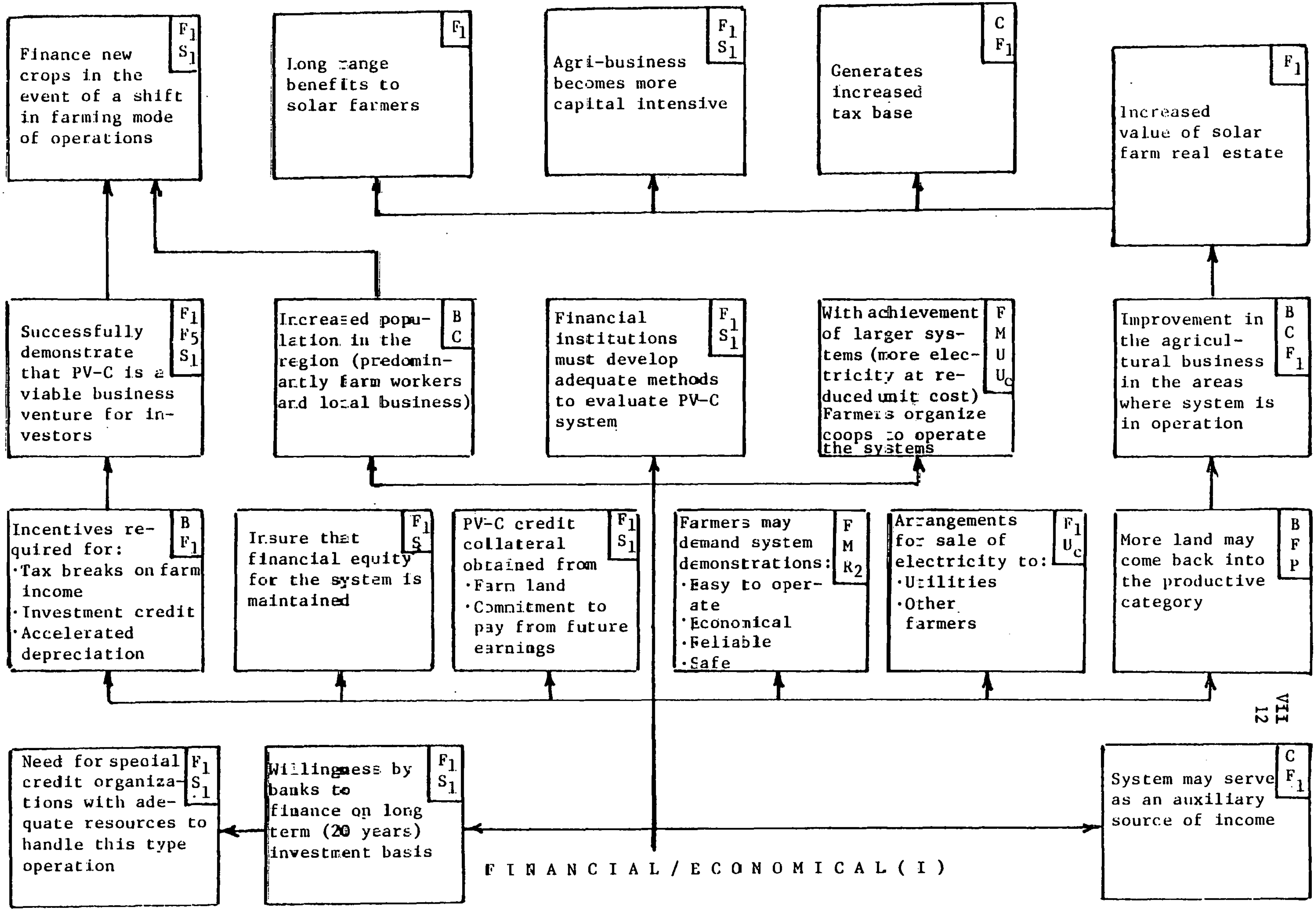
## AFFECTED PARTIES

| | | |
|---|---|---|
| A | Federal agencies | |
| B | Local business community | |
| C | Rural community | |
| F | Members of farming business | |
| | $F_1$ | Solar farmers |
| | $F_2$ | Other farmers |
| | $F_3$ | Manufacturers of farm implements |
| | $F_4$ | Farming institutions |
| | $F_5$ | Agricultural research institutions |
| L | Legal institutions | |
| M | Manufacturers/suppliers of solar system | |
| P | General public/society | |
| R | Research and Development (R&D) | |
| | $R_1$ | Industrial |
| | $R_2$ | Department of Energy |
| | $R_3$ | Research institutions |
| S | Financial institutions | |
| | $S_1$ | Bankers, savings & loan, credit unions |
| | $S_2$ | Insurance companies |
| U | Utilities | |
| $U_c$ | Utilities Commission | |

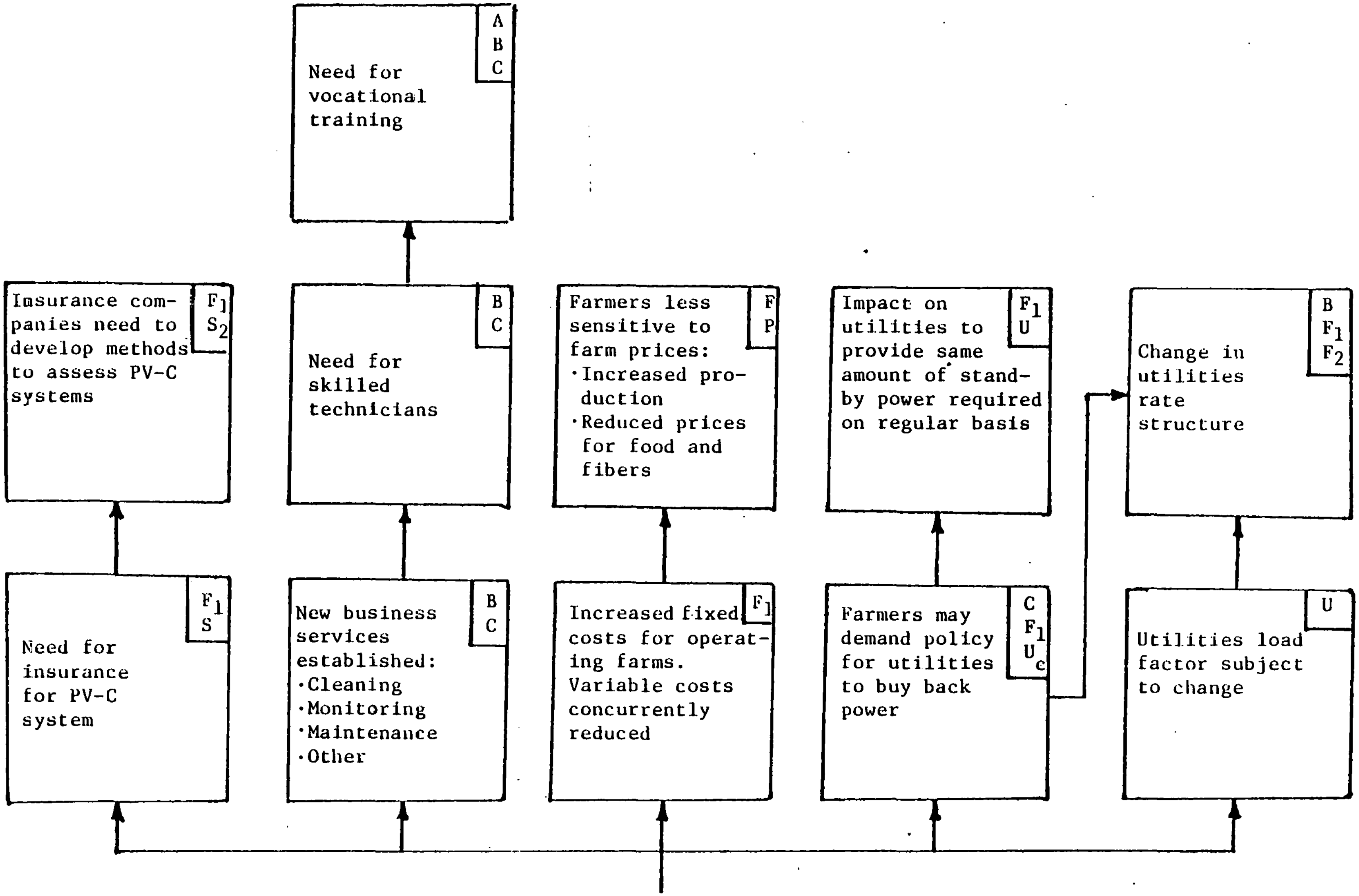


Change the type of crops grown
F1
Farmers go to year-round farming
F1
Provide recommendations for the best farming methods to use with the system
F5
Define the best blend of crops to employ with the system
F4 F5
Increased variety of farming operations
F1
New businesses, skill levels, & financial services emerge to assist in conducting new operations
B C
Provide appropriate guidance and know-how to ensure proper implementation of new grazing ventures
A F3 F5
Farmers demand appropriate regional support services
A F1 F4
Farmers initiate new ventures into grazing and ranching operations
F1 F3
Increased willingness to accept advanced farming technologies
F1 F4
Generates increased demand for technical knowledge
A F1 F4
Farm management becomes more complex
F1
Greater dependency on higher farming technology and reliance on service organizations
F1
Some farmers are unable to operate the system satisfactorily
F1
Use of energy for other farming activities (cotton gins, grain drying, etc.)
B F1 F3
Get soured on the system; incur financial losses; and terminate involvement
B F1 M S
Restrictions result in lowering the value of surrounding farmlands of non-solar farmers
B F2
Restrictions placed on certain airsprays to protect solar collectors (ie, types of chemicals, spraying routes)
A C F2 F5
AGRICULTURAL

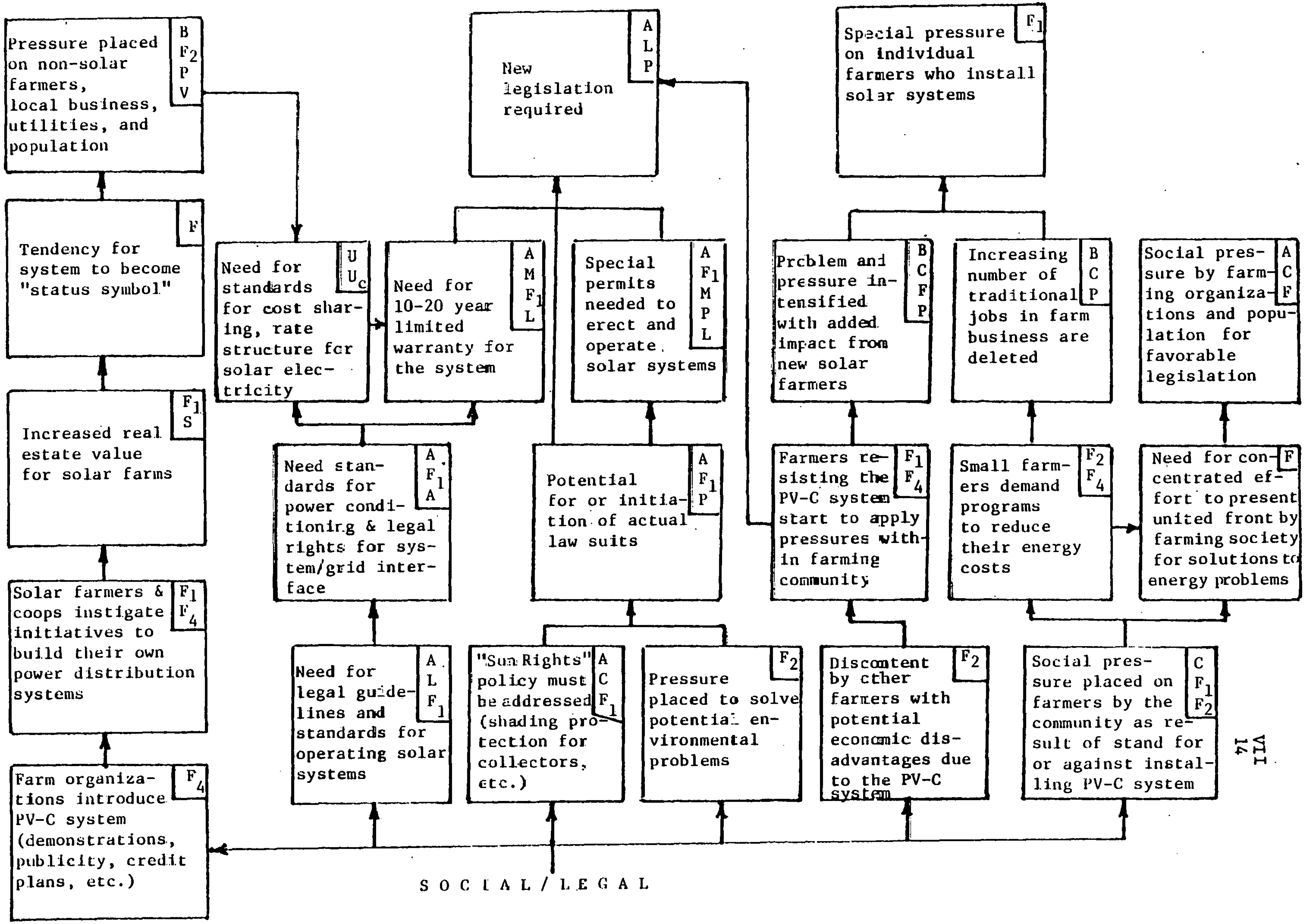

Decreased solar system prices may out-date current PV-C technology
F S
Development and production of improved, 2nd generation PV-C system
M R
Increased availability of subsidiary energy sources
M P
Utilities may be forced to change the rate structure for electricity
A U U_c
Increased credibility and public acceptance of PV-C system
A C F1 P
Improved cost/performance ratio realized for PV-C system
M R
Accelerated development of other applications of technology
M R
Strong pressure exerted to obtain a self-contained stand-by capacity for solar users
F1 U
Need for modification of long range planning methodology for electrical utilities
F U
Technical solutions achieved for most of the major environmental problems
M R
Reduced solar cell costs due to mass production
M R1
R&D efforts in power conditioning enable economic conversion of DC to AC power. Increased system reliability achieved
M R1 R3
Successful R&D efforts in power storage systems result in increased capability and decreased life-cycle costs
M R
Demand pattern for electricity is subject to changes due to the deployment of solar systems
F U U_c
R&D efforts directed toward the elimination of adverse environmental impacts
A R
Successful demonstration of technical feasibility of PV-C system projects
A F R
Increased emphasis by industrial R&D directed to efforts on related technology
R1 R3
Increased commercial application of technology. Concurrent increase in the number of suppliers/vendors
F M R1
TECHNOLOGICAL

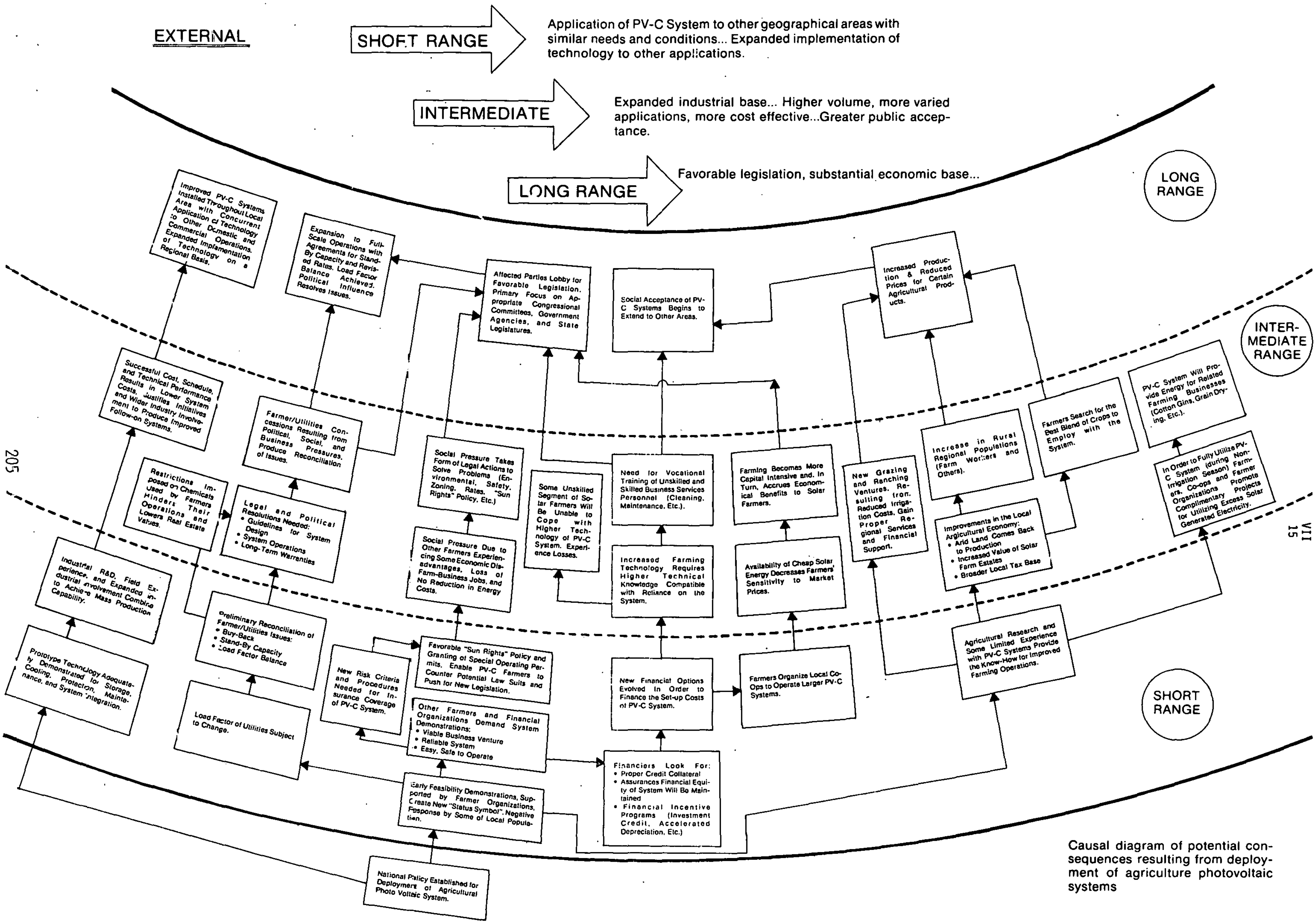



FINANCIAL/ECONOMICAL (I)




FINANCIAL/ECONOMICAL(II)


Pressure placed on non-solar farmers, local business, utilities, and population
B F2 P V
Tendency for system to become "status symbol"
F
Increased real estate value for solar farms
F1 S
Solar farmers & coops instigate initiatives to build their own power distribution systems
F1 F4
Farm organizations introduce PV-C system (demonstrations, publicity, credit plans, etc.)
F4
Need for standards for cost sharing, rate structure for solar electricity
U Uc
Need for 10-20 year limited warranty for the system
A M F1 L
Need standards for power conditioning & legal rights for system/grid interface
A F1 A
Need for legal guidelines and standards for operating solar systems
A L F1
New legislation required
A L P
Special permits needed to erect and operate solar systems
A F1 M P L
Potential for or initiation of actual law suits
A F1 P
"Sun Rights" policy must be addressed (shading protection for collectors, etc.)
A C F1
Pressure placed to solve potential environmental problems
F2
Special pressure on individual farmers who install solar systems
F1
Problem and pressure intensified with added impact from new solar farmers
B C F P
Increasing number of traditional jobs in farm business are deleted
B C P
Social pressure by farming organizations and population for favorable legislation
A C F
Farmers resisting the PV-C system start to apply pressures within farming community
F1 F4
Small farmers demand programs to reduce their energy costs
F2 F4
Need for concentrated effort to present united front by farming society for solutions to energy problems
F
Discontent by other farmers with potential economic disadvantages due to the PV-C system
F2
Social pressure placed on farmers by the community as result of stand for or against installing PV-C system
C F1 F2
SOCIAL/LEGAL




Causal diagram of potential consequences resulting from deployment of agriculture photovoltaic systems

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER VIII
# FINAL REPORT OF TASK TEAM-8
# SITE LOCATION AND ANALYSIS

**Submitted To:**

**Texas Tech University**
**Department of Systems**
**College of Engineering**
**Lubbock, Texas 79409**

**Prepared By:**


**Dr. M.L. Smith (Department of Industrial Engineering)**
**Dr. R.M. Bethea ( Department of Chemical Engineering)**
**Dr. F.P. Wagner ( Department of Engineering Technology)**
**College of Engineering**
**Texas Tech University**
**Lubbock, Texas 79409**


**28 February 1979**

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER VIII

## FINAL REPORT OF TASK TEAM-8 SITE LOCATION AND ANALYSIS

Equipment for measurement of solar insolation was purchased in June, 1978 and received in August. This equipment purchased included the following:

1. Eppley black and white pyranometer (8-48)
2. Eppley solar tracker (ST-1)
3. Campbell digital recorder (CR5) and four channel integrator (A104V)

An Eppley normal incidence pyrheliometer (NIP) was obtained on loan from the Department of Mechanical Engineering at Texas Tech.

This equipment was deployed in August, 1978 on the top of the Security State Bank building of Pecos. Mr. Jay Dycus was designated to see that the tracker was adjusted at the start of each day except for weekends. Data recorded include hourly integrated values of direct and total insolation. This data has been tabulated and will be available along with corresponding hourly observations on dry bulb and wet bulb temperatures, wind velocity and wind speed at Wink, Texas.

The needs for fencing and lighting at the site were studied. A seven foot chain link fence with vehicle and personnel gates was recommended. Lighting only for the site headquarters area was recommended.

Attempts to characterize hail occurrences at Pecos led to a qualitative description only. No hail pad data giving size distributions, frequencies or impact angles were available. Verbal descriptions of hail storms were obtained from several persons who lived in Pecos for many years. Their accounts generally indicated about two hailstorms occurred each year. Most hailstones were small, but some thunderstorms produced very large hail. Mr. Don Petty at the FAA Flight Service Station at Wink reported pea size hail fell in 1976, 1977 and 1978 but in 1975 hail the size of baseballs fell at the station

This and other reports indicate hail may be sufficiently large to damage solar collectors.

Samples of materials proposed to be used for the reflector in the photovoltaic module at Pecos were subjected to impact tests using ice balls. The 1" thick Hexcel with 3/8" honeycomb showed significant defocusing of the reflector were caused by impacts on the back side of the Hexcel; the missile was a 1 1/2" iceball at a velocity of 70 miles/hour. This indicated this reflector material was vulnerable to 1 1/2" hailstones since the wind-blown hailstone 1 1/2" in diameter may have velocities in excess of 70 miles/hour.

Other tests were performed with 3/8" thick Hexcel with 1/8" honeycomb; this material was more resistant to impact than that described previously; however the material selected was 3/8" thick Hexcel with 3/8" honeycomb. While samples of the material were not available for testing, it is very likely that hail impact damage will be severe for 1 1/2" hailstones.

Material for protecting the reflectors from hail impact were investigated. Styrofoam samples placed over the impact point provided little protection. Polyethylene foam supplied by Packaging Materials Company in Philadelphia (Mr. Vernick 215-355-0500) were tested with good results. The 2 $lb/ft^3$ density foam in 1 3/8" thick planks prevented any noticeable damage from

1 1/2" ice balls at 69 miles/hour, and very little defocusing occurred from 1.8" iceballs at velocities up to 92 miles/hour. These tests were performed on the 3/8" Hexcel.

A method for attaching the foam to the back side of the reflector was devised. This consists of plastic studs cemented to the surfact of the reflector backside; a washer and push on fastener will be placed on the stud over the foam.

The Trans Pecos Photovoltaic Project site is subject to drifting of agricultural herbicides and pesticides. In order to determine the possibility of damage through corrosion or staining of surfaces, a study was performed to identify the agricultural chemicals commonly used in the Trans Pecos region. The following chemicals currently are used:

Pesticides: Pyretheriods, Parathion, Lannate, Galecron, Fundal, Ambush, Pydrin, Azichen, Bolstar, Thuricide and ovicides such as Dipel.

Herbicides: Paraquat, arsenic acid

A categorization of pesticides was made since general formulations may include several brand names. The groups of pesticides are:

I. Synthetic Pyrethroids (Ambush, Pounce, Pydrin)

II. Carbamates (Lannate, Nudrin)

III. Organic Phosphates (Parathion, Galecron, Fundal, Bolstar, Monitor)

IV. Chlorinated Hydrocarbons (Toxaphene)

V. Bacterial Agents (Dipel, Thuricide, Arizidon)

Samples from each group were obtained for use in testing reflector material and cover glasses for resistance to the chemicals. The samples consisted of the following:

| Group | Chemical |
|---|---|
| I | Ambush |
| II | Nudrin |
| III | Monitor |
| IV | Toxaphene |
| V | Dipel |

Descriptions of applications, precautions and formulations of the common agricultural pesticides are given in the Form Chemicals Handbook.

Herbicides that may be used in the Trans Pecos area include Paraquat, arsenic acid, 24-D, Banvel and Dow General (DINOSEB). These also are described in the Farm Chemicals Handbook. Samples of Paraquat and arsenic acid were obtained for corrosion tests.

The types and quantities of dust particles in the atmosphere at the site are being determined through dust sampling studies. Two dust samplers were installed at the farm headquarters site in November, 1978 and were operated about 100 days for background dust levels; Mr. Garvin Passmore monitored the equipment and changed filters daily. During dust-storms the equipment will be operated to collect dust particles for analysis. This will extend through May, 1979.

Mr. Al Cates at the Maderea Valley Water Supply Company at Verhalen, Texas (915-375-2556) was contacted concerning a supply of water to the site. It appears feasible to extend an underground line from the farm headquarters to the site. Up to 2000 gallons/day should be available. Water quality during the summer is lower than during months of lower demands due to the wells used to meet high demands. Dissolved solids for the water are given in Table I.

Water prices are:

| | |
|---|---|
| 1st 2000 gallons/month | $8.00 |
| next 2000 gallons | $1.50/1000 gallons |
| next 3000 gallons | $ .90/1000 gallons |
| next 4000 gallons | $ .80/1000 gallons |
| next 7000 gallons | $ .70/1000 gallons |

Table I. Water Quality From Madereal Valley

| | mg/l. | |
|---|---|---|
| Solid | Summer Months | Other Months |
| Calcium | 118 | 41 |
| Magnesium | 40 | 4 |
| Sodium | 184 | 11 |
| Manganese | 7.05 | 7.05 |
| Iron | .11 | .02 |
| Bicarbonates | 235 | 212 |
| Sulfate | 277 | 18 |
| Chloride | 252 | 8 |
| Fluoride | .8 | .6 |
| Nitrate | .8 | .9 |
| Total | 1110 | 213 |
| Alkalinity | 193 | |
| Total Hardness | 460 | 217 |

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CHAPTER IX

FINAL REPORT OF TASK TEAM-9

SYSTEMS ANALYSIS

Submitted To:

Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:

Dr. J.R. Burns
Department of Systems
College of Engineering
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# Team 9
# Systems Analysis
# Final Report

## INTRODUCTION

Team 9 has spent all of its time working on Task III, Systems Analysis and Design Trade-Offs. Within this context the team has worked on the following subtasks.

1. Development, test, and documentation of a computer program to compute annualized costs for the concentrating photovoltaic system using the ERDA/JPL economic model.

2. Sensitivity studies of the ERDA/JPL economic model to determine whether annualized costs are most sensitive to capital or recurrent costs.

3. Simulation modeling studies to address many questions relating to cleaning frequencies, economies of scale, cell temperatures, etc.

Reports describing each of these initiatives are attached as appendices and summarized in this report.

The team completed the following action items.

1. Determine which economical model to use--JPL or EPRI (JPL or ERDA/JPL model was chosen).

2. Consider how to make future economic projections for use of this type of system.

## RESULTS

Detailed descriptions of the analyses and studies produced by Team 9 are provided in Appendices F., G., and H.. Summarizing statements about this material are provided here.

Appendix F. Appendix F describes the Solar-Economic Cost-Accounting Computer Program. The material provided in the appendix is intended to serve as a User's Manual and Documentation. The report describes how to use the computer program and provides supporting information about the program itself.

The cost account structure is described in detail and this is followed by a detailed description of that computer code generated to implement the cost account structure. Provided as well is a listing of the computer program and an associated numerical illustration. An example of how to set-up the input card data is provided and the outputs produced by the program are illustrated. The output produced is intended to conform to the Department of Energy's "Proposal Preparation and Evaluation, Phases II and III: Photovoltaic Concentrator Applications Experiments".

Appendix G. Appendix G describes studies of sensitivity performed on the ERDA/JPL Solar Economic Model [1]. Both analytical and computational sensitivity studies were performed upon the model itself. These were found to give good agreement, adding strength to the conclusions and findings of the studies.

These analyses demonstrate that, within cost categories, all cost items have the exact same sensitivity to annualized costs, provided the items are purchased in the same year. In order to study the sensitivity of the solar power system to different items within a cost category, it will be necessary to observe the change in the expected annual system energy output produced by a small perturbation in one of the items.

The analysis also demonstrates that the annualized cost is slightly more sensitive to capital investment expenditures than to equivalent recurrent costs (such as fuel, maintenance, and operations). This is true provided the nominal values used in the analysis are close to reality.

<u>Appendix H</u>. Appendix H describes a dynamical simulation model that was developed in an effort to simulate the system over short duration time periods. This dynamic model exhibits the dynamical consequences of pairs, triplets, and larger groups of causes. As it presently exists, the model is incomplete and uncalibrated. Even so it does illustrate insightful dynamical behavior. For example, excessively hot sunny days may produce lower kilowatt output because of the higher operating temperature of the cells. Kilowatt output therefore does not increase in direct proportion to solar insolation. Kilowatt output does vary in partial proportion to the reflectivity condition of the reflectors, and, as expected, more frequent cleaning does produce some growth in total accumulated kilowatt hours over a period of a year. It was also observed that more frequent cleaning enables instantaneous kilowatt output to be higher, but more smooth and continuous. Other behavioral observations are described in Appendix H .

# REFERENCES

1. The Cost of Energy from Utility-Owned Solar Electric Systems, Jet Propulsion Laboratory, California Institute of Technology, June 1976.

# CHAPTER X

# FINAL REPORT OF TASK TEAM-10

# IRRIGATION AND AGRICULTURE

Submitted To:
Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:
Dr. R.P. Kennedy
Mr. S.R. Gossett
College of Agriculture
Texas Tech University
Lubbock, Texas 79409

28 February 1979

X-i

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# CHAPTER X

## FINAL REPORT OF TASK TEAM-10 IRRIGATION AND AGRICULTURE

### INTRODUCTION

The Trans-Pecos area consists primarily of Reeves, Pecos, and Culberson Counties in Texas. Ward County and parts of Hudspeth County are sometimes included in agricultural reporting of crops produced and of acres irrigated. As recent as 1964 this area irrigated up to 284,000 acres whereas only 100,000 acres are estimated to be irrigated now. There have been two major contributing factors affecting the decline in irrgation in the Trans-Pecos area: A) The high level of soluble salts (about 4 tons per acre-foot) combined with varied water availability along the Pecos River; and B) the rapid rise in cost of production, expecially energy. Since the crop production in this area is totally dependent upon irrigation, the energy demands for pumping are a very big part of production costs.

The Trans-Pecos is an arid area of Texas where sunshine is plentiful and the growing season is long (210 days). This combination has created an interest in developing solar energy conversion systems in the area. Ideally, if energy could be obtained from the sun at a competitive price, then a large portion of the production costs could be maintained at a practical level. Because of it's energy source (the sun), the energy produced would not be expected to increase in price over time as would energy from conventional fossil sources. Such a source of energy, if priced right, could help to relieve the pressures of inflation on irrigation in this agriculture producing region. The main question to be answered then is, "Are there sufficient crops and other products to utilized the energy that could be produced on a year round basis?"

## OBJECTIVES

The overall objective to be addressed is the feasibility of utilizing energy from a Photovoltaic Concentrating (PVC) system on a year round basis for the irrigation of agricultural crops in the Trans-Pecos Region. These crops must have a need for the water that could be pumped as a result of the continual source of energy produced by the PVC.

More specific objectives are:

A) Identify a spectrum of crops suitable to the Trans-Pecos Region and specify their respective irrigation or moisture demands.

B) Develop economic evaluation of each crop selected in A.

C) Determine water availability from the three irrigation wells and the amount of electrical energy needed to pump that water.

D) Determine break-even product prices for the various crops produced in the Trans-Pecos Region, based on estimated costs of the PVC system, and related costs of the energy produced.

E) Coordinate the combined use of conventional and solar energy sources so as to guarantee a continual source of electricity for the irrigation wells.

## PROCEDURES

Budgets estimating costs and returns for typical management of upland cotton, wheat, alfalfa, barley, grain sorghum, Jose wheat grass, and forage sorghums were obtained from the Texas Agricultural Extension Service and modified as to price for inputs to reflect net returns to management. Cotton was divided into varing levels of irrigation and the small grain crops were allowed varied harvesting methods (i.e. mechanical, or animal). The budgets outline the irrigation practices typical in the Trans-Pecos Region, emphasizing the timing and quantity of irrigation water applied. These irrigation practices represent the typical practices of the farmers in the area and do not necessarily represent the most efficient or profitable levels. However, these are sound practices and worthy of consideration in this study. The various crops and their total costs of production, less irrigation costs, are given in Table 1. Table 1 also lists the irrigation water required for each crop considered.

The Texas Board of Water Engineers (Report 6019) tabulated the consumptive use of water by major crops in major land resource areas in Texas. From this report, the crops grown in the Trans-Pecos Region can be characterized as to their needs for water and when irrigation applications should be made. The amount of water to be applied to meet the plants' needs (consumptive use) will vary with the efficiency of irrigation distrubution systems, the soil structure, and the rate of evaporation from the soil. Dividing the given consumptive use by the overall efficiency of applying the water (system plus soil plus evaporation) determines the amount of water needed to be applied. Cotton, for example, will consume 5.7 inches of water during June. With an overall efficiency of 75% (75 percent of water pumped used by plants) over 7.5 inches of water would have to be pumped to meet the needs of the cotton for that period. Figure 1 graphically illustrates the consumptive needs of the four major crops grown in the Trans-Pecos Region.

Linear programming was utilized as a tool for allocating the limited

Table 1. The Total Cost of Producing One Acre of Various Crops in Trans-Pecos Region, Less Costs of Irrigation, and Acre Inches of Water Required for Each Crop. Product Prices Assumed for Crops Produced.

| Crop | Product Prices | Production Costs/Acre | Irrigation Acre/Inches |
|---|---|---|---|
| Upland Cotton PP+1 | $ .70/# | $ 223.30 | 15 |
| Upland Cotton PP+2 | .70/# | 268.25 | 20 |
| Upland Cotton PP+3 | .70/# | 307.99 | 25 |
| Upland Cotton PP+4 | .70/# | 330.69 | 30 |
| Grain Sorghum PP+2 | 3.50/cwt. | 171.01 | 20 |
| Sorghum for Silage | 17.00/T | 142.49 | 25 |
| Winter Wheat for Grain | 3.00/bu. | 208.43 | 20 |
| Winter Wheat for Grazing | 6.00/aum* | 187.93 | 25 |
| Spring Wheat for Grain | 3.00/bu. | 195.97 | 25 |
| Winter Barley | 2.50/bu. | 178.60 | 25 |
| Spring Barley | 2.50/bu. | 178.54 | 25 |
| Alfalfa | 60.00/T | 283.09 | 45 |
| Forage Sorghum for Grazing | 6.00/aum* | 142.49 | 30 |
| Jose Wheat Grass for Grazing | 6.00/aum* | 99.72 | 61 |

PP+ represents "Preplant irrigation plus" x numbers of post plant applications.

* aum = Animal Unit Month

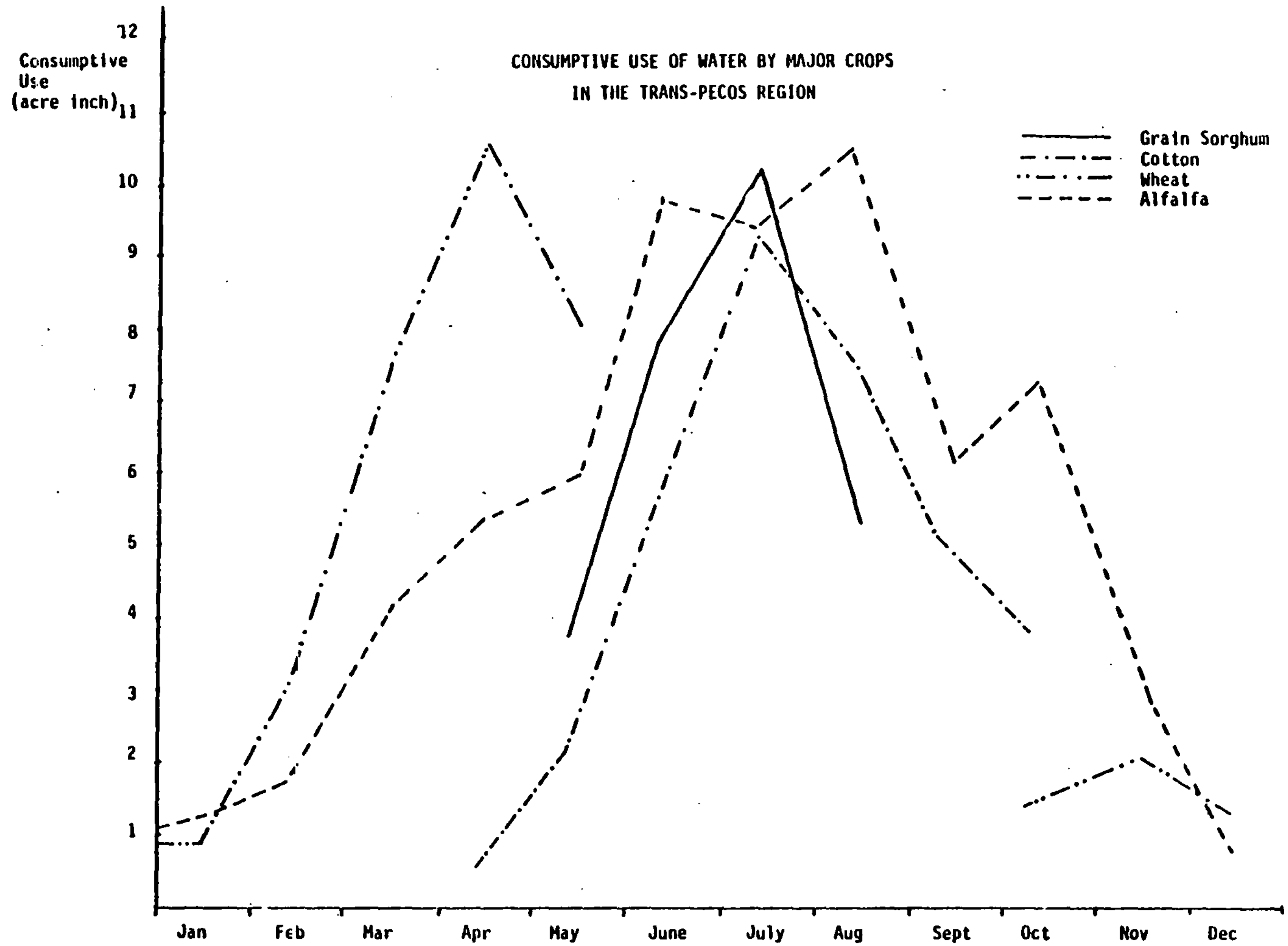

CONSUMPTIVE USE OF WATER BY MAJOR CROPS
IN THE TRANS-PECOS REGION
Consumptive Use (acre inch)
12
11
10
9
8
7
6
5
4
3
2
1
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Grain Sorghum
Cotton
Wheat
Alfalfa

Figure 1.

X
5

resources, primarily water, to the various crop alternatives competing for those resources. The various crop "activities" indicated their demand for water during six separate periods of the year. Each of these periods had a designated maximum amount of water that would be available. This maximum was calculated by multiplying the daily output of the well by the number of days in the period. The Passmore wells are capable of producing approximately 700 gallons per minute. On a 24 hour a day basis, assuming no down time, the well would produce 37.2 acre inches per day. Table 2 indicates the six periods chosen and the water limitations associated with each.

The 200 hp motor on the well requires 150 kw of power and is capable of pumping 1.547 acre inches per hour. In order to determine the cost of energy for the irrigation "activities", a series of energy transfer equations were set up to direct the electricity from its source (solar or conventional) to its final use (irrigation well). These transfer equations were set up to prevent the electricity produced in summer from being used in the winter or vice versa. The periods for energy production correspond to the same periods of the water output. Likewise, conventional energy is made available in the respective periods but at two different rates.

The two rates are a result of the utility company in Reeves County offering a split rate on electricity for summer and winter use. The current rates are \$ .02 per kwh during the months of September through March and \$ .028 per kwh for the months April through August. These rates were set in 1974 and are therefore subject to the fuel cost adjustment pass through which has increased some 39 percent since 1974. The current pass through is equal to approximately \$ .0103 per kwh and an increase of

Table 2. Irrigation Periods and Pumping Limitations Associated With Each.

| Irrigation Periods | Maximum Water Available (Acre/Inches) |
|---|---|
| December - January | 5619 |
| February - March | 5647 |
| April - May | 5528 |
| June - July | 5528 |
| August | 2809 |
| September - November | 8247 |

near fifteen percent is expected soon. The resultant electric rates expected in 1979 would be approximately \$ .03197 and \$ .04476 per kwh for winter and summer periods respectively.

The linear program was run at three levels of pricing for electricity. Two price levels were used for solar generated electricity \$ .01 and \$ .06 per kwh. Two price levels were also used for electricity from conventional sources for each of the seasonal variations mentioned above. Conventionally generated electricity was priced in the first two runs at the \$ .03197 and \$ .04476 per kwh for winter and summer respectively. Solar generated electricity was allowed to change from the \$ .01 per kwh in the first level to \$ .06 per kwh in the second and third levels. Conventionally supplied electricity increased in the third level to \$ .06 and \$ .084 per kwh in winter and summer respectively. (These prices are what could be expected in eight years with an 8% increase annually.) At that time, the winter rate would equal the projected cost per kwh for PVC generated electricity. It was expected that by raising the cost of energy only that the crops produced would not change dramatically but would decrease in acreage as profitability decreased.

## FINDINGS

The electricity rates used in the first level were; solar generated, \$ .01 per kwh; winter rate for conventional source, \$ .03196 per kwh, and summer rate for conventional source, \$ .04476 per kwh. At this level, 88.16% of total output of the PVC system was utilized. An additional 800,000 kwh was also purchased to supplement the 732,740 kwh supplied by the PVC. The purpose of setting the cost of solar energy low was to

Table 3. Crop Prices Necessary in Order to be Competitive With Silage and Alfalfa When Energy Costs are Low,* all Other Factors Held Constant.

| Crop | Necessary Price | Assumed Product Price |
|---|---|---|
| Cotton PP+1 | $ .7632/# | $ .50/# |
| Cotton PP+2 | .6945/# | .50/# |
| Cotton PP+3 | .6834/# | .50/# |
| Cotton PP+4 | .6730/# | .50/# |
| Grain Sorghum PP+2 | 9.75 /cwt. | 3.50/cwt. |
| Winter Wheat | 4.57 /bu. | 3.00/bu. |
| Spring Wheat | 4.13 /bu. | 3.00/bu. |
| Barley | 3.79 /bu. | 2.50/bu. |
| Silage | 17.00 /T | 17.00/T |

PP+ represents "Preplant irrigation plus" x numbers of post plant applications.

* Solar cost = $ .01/kwh, Winter conventional = $ .03197/kwh, Summer conventional = $ .04476.

identify what periods of the year would have the greatest demand for energy should that happen to be an inexpensive source. The result was that 100% of the energy produced by the PVC system would be utilized in 8 of the 12 months and not less than 55% in the remaining 4 months. Approximately 50% of the land was used (450 acres of 900) in the production of two crops; sorghum silage (238 acres); and alfalfa (218 acres). Sorghum silage utilizes water primarily in spring and summer. Alfalfa needs water throughout most of the year. The major limiting resources indiciated at this level was the availability of water in the April-May period. With all 5528 acre-inches being utilized, sensitivity analysis indicates that the availability of one additional acre of water would add $ 4.10 to net income.

Other crops that were considered yet not included in the solution are shown in Table 3. The product prices necessary for each of these crops to be a part of the solution are listed along with the crops. These are not break-even prices but prices necessary to compete with the crops in the solution.

The second pricing level was at current prices for commercial electricity and $ .06 per kwh for solar generated electricity. The purpose of pricing solar power at a higher rate than conventional sources was to determine the crops that could be produced as conditions now exist. The results indicate that 368 acres of sorghum for silage should be planted. This acreage was again limited by the supply of water in the April-May period (5528 acre inches). Again an additional acre inch of water available during that period would have added $ 4.10 to net income.

The prices for products and production costs were held constant

Table 4. Crop Prices Necessary in Order to be Competitive With Silage at Moderate Energy Costs,* all Other Factors Held Constant.

| Crop | Necessary Price | Assumed Price |
|---|---|---|
| Cotton PP+1 | $ .7632/# | $ .50/# |
| Cotton PP+2 | .6945/# | .50/# |
| Cotton PP+3 | .6644/# | .50/# |
| Cotton PP+4 | .6560/# | .50/# |
| Grain Sorghum PP+2 | 9.75 /cwt. | 3.50/cwt. |
| Winter Wheat | 4.65 /bu. | 3.00/bu. |
| Spring Wheat | 4.13 /bu. | 3.00/bu. |
| Barley | 3.85 /bu. | 2.50/bu. |
| Silage | 17.00 /T | 17.00/T |

PP+ represents "Preplant irrigation plus" x numbers of post plant applications.

* Solar cost = $ .06/kwh, Winter Conventional = $ .03197, Summer conventional = $ .084.

throughout each run in order to show the reaction to changes in cost of energy only. At today's energy costs as indicated in the second run, net return to management was only $ 61.62 per acre while low energy costs would net management $ 86.75 per acre. This represents a reduction of 29% per acre, but an overall reduction of 42.5% due to the reduced number of acres.

Likewise, in the third price level total acreage utilized, total profits, and profits per acre were substantially lower. Only 92.7 acres of land were planted, all to sorghum for silage production. A total net return to management of $2,279 was only $ 24.58 per acre. The total net return was down 94.2% from the total at low energy costs and down 90% from the mid-range energy costs. Per acre returns were down 72% and 60% respectively for the low and mid prices for energy.

The significant limitation for the third level was the availability of energy during the April and May irrigation period. For this period, 134,791 kwh are estimated to be produced by the PVC system. Since the cost of solar generated electricity was equal to the winter rate for conventional sources, and less than the summer rate, sorghum silage was still more profitable than a winter crop. Sensitivity analysis indicates that for each additional kwh made available during April or May net income would increase by $ .01691. This would probably hold true until such a level is reached where water would again be the limiting resource. To pump 5528 acre inches would require 536,005 kwh, or nearly 4 times the capacity of the PVC system.

Table 5 represents the prices necessary for all of the other crops to compete with sorghum silage when energy costs are high and all other

Table 5. Crop Prices Necessary in Order to Compete With Silage at High Energy Costs*, all Other Factors Held Constant.

| Crop | Necessary Price | Assumed Product Price |
|---|---|---|
| Cotton PP+1 | $ .7572/# | $ .50/# |
| Cotton PP+2 | .7037/# | .50/# |
| Cotton PP+3 | .6484/# | .50/# |
| Cotton PP+4 | .6521/# | .50/# |
| Grain Sorghum PP+2 | 9.50 /cwt. | 3.50/cwt. |
| Winter Wheat | 4.61 /bu. | 3.00/bu. |
| Spring Wheat | 4.16 /bu. | 3.00/bu. |
| Barley | 3.96 /bu. | 2.50/bu. |
| Silage | 17.00 /T | 17.00/T |

PP+ represents "Preplant irrigation plus" x numbers of post plant applications.

* Solar cost = $ .06/kwh, Winter conventional = $ .06/kwh, Summer conventional = $ .084.

variables were held constant. In comparing Tables 3, 4, and 5 one will notice the relatively stable price relationships. This can be explained because the production costs and product prices were not changed as energy costs were changed. The prices necessary for other crops to make the same profit as silage varied only slightly from one level of energy cost to another. Only the total cost of energy was allowed to change. However, had production costs also been increased at the 8% per year rate, then the prices necessary to compete with crops (or to break-even) would have increased accordingly.

It is interesting to note that although the necessary prices given in Tables 3, 4, and 5 are all higher than current markets, the price of wheat and cotton have reached such levels in recent years.

## SUMMARY and LIMITATIONS

Whether one crop is more profitable than another in any particular year should not be allowed to hide the fact that a wide variety of crops are adaptable to the Trans-Pecos Region. Sufficient crops can be grown to utilize the water made available as a result of the energy produced from the PVC system. Therefore, one should not conclude that only one crop, such as sorghum silage, will be grown in the area.

When an energy source can be provided which will maintain a relatively stable price, then will the farmer have a fighting chance to remain in business in the Trans-Pecos Region. As long as energy costs can be expected to be over 50% of the cost of production, and still rising, then the farmer certainly will continue to be a victim of the energy crisis.

With current technologies in irrigation pumping and distribution systems, total reliance upon the PVC system for electrical energy would appear limited in the Trans-Pecos area. The high salt and mineral content of the water make it highly abrasive. Each time the pump is shut off, these particles fall out of supspension and settle in the pump bowls, For a short period after starting the pump again, this concentration of abrasive particles damage the impellers at a faster rate than if the pump has been running for several hours. The starting and stopping action required by exclusive dependence upon the PVC system would thereby tend to wear the pump out faster than if the pump operated 24 hours a day. Of course, twenty-four hour pumping would require either storage for the PVC produced electricity or the purchase of commercially supplied electricity.

Another place where electricity is demanded at night is in the sprinkler distribution systems. Current research at the Pecos Experiment Station indicates that "salting problems" are significantly less severe as a result of using sprinkler irrigation at night. Logically, this is due to the lower rate of evaporation at night. Whether the irrigation system is a "water drive" or electric drive" makes little difference in the need for complimentary sources of electricity.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CHAPTER XI

FINAL REPORT OF TASK TEAM-11

SURVIVABILITY, SAFETY, AND MAINTENANCE

Submitted To:

Texas Tech University
Department of Systems
College of Engineering
Lubbock, Texas 79409

Prepared By:

Dr. William J. Kolarik
Department of Industrial Engineering
Texas Tech University
Lubbock, Texas 79409

28 February 1979

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# TEAM 11
# SURVIVABILITY, SAFETY, AND MAINTENANCE
by
William J. Kolarik

## FAILURE MODE AND HAZARD ANALYSIS

A failure mode and hazard analysis has been made for the Trans Pecos PV Experiment installation. This analysis consisted of developing a general fault tree analysis diagram. The diagram is shown in the Appendix to the Team 11 report, Section A. This type of information helps people visualize the many ways in which the system might fail, allowing designers to compensate for such possibilities in the design process.

Helping to assure good system performance, from design, installation, and operations standpoints, for the Trans Pecos System was a difficult task. Many informal design reviews of general concepts and assemblies were performed in project review sessions. Team 11, as well as other teams, helped to identify many problems. In most cases, problem solutions were forthcoming. This interteam interface was extremely valuable in developing better approaches to many aspects of system designs. Through this procedure the project design evolved in many respects. The evolution from a single cantilever mounted collector per pedestal to two opposed collectors per pedestal made a significant contribution in assuring system performance. This change allowed for a more symmetrical and stable collector design. It allowed for a simpler mechanized wash system. In addition, it allowed for a simpler system from a maintenance standpoint, less pedestals, gear boxes, linkages, motors, etc. Aspects of hail and lightning, as well as dirt, wind, moisture, and herbicide/pesticide damage were considered. Designers have now taken appropriate steps to protect the system from such hazards.

Team 11's primary efforts in assuring the survivability of the system were made in the design conceptualization stage by playing a critics role. However, drawings were reviewed when available. Efforts were concentrated on conceptually new subsystems such as the collector, cooling, and cleaning subsystems rather than on the more proven subsystems such as the irrigation, power processing, and utility grid subsystems.

In the end, a PV system has been designed which will be capable of surviving all but the most severe environmental acts. It was not economically feasibly to design and build a system that would be virtually indestructible. However, the Trans Pecos System has been designed to survive any relatively likely environmental condition in the Pecos region.

Care was taken throughout the design effort to design the system for good maintainability. Consideration was given as to the types of maintenance expertise available in the area and to the types of maintenance expertise which will have to be brought in periodically to support the system. Some of the most technical parts, such as the solar cell arrays and extrusion mountings, have been designed in a modular fashion so that they may be removed and replaced quickly. A thorough job of designing reliability and maintainability into the system was accomplished; however, during the operations phase, further improvements will develop.

## CLEANING SYSTEM

Designing a cleaning system for a relatively large photovoltaic installation, about .75 acres of reflective surfaces, is a difficult task. The major problem is that very little information exists on cleaning techniques and degradation characteristics for solar collector fields. Available information was obtained from Sandia Laboratories as well as equipment manufacturers. By reviewing available literature on the subject and discussing the problem with individuals who have some experience in cleaning reflective surfaces, primarily glass mirrored surfaces, Team II was able to address the cleaning problem.

The criteria by which cleaning systems must be judged are cleaning ability, cost effectiveness, and speed. Cleaning ability is very important. If residues and/or dirt are left on the surface, the reflectance recovered will be reduced. In the case of aluminized surfaces, as in the Trans Pecos installation, permanent degradation may result from water or detergent residues. Thus, very pure water and a detergent suitable for cleaning solar collectors is paramount.

Cleaning systems must also be cost effective if they are to be used in commercial solar installations. Cost effectiveness is a function of the surface degradation experienced in the area, the reflectivity recovered by cleaning, and the value of the electricity the installation is producing. In other words, the value of the amount of electricity gained by cleaning must more than offset the cleaning cost.

The speed at which a field of collectors can be cleaned is also important. If the field's reflectance is suddenly degraded by a storm or hit by reflective surface attacking chemicals, it is important to be able to clean the field quickly.

Team II conceptualized many different cleaning systems for the Trans Pecos installation. These cleaning systems were of three primary forms; manual, mechanized, and automatic. Manual systems are characterized by being labor intensive, but they require very little capital equipment. Automatic systems are characterized by high capital equipment costs and minimal labor requirements. Mechanized systems provide for a balance between labor and capital equipment requirements.

The cleaning system designed for the Trans Pecos installation was a one man, mechanized cleaning system compatible with cleaning experimentation. Other general forms of cleaning systems, along with their advantages and disadvantages, are described in the Team 11 report Appendix, Section B. The initial portion of the cleaning system designed consists of an automatic recharging water de-ionization unit which feeds into a 1500 gallon holding tank. This provides and maintains a source of pure water for washing operations. The Continental Water Laboratories in El Paso, Texas provided expertise and guidance on the necessary water purity and water treatment equipment needed to avoid water residue on the aluminized reflector surface.

A 1-ton, 4-wheel drive wash vehicle was selected to propel the spray wash equipment through the collector field. The spray wash equipment designed (mounted on the wash vehicle) consists of a 500 gallon holding tank and a high pressure (up to 2000 psi) pump capable of pumping DI water. The water will be divided into two streams; one for a detergent application and one for a rinse. A water-detergent mix will be applied to collector surfaces via a spray bar located toward the front of the wash vehicle. Detergent will be injected into the stream at or near the spray bar. Rinse water will be applied to the collectors by a spray bar at the rear of the spray vehicle, as the vehicle slowly makes its way through the collector field. Only small amounts (about 1 to 1-1/2 gallons) of a biodegradable detergent will be used per wash. The system will also be capable of nondetergent washes, using only DI water. For the entire field of 102 sets of collector pairs, about 2000 gallons of water will be required per wash. More detailed specifications for the cleaning system are shown in the Appendix to this team report, Section C.

The cleaning procedure will be to drive slowly along the side of a row of collectors which have been rotated so that they are facing into the vehicle spray bars. One pass will be sufficient to clean the reflective surfaces. Total cleaning time is estimated to be about five hours. At this time, it is very difficult to say how often cleaning will be necessary. Very little is known about the specific degradation that will be encountered in the Pecos area. This degradation will undoubtedly vary throughout the year. Sandia has monitored the degradation of glass mirrored surfaces in Albuquerque, New Mexico recently. This data shows that, in addition to environmental degradation, natural wash cycles (gentle rain and melting snow) occur which effectively clean the reflective surfaces.

Whereas the Sandia data might suggest a wash every month or so, the environment in the Pecos area is anticipated to be much more severe in the way of dust collection. In addition, very little in the way of natural cleaning cycles can be expected in the Pecos area. Based on present knowledge, a wash cycle of about a week to a month, on the average, is anticipated for the Trans Pecos installation.

Estimated costs per wash for the Trans Pecos installation were estimated for the cleaning system discussed above. These estimates, shown in Table 11-1, were made based on labor at $5 per hour, about $40,000 worth of wash equipment, detergent at $25 per gallon, and a 7% cost of money. From 3% to 10% of initial cost was allowed for maintenance, depending on the wash frequency, and a 20 year lifetime was assumed.

Table 11-2 shows estimated wash costs for an alternate system similar to the one previously described, but more labor intensive. This is still a one man system; however, the operator stops the vehicle at each collector pair and washes the collectors with a hand wand. The idea here is to trade off some of the capital equipment costs (by using a smaller motor and pump, etc.) for labor costs (hand wand operation).

Table 11-1
Estimated Cleaning Costs for Designed Cleaning System

| Item | Wash Frequency | | | | |
|---|---|---|---|---|---|
| | 2 washes/ wk | 1 wash/ wk | 1 wash/ 2 wks | 1 wash/ 3 wks | 1 wash/ 4 wks |
| Cleaning Equipment | 91.5 | 137.0 | 213.0 | 292.0 | 364.0 |
| Water & Water Processing Equipment | 30.0 | 39.0 | 54.0 | 70.0 | 85.0 |
| Detergent | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| Labor | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Total | $184.0 | $238.5 | $329.5 | $424.5 | $511.5 |

Table 11-2
Estimated Cleaning Costs for Alternate Cleaning System

| Item | Wash Frequency | | | | |
|---|---|---|---|---|---|
| | 2 washes/ wk | 1 wash/ wk | 1 wash/ 2 wks | 1 wash/ 3 wks | 1 wash/ 4 wks |
| Cleaning Equipment | 64.0 | 82.0 | 112.0 | 143.0 | 171.0 |
| Water & Water Processing Equipment | 30.0 | 39.0 | 54.0 | 70.0 | 85.0 |
| Detergent | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| Labor | 118.0 | 118.0 | 118.0 | 118.0 | 118.0 |
| Total | $249.5 | $276.5 | $321.5 | $368.5 | $411.5 |

Estimates shown in Table 11-2 were made based on labor at $5 per hour, about $13,000 worth of wash equipment, detergent at $25 per gallon, and a 7% cost of money. Again, from 3% to 10% per year of initial investment was allowed for maintenance and a 20 year lifetime was assumed.

For wash intervals in the range of one to two weeks there is very little difference in the estimated costs of the two wash systems. The system chosen is compatible with more frequent washings. It should also be noted that the system chosen (at the system cost used in the analysis) also contains many experimental provisions. These provisions will provide a means to experiment with hand wand washing, variable pressure, variable flow rates, etc.

The system selected will also serve as a test cleaning vehicle which could be applied to much larger collector fields. The wash system, as designed, could theoretically serve a collector field from five to ten times the size of the Trans Pecos field. Applied to such a large field, this wash system could become much more cost effective. It is quite conceivable that future solar fields will be much larger than the 200 kw Trans Pecos field.

For a total analysis of a cleaning scenario, the value of the additional electricity produced by cleaning must be weighed against the cost of cleaning. Using current power rates of about 4¢ per kwh, a high percentage of reflectance must be lost very rapidly to justify frequent cleaning. Utilizing a power rate at about the cost of current PV electivity (15¢ to 30¢ per kwh) washing could be justified with fairly small degradation losses. Calculations based on Sandia's Albuquerque, New Mexico degradation data, the cost of washing via the wash system designed for the Trans Pecos installation (Table 11-1), and electricity in the 30¢ per kwh range, indicate that wash intervals of one to three weeks can be justified (see the Appendix to this team report, Section D). For the Pecos area, the degradation will probably be somewhat greater than that shown in the analysis, but the cost per kwh will probably be somewhat less. So, on the average, a one to three week wash cycle is anticipated.

OPERATION AND EVALUATION PLAN

Operation and evaluation plans were developed by Team 11 with respect to reliability and maintainability experiments and analyses as well as reflective surface cleaning experiments and analyses. These plans are contingent on construction and operation of the installation. Both plans are documented in detail in the Team 11 report Appendix, Sections E and F. The reliability and maintainability plan consists of a series of reliability and maintainability analyses with the purpose of improving the Trans Pecos installation as well as providing information applicable to other similar systems. Data for these analyses will come primarily from normal system operations. Special reliability/maintainability experiments will be designed when necessary. Data will be collected in the form of operation/maintenance logs. These logs will be kept for the duration of system operations. Logs will be documented to the extent that data pertaining to any specific component can be extracted for analysis. Thus, analyses can be made on a system, subsystem, and/or component basis.

Most analyses will center on the photovoltaic collector subsystem, since this subsystem represents a state-of-the-art application of solar technology. The cleaning, cooling, instrumentation/control, and power processing subsystems will also be analyzed, since they too represent state-of-the-art applications. The utility, irrigation, power transmission, and emergency power subsystems are based on previously developed technology and applications. Reliability/maintainability studies of these subsystems will be made if the situation warrants them.

A sequence of cleaning experiments have been conceptualized to determine an optimal cleaning strategy for the reflective surfaces of the Trans Pecos Photovoltaic System. The primary means of cleaning will be a cleaning vehicle capable of washing the reflective surfaces via a mechanized (one man/spray bar) method, a hand wand method, or a combination of mechanized and hand wand methods. General performance specifications for this system have been set based on cleaning knowledge obtained from Sandia and various manufacturers. However, specific reflective surface degradation and specific cleaning techniques and strategies are not known at this time. The purpose of the cleaning experiments is to gain sufficient knowledge in areas of surface degradation at the site and specific techniques of recovering surface reflectance.

The desired cleaning strategy, in general, is to clean when necessary in an optimal manner. This suggests that a means must be established to determine specifically when to clean as well as specifically how to clean for a given level of degradation. Such a strategy can be developed through experimentation and analysis.

Cleaning optimization will be accomplished by developing a sequence of experiments. These experiments will concentrate on factors which are generally considered to be the most fundamental to the cleaning process. At the present time, the following factors are considered to affect the cleaning process: reflector degradation, cleaning cycle, pressure, cleaning agent, cleaning methods, flow volume/cleaning vehicle speed, and seasonal conditions. The response measured in these experiments will be the specular reflectance of the collector surface. After basic knowledge is gained pertaining to fundamental factors, experimentation will be initiated with respect to other recognized factors.

## SAFETY

Team 11 has investigated many aspects of safety with respect to the Trans Pecos installation. The objective of the safety effort was to assure a safe work environment for people working at the site as well as for visitors. The entire site will be enclosed in a cyclone fence to keep animals and intruders out. The perimeter will be clearly marked with signs warning people to keep out. Wording will be both in English and Spanish. All entrances will be posted as per safety regulations. Appropriate danger and warning signs have been specified for the installation (see the Team 11 report Appendix, Section G.). Danger and warning tags have been selected for use so that attempts will not be made to turn equipment on/off when harm may result to either people or equipment. In addition, fire extinguishers and smoke alarms have been specified for use in site buildings.

Equipment has been designed to recognized industry standards to help assure operating safety. In addition, the PV system will include various capabilities for manual overrides of automatically controlled system functions. Key interlocks have been designed into the various overrides, etc., where safety hazards might exist. All possible efforts have been made to locate potential safety hazards in the design stage so that they may be corrected in the design process. During the design review meetings, safety aspects were identified and possible solutions were discussed. Thus, all design teams have interacted, with respect to potential safety hazards, to assure a safe working place.

Operations at the site will not be covered by OSHA; however, OSHA regulations and guidelines have been followed. All signs and tags will conform to OSHA standards. Safety procedures and records will also conform to OSHA standards.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980—640-258/1721