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A 50 KW ON-SITE CONCENTRATING SOLAR PHOTOVOLTAIC POWER SYSTEM

Phase I — Design

Final Report, June 1, 1978—February 28, 1979

March 30, 1979

Work Performed Under Contract No. ET-78-C-04-4277

Westinghouse R&D Center
Pittsburgh, Pennsylvania

U.S. Department of Energy

Solar Energy

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A 50 KW ON-SITE CONCENTRATING SOLAR PHOTOVOLTAIC POWER SYSTEM
PHASE I - DESIGN

FINAL REPORT
for the Period 1 June, 1978 to 28 February, 1979

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UNDER CONTRACT ET-78-C-04-4277

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ABSTRACT

This contract is part of a three phase program to design, fabricate, and operate a solar photovoltaic electric power system with concentrating optics. The system will be located beside a Local Operating Headquarters of the Georgia Power Company in Atlanta, Georgia and will provide part of the power for the on-site load. Fresnel lens concentrators will be used in 2-axis tracking arrays to focus solar energy onto silicon solar cells producing a peak power output of 56 kW. The present contract covers Phase I which has as its objective the complete design of the system and necessary subsystems.

SUMMARY

A 50 kWp solar photovoltaic electric power system has been designed for installation at the Minola Road local operating headquarters of the Georgia Power Co. near Atlanta, GA. The system is of sufficient size to supply about 20% of the peak on-site load, the remainder being supplied by the utility grid.

The work done during Phase I has resulted in the detailed design of the solar photovoltaic electric power system. The solar arrays use linear Fresnel lenses, and together with air-cooled silicon Solar Cell Assemblies, form Lens/Cell Modules which are mounted on large, 2-axis tracking structures.

The array field comprises fifteen 2-axis tracking structures arranged in six rows. The centers of the arrays are located on an equilateral triangle grid 50 ft. on a side. Each array contains a steel frame matrix on which 48 Lens/Cell Modules are located. Each Lens/Cell Module involves two 16" x 32" linear Fresnel lenses which concentrate the sun's radiation on two linear arrays of air-cooled silicon solar cells. The geometric concentration ratio of the optical system is 50:1.

The arrays track the sun through an open loop control system which uses a minicomputer to calculate the sun's azimuth and elevation, and provides tracker drive commands to orient the planes of the lenses toward the sun. The minicomputer also performs the functions of system supervisory control and data logging.

The outputs of all fifteen arrays are combined on a single dc bus which connects to a 50 kWp power conditioner of the type developed for the Sandia Laboratories by Westinghouse under a separate contract specifically for use in solar photovoltaic electric power systems. The power conditioner provides maximum power tracking of array output, and yields

three phase, 60 Hz ac power of utility quality.

A major goal of the PRDA is to develop a collector subsystem design which can be produced at less than \$2/Wp (in 1975 dollars) in high volume production (>10 MWp/yr). The design developed is anticipated to have a high volume production material cost of \$1.38/Wp, using material unit cost values furnished by DOE. Using highly automated assembly techniques, the high volume production cost of the collector subassembly should then be well below the goal of \$2/Wp.

INTRODUCTION

The work done during this contract is part of the National Photovoltaic Program which is managed by the Department of Energy and has as its goal the development of photovoltaic conversion of solar energy as an economically viable energy source.

This contract was awarded as part of the PRDA 35 solicitation which defines a three-phase program for the development of concentrating solar photovoltaic electric power systems. Phase I of the PRDA 35 Program, which has just been completed, calls for the detailed design of a concentrating solar photovoltaic power system. Phase II calls for construction of the system, and Phase III calls for its operation over a two-year period together with its technical and economic evaluation.

The contract for Phase I covered the period from June 1, 1978 to February 28, 1979, and required the delivery of a technical proposal covering Phases II and III at the end of January, and delivery of a cost proposal for Phases II and III by the end of February.

The system proposed by Westinghouse incorporates a 2-axis tracking structure together with linear Fresnel lenses which concentrate the sun's radiation onto thin lines of solar cells. Westinghouse has for some time worked on 2-axis tracking structures for heliostat applications, and as a result, feels confident in proposing a system which employs them. In addition, Westinghouse has done considerable research on the silicon web crystal growth process for the production of solar cells. The linear array of solar cells, illuminated by a linear Fresnel lens in the system proposed, is compatible with the eventual use of cells made from web grown material. Westinghouse has also developed a power conditioning unit for the Sandia Laboratories which is ideally suited for use in the system proposed.

The detailed design of the system has been completed, and it appears that the DOE goal of \$2/Wp for the cost of the collector subsystem in high volume production is attainable.

1. CONCEPTUAL SYSTEM DESIGN AND ANALYSIS

1.1 Application

The solar photovoltaic energy system designed provides electrical power for part of the load of a local operating headquarters of the Georgia Power Company. Its output, which is a maximum of 50 kW, can be connected to deliver power to the local load when appropriate and/or to the utility grid if desired.

1.1.1 Rationale for Site Selection

The proposed site was selected giving due consideration to the purposes of the PRDA which are to provide technical, operational, and performance data for concentrating systems employed in on-site power generation applications, and to obtain information on all identifiable non-technical issues.

This specific site was chosen because it contains an on-site load of proper profile and size to allow a solar photovoltaic power system of reasonable size to be connected to it. The solar plant size of 50 kW_p enables it to supply about 20% of the site peak demand of 250 kW, making it a good compromise between being a dominant power source and one insignificantly small. In addition, a solar plant size of 50 kW_p seems reasonable considering the anticipated program funding relative to the number of systems to be built.

The selection of a utility-owned application minimizes interface problems which could occur if the application were separately owned. In such an experiment, the utility stands to gain important knowledge and experience of value to it in the future, but an independent owner of the application would stand to gain only slightly from reduced electrical costs while being subjected to considerable inconvenience and some capital expense. Also, utility ownership of the load eliminates

questions of ownership as well as operation and maintenance responsibilities when the experiment is concluded.

Because the utility owns the on-site load, experiments and worth analyses can be carried out to evaluate the plant either as one owned by the proprietor of a private business who provides some of his electrical energy himself and purchases the remainder from a utility, or it can be evaluated as a utility-owned power plant feeding the utility grid. The in-depth knowledge of rate structures by the utility simplifies such analyses.

1.1.2 Location

The facility is a Local Operating Headquarters of the Georgia Power Company located on Minola Road in Dekalb County, Georgia, approximately 13 miles east of Atlanta on Interstate Route I-20. The facility is complete and has been in operation for more than 5 years.

Figure 1.1.1 is an aerial photograph of the site. Access driveways adjoin Minola Road which is served by exit ramps from Interstate Route I-20. The access driveways lead to a parking lot adjoining the local operating headquarters building (Structure A), and the maintenance garage (Structure B) located to the west of the operating headquarters building. The array field location is readily visible to motorists passing by on Interstate Route I-20.

1.1.3 Site Activity

The site houses a local operating headquarters sometimes referred to as a service center. Its function is to provide all of the services necessary for the distribution of electric power within its area of responsibility. Approximately 50 people are assigned to the facility, including accounting personnel, meter reading personnel, distribution engineers, line crews, and supervisory and management personnel. It also includes a warehouse for necessary materials and supplies (transformers, poles, wire, etc.). A garage located on the site houses vehicle maintenance activities.

Figure 1.1.1 Aerial photograph of Minola Road Site

Because of the multi-use nature of the facility, its energy use pattern is representative of various commercial and light industrial loads, such as general warehousing and distribution centers.

The facility is open to the public (bill payment and information services, etc.) five days a week from 8:30 am to 5:00 pm. Emergency trouble crews are assigned on continuous basis. With adequate security, it can be open to the public at any time including weekends.

1.1.4 System Size Selection

The rationale for the choice of system size involves consideration of several factors. One of these is the peak power demand of the on-site load which is approximately 250 kW. The 50 kW peak power capability chosen for the solar photovoltaic system enables it to supply 20% of the peak on-site load which is a good compromise between having the solar energy system be the dominant power source and having it negligibly small. A second factor is the size of a suitable available power conditioner. The only power conditioner designed specifically for use in solar photovoltaic power systems is the one developed by Westinghouse for Sandia, and its peak power capability is 50 kW adding to the arguments for a 50 kW_p system. A third factor is anticipated availability of funds for Phases II and III of this PRDA.

The size of the system chosen is not optimized for this application in the same sense that residential power system sizes are optimized using incremental economic analysis techniques. Such an analysis is not appropriate for an early prototype system such as this which has as its principal objective the development of construction and operating experience with concentrating solar photovoltaic power systems whose costs are still too high to make possible economic viability.

1.1.5 Site Layout for Photovoltaic System

An artists concept of the solar array field is shown in Figure 1.1.2.

**50 KW
CONCENTRATING
PHOTOVOLTAIC SYSTEM**

Figure 1.1.2 Artist's concept drawing of Minola Road 50 kW solar photovoltaic power system array field

A detailed layout of the solar array field is shown in Figure 1.1.3. For reasons of safety, the array field is surrounded by a fence to keep out intruders and wildlife.

The array field includes fifteen two-axis tracking arrays laid out in rows as shown in the figure. The arrays are separated by a sufficient distance in both directions that the loss of power resulting from shading of one by another will be negligible. The best spacing between arrays was determined to be 50 ft. There are no trees or hills to the south of the proposed site of the array field which could cause shading, and sufficient property clearance to the south of the field is owned by the Georgia Power Company so that no new planting or construction will occur to cause shading in the future.

Controls for the entire solar photovoltaic power system are housed in the data building located at the southern boundary of the array field as shown in Figure 1.1.3. The data logging equipment is located there also. The building is large and offers convenient access to visitor parking areas.

1.2 System Block Diagram

The system configuration chosen for this application contains no electrical energy storage, and it includes arrays which are passively air cooled eliminating the need for a thermal energy system. The rationale which led to the choice of this type of system included the assumption that the principal purpose of this PRDA is to obtain experience with concentrating solar photovoltaic systems. With this goal in mind, considerations of the use of energy storage and active thermal energy systems were dismissed owing to the possibility that problems with them could detract from the original purpose of the program.

The overall block diagram of the system is shown in Figure 1.2.1. A description of each of the subsystems is contained in the following sections.

Fig. 763... 77

Figure 1.1.3 Layout of array field

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Figure 1.2.1 System configuration of 50 kW concentrating solar photovoltaic electric power system

1.2.1 Array Field

The array field includes 15 two-axis tracking arrays. Each array consists of a tracking structure and 48 Lens/Cell Modules. The tracking control electronics includes a central minicomputer that interfaces with a microprocessor in each tracking array, computes the elevation and azimuth angles of the sun, and aims each array toward it to within one milliradian accuracy.

Each Lens/Cell Module incorporates dual linear Fresnel lenses and silicon Solar Cell Modules supported by the Lens/Cell Module structure. The Solar Cell Assemblies consist of finned aluminum heat sinks on which 13 solar cells are fastened and connected in electrical series. The cells are covered by a Sunadex cover glass using an RTV adhesive. The array design affords field removal of modules for repair or replacement of either Solar Cell Assemblies or lenses.

The Fresnel lenses concentrate the incident solar energy onto the 0.32 in. x 32 in. strings of solar cells. The geometric concentration ratio is 50:1, but with lens and off-target losses, the integrated solar flux ratio is 40:1. The output of each Solar Cell Assembly nominal test conditions (1 kW/m^2 solar intensity, 28°C ambient air temperature and 7.8 mph wind) is about 40 watts. Thus, the nominal output of each tracking array, which contains 96 Solar Cell Assemblies (two Solar Cell Assemblies incorporated in each Lens/Cell Module) is 3.7 kW yielding a nominal peak array field output of 56 kW.

Each tracking array contains three parallel strings of Solar Cell Assemblies. The outputs of all arrays in the field are wired in parallel to a common dc bus in the data building.

1.2.2. Power Conditioner

The power conditioner chosen for use in this system is one developed especially for solar photovoltaic power systems by Westinghouse for the Sandia Laboratories, and therefore is ideally suited to this task. It converts varying dc power at the input to

regulated, 3 phase, 60 Hz power of utility quality at the output. Its peak power rating is 50 kW matching the peak power capability of the array field. Its full load efficiency is 91%, and the total harmonic distortion is less than 5%.

The power conditioner includes the inverter as well as all logic, control, and protection circuitry. The inverter employs a self-commutated power output stage providing the option of either line-synchronized or stand-alone operation. All sensing and logic circuitry necessary to maintain utility line synchronization and load sharing are included.

The VI characteristic of the array field has a form which implies that maximum power transfer can occur only if the inverter loads the array at the correct level. In addition, the array field VI characteristic will vary as ambient temperature and insolation vary. These factors dictate that the operating dc input voltage range of the power conditioner should be as wide as possible, and that the power conditioner should employ maximum power tracking. The power conditioner chosen meets both of these criteria. The input voltage range is from 200 V to 350 V, and maximum power tracking is included.

1.2.3 Utility System Protection

The solar photovoltaic energy system power conditioner includes input and output mechanical contactors controlled by the logic of the power conditioner itself. When an overcurrent or an over- or undervoltage condition is sensed by the power conditioner, it will open these contactors to protect itself.

When the solar photovoltaic system is supplying part of the on-site load together with the utility, a remote fault on the utility line may cause utility power to be disconnected at or near its source, while the power from the solar energy system causes the disconnected line to remain active. This condition could present a safety hazard to line repairmen.

To avoid this, the system is designed so that the on-site load at the Local Operating Headquarters is always in excess of 50 kW. Then, if the utility power source becomes disconnected, the power conditioner immediately becomes overloaded causing it to open its output contactor de-energizing the line. Included also in the utility protector are undervoltage and underfrequency relays which operate in the event that the power conditioner protection system malfunctions.

1.2.4 Instrumentation System

Not shown in the block diagram but an integral part of the system also is the instrumentation system. It comprises the following three parts.

1.2.4.1 Solar Photovoltaic System Instrumentation

The minicomputer used principally to track the arrays will have sufficient spare capacity that it can be used to log data as desired. Because it is programmable, it is quite flexible and its versatile data logging capability will be used to conduct experiments as part of Phase III.

1.2.4.2 Georgia Power Company Instrumentation

The type of metering commonly used for revenue purposes will be installed by the Georgia Power Company so that calculations of energy costs and worth analyses can be made in Phase III.

1.2.4.3 Government Furnished Instrumentation System

A data logging system furnished by the government will be included to log several hundred variables. This system can use some or all of the sensors or transducers in common with the first two systems, but its existence and operation will have no effect on the operation of the system.

1.3 Modes of Operation

The system has three basic modes of operation which are described in the following sections.

1.3.1 Supplying On-Site Load Together With Utility

This mode is the one to be used most of the time and is the normal mode of operation. The on-site load is supplied jointly by energy from the utility grid and energy from the solar energy system. The maximum power available from the solar energy system will always be utilized, and the remaining load supplied by the utility.

1.3.2 Supplying the Utility Grid

The on-site load will either be removed (or ignored) and all energy produced by the solar energy system will be considered to be delivered to the utility grid in the same way as power generated at a conventional utility generating plant. This mode of operation will be used to conduct experiments to provide data for various types of worth analyses.

1.3.3 Stand Alone Supplying On-Site Load

This mode of operation will be used only to conduct special experiments. In this mode, the utility connection is removed, and the entire on-site load is supplied by the solar energy system. To do this, the level of the on-site load must be reduced to the place where it is within the normal operating power level of the solar energy system. This restriction implies that this mode of operation would probably be used only on weekends or at certain special times of the year.

Because the system does not include battery storage, control of the system operating in the mode will be difficult, possibly requiring connection of a fixed load for voltage regulation.

1.4 System Performance Analysis and Simulation

1.4.1 Weather Data

Two sources were used to obtain weather data for the Atlanta area. Descriptions of these sources and the uses made of the data obtained are described in the following sections.

1.4.1.1 Local Measurements

Measurements of weather conditions have been made for many years at three local weather stations. These are: (1) The Atlanta Airport, (2) Griffin, GA, and (3) Auburn University. Although all stations have not recorded all variables continuously, considerable data are available for many years with respect to insolation, wind direction and velocity, temperatures, and precipitation.

Data from these sources were used to specify the design requirements for the 2-axis tracking structure which must survive a 100 mph wind in the stowed position, and must survive the static loading of 2" of ice. A summary of the high and low temperatures as well as average wind data taken from these sources is shown in Table 1.4.1.

1.4.1.2 Shenandoah Model Year

A weather tape providing hourly weather data was generated for the Atlanta area by Georgia Tech. This tape, called the "Shenandoah Model Year", provides one year of data by synthesizing a full year from twelve average months. Weather for a given month was chosen by examining weather for that month over a span of many years, and choosing an average or typical month which avoids weather extremes.

Insolation, temperature, and wind data were taken as needed directly from the tape for annual energy simulations. An interesting technique used to display this type of data is to present it as "Bin" data as shown for temperature in Table 1.4.2. Bins of temperature 5°F wide are defined, and for each month, the number of daylight hours the temperature fell into each bin are shown. This type of display shows both magnitudes of the extremes and their durations. Similar data for average wind speed are shown in Table 1.4.3. This data, derived from the Shenandoah Model Year tapes, correlates well with that obtained from local weather station observations summarized in Table 1.4.1.

Because the high concentration ratio optics employed makes negligible use of diffuse energy, only the direct insolation is of

TABLE 1.4.1

ATLANTA WEATHER

Summary of Data Taken at Atlanta Airport, GA, and Auburn University

TEMPERATURE

High - A temperature of 100°F (38°C) occurs in only one year in three.

The highest temperature ever recorded was 108°F (43°C).

Low - Sub-zero temperatures were recorded only 3 times.

The lowest temperature ever recorded was -9°F (-23°C).

WIND

July Average	7.8 mph
January Average	11.5 mph
Annual Average	9.6 mph

Table 1.4.2 - Bin Data for ambient temperature from the Shenandoah
model year

NOV. 20, 1978 * 10:52:30 AM * DATA

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA EXAMINATION

AMBIENT TEMPERATURE DISTRIBUTION

BIN (°F)

	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
JAN	0	0	0	0	0	0	0	0	0	2	3	29	38	28	48	78	47	22	15	0	1	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	4	8	21	18	32	22	24	23	40	43	41	18	0	0	0	0	0	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0	4	8	37	36	66	56	46	42	32	17	10	5	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0	0	0	0	4	19	25	28	39	63	88	51	42	14	6	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	14	15	66	64	80	87	67	23	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	47	73	83	104	80	2	14	0	0	0
JUL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	36	78	107	121	48	20	3	0	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	24	64	56	122	91	16	13	0	0	0
SEP	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	8	35	36	55	66	62	69	14	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0	0	0	0	2	12	17	45	52	63	47	45	34	2	7	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0	0	5	13	26	48	43	61	41	28	25	3	7	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0	0	4	9	36	25	51	34	25	60	55	4	4	5	0	0	0	0	0	0	0

TABLE 1.4.3

Bin data for average wind speed
From the Shenandoah Model Year

NOV. 20, 1978 * 11:36:33 AM * DATA

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA EXAMINATION

WIND SPEED					
BIN (MPH)					
	0-2.6	2.6-7.8	7.8-15.6	15.6-26.0	26.0-*****
JAN	8	67	97	125	13
FEB	1	95	99	96	3
MAR	0	56	176	120	5
APR	5	101	181	89	0
MAY	5	90	223	98	4
JUN	0	121	166	127	6
JUL	1	239	150	29	0
AUG	19	195	118	55	1
SEP	10	142	139	54	1
OCT	0	101	160	65	0
NOV	0	93	141	66	0
DEC	0	130	132	49	0

TABLE 1.4.4

MEAN DAILY INSOLATION FOR SHENANDOAH
SOLAR MODEL YEAR (kWh/M²)

<u>MONTH</u>	<u>GLOBAL</u>	<u>DIRECT</u>
January	2.34	2.92
February	3.46	4.19
March	4.48	4.55
April	5.69	5.05
May	6.30	5.28
June	6.21	4.88
July	6.12	5.05
August	5.72	4.86
September	4.93	4.64
October	4.04	5.00
November	3.20	4.76
December	<u>2.42</u>	<u>3.67</u>
Annual Average	4.58	4.57

interest for calculations of system annual energy performance. Mean daily insolation values by month taken from the Shenandoah Model Year tape are shown in Table 1.4.4. Although only the direct insolation is of interest, global insolation is included, and on an annual basis, it can be seen that the two are almost equal.

1.4.2 Load Data

The Minola Road local operating headquarters is an all-electric building which uses resistance heating during the winter and includes air conditioning for a portion of the building in the summer. The necessary convenience hot water is resistance heated. Table 1.4.5 presents a summary of the building and installed loads.

TABLE 1.4.5
BUILDING AND INSTALLED LOAD CHARACTERISTICS OF THE MINOLA RD. FACILITY

- All electric building
- Electrical service: 277/480 V, 3Ø, 4 wire
- Lighting Load: 54 kW
- Air conditioning load: 44 kW
- Resistance heating load: 268 kW
- Water heating load: 21 kW
- Miscellaneous loads: 10 kW

Typical daily load profiles of the Minola Road facility are shown in Figure 1.4.1 on an hourly basis. Because much of the load varies seasonally, four different curves are presented, one for each season of the year.

In contrast to the load of the local operating headquarters which peaks in the winter, the total load on the Georgia Power Company grid peaks in the summer. The data shown in Figure 1.4.2 includes a daily load profile of each day during the week in 1977 when the peak

Figure 1.4.1 Typical daily load profiles of the Minola Road Local Operating Headquarters

Figure 1.4.2 Daily load profile for the Georgia Power Company grid during peak week of July 18-24, 1977.

load occurred on the grid - Thursday, July 21, at about 6:00 pm. If the solar photovoltaic power system is considered to be feeding the utility grid instead of the local load, it would have a substantial theoretical power output during the time of the system peak, and should deserve some capacity credit. Because the summer peak loads on the Georgia Power Company grid are heavily dependent on air conditioning, there is probably a beneficial correlation between solar photovoltaic plant output and peak utility loading, both of which are functions of weather.

1.4.3 Performance Analysis

The performance analysis described in this section was made at a set of reference conditions which were used throughout the program to estimate the capital cost of the collector subassembly relative to the high volume cost goal of \$2/Wp. A reference ambient temperature of 28°C was used, and an average summer wind velocity of 7.8 mph, obtained from local weather observations over a period of time, was used also. All of the cost/performance trade-off analyses described in later sections were performed using these conditions as well. In addition, all cost figures are quoted in terms of 1975 dollars.

The results of the array performance analysis can best be presented in the form of an energy balance budget as shown in Table 1.4.7. The energy balance is based on the energy incident on the faceted area of one Lens/Cell Module which is 660 W at a solar intensity of 1 kW/m². Internal lens losses as well as off-target losses reduce the incident energy on the Solar Cell Assemblies to 549 W. Reflections and losses at the assemblies then reduce the energy absorbed by the solar cell to 451 W, of which 81 W are converted to useable electrical energy leaving 370 W to be dissipated as thermal energy.

Because a 2-axis tracking array contains 48 LCM's, the output of one tracking array becomes 3744 W making the output of the 15 tracking array field 56.2 kW.

In the system designed, the size of the wire used to carry the dc currents from the tracking arrays to the data building where the

TABLE 1.4.7
 ARRAY ENERGY BALANCE
 (1000 W/m² Insolation, 28°C Ambient)

<u>LENS/CELL MODULE</u>	<u>Disposition</u>	<u>Availability</u>
Energy Incident on Lenses		660 W
Lens reflection and absorption losses	66 W	
Lens off-target loss (perfect alignment)	33	
Lens off-target loss (avg. misalignment)	12	
Energy Incident on Solar Cell Assemblies		549
Energy reflected at air/glass interface	27	
Energy absorbed by cover glass	8	
Energy reflected by glass/silicon interface	8	
Energy reflected by upper contacts	55	
Energy absorbed by solar cells		451
Electrical output (16% of 506 W)*	81	
Electrical mismatch and wiring losses (4%)	3	
Thermal output	370	
<u>2-Axis Tracking Array</u>		
Electrical Output		3744 W
<u>Array Field</u>		
Electrical Output		56.2 kW

*Cell efficiency includes upper contact losses.

power conditioner is located was chosen to yield an average power loss of 1%. The effective input to the power conditioner is then 55.6 kW.

The power conditioner efficiency at full load is specified to be 91%, and at solar noon, the total tracking power is 450 W assuming that only azimuth tracking is occurring. Therefore the ac output power of the system at an insolation of 1 kW/m^2 and 28°C ambient is 50 kW.

1.4.4 Annual Energy Simulation

The annual energy output of the system was determined using weather data taken from the Shenandoah Model Year weather tape which contains a synthetic year made up of a collection of average months chosen from weather data available for the Atlanta area for a number of years. Only the direct insolation was included because the concentrating optics used has negligible response to diffuse radiation. The plot of daily total energy from direct radiation, shown in Figure 1.4.3, looks as expected indicating that the source data appears valid.

System operation was simulated on an hourly basis using insolation from the weather tape and loads as shown in Figure 1.4.1 which are typical of the Minola Road local operating headquarters for different times of the year.

Constants for the analytical model used for the solar cell were obtained from the cell developer, OCLI. The general equation used for the cell model is as follows:

$$I = I_L - I_0 \exp \left(\frac{V + IR}{V_0} \right)$$

where I_L and R are constants independent of temperature, and I_0 and V_0 are constants which depend on temperature. The variables I and V are solar cell current and voltage, respectively.

The thermal model used to describe the relationship between the temperature of the heat sinks and the heat flow is as follows:

JAN. 20, 1979 * 11:30:38 AM * DATAPLOT

SOLCN * DAILY ARRAY FIELD OUTPUT

Figure 1.4.3 Scatter plot of daily total direct normal insolation for Atlanta, GA from the Shenandoah Model Year weather tapes

$$\Delta T_{SA} = \frac{26.1 \ q/q_{test}}{[1 + .78 \ W_s^2]^{1/3}}$$

where q_{test} is the heat flow at the test condition used to determine model constants, W_s is wind speed, and ΔT_{SA} is the temperature difference between the heat sink and ambient air. The thermal resistance used for heat flow between the solar cell and heat sink is 0.0193°C/W .

The results of the simulation are summarized in Table 1.4.8 and presented on a daily basis in Table 1.4.9. On an annual basis, 12% of the energy demand of the on-site load is supplied by the solar energy system, the remaining energy being supplied by the utility grid. Very little energy from the solar energy system flows into the utility grid because the on-site load is large enough to absorb all of the energy from the solar energy system most of the time.

1.5 Tradeoff Studies

1.5.1 Concentration Ratio

Using high volume estimates for material provided by DOE, the capital cost per watt of the concentrator subsystem was calculated as a function of concentration ratio for different values of solar cell temperature. The results are presented in Figure 1.5.1 which shows that a shallow minimum exists near a concentration ratio of 50 for the solar cell temperatures anticipated. Because the minimum is broad, the value used for the concentration ratio is not critical, and it appears that the value of 50 is a good choice.

Tracking accuracy is a consideration also in the choice of concentration ratio. The system to be used will track to within 1 milliradian of the azimuthal direction which is most sensitive to tracking accuracy. A calculation was made to determine the effect on incident energy of such an error, with the result that it would cause a 5% reduction in incident solar flux. A reduction of 5% is the maximum which can be tolerated in an energy efficient system indicating that a concentration ratio of 50 is the largest that should be considered.

TABLE 1.4.8

Summary of annual energy simulation

JAN. 23, 1979 * 9:52:54 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOIMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15%/

	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
JAN	5490.	98270.	5490.	6.	92780.	0.
FEB	7190.	88760.	7190.	8.	81570.	0.
MAR	8571.	42780.	8489.	20.	34291.	82.
APR	8633.	41400.	8481.	20.	32919.	152.
MAY	9004.	42780.	8937.	21.	33843.	67.
JUN	7874.	53100.	7872.	15.	45228.	2.
JUL	8420.	54870.	8420.	15.	46450.	0.
AUG	8059.	54870.	8059.	15.	46811.	0.
SEP	7682.	64650.	7682.	12.	56968.	0.
OCT	8882.	66805.	8882.	13.	57923.	0.
NOV	8544.	64650.	8544.	13.	56106.	0.
DEC	6808.	98270.	6808.	7.	91462.	0.
	95158.	771205.	94855.	12.	676350.	303.

TABLE 1.4.9a

JAN. 23, 1979 * 9:28:25 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

JAN	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	370.5	3170.0	370.5	11.7	2799.5	0.0
2	0.4	3170.0	0.4	0.0	3169.6	0.0
3	32.4	3170.0	32.4	1.0	3137.6	0.0
4	256.8	3170.0	256.8	8.1	2913.2	0.0
5	351.7	3170.0	351.7	11.1	2818.3	0.0
6	326.4	3170.0	326.4	10.3	2843.6	0.0
7	96.1	3170.0	96.1	3.0	3073.9	0.0
8	0.0	3170.0	0.0	0.0	3170.0	0.0
9	23.0	3170.0	23.0	0.7	3147.0	0.0
10	1.3	3170.0	1.3	0.0	3168.7	0.0
11	211.7	3170.0	211.7	6.7	2958.3	0.0
12	443.5	3170.0	443.5	14.0	2726.5	0.0
13	243.0	3170.0	243.0	7.7	2927.0	0.0
14	101.8	3170.0	101.8	3.2	3068.2	0.0
15	68.8	3170.0	68.8	2.2	3101.2	0.0
16	171.4	3170.0	171.4	5.4	2998.6	0.0
17	42.1	3170.0	42.1	1.3	3127.9	0.0
18	38.0	3170.0	38.0	1.2	3132.0	0.0
19	363.5	3170.0	363.5	11.5	2806.5	0.0
20	6.1	3170.0	6.1	0.2	3163.9	0.0
21	115.8	3170.0	115.8	3.7	3054.2	0.0
22	378.9	3170.0	378.9	12.0	2791.1	0.0
23	3.8	3170.0	3.8	0.1	3166.2	0.0
24	1.7	3170.0	1.7	0.1	3168.3	0.0
25	452.8	3170.0	452.8	14.3	2717.2	0.0
26	251.9	3170.0	251.9	7.9	2918.1	0.0
27	75.6	3170.0	75.6	2.4	3094.4	0.0
28	137.0	3170.0	137.0	4.3	3033.0	0.0
29	430.5	3170.0	430.5	13.6	2739.5	0.0
30	445.3	3170.0	445.3	14.0	2724.7	0.0
31	48.1	3170.0	48.1	1.5	3121.9	0.0
JAN	5490.	98270.	5490.	6.	92780.	0.

TABLE 1.4.9b

JAN. 23, 1979 * 9:35:19 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

FEB	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	548.3	3170.0	548.3	17.3	2621.7	0.0
2	252.6	3170.0	252.6	8.0	2917.4	0.0
3	1.2	3170.0	1.2	0.0	3168.8	0.0
4	2.5	3170.0	2.5	0.1	3167.5	0.0
5	419.4	3170.0	419.4	13.2	2750.6	0.0
6	412.9	3170.0	412.9	13.0	2757.1	0.0
7	1.0	3170.0	1.0	0.0	3169.0	0.0
8	34.6	3170.0	34.6	1.1	3135.4	0.0
9	533.0	3170.0	533.0	16.8	2637.0	0.0
10	546.8	3170.0	546.8	17.3	2623.2	0.0
11	489.9	3170.0	489.9	15.5	2680.1	0.0
12	79.5	3170.0	79.5	2.5	3090.5	0.0
13	13.6	3170.0	13.6	0.4	3156.4	0.0
14	529.5	3170.0	529.5	16.7	2640.5	0.0
15	217.4	3170.0	217.4	6.9	2952.6	0.0
16	315.1	3170.0	315.1	9.9	2854.9	0.0
17	126.6	3170.0	126.6	4.0	3043.4	0.0
18	373.6	3170.0	373.6	11.8	2796.4	0.0
19	100.3	3170.0	100.3	3.2	3069.7	0.0
20	188.2	3170.0	188.2	5.9	2981.8	0.0
21	6.8	3170.0	6.8	0.2	3163.2	0.0
22	201.0	3170.0	201.0	6.3	2969.0	0.0
23	493.4	3170.0	493.4	15.6	2676.6	0.0
24	435.1	3170.0	435.1	13.7	2734.9	0.0
25	363.8	3170.0	363.8	11.5	2806.2	0.0
26	0.2	3170.0	0.2	0.0	3169.8	0.0
27	425.1	3170.0	425.1	13.4	2744.9	0.0
28	78.9	3170.0	78.9	2.5	3091.1	0.0
FEB	7190.	88760.	7190.	8.	81570.	0.

TABLE 1.4.9c

JAN. 23, 1979 * 9:36:46 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15%/°

MAR	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	320.8	1380.0	320.4	23.2	1059.6	0.4
2	383.2	1380.0	382.6	27.7	997.4	0.7
3	24.7	1380.0	24.7	1.8	1355.3	0.0
4	308.1	1380.0	308.1	22.3	1071.9	0.0
5	214.3	1380.0	214.3	15.5	1165.7	0.0
6	0.3	1380.0	0.3	0.0	1379.7	0.0
7	443.7	1380.0	436.2	31.6	943.8	7.5
8	263.9	1380.0	263.9	19.1	1116.1	0.0
9	22.1	1380.0	22.1	1.6	1357.9	0.0
10	433.9	1380.0	427.5	31.0	952.5	6.4
11	525.7	1380.0	512.5	37.1	867.5	13.2
12	343.6	1380.0	335.8	24.3	1044.2	7.9
13	430.4	1380.0	426.0	30.9	954.0	4.4
14	267.1	1380.0	266.4	19.3	1113.6	0.7
15	176.9	1380.0	176.9	12.8	1203.1	0.0
16	2.4	1380.0	2.4	0.2	1377.6	0.0
17	127.6	1380.0	127.6	9.2	1252.4	0.0
18	0.6	1380.0	0.6	0.0	1379.4	0.0
19	418.6	1380.0	418.5	30.3	961.5	0.1
20	347.5	1380.0	347.1	25.2	1032.9	0.5
21	386.0	1380.0	385.0	27.9	995.0	1.0
22	430.8	1380.0	425.0	30.8	955.0	5.8
23	12.1	1380.0	12.1	0.9	1367.9	0.0
24	347.8	1380.0	347.2	25.2	1032.8	0.6
25	8.2	1380.0	8.2	0.6	1371.8	0.0
26	410.6	1380.0	408.0	29.6	972.0	2.6
27	381.8	1380.0	365.3	26.5	1014.7	16.5
28	474.5	1380.0	470.4	34.1	909.6	4.1
29	408.6	1380.0	408.6	29.6	971.4	0.0
30	231.3	1380.0	231.3	16.8	1148.7	0.0
31	423.9	1380.0	414.2	30.0	965.8	9.7
MAR	8571.	42780.	8489.	20.	34291.	82.

TABLE 1.4.9d

JAN. 23, 1979 * 9:38:13 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

APR	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY SOLAR ENERGY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	5.7	1380.0	5.7	0.4	1374.3	0.0
2	407.8	1380.0	402.6	29.2	977.4	5.2
3	11.3	1380.0	11.3	0.8	1368.7	0.0
4	121.1	1380.0	121.1	8.8	1258.9	0.0
5	117.1	1380.0	117.1	8.5	1262.9	0.0
6	288.6	1380.0	287.0	20.8	1093.0	1.6
7	87.5	1380.0	87.5	6.3	1292.5	0.0
8	183.7	1380.0	182.8	13.2	1197.2	0.9
9	427.1	1380.0	418.6	30.3	961.4	8.5
10	291.5	1380.0	291.5	21.1	1088.5	0.0
11	275.9	1380.0	273.5	19.8	1106.5	2.4
12	212.1	1380.0	212.1	15.4	1167.9	0.0
13	502.2	1380.0	488.9	35.4	891.1	13.3
14	348.8	1380.0	339.7	24.6	1040.3	9.0
15	78.1	1380.0	78.1	5.7	1301.9	0.0
16	508.8	1380.0	487.8	35.3	892.2	20.9
17	472.3	1380.0	452.7	32.8	927.3	19.5
18	500.4	1380.0	482.0	34.9	898.0	18.4
19	133.0	1380.0	133.0	9.6	1247.0	0.0
20	149.7	1380.0	147.7	10.7	1232.3	2.0
21	328.5	1380.0	328.1	23.8	1051.9	0.4
22	404.7	1380.0	404.4	29.3	975.6	0.3
23	403.1	1380.0	402.6	29.2	977.4	0.5
24	448.8	1380.0	447.2	32.4	932.8	1.6
25	152.2	1380.0	152.2	11.0	1227.8	0.0
26	165.6	1380.0	165.0	12.0	1215.0	0.6
27	116.7	1380.0	114.6	8.3	1265.4	2.2
28	475.6	1380.0	466.5	33.8	913.5	9.1
29	485.3	1380.0	467.0	33.8	913.0	18.3
30	530.3	1380.0	513.2	37.2	866.8	17.0
APR	8633.	41400.	8481.	20.	32919.	152.

TABLE 1.4.9e

JAN. 23, 1979 * 9:39:41 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

MAY	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	90.6	1380.0	90.6	6.6	1289.4	0.0
2	34.0	1380.0	34.0	2.5	1346.0	0.0
3	26.4	1380.0	26.4	1.9	1353.6	0.0
4	31.4	1380.0	31.4	2.3	1348.6	0.0
5	332.3	1380.0	332.1	24.1	1047.9	0.2
6	545.3	1380.0	516.8	37.5	863.2	28.5
7	486.9	1380.0	472.3	34.2	907.7	14.7
8	347.0	1380.0	346.8	25.1	1033.2	0.1
9	372.7	1380.0	370.5	26.8	1009.5	2.2
10	28.4	1380.0	28.4	2.1	1351.6	0.0
11	102.9	1380.0	102.9	7.5	1277.1	0.0
12	278.1	1380.0	278.1	20.2	1101.9	0.0
13	340.8	1380.0	340.5	24.7	1039.5	0.2
14	235.7	1380.0	235.7	17.1	1144.3	0.0
15	249.1	1380.0	249.1	18.1	1130.9	0.0
16	469.8	1380.0	463.4	33.6	916.6	6.4
17	344.2	1380.0	344.2	24.9	1035.8	0.1
18	295.6	1380.0	295.5	21.4	1084.5	0.1
19	303.5	1380.0	302.6	21.9	1077.4	0.9
20	454.1	1380.0	453.5	32.9	926.5	0.6
21	333.3	1380.0	333.1	24.1	1046.9	0.2
22	402.7	1380.0	402.7	29.2	977.3	0.0
23	460.5	1380.0	458.6	33.2	921.4	1.9
24	204.1	1380.0	204.1	14.8	1175.9	0.0
25	405.4	1380.0	405.4	29.4	974.6	0.0
26	430.8	1380.0	430.2	31.2	949.8	0.5
27	443.4	1380.0	441.4	32.0	938.6	2.0
28	414.8	1380.0	407.2	29.5	972.8	7.6
29	183.6	1380.0	183.6	13.3	1196.4	0.0
30	34.9	1380.0	34.9	2.5	1345.1	0.0
31	321.5	1380.0	321.0	23.3	1059.0	0.5
MAY	9004.	42780.	8937.	21.	33843.	67.

TABLE 1.4.9f

JAN. 23, 1979 * 9:41:09 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION.

NOMINAL CELL EFFICIENCY = 15%/

JUN	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	393.6	1770.0	393.1	22.2	1376.9	0.5
2	398.6	1770.0	398.6	22.5	1371.4	0.0
3	217.4	1770.0	217.4	12.3	1552.6	0.0
4	48.6	1770.0	48.6	2.7	1721.4	0.0
5	238.9	1770.0	238.9	13.5	1531.1	0.0
6	120.9	1770.0	120.9	6.8	1649.1	0.0
7	215.0	1770.0	215.0	12.1	1555.0	0.0
8	47.3	1770.0	47.3	2.7	1722.7	0.0
9	60.1	1770.0	60.1	3.4	1709.9	0.0
10	1.9	1770.0	1.9	0.1	1768.1	0.0
11	159.8	1770.0	159.8	9.0	1610.2	0.0
12	406.0	1770.0	405.5	22.9	1364.5	0.5
13	318.8	1770.0	318.8	18.0	1451.2	0.0
14	332.6	1770.0	332.6	18.8	1437.4	0.0
15	463.0	1770.0	463.0	26.2	1307.0	0.0
16	366.8	1770.0	366.8	20.7	1403.2	0.0
17	418.1	1770.0	418.1	23.6	1351.9	0.0
18	384.4	1770.0	384.4	21.7	1385.6	0.0
19	290.3	1770.0	298.3	16.9	1471.7	0.0
20	377.1	1770.0	377.1	21.3	1392.9	0.0
21	327.9	1770.0	327.2	18.5	1442.8	0.7
22	303.2	1770.0	303.2	17.1	1466.8	0.0
23	361.9	1770.0	361.9	20.4	1408.1	0.0
24	215.5	1770.0	215.5	12.2	1554.5	0.0
25	193.7	1770.0	193.7	10.9	1576.3	0.0
26	263.7	1770.0	263.7	14.9	1506.3	0.0
27	198.5	1770.0	198.5	11.2	1571.5	0.0
28	87.5	1770.0	87.5	4.9	1682.5	0.0
29	462.5	1770.0	462.5	26.1	1307.5	0.0
30	192.5	1770.0	192.5	10.9	1577.5	0.0
JUN	7874.	53100.	7872.	15.	45228.	2.

TABLE 1.4.9g

JAN. 23, 1979 * 9:42:37 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0/0.

JUL	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	333.6	1770.0	333.6	18.8	1436.4	0.0
2	342.1	1770.0	342.1	19.3	1427.9	0.0
3	354.4	1770.0	354.4	20.0	1415.6	0.0
4	238.5	1770.0	238.5	13.5	1531.5	0.0
5	450.0	1770.0	450.0	25.4	1320.0	0.0
6	328.8	1770.0	328.8	18.6	1441.2	0.0
7	425.8	1770.0	425.8	24.1	1344.2	0.0
8	220.7	1770.0	220.7	12.5	1549.3	0.0
9	227.1	1770.0	227.1	12.8	1542.9	0.0
10	395.9	1770.0	395.9	22.4	1374.1	0.0
11	426.0	1770.0	426.0	24.1	1344.0	0.0
12	418.4	1770.0	418.4	23.6	1351.6	0.0
13	221.7	1770.0	221.7	12.5	1548.3	0.0
14	193.4	1770.0	193.4	10.9	1576.6	0.0
15	257.2	1770.0	257.2	14.5	1512.8	0.0
16	236.0	1770.0	236.0	13.3	1534.0	0.0
17	435.7	1770.0	435.7	24.6	1334.3	0.0
18	291.1	1770.0	291.1	16.4	1478.9	0.0
19	277.4	1770.0	277.4	15.7	1492.6	0.0
20	146.0	1770.0	146.0	8.2	1624.0	0.0
21	37.6	1770.0	37.6	2.1	1732.4	0.0
22	8.0	1770.0	8.0	0.5	1762.0	0.0
23	186.4	1770.0	186.4	10.5	1583.6	0.0
24	220.4	1770.0	220.4	12.5	1549.6	0.0
25	288.2	1770.0	288.2	16.3	1481.8	0.0
26	154.7	1770.0	154.7	8.7	1615.3	0.0
27	385.9	1770.0	385.9	21.8	1384.1	0.0
28	187.0	1770.0	187.0	10.6	1583.0	0.0
29	253.3	1770.0	253.3	14.3	1516.7	0.0
30	343.7	1770.0	343.7	19.4	1426.3	0.0
31	135.1	1770.0	135.1	7.6	1634.9	0.0
JUL	8420.	54870.	8420.	15.	46450.	0.

TABLE 1.4.9h

JAN. 23, 1979 * 9:45:34 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0/-

AUG	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	264.4	1770.0	264.4	14.9	1505.6	0.0
2	322.5	1770.0	322.5	18.2	1447.5	0.0
3	342.4	1770.0	342.4	19.3	1427.6	0.0
4	241.5	1770.0	241.5	13.6	1528.5	0.0
5	234.1	1770.0	234.1	13.2	1535.9	0.0
6	205.7	1770.0	205.7	11.6	1564.3	0.0
7	165.7	1770.0	165.7	9.4	1604.3	0.0
8	217.7	1770.0	217.7	12.3	1552.3	0.0
9	395.9	1770.0	395.9	22.4	1374.1	0.0
10	307.1	1770.0	307.1	17.3	1462.9	0.0
11	288.8	1770.0	288.8	16.3	1481.2	0.0
12	295.1	1770.0	295.1	16.7	1474.9	0.0
13	284.6	1770.0	284.6	16.1	1485.4	0.0
14	95.7	1770.0	95.7	5.4	1674.3	0.0
15	79.6	1770.0	79.6	4.5	1690.4	0.0
16	199.2	1770.0	199.2	11.3	1570.8	0.0
17	348.0	1770.0	348.0	19.7	1422.0	0.0
18	165.0	1770.0	165.0	9.3	1605.0	0.0
19	245.6	1770.0	245.6	13.9	1524.4	0.0
20	256.0	1770.0	256.0	14.5	1514.0	0.0
21	303.4	1770.0	303.4	17.1	1466.6	0.0
22	426.8	1770.0	426.8	24.1	1343.2	0.0
23	355.4	1770.0	355.4	20.1	1414.6	0.0
24	329.6	1770.0	329.6	18.6	1440.4	0.0
25	354.2	1770.0	354.2	20.0	1415.8	0.0
26	307.3	1770.0	307.3	17.4	1462.7	0.0
27	218.1	1770.0	218.1	12.3	1551.9	0.0
28	405.5	1770.0	405.5	22.9	1364.5	0.0
29	217.5	1770.0	217.5	12.3	1552.5	0.0
30	149.0	1770.0	149.0	8.4	1621.0	0.0
31	37.2	1770.0	37.2	2.1	1732.8	0.0
AUG	8059.	54870.	8059.	15.	46811.	0.

TABLE 1.4.9i

JAN. 23, 1979 * 9:47:03 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

SEP	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY SOLAR ENERGY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	335.3	2155.0	335.3	15.6	1819.7	0.0
2	242.2	2155.0	242.2	11.2	1912.8	0.0
3	300.7	2155.0	300.7	14.0	1854.3	0.0
4	179.2	2155.0	179.2	8.3	1975.8	0.0
5	280.5	2155.0	280.5	13.0	1874.5	0.0
6	140.2	2155.0	140.2	6.5	2014.8	0.0
7	68.2	2155.0	68.2	3.2	2086.8	0.0
8	400.7	2155.0	400.7	18.6	1754.3	0.0
9	334.5	2155.0	334.5	15.5	1820.5	0.0
10	291.1	2155.0	291.1	13.5	1863.9	0.0
11	289.1	2155.0	289.1	13.4	1865.9	0.0
12	277.7	2155.0	277.7	12.9	1877.3	0.0
13	217.0	2155.0	217.0	10.1	1938.0	0.0
14	12.5	2155.0	12.5	0.6	2142.5	0.0
15	20.1	2155.0	20.1	0.9	2134.9	0.0
16	312.1	2155.0	312.1	14.5	1842.9	0.0
17	323.1	2155.0	323.1	15.0	1831.9	0.0
18	111.2	2155.0	111.2	5.2	2043.8	0.0
19	386.7	2155.0	386.7	17.9	1768.3	0.0
20	379.8	2155.0	379.8	17.6	1775.2	0.0
21	379.0	2155.0	379.0	17.6	1776.0	0.0
22	270.0	2155.0	270.0	12.5	1885.0	0.0
23	400.9	2155.0	400.9	18.6	1754.1	0.0
24	504.0	2155.0	504.0	23.4	1651.0	0.0
25	477.5	2155.0	477.5	22.2	1677.5	0.0
26	244.1	2155.0	244.1	11.3	1910.9	0.0
27	8.4	2155.0	8.4	0.4	2146.6	0.0
28	0.0	2155.0	0.0	0.0	2155.0	0.0
29	213.6	2155.0	213.6	9.9	1941.4	0.0
30	282.6	2155.0	282.6	13.1	1872.4	0.0
SEP	7682.	64650.	7682.	12.	56968.	0.

TABLE 1.4.9j

JAN. 23, 1979 * 9:48:31 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

OCT	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	421.9	2155.0	421.9	19.6	1733.1	0.0
2	365.8	2155.0	365.8	17.0	1789.2	0.0
3	228.3	2155.0	228.3	10.6	1926.7	0.0
4	349.9	2155.0	349.9	16.2	1805.1	0.0
5	370.8	2155.0	370.8	17.2	1784.2	0.0
6	317.7	2155.0	317.7	14.7	1837.3	0.0
7	129.1	2155.0	129.1	6.0	2025.9	0.0
8	0.9	2155.0	0.9	0.0	2154.1	0.0
9	5.5	2155.0	5.5	0.3	2149.5	0.0
10	406.9	2155.0	406.9	18.9	1748.1	0.0
11	419.2	2155.0	419.2	19.5	1735.8	0.0
12	340.5	2155.0	340.5	15.8	1814.5	0.0
13	414.3	2155.0	414.3	19.2	1740.7	0.0
14	286.8	2155.0	286.8	13.3	1868.2	0.0
15	378.3	2155.0	378.3	17.6	1776.7	0.0
16	102.8	2155.0	102.8	4.8	2052.2	0.0
17	14.0	2155.0	14.0	0.7	2141.0	0.0
18	219.0	2155.0	219.0	10.2	1936.0	0.0
19	509.0	2155.0	509.0	23.6	1646.0	0.0
20	436.8	2155.0	436.8	20.3	1718.2	0.0
21	400.2	2155.0	400.2	18.6	1754.8	0.0
22	344.3	2155.0	344.3	16.0	1810.7	0.0
23	372.1	2155.0	372.1	17.3	1782.9	0.0
24	193.6	2155.0	193.6	9.0	1961.4	0.0
25	378.5	2155.0	378.5	17.6	1776.5	0.0
26	418.3	2155.0	418.3	19.4	1736.7	0.0
27	109.6	2155.0	109.6	5.1	2045.4	0.0
28	450.2	2155.0	450.2	20.9	1704.8	0.0
29	481.6	2155.0	481.6	22.3	1673.4	0.0
30	16.3	2155.0	16.3	0.8	2138.7	0.0
31	0.0	2155.0	0.0	0.0	2155.0	0.0
OCT	8882.	66805.	8882.	13.	57923.	0.

TABLE 1.4.9k

JAN. 23, 1979 * 9:49:59 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

NOV	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY SOLAR ENERGY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	0.0	2155.0	0.0	0.0	2155.0	0.0
2	384.4	2155.0	384.4	17.8	1770.6	0.0
3	444.5	2155.0	444.5	20.6	1710.5	0.0
4	527.9	2155.0	527.9	24.5	1627.1	0.0
5	462.7	2155.0	462.7	21.5	1692.3	0.0
6	424.5	2155.0	424.5	19.7	1730.5	0.0
7	480.6	2155.0	480.6	22.3	1674.4	0.0
8	432.2	2155.0	432.2	20.1	1722.8	0.0
9	475.2	2155.0	475.2	22.1	1679.8	0.0
10	408.1	2155.0	408.1	18.9	1746.9	0.0
11	296.5	2155.0	296.5	13.8	1858.5	0.0
12	359.4	2155.0	359.4	16.7	1795.6	0.0
13	467.0	2155.0	467.0	21.7	1688.0	0.0
14	222.1	2155.0	222.1	10.3	1932.9	0.0
15	397.3	2155.0	397.3	18.4	1757.7	0.0
16	443.1	2155.0	443.1	20.6	1711.9	0.0
17	118.6	2155.0	118.6	5.5	2036.4	0.0
18	430.3	2155.0	430.3	20.0	1724.7	0.0
19	476.7	2155.0	476.7	22.1	1678.3	0.0
20	112.4	2155.0	112.4	5.2	2042.6	0.0
21	0.9	2155.0	0.9	0.0	2154.1	0.0
22	0.8	2155.0	0.8	0.0	2154.2	0.0
23	381.0	2155.0	381.0	17.7	1774.0	0.0
24	6.5	2155.0	6.5	0.3	2148.5	0.0
25	435.4	2155.0	435.4	20.2	1719.6	0.0
26	30.1	2155.0	30.1	1.8	2116.9	0.0
27	5.8	2155.0	5.8	0.3	2149.2	0.0
28	58.6	2155.0	58.6	2.7	2096.4	0.0
29	2.9	2155.0	2.9	0.1	2152.1	0.0
30	250.9	2155.0	250.9	11.6	1904.1	0.0
NOV	8544.	64650.	8544.	13.	56106.	0.

TABLE 1.4.91

JAN. 23, 1979 * 9:51:27 PM * SIM2

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA * ARRAY FIELD SIMULATION

NOMINAL CELL EFFICIENCY = 15.0%

DEC	SOLAR ARRAY FIELD ENERGY OUTPUT (KWH)	LOAD (KWH)	SOLAR ENERGY SUPPLIED TO LOAD (KWH)	% LOAD SUPPLIED BY SOLAR	ENERGY SUPPLIED BY UTILITY TO LOAD (KWH)	SOLAR ENERGY SUPPLIED TO UTILITY (KWH)
1	147.5	3170.0	147.5	4.7	3022.5	0.0
2	213.4	3170.0	213.4	6.7	2956.6	0.0
3	357.0	3170.0	357.0	11.3	2813.0	0.0
4	439.8	3170.0	439.8	13.9	2730.2	0.0
5	439.1	3170.0	439.1	13.9	2730.9	0.0
6	459.4	3170.0	459.4	14.5	2710.6	0.0
7	454.2	3170.0	454.2	14.3	2715.8	0.0
8	413.5	3170.0	413.5	13.0	2756.5	0.0
9	186.4	3170.0	186.4	5.9	2983.6	0.0
10	192.6	3170.0	192.6	6.1	2977.4	0.0
11	25.0	3170.0	25.0	0.8	3145.0	0.0
12	143.4	3170.0	143.4	4.5	3026.6	0.0
13	321.2	3170.0	321.2	10.1	2848.8	0.0
14	369.5	3170.0	369.5	11.7	2800.5	0.0
15	9.8	3170.0	9.8	0.3	3160.2	0.0
16	0.4	3170.0	0.4	0.0	3169.6	0.0
17	306.4	3170.0	306.4	9.7	2863.6	0.0
18	402.2	3170.0	402.2	12.7	2767.8	0.0
19	153.9	3170.0	153.9	4.9	3016.1	0.0
20	4.5	3170.0	4.5	0.1	3165.5	0.0
21	44.2	3170.0	44.2	1.4	3125.8	0.0
22	96.7	3170.0	96.7	3.1	3073.3	0.0
23	3.2	3170.0	3.2	0.1	3166.8	0.0
24	467.0	3170.0	467.0	14.7	2703.0	0.0
25	17.9	3170.0	17.9	0.6	3152.1	0.0
26	329.5	3170.0	329.5	10.4	2840.5	0.0
27	400.7	3170.0	400.7	12.6	2769.3	0.0
28	398.6	3170.0	398.6	12.6	2771.4	0.0
29	1.0	3170.0	1.0	0.0	3169.0	0.0
30	9.1	3170.0	9.1	0.3	3160.9	0.0
31	0.9	3170.0	0.9	0.0	3169.1	0.0
DEC	6808.	98270.	6808.	7.	91462.	0.

Figure 1.5.1 Results of concentrator subsystem cost analysis (1975 dollars)

Because concentration ratios much below 50 result in an increased cost per watt of output, the value of 50 is optimum for use in this system.

1.5.2 Heat Sinks

Calculations were made for different heat sink sizes using a concentration ratio of 50 to seek a minimum in concentrator cost. Four different heat sinks with different fin widths were considered which resulted in heat sink temperatures ranging from 45°C to 75°C with a 25°C ambient and a 7.8 mph wind.

The results of the calculations showed that a broad minimum exists for heat sink temperatures in the 55 to 65°C range. In terms of heat sink fin width, the results show that 12" is too wide while 3" is too narrow. The fin width used is about 6" and is near the center of the range of the cost minimum.

Overall weight of all of the heat sinks is of concern also because of its effect on tracker structural stress. From this standpoint, the size of the heat sink chosen should lean toward the end of the range with smaller fins to minimize overall weight. The 6" wide fin therefore appears to be a good choice.

Because of the interrelationship of the heat sink with all other parts of the Solar Cell Assembly, a thermal analysis of the entire assembly was performed. The results are presented in four parts as described in the following sections.

1.5.2.1 Cell-to-Sink Thermal Analyses

The conditions used for this analyses are those listed in Table 1.4.7. Because the table describes a Lens/Cell Module, which contains two Solar Cell Assemblies, all power levels listed in the table must be divided by two for this analysis.

As given in the table, the thermal flux which must be carried from the cells of one SCA is 185 W. A crosssection of the solar cell mounting arrangement through which this thermal energy must flow is

shown in Figure 1.5.2. A small portion of the thermal flux shown generated at the solar cell (1.40 W) flows to the front surface and is transferred by convection and radiation to the ambient air.

The equation used to determine the coefficient portion of convective heat transfer between the front cover glass and the ambient air is:

$$h_c = 5.678 \times 10^{-4} (1 + 0.3 W_s) \text{ Watts/cm}^2\text{°C} \quad (1.5.1)$$

where W_s = wind velocity in mph

The radiative heat transfer is assumed to be negligibly small compared to the transfer by convection. By far the greater portion (183.60 W) flows to the aluminum heat sink and is eventually dissipated to the ambient air also. The thermal resistance between the solar cell and heat sink is 0.0193°C/W for the SCA as shown in Figure 1.5.2, making the temperature difference between the cell and sink 3.54°C.

1.5.2.2 Sink-to-Ambient Thermal Analysis

Heat is transferred from the sink to the air by convection and radiation. For convection, the thermal flux is related to the temperature difference by the following equation:

$$q_c = h_c A_c \Delta T_{SA} \quad (1.5.2)$$

where q_c = thermal flux transferred by convection

h_c = coefficient of convective heat transfer

A_c = area through which the heat flows

ΔT_{SA} = temperature difference between sink and air

For this calculation, temperature gradients within the heat sink are assumed to be negligibly small compared to ΔT_{SA} . Convection cooling was assumed resulting from a 7.8 mph wind blowing parallel to the direction of the fins. For these conditions, the value of h_c becomes 0.00658 Watts/in²°C.

The relationship between thermal flux transferred by radiation and the temperature difference between sink and ambient is given by the following equation:

$$R = \frac{\text{Thickness}}{\text{Conductivity} \times \text{Area}}$$

$$\text{Area} = .81 \text{ cm} \times 13 \text{ cells} \times 6 \text{ cm} \frac{\text{Long}}{\text{Cell}} = 63.18 \text{ cm}^2 = 9.79 \text{ in}^2$$

Figure 1.5.2 Solar cell assembly configuration used for thermal analysis

$$q_r = h_r A_r \Delta T_{SA} \quad (1.5.3)$$

where q_r = thermal flux transferred by radiation

h_r = coefficient of radiative heat transfer

A_r = area through which heat flows

ΔT_{SA} = temperature difference between sink and air

The expression for the coefficient of radiative heat transfer is as follows:

$$h_r = 4eP\Delta T_{SA}^{-3} \quad (1.5.4)$$

where e = sink surface emissivity

P = Stefan-Boltzmann constant

1.5.2.3 Heat Sink Design

The heat sink design was made based on the assumption that the solar cell temperature must be held to 40°C for an ambient air temperature of 28°C, a wind of 7.8 mph, and an insolation level of 1 kW/m².

From Figure 1.5.2, the thermal flux to be dissipated by the sink is 183.60 W, and from Section 1.5.2.1, the temperature difference between cell and sink for this value of thermal flux is 3.54°C. The sink temperature must then be (40-3.54) or 36.46°C. Because the assumed ambient temperature is 28°C, the difference temperature between the sink and ambient (ΔT_{SA}) must then be (36.46-28) or 8.46°C.

The required fin area was found to be 77.9 in² using equations 1.5.2, 1.5.3 and 1.5.4 as well as the values of thermal flux and ΔT_{SA} discussed previously. In order to construct a prototype SCM in a cost effective manner for testing during Phase I of this program, it was decided that an extruded aluminum heat sink with a fin area most closely approximating the calculated design value should be selected from those listed in a suppliers catalog. Using a catalog of readily available extrusions, the one which most closely approximated the required fin area determined from the preceeding analysis had an area of 85.2 in² yielding a calculated ΔT_{SA} of 9.25°C.

1.5.2.4 Heat Sink Experimental Results

The aluminum extrusion chosen was tested in a wind tunnel at various air velocities. A number of power resistors were mechanically mounted along the length of the extrusion to simulate the solar cell thermal configuration. A thermally conductive grease was used to improve heat flow between the resistors and the heat sink. The outer surface of the resistors was covered with a fiberglass ribbon to prevent convective heat flow directly between the resistors and the ambient air.

The wind tunnel used was 1 ft. by 3 ft. in cross section and 8 ft. long. The heat sink was mounted in the center of the tunnel, with the air flowing parallel to the sink axis. The free convection tests (0 velocity) were performed with the heat sink horizontal.

The results of these tests are shown plotted in Figure 1.5.3. The experimental data shown in the figure may be described approximately using the following equation:

$$\Delta T_{SA} = \frac{\tau_0 \times (q/q_{test})}{[1 + (\frac{\tau_0}{\tau_1})^3 (\frac{V}{7.8})^{2 1/3}]} \quad (1.5.5)$$

where τ_0 = measured ΔT_{SA} using free convection

τ_1 = measured ΔT_{SA} at 7.8 mph (686 FPM)

q_{test} = thermal flux at which τ_0 and τ_1 are measured

q = desired thermal flux

W_s = desired air velocity

The test results show a 7.0°C rise of the sink above the ambient air at 183 watts with a 7.8 mph (686 FPM) air velocity, compared to the calculated value of 9.25°C.

The solar cell operating temperature with a 28°C ambient would therefore be

$$T_c = 28^\circ\text{C} + 7.0^\circ\text{C} + 3.54^\circ\text{C} = 38.54^\circ\text{C}$$

Curve 714707-A

Figure 1.5.3 Results of thermal analysis of Wakefield heat sink

As it turns out, this heat sink design is somewhat conservative because the solar cell will operate at only 38.54°C instead of the design temperature of 40°C.

1.5.3 Array Field Voltage

The limits of the array field voltage are determined by the operating range of the power conditioner which is 200 V to 350 V dc. The voltage produced by the smallest array building block, the Lens/Cell Module (LCM), is about 13 V, and therefore it is necessary to connect many LCM's in series to reach the array field output voltage level required.

A tracking array structure contains 48 LCM's arranged in three sections as shown in Figure 1.5.4. Each LCM contains two Solar Cell Assemblies (SCA's) designated by vertical line segments and identified by a row number, a column number, and a section letter. The voltage of each LCM is such that if all modules in any array are connected in three parallel series strings, the required array field output voltage should be obtained.

The interconnection of the modules cannot be arbitrarily done, however, because systematic temperature variations over the face of the array could result in unequal current sharing of the three paralleled series strings. The forms of the temperature variations are shown in Figure 1.5.4. Horizontally, temperature decreases symmetrically about the centerline, and vertically, temperature increases upwards.

A suitable LCM interconnection scheme which balances out both horizontal and vertical temperature variations is listed in Table 1.5.1. Using this system, the average LCM temperature should be the same for each series string providing nearly equal current sharing when they are connected in parallel.

The results of a simulation of the VI characteristic of the entire array field for various ambient conditions is shown in Figure 1.5.5. This simulation is based on a solar cell model with parameters provided by OCLI and passive cooling using the thermal model described in Section 1.5.2.4. The simulation is for an insolation of 1 kW/m^2 .

Figure 1.5.4 Lens/Cell module estimated temperature profile

TABLE 1.5.1

ARRAY LCM INTERCONNECTION DESIGNATION

<u>Series String #1</u>	<u>Series String #2</u>	<u>Series String #3</u>
11A	12A	13A
21A	22A	23A
31A	32A	33A
41A	42A	43A
12B	11B	14A
22B	21B	24A
32B	31B	34A
42B	41B	44A
11C	14B	13B
21C	24B	23B
31C	34B	33B
41C	44B	43B
12C	13C	14C
22C	23C	24C
32C	33C	34C
42C	43C	44C

(Row, Column, Section)

Curve 714611-A

Figure 1.5.5. System operating conditions at various ambients

NOV. 20, 1978 * 11:51:31 AM * DATAPLOT

SOLCN * SHENANDOAH, GA. * TMY SOLMET DATA EXAMINATION

Figure 1.5.6 Scatter plot of average daily wind speed for Atlanta, GA from Shenandoah Model Year weather tape

The ambient temperature during daylight hours for a "typical" year in Atlanta, GA as derived from the Shenendoah Model Year tape are presented in Table 1.4.2 in the form of Bin Data. From this table, it can be seen that no temperatures below 12°F or above 103°F were recorded during daylight hours.

The average daily windspeeds for this "typical" year in Atlanta are indicated in Figure 1.5.6. It is seen that the average daily windspeed varies from approximately 4 mph to 25 mph.

Referring to Figure 1.5.5, one can observe that the lowest voltage developed across the array field occurs during the hottest day of the year and with minimum wind velocity. For an ambient temperature of 103°F and a wind speed of 3.9 mph, the open circuit voltage of the array is 259 volts, decreasing to 194 volts at the maximum power point.

Alternately, the highest voltage developed across the array occurs during the coldest day of the year and with maximum wind velocity. At an ambient temperature of 12°F and a wind speed of 25 mph, the highest open circuit voltage is 376 volts with the maximum powerpoint voltage being 306 volts.

It can be seen that for this design, the voltage developed across the array can fall outside the permitted limits of operation of the power conditioning unit. Assuming an average annual windspeed of 10.7 mph (see Figure 1.5.6), it is estimated that the Power Conditioner Unit (PCU) would become inoperable due to a high input voltage (open circuit voltage exceeds 350 V) approximately 1.0 percent of the time available for solar power generation, while no time would be lost because of low input voltage (maximum power point voltage below 200 V). Since the amount of time during which the input voltage would exceed 350 V is relatively brief, voltage clamping or shunt loading at the input of the PCU will not be necessary.

Another motivation for this simulation was to see if the range of the variation of array output voltage with ambient conditions would be a poor fit to the PCU operating voltage range. If this were the case, the solar cell length could be changed to correct it. However, because the fit is good, no change in solar cell length is required.

1.5.4 Array Spacing Optimization Studies

Optimal deployment of the arrays in the proposed application was determined using tradeoff studies performed to minimize shadowing. To perform these studies, a computer program was developed to determine when shadowing occurs for a given array spacing distance, tracker size, site location, and day of the year.

Two conditions must be satisfied for an array to be shaded by a neighbor. First, the sun's azimuth must be such that if the shadow of the neighbor is long enough, some of the shadow will fall on the neighboring array. Second, the length of the shadow of the neighbor must be greater than the shortest distance between the arrays.

Equations have been derived for the calculation of the parameters needed to determine whether or not the two shading conditions are satisfied. The equations assume deployment of arrays at intersection points of grids which are based on equilateral triangles, isosceles triangles, or rectangles all having east-west baselines.

The quantities that can be calculated using the equations are: azimuth angle between extremities of neighboring arrays, the shortest distance between horizontal axes of these arrays, and the lengths of the shadows from the arrays. These quantities can be calculated for the following assignable input variables: latitude of the site, day of the year, time of day, length of array, width of array, and distance between adjacent arrays.

Two general conclusions about spacing have been found with the help of the computer program. First, deployment of arrays on triangular grids is better than deployment on rectangular grids. For an array similar to the one proposed, it was found that 20 percent more land area is required for rectangular spacing than for equilateral triangular spacing assuming the same shade-free period. Second, the optimum spacing arrangement for the proposed arrays is a grid based on an isosceles triangle whose east-west baseline is 50 ft. long and whose other two sides are 54.07 ft. long. Such spacings give the following periods which are totally free from shading for Atlanta siting.

<u>Time of Year</u>	<u>Shade Free Period (local solar time)</u>	<u>Sun's Elevation When Partial Shading Begins</u>
Summer Solstice	6:12 am to 5:48 pm	15.1°
Equinoxes	7:10 am to 4:50 pm	14.5°
Winter Solstice	9:11 am to 2:48 pm	20.1°

However, dimensional constraints of the proposed installation site require locating the arrays on a grid based on an equilateral triangle whose east-west baseline is 50 ft. This will produce a minimal amount of shading in interior arrays about one hour longer at the summer solstice and at the equinoxes. Effects of this shading will be evaluated in Phase III by comparing average outputs of shaded interior arrays with unshaded border arrays.

1.5.5 Effects of Tracking, Alignment, and Thermal Expansion Errors

Any factors which result in a displacement of the plane of the Solar Cell Assemblies relative to the plane of the Fresnel lenses will potentially produce a reduction in output power. Moving the center of the cell laterally relative to the lens, i.e., at right angles relative to the lens facets, will cause increased off-target losses and result in a loss of power. Moving the cell toward or away from the lens will produce de-focusing, also reducing power.

Using the Fresnel lens energy flux distribution in conjunction with the spectral response of the solar cells, a cell output distribution curve was generated. This curve was used to quantify effects of lateral misalignment and de-focusing.

Figure 1.5.7 is a plot of fractional power loss as a function of lateral misalignment (expressed in terms of cell displacement from the perfectly aligned position or angular displacement). The proposed system has been designed to restrict total displacement caused by construction alignment, azimuth tracking errors, and thermal expansion to less than 0.05 inch (3 milliradians). Worst case combinations are therefore held to about five percent loss.

Figure 1.5.7 Results of the analyses of the effect on output power of tracking, alignment, and thermal expansion errors

The proposed design will restrict de-focusing to a maximum of 1/16 inch from the perfectly aligned position. Power losses associated with 1/16 inch de-focusing in either direction are approximately three percent. Statistically, combined losses from misalignment due to tracking, assembly or thermal expansion should be held to less than two percent.

Motion of the cell assemblies laterally relative to the lens in a direction parallel to the lens facets (due to assembly errors or elevation tracking error) within design limits will produce no measurable power losses since there is no solar concentration in this plane.

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2. COMPONENT SPECIFICATION

2.1 Tracking Solar Array

The solar energy system designed utilizes a group of two-axis tracking arrays with linear Fresnel lenses to concentrate the solar energy onto strips of solar cells. A single tracking solar array is shown in Figure 2.1.1. Each solar array consists of a tracking structure on which is mounted an array of forty eight (48) Lens/Cell Modules. Each Lens/Cell Module consists of a dual linear Fresnel lens assembly which concentrates the incident solar energy onto a pair of silicon solar cell strips centered behind the lenses.

The design of the proposed tracking structure and the Lens/Cell Module were completed during Phase I of the program. A full-size demonstration unit of the two-axis tracking structure was built and is shown in the photograph presented in Figure 2.1.2. Preliminary testing of the unit has confirmed that the structure will meet all functional requirements for which it was designed. For expediency, the demonstration unit was designed to allow fabrication from commercially available structural shapes resulting in material weights somewhat higher than required. However, the experience gained during the design and fabrication of the prototype unit has been invaluable in directing the development of the tracking structure final design.

A prototype Lens/Cell Module was also designed, fabricated, and tested to assess the performance of the lenses and solar cells. Both the lenses and Solar Cell Assemblies were developed under subcontracts with suppliers specifically to meet the requirements of this application. The experience gained from design and fabrication of the prototype unit in Phase I has been factored into the design proposed for Phase II to simplify fabrication and reduce costs. The principal changes made were with respect to the methods of attachment of the Fresnel lens and Solar Cell Assemblies to the

Figure 2.1.1 Artist's concept drawing of a single 2-axis tracking array

Figure 2.1.2 Photograph of the full size demonstration unit
of the 2-axis tracker built by Westinghouse

Lens/Cell Module structure. Preliminary in-house testing of the Phase I Lens/Cell Module has demonstrated that the units will perform as designed to meet the 50 kW peak power requirements of the system.

Optimum material thicknesses, cross-sections, joint designs, and basic configurations for the system components were determined from detailed structural analyses performed during Phase I using the WECAN* computer program.

Environmental design conditions shown in Table 2.1.1 were used as the basis for establishing structural requirements of the proposed design. These conditions were chosen as representative of extreme conditions for typical locations suitable for solar photovoltaic power systems. Thus the proposed design is suitable for use at any location with environmental conditions meeting these requirements. The Atlanta, Georgia, environmental conditions (Section 1.4.1) do not exceed any of the requirements listed.

2.1.1 Tracking Structure

The basic functions of the tracking structure are: (1) to support an array of 48 Lens/Cell Modules, and (2) to provide the two-axis movement capability required to aim the Lens/Cell Modules directly at the sun during daylight hours.

Drawing 712J520 contained in Appendix A shows the basic features of the tracker array structure. A rectangular lattice structural frame, 12 ft. by 40 ft., provides support for the 48 Lens/Cell Modules. This structural frame is supported by two 13.5 ft. diameter elevation wheels. The frame is braced by tie rods connecting the ends of the longitudinal beams to the rims of the elevation wheels. The elevation wheels turn on rollers mounted on pedestals secured to an azimuth ring and the azimuth ring turns on rollers atop pedestals which are secured to the foundation

*"Westinghouse Computer Analysis:" General purpose finite element computer program routinely used in the Corporation for analyzing static, nodal, harmonic, and dynamic structural problems.

TABLE 2.1.1 ENVIRONMENTAL DESIGN CONDITIONS

<u>Item</u>		<u>Requirement</u>	
1.	Design Wind Speed		
a.	Performance	25 mph	
b.	Stowage Initiation	26 mph	
c.	Survival (any orientation), without damage	22 m/s (50 mph), including gusts	
d.	Stowed, without damage	40 m/s (90 mph) at an angle of attack ± 10 degrees, including gusts	
2.	Ambient Air Temperature		
a.	Performance		
b.	Survival	-30°C (-22°F) to + 50°C (122°F)	
3.	Ice Accumulation		
a.	Stowed, without damage	50 mm (2 inches) thick	
4.	Snow Load		
a.	Stowed, without damage	250 pascals (5.2 lb/ft ²) at deposition rate of 0.3 m (1 ft) in 24 hours	
5.	Hail	<u>Diameter</u>	<u>Spec. Gravity</u> <u>Term Vel.</u>
a.	Any Orientation	20mm (0.79 in)	0.9 20 m/s (66 fps)
b.	Stowed	20mm (1.0 in)	0.9 23 m/s (75 fps)
6.	Design Gravity Loading	2 g	

columns. Positioning of the tracker array is accomplished using two belt drives fastened to the azimuth ring and to one of the elevation wheels.

The Lens/Cell Module support structure consists of the two longitudinal beams and thirteen transverse beams. The longitudinal beams are rectangular box sections 2.00 inches wide by 3.00 inches deep with a .065 inch wall thickness. The transverse beams are "hat" sections 2.00 inches high by 4.88 inches wide and .060 inch thick. The transverse beams are riveted to the longitudinal beams and the Lens/Cell Modules are secured to the transverse beams by bolts located near the corners of the modules. Shims are used to compensate for any frame misalignment and provide proper alignment of modules in the frame.

The tie rods that support the ends of the horizontal beams are secured to the rims of the elevation rings to obtain deep trusses providing efficient horizontal beam support. The rods on the lens side of the support structure are made of 0.180 inch diameter galvanized cold-drawn steel rod; whereas, the rods on the back side of the support structure are made from 0.500 inch diameter galvanized hot-rolled steel rod. This arrangement permits a high strain preload in the smaller rods, which enables them to function as springs to avoid large reductions in their preload due to heating by incident insolation. The tie rods are criss-crossed between the elevation wheels so that the driving torque can be applied at only one wheel without twisting the Lens/Cell Module support structure. The elevation rings, as described below, carry the Lens/Cell Module support structure and provide for elevation angle motions of the Lens/Cell Module support structure. The form selected for the ring cross section resulted from investigation of open forms and either circular or rectilinear closed forms to achieve the lowest cost ring. The elevation rings are made from 3.5 inch square tubing manufactured from 11-gauge galvanized steel sheet and have a diameter of 13.5 feet and weigh 268 pounds each. A 3.5-inch-square diametral spoke made from 11-gauge galvanized steel sheet is pin connected across the elevation ring to provide a means for transmitting the Lens/Cell Module support structure loads to the rim.

The elevation rings rotate on rollers supported by pedestals mounted on the azimuth ring and are held in contact with the rollers under the most severe design conditions by drive and idler cable assemblies. The rollers for the driving elevation ring have flanges that restrain the ring axially, but the rollers for the driven ring provide only radial support and allow that ring to float axially as dictated by the driving ring.

The azimuth ring is used to position the Lens/Cell Modules in azimuth and transmit the Lens/Cell Module support structure loads from the elevation rings to the foundations. The azimuth ring is made from .188 inch thick galvanized steel tubing with a cross-section 4.00 inches square and is 16.5 feet in diameter and weights 575 pounds.

Rectangular, 6 inch square, galvanized 16-gauge steel tubing braced with 16-gauge galvanized steel sheet gusset plates make up the elevation ring roller pedestals that are welded to the azimuth ring rim. The pedestals transmit the elevation ring roller loads to the azimuth ring rim, which in turn transmits them to the foundation rollers.

The azimuth ring rotates on rollers mounted on three supports which are attached at their base to three foundations. The rollers are flanged to restrain the azimuth ring laterally. Latches secured to each roller support engage the bottom wall of the drive cable groove in the azimuth ring and are required to secure the ring to the foundation under high wind conditions after the array is stowed. A motor mount with gusset plates for additional strength is welded to one of the supports. The azimuth ring motor and reduction gear box are located on this mount.

2.1.1.1 Elevation and Azimuth Drives

The elevation and azimuth drives include the motors, motor controllers, the gear speed reducers, and the drive belt assemblies. The motor and motor controller design is discussed in Section 2.4.3.

The gear box provides a two-stage speed reduction of 1600 to 1 for both the elevation and azimuth drives, and the elevation and azimuth rings with the sprockets and cable assemblies provide a third stage speed

reduction of 15.0 to 1 and 17.7 to 1 for the elevation and azimuth drives, respectively. These third stage speed reductions substantially reduce the loads and torques at the speed reducer output shaft. Wire cages are provided around the sprockets and cables to prevent injury to maintenance personnel and avoid jamming of the drives by weeds and small animals. The combined weight of both the elevation and azimuth drives is 500 pounds.

The same gear box design is used in both the elevation and azimuth drives. It is an inexpensive, commercial, two-stage worm gear speed reducer with a speed ratio of 1600 to 1 and maximum backlash of 2.9 mrad. This backlash will allow a Lens/Cell Module rotation or less than 0.2 mrad. The speed reducer gear is made from high tin content bronze centrifugally cast. This alloy has a relatively high hardness and a low coefficient of friction when running with a hardened steel worm, ensuring good resistance to wear and high efficiency. The gear box has a built-in oil lubrication system for maintenance free, long-life operations. Since it incorporates worm gears, the gear box is self-locking and will not allow the drive system to be rotated by external loads.

2.1.1.2 Foundations

The tracker is supported by a foundation arrangement consisting of three independent columns of concrete and steel. The Foundation Requirements Drawings 102E218 and 389D857 are included in the Appendix A drawing package. The three columns are equally spaced on a circle of essentially the same diameter as the tracker azimuth ring. The three point support system naturally establishes a stable reference plane for operation of the tracker and distributes ground reaction loads over a wide area.

After the base location for each tracker is established, the specific individual column sites are determined. The column that carries the tracker azimuth drive assembly will always be north of the tracker center. Each foundation column is formed in place. A two-foot diameter hole is bored into the ground to a depth required by local soil conditions. After boring the holes for the foundation, steel columns are

set one-foot deep into the earth at the bottom of the hole. Each column is preassembled with a flange at the upper end. The flanges in the ends of the column interface with the azimuth ring support column. During foundation construction, the flanges at the upper ends of the foundation columns are assembled to a fixture as shown in Figure 2.1.3 and all three columns are set simultaneously and held in position while the concrete is poured. The concrete bears directly against the earthen walls of the foundation excavation.

The flange on the foundation column carries studs for attachment of the azimuth ring support column. The studs are long enough to permit adjustment of the height of the azimuth ring support column by means of nuts on each side of the azimuth ring support column flange. The flange of the azimuth ring support column has large stud clearance holes to permit radial and tangential adjustment of the column location relative to the foundation. These features provide two benefits: first, the need for precision placement of the foundation structure is obviated; and second, the position of the tracker can be readily adjusted if significant foundation movement occurs.

2.1.2 Lens/Cell Module

2.1.2.1 Lens/Cell Module Structure

Figure 2.1.4 and Drawings 712J518, 712J519, 389D860, and 389D976 contained in Appendix A illustrate the basic features of the Lens/Cell Module. Each Lens/Cell Module is 36 inches by 37.5 inches by approximately 19.5 inches deep and supports a single linear Fresnel lens with dual faceted areas positioned in front of a pair of silicon Solar Cell Assemblies. The purpose of the Lens/Cell Module structure is to support the lens and Solar Cell Assemblies and keep them in the proper spatial relationship to maximize the energy output of the solar cells during normal operation. The structure has been designed to accept the loads applied by the lens and Solar Cell Assemblies plus high wind and ice loads without permanent deflections which would decrease the performance of the system. In addition, the structure is designed so that the solar cells can be positioned

Figure 2.1.3 Fixture for simultaneously installing and aligning the foundation columns of the 2-axis tracker prior to pouring concrete

Figure 2.1.4 Artist's concept sketch of the Lens/Cell Module

relative to the lens at assembly to offset manufacturing and assembly tolerances of structural components.

To achieve an optimum design for the Lens/Cell Module structure, several design studies were performed. The basic design requirements were: (1) high strength and low weight, (2), adaptability to automated manufacturing techniques, (3) minimal restriction to free movement of air currents around the Solar Cell Assemblies for convective cooling, and (4) rigid and uniformly flat support surfaces for the lens assemblies. The optimized design meets these requirements with a truss arrangement utilizing this (22 gauge), low carbon sheet steel to form the members of the truss. Using automated manufacturing techniques, the two identical sections of the structure can be die stamped, formed and folded to the required cross-sections and shape and welded together to form the Lens/Cell Module structure frame. Electric resistance spot welding is specified because of its adaptability to mass production.

An aspect of an open structure design is that rains or occasional washing with a spray of water from a hose should be sufficient to keep the facets free of dirt. The additional complications inherent with a closed structure design cannot be justified. The array always places the lenses facing up, thus the faceted surfaces of the lenses are toward the ground offering protection from falling objects (e.g., hail) and dirt settling out of the air. The open structure design, however, readily lends itself to installation of covers over the openings should they become needed at a future date. The Fresnel lens is attached to and supported by the Lens/Cell Module structure along a one inch wide section between the dual faceted areas and along the two edges which are parallel to the length of the facets. At three points along each support, screws extend through holes in the lens and structure, and are secured to the structure with lock nuts. Because the lens is made of clear optical grade acrylic which has an average thermal expansion coefficient approximately six times as large as the carbon steel structure to which it is fastened, the attachments were designed with clearances between the head of the screw and the lens to allow expansion or contraction of the lens independent

of the structure. All expansions and contractions are controlled from the center of the lens outward to the edges. Rotation of the lens relative to the structure is prevented during expansion or contraction by a close-fitting hole in the center of the lens and a slot at the outboard edge of the center support which allow motion in one direction only. The lens can slide freely at all remaining attachments since large diametrical clearances exist between the screws and the holes in the lens, and the bushings are slightly longer than the lens thickness. A desirable feature resulting from this type of connection is that no clamping loads are applied to the acrylic lens which could affect focusing.

Each Solar Cell Assembly is connected to the Lens/Cell Module structure through brackets that are attached to each end of the aluminum heat sink and to the bottom members of the structure. The attachments are located as close as possible to the intersection points of the individual members so that the loads can be taken out as axial forces rather than moments. The brackets are attached to the structure with screws which are tightened after the Solar Cell Assembly has been positioned relative to the lens for optimum performance. The difference in thermal expansion between the aluminum heat sink and the steel structure is accommodated by fixing one end of the heat sink to the bracket and allowing the other end to move by providing a slotted bracket with controlled clearances between the bracket and the heat sink.

The Lens/Cell Modules are attached to the tracking structure along the two edges which run parallel to the length of the lens facets. One mounting hole is located in each of the four (4) corners of the structure support flange. Each Lens/Cell Module is attached to the tracking structure with four screws through corresponding holes in the transverse beams. Shim washers placed between the Lens/Cell Modules and the transverse beams are used to adjust the orientation of each Lens/Cell Module. Thus, when the entire array is directed toward the sun, all Lens/Cell Modules will provide optimum performance.

2.1.2.2 Fresnel Lens

The solar photovoltaic power system incorporates a linear Fresnel lens array to concentrate solar energy onto the solar cells.

Westinghouse Drawing 389D858 in Appendix A is the manufacturing drawing to which the Fresnel lenses are procured. The basic specifications for the design of the lens are as follows:

- Aperture width. 16 inches
- Focal length. 16 inches
- Target (solar cell) width 0.32 inches
- Peak concentration on target. . . . 60 suns
- Solar distributions Air Mass 2

Since the lens plays a key role in determining operating performance of the proposed system, Westinghouse has opted to procure and evaluate prototype lenses manufactured to the above specification, from two suppliers: Swedlow, Inc., and 3M Co.

Manufacture of the Swedlow lens involves the direct casting of an acrylic formulation in a master mold containing the desired lens geometry. This casting process allows the formation of a high molecular weight, crosslinked polymer structure, designated as Acrivue 360 having an extremely high allowable service temperature (180°F). The weather resistance of cast acrylic has been determined experimentally to be satisfactory for the intended application.* Solar energy transmission through a flat sheet of acrylic is nearly 88% over the sun's spectrum, and drops to only about 78% after extreme aging. In the form of a Fresnel lens, transmission remains above 80%, the additional losses being due to increased surface reflectance from the steep facet angles and a slight increase in scattering. As a structural material, acrylic possesses excellent properties, amply demonstrated in pressurized fighter aircraft

* Sandia Laboratories report SAND 74-0241, "Effect of Outdoor Aging on Acrylic Sheet", 1974.

canopies. The tensile module of elasticity is 2.8 GPa (400,000 psi) with an ultimate tensile strength of 65 MPa (9,500 psi) at 4% elongation. Hail impact testing of Fresnel lenses has been initiated with limited impacts from 25.4 mm (1.0 inch) hailstones. At near terminal velocity, negligible damage was produced to 4.77 mm (0.188 inch) thick by 304.8 mm (12 inch) square acrylic lenses.

The 3M Fresnel lens is produced by manufacturing a high quality grooved film in a thin cross section in continuous rolls at high speed. This process, called the 3M ribbon lens film process, produces the optics at potentially very low cost.

The thin cross section film is then laminated to a heavy (3/16 inch) substrate manufactured by the fastest and most economical process. The cost of lamination is felt, by the manufacturer, to be more than offset by reductions in other costs. A sample of laminate has been subjected to 1500 hours of accelerated aging in an Atlas weatherometer corresponding to approximately 3-5 years field operation. Faint evidence of yellowing was observed, but the optical effects should be negligible.

A second potential advantage of the 3M process is that it reproduces accurately the fine groove structure that exists in precision master tooling, with the result that higher groove or facet frequencies can be produced (50 to 200 grooves per inch). Since each facet is a prismatic chord approximation of a curved surface, the higher frequency should improve optical performance.

2.1.2.3 Solar Cell Assembly

The Solar Cell Assembly (SCA) is composed of a series string of silicon solar cells mounted on a finned aluminum heat sink which acts as a substrate. The heat sink and cells will be described separately followed by a description of their assembly.

2.1.2.3.1 Aluminum Substrate

The configuration of the anodized aluminum substrate used as the base of the SCA is shown in Westinghouse Drawing 389D861 in Appendix A. It is formed in the cross section shown by extrusion through a die. The upper flat surface on the unfinned side of the bridge adjoining the two sets of fins is where the solar cells are mounted.

2.1.2.3.2 Solar Cell

The solar cell was developed by the Optical Coating Laboratories Inc. The cells are made from boron doped, single crystal silicon of 1 ohm-cm bulk resistivity. The junction is formed by thermal diffusion of phosphorus. The depth of the junction is approximately 0.4 micrometers. Aluminum is alloyed to the back side of the cell to form a P+ layer. Photolithography is used to define the grid pattern. Titanium-palladium-silver metals are evaporated and sintered under a reducing atmosphere to form the N and P contacts. To increase the conductance, the silver on the front contact and grids is built up by electrolytic plating. A double layer (Al_2O_3 and TiO_2) antireflection coating is applied to the active surface to minimize the reflection loss.

The mechanical dimensions of the cell are shown in Drawing No. TAA-12289, Revision A, included in Appendix A.

Measured cell performance at 50X and 44°C is as follows:

$V_{OC} = 0.66$ Volts	$V_{MAX} = 0.475$ Volts	$P_{MAX} = 3.8$ Watts
$I_{SC} = 9$ Amp	$I_{MAX} = 8$ Amps	FFF = 15.6%

2.1.2.3.3 Assembly

The material specifications, assembly procedures, and quality assurance provisions for the SCA's are described in the two specifications contained in the drawing package entitled, "Specification For A Concentrator Cell Module", and "Design of Westinghouse Concentrator Cell Module". These specifications, together with eight OCLI drawings describe the design and fabrication of the assembly, and are contained in Appendix A.

The copper spring interconnect system is unique and difficult to visualize from two-dimensional drawings. Shown in Figure 2.1.5 is a three-dimensional drawing portraying the method of using the copper springs to attach to the back contact of one cell through the silicon spacer, while attaching to the front contact of the adjacent cell.

The materials used to fasten the cell to the substrate and fasten the cover glass to the cell are identified in the cross section of the Solar Cell Assembly shown in Figure 2.1.6.

2.1.2.3.4 Prototype SCA Test Results

Two prototype Solar Cell Assemblies were fabricated. The physical shape and features of the units are shown in the photograph presented in Figure 2.1.7.

Because of the shortage of time, electrical tests on the SCA's were performed only at 1 sun and 28°C using an AM1 simulator. The resulting test data for one SCA is shown in Figure 2.1.8. The maximum power point of 979 mW occurs at 5.9 V. The short circuit current is 180 ma, and at 50X would be approximately 9 A which correlates well with the measured cell short circuit current discussed in Section 2.1.2.3.2. An approximate calculation of module efficiency at AM1 and 28°C yields 15.5% for the SCA tested.

2.1.2.4 Lens/Cell Module Interconnection

Each tracking array contains 48 Lens/Cell Modules which must be interconnected into three series strings of 16 each to be paralleled at the field DC bus voltage. The interconnection scheme cannot be arbitrary because of systematic temperature variations over the plane of the tracker. If the interconnection scheme is not properly chosen, these temperature variations would give rise to improper current division between the three series strings.

Figure 2.1.5 Solar Cell Assembly interconnection technique

Dwg. 7690A61

Solar cell assembly mounting configuration

Figure 2.1.6 Cross section of the Solar Cell Assembly showing the cell mounting techniques used

Figure 2.1.7 Photograph of the prototype Solar Cell Assembly constructed

Figure 2.1.8 Final test results on Solar Cell Assembly #2
at 1 sun taken before shipment to Westinghouse

An analysis was made to determine an optimum interconnection scheme as described in Section 1.5.3. This has resulted in the interconnection diagram shown in Drawing 102E238 included in Appendix A.

2.1.3 Annual Array Efficiency

The annual array efficiency, n_a , is defined as follows

$$n_a = \frac{\text{annual array field energy output}}{\text{annual array field energy incident on faceted lens area.}}$$

From the results of the annual energy simulations described earlier, n_a is evaluated as follows;

$$\frac{95,200\text{kWh}}{757,000\text{kWh}} = 12.6\%$$

2.1.4 Array Material Costs

An estimate was made of array material costs in 1975 dollars assuming large volume production. Material unit costs used are listed in Table 2.1.2 which is taken from Appendix B of the Proposal Instructions.

The results are presented in Table 2.1.3 which shows an array unit cost of \$5,180 or \$155.34/m² of lens aperture area. Material weights were calculated using the drawings included in Appendix A. It should be noted that the Westinghouse tracker assembly has been designed along the lines of farm machinery. That is, weight has been sacrificed to eliminate the need for precision-machined (and therefore costly) elements. For this reason, it is anticipated that the actual cost per pound of material associated with volume production of our proposed system should be substantially lower than that of devices requiring precision elements (i.e., the cost per pound of tractors is significantly lower than the cost per pound of wrist watches). For the same reasons, high volume assembly labor costs are also minimized with the proposed design.

Using the cost data in Table 2.1.3 in conjunction with the array energy balance presented previously in Table 1.4.7, an array material cost of \$1.38/Wp of array power generation is determined.

TABLE 2.1.2

MATERIAL COST LIST FOR CALCULATING PV ARRAY MATERIAL COSTS
(Taken From RFQ EG-77-D-04-0035, Appendix B)

Aluminum

Extruded	\$ 0.85/pound
Sheet 5052	1.10/pound
Honeycomb	11.00/pound
Structural	1.05/pound

Steel

Structural	0.38/pound
Sheet	0.25/pound
Gears, chains, linkages	4.00/pound
Gear boxes	4.00/pound
Misc. steel parts	0.50/pound

Motors

3.00/pound

Aluminum

15.00/pound

Copper

1.70/pound

Glass

Low iron soda lime	1.20/pound
Window glass	0.30/pound

Plastic

ABS	0.75/pound
PVC	0.35/pound
Acrylic	0.90/pound

Aluminized Films0.20/ft²Kovar

23.00/pound

Silvering Glass0.50/ft²Sagging Glass0.75/ft²Cells and Interconnections0.25/cm²

TABLE 2.1.3

PHOTOVOLTAIC ARRAY MATERIAL COST SUMMARY

<u>Item</u>	<u>Quantity Per Tracker</u>	<u>Estimated Cost</u>		
		<u>Unit*</u>	<u>Total (\$)</u>	<u>Cost/m²**</u>
Heat Sinks	1672 lb	\$0.85	1421	44.82
Lenses	480 lb	0.90	432	13.62
Cells & Interconnections	6086 cm ²	0.25	1521	47.99
Steel, Structural	270 lb	0.38	103	3.24
Steel, Sheet	2368 lb	0.25	592	18.67
Steel, Miscellaneous	200 lb.	0.50	100	3.15
Gearboxes	206 lb	4.00	824	25.98
Motors	39 lb	3.00	117	3.69
Copper, Wire	10 lb	1.70	18	0.56
Insulation, Wire	10 lb	0.35	4	0.11
Electrical/Electronic, Misc.	<u>16 lb</u>	<u>3.00</u>	<u>48</u>	<u>1.51</u>
TOTAL	5282 lb.		\$5180	\$163.34

*See Table 2.1.2

**Cost per square meter calculated on basis of array faceted lens area (31.7 m²).

2.2 Power Conditioning Subsystem

The Power Conditioner (PC) to be used is Westinghouse Model AVI 503-A 50kVA power conditioner for photovoltaic applications developed for the Sandia Laboratories by the Westinghouse Aerospace Electrical Division under Contract No. 07-6940. The details of the design, prototype construction, and test results are contained in the final report on the contract.*

The PC to be used contains two major subsystems in the power flow path as shown in Figure 2.2.1. The varying DC voltage from the solar array field feeds into a chopper regulator which provides a regulated output of 300 V when the input is in the range of 200 to 300 V. When the input is in the range of 300 to 350 V, the DC link voltage is not regulated.

The output of the chopper/regulator feeds into a DC-to-AC inverter which produces a high quality 60 Hz sinewave output. The inverter is self-commutated and synthesizes the sinewave output by adding a number of phase-shifted 60 Hz squarewave voltages. An advantage of this type of inverter circuit is its high part load efficiency.

The PC incorporates a Power Control Unit which performs all logic and control functions required PC. As shown in Figure 2.2.2, the Power Control Unit, which includes a microprocessor, provides all drive signals for the power semiconductors in the chopper/regulator and DC-to-AC inverter, and in addition, it controls the input and output conductors of the PC

Further information regarding detailed performance specifications is contained in the product description brochure reproduced in the following

*"Design and Construction of a 50kVA Power Conditioning Unit for Photovoltaic Power Systems; Task II - Detail Design/Task III Construction and Test Program", SAND 79-7010, April 1979. Final report to be published.

Dwg. 6449A86

DC Input Voltage Range	200 - 300 VDC
Extended Range With Specification Deviations	300 - 350 VDC
Output Voltage	277/480 V, 3 Φ, 4 Wire
Output Power	50 KVA (Unity PF, Balanced Loads)
Output Voltage Regulation	± 5%
Total Harmonic Distortion	5% Max
Utility Paralleling Capability	Included
Load Sharing Capability	Included
Array Maximum Power Point Tracking Capability	Included

Figure 2.2.1 Power conditioner performance specifications

Figure 2.2.2 Block diagram of power conditioner

AVI 503-A

- High-quality 60-Hertz, 3-phase output with synchronization and AUTOMATIC PARALLELING with the utility grid.
- Microprocessor-controlled PEAK POWER TRACKING and HIGH PART-LOAD EFFICIENCY to maximize the photovoltaic system output under varying operational conditions.
- STAND-ALONE operation or MULTI-UNIT PARALLELING with the utility grid.
- UNATTENDED OPERATION with automatic/manual startup and breaker/contacter control with a UNIQUE STARTUP SEQUENCE to verify the array power integrity.
- Enhanced INSTALLATION and MAINTAINABILITY by a single cabinet configuration with integral cooling and internal modularity.
- ENERGY STORAGE CONTROL interface signal for battery charge/utilization.

Westinghouse

**Power
Conditioning
Units for
Photovoltaic
Applications**

**A family of standard
power conditioning units
with a unique control
concept to meet your
operational requirements.**

The **Westinghouse AVI 503-A** is the first unit of a family of ratings specifically designed to meet the wide range of applications for Photovoltaic Systems, with enhanced performance. Westinghouse has an extensive history in the successful application of new technology in meeting power system requirements. This expertise has been fully utilized in the design of the AVI 503-A.

The **Westinghouse AVI 503-A** provides the COMPLETE INTERFACE between the solar photovoltaic array and the loads/utility grid with optimum performance.

**The Westinghouse
AVI 503-A
POWER CONDITIONING
UNITS**

Special Features

Power Quality

The power output is equivalent to utility power quality, permitting the operation of all normal loads in both the stand-alone or utility-tie configuration.

Automatic Operation

The Power Conditioning Unit can be operated unattended. The unique control system provides for automatic startup when the solar photovoltaic array can sustain loads. It also automatically parallels with the utility grid.

Simplified Installation

Installation of the unit is simplified by the single cabinet design with integral cooling. All normal contactors are provided for system control. IT PROVIDES ALL THE INTERFACE ITEMS FOR MOST INSTALLATIONS.

Protection

Protective functions exist for both the load and the Power Conditioning Unit.

Unit Paralleling

As many units as required for the system rating can be paralleled with the utility grid.

Utility Grid Compatibility

Total harmonic distortion is less than 5 percent. Automatic tracking of frequency and voltage over a wide range eliminates disturbance to the utility grid.

Peak Power Tracking

The microprocessor Power System Controller provides peak power tracking to maximize the solar photovoltaic output without resorting to simulation or a separate solar sensing element.

Metering and Output Signals

A variety of metering connections and output signals for a wide latitude in system configurations for special or experimental applications is provided.

**For additional information contact:
Marketing Manager
Westinghouse Electric Corporation
P.O. Box 989
Lima, Ohio 45802
Telephone (419)224-0134**

Parameters

Part Number	947F901-1
KVA	50 continuous, 100 for 5 seconds
Output	60 Hz, 3-phase, 4-wire, 120/208 volts
Harmonic Distortion	Less than 5 percent
Efficiency	At 0.9 power factor: under 5% load, 64% under 25% load, 86% under 100% load, 91%
Output Protection	Over voltage Under voltage Over current Abnormal frequency
Input	200-300 Volts DC (up to 350 volts DC with slight deviations to specifications)
Environmental	Ambient Temperature: -10° to +45° celsius Relative Humidity: 96% (non-condensing) Barometric Pressure: 790-520mm Hg
Weight (lbs)	1830
Size	24-inch standard rack on 4-inch casters 28.3 inches wide, 30.3 inches deep, 91.0 inches high including casters
Additional Information	Solar Photovoltaic array peak power tracking Load shed signal on overload Battery charger control signal Automatic startup and utility grid paralleling

pages. In addition, the following drawings relating to the PCU are contained in Appendix A.

ED385759 Block Diagram of Logic for PCU

ED385760 Schematic-Sandia Labs. PCU Power Stage

ED385761 Interconnection Diagram for PCU

ED386071 System Logic Diagram for PCU

Y947F995 Outline Drawing for PCU

2.3 Utility Protection System

The prime protection in the system will be provided by the system control computer, which will open the power conditioner's main contactor when necessary. The utility protective relaying system will operate secondary to the system control computer. A schematic diagram is shown on Drawing 102E239, Appendix A.

The basic utility protection is provided by an over and under voltage relay. If a fault occurs on the utility distribution line, an overcurrent and/or undervoltage condition can exist which will open the substation circuit breaker or line recloser. The power conditioner will then go into an overload condition by attempting to supply all of the on-site load and its output contactor will open. If for some reason this should fail to occur, then the utility undervoltage relay will operate to disconnect the solar energy system from the utility grid.

There are a variety of sources that can cause overvoltage in an electrical system. These include, for example: 1) static, 2) switching surges and transients, 3) lightning, and 4) resonance in series inductive-capacitive circuits. The overvoltage relay will protect against any high voltage condition in the event of malfunction or failure of the power conditioner output contactor to open.

An underfrequency relay is also included in the utility protection system to disconnect in the event of any frequency deviation malfunction problems.

The utility protection system is housed in a steel cabinet to be located adjacent to the data building. Power from the power conditioner will be connected to the utility grid system within this cabinet via the secondary terminals of the main power transformer serving the maintenance facility.

Although the Power Conditioning equipment is basically self-protecting, a protective system consisting of 3-potential transformers rated 480-120 volts and a General Electric Co. Model #121AV51D1A over voltage relay will be installed to open the Power Conditioners output contractor if a ground occurs on the section of bus between the Power Conditioner and the pad mount step-down transformer secondary winding. The potential transformers are connected with the 480 volt winding wye-grounded and the 120 volt winding broken delta, with the ends of the broken delta winding connected to the relay.

2.4 Electronic Subsystem

The electronic subsystem (ES) of the 50 kW concentrating solar photovoltaic power system has the following functions:

- Aiming each tracking array directly at the sun during daylight hours
- Providing automatic or manual control of the arrays to satisfy all operation/maintenance requirements.
- Acquiring, evaluating, displaying, and storing of performance data.
- Providing system supervisory control

The electronic subsystem is made up of the following components:

- Distributed Digital Computer Network
- Tracker Assembly Elevation and Azimuth Encoders
- Tracker Assembly Elevation and Azimuth Drive Motors and Motor Controller

A block diagram for the ES is presented in Figure 2.4.1. The computer hardware is manufactured by Texas Instruments. The ES design and component selection are based on achieving the lowest possible cost (large volume production), while providing the operational flexibility required to generate meaningful data during Phase III of the proposed program. The prototype electronic system hardware used for Phase I testing is shown in Figure 2.4.2.

2.4.1 Distributed Digital Computer Network

The distributed digital computer network utilizes a minicomputer as a Master Controller (MC) and 15 microcomputers, one on each Tracker Assembly Controller (TAC). An open loop sun-tracking configuration is utilized in which sun position is calculated in real time at the MC from date, time, and geographical position data, and is transmitted to each TAC. At each TAC, the sun angles are compared with the tracker

Figure 2.4.1 Distributed computer configuration and control block diagram of the tracking electronic subsystem

Figure 2.4.2 Electronic system demonstration hardware

angular position measured by two encoders, one in elevation and one in azimuth. Upon evaluation of the MC sun data and the local encoder output, the TAC determines commands for the tracker assembly drive motor controllers. The motors are turned on with the appropriate track or slew speed (depending on the tracker position error) in the proper direction until the correct tracker orientation is achieved (when the MC sun angles are identical to the position encoder angles). The motor is then de-energized until an error between the respective tracker angle and sun angle, or any other angle commanded by the MC, is again developed in either azimuth, elevation, or both. In order to compensate for any array drift which may occur during the life of the system, the TAC microcomputer performs occasional pointing optimization by maximizing the total array power output.

In the design of the distributed digital computer network for the ES, the latest advances in microcomputer technology have been fully exploited to minimize both hardware costs and software efforts. As depicted in the block diagram of Figure 2.4.1, the network consists of the Texas Instrument 16-bit minicomputer Model 990/10, with associated peripheral equipment in the MC. A Model TM 990/100 (also by Texas Instruments) is in each of the 15 TACs at the respective tracker assemblies. All 15 terminals are serviced by a single serial asynchronous communication line by means of a twisted shielded pair from which all TACs are "multidropped." The MC message for any of the TACs is preceeded by the address for the particular unit. The addressed TAC accepts the message by recognizing the respective address while all the other units ignore it. There is also a common address for messages to be received simultaneously by all TACs. The common address is used, for example, for the transmission of sun data if all units are to track the sun. The TACs respond on the same communications line by sending the data required by the MC each time a message is received. At each of the TACs, a Texan Instrument 16-bit microcomputer Model TM 990/100 is used to implement the commands received from MC. The microcomputer board contains a single chip microprocessor and associated Erasable Programmable Read Only Memory (EPROM), Random Access Memory (RAM), and Input/Output (I/O) programmable controllers.

The microcomputer inputs are data received on the serial communications line described previously, as well as the outputs of the two position sensors. The position sensor data are accepted through a specially designed logic circuit in the microcomputer. The logic circuit also includes provisions for monitoring the array power output as well as other signals used for control and data acquisition.

The minicomputer and microcomputers used for the implementation of the ES are completely compatible with each other. High level languages, PASCAL and BASIC, are used in the software to permit a minimum level of specialization required in the program development, maintenance, and updating. The main program for the TAC resides in EPROM and can be easily modified and updated during system operation. The MC minicomputer is used for both power system control and for microcomputer software development. The communication subroutines use a checksum (the sum of all bytes comprising a message) at the end of each message so that the occurrence of transmission errors can be detected at the receiving end of the message. The minicomputer and microcomputer software has the basic overall function of ensuring that the commanded action, including tracking of the sun, is implemented at the tracking assembly. The appropriate software routines are called into execution to implement the various modes of operation, including startup, normal tracking, synthetic tracking, maintenance, shutdown, emergency operation, and contingency operation. Manual intervention is always permissible during any phase of the power system operation.

2.4.2 Tracker Assembly Position Sensor

The position encoder selected for measurement of the tracker azimuth is a 9-bit absolute encoder, available from Vernitech, mounted on the azimuth drive sprocket. The encoder provides an unambiguous measurement of the sprocket orientation while the number of sprocket revolutions is evaluated in the microcomputer software. With the ratio of the azimuth ring diameter and sprocket diameter of 16:1 (approximately), the effective accuracy of a 13-bit encoder (0.75 milliradians) is achieved in this configuration. This is the required accuracy for the tracker azimuth.

The elevation position of the tracker needs only to be measured with one-fiftieth of the accuracy required for azimuth position encoding. A more economical system of incremental counts, available from Sprague, is used on the elevation sprocket.

The microcomputer software keeps track of the total count accumulated from the elevation sprocket, representing the tracker elevation angle, and the total number of azimuth sprocket revolutions. If these two data are lost for any reason (power interruptions, etc.), the tracker is moved until an initializing pulse is received from the elevation and azimuth ring. The pulse, one for each angle, is given by a precisely positioned switch on the respective ring and is used by the computer for re-initializing the elevation sprocket count and the azimuth sprocket revolution count.

Westinghouse evaluated a large number of encoder techniques with in-house funding during Phase I of the program and has concluded that the selected approach is the most reliable and provides the most attractive cost projection for large quantities.

2.4.3 Tracker Assembly Drive Motors and Controllers

Solid state frequency speed control of AC induction motors has been selected as the most cost effective and reliable way to achieve tracker control for both the elevation and azimuth axes. Drawing 102E221, Appendix A, shows the overall block diagram of the motor/control system.

Two-frequency changing speed controllers manufactured by Ramsey Controls provide the tracking power for all the azimuth drive motors. One of the units controls eight azimuth motors while the second unit controls seven azimuth motors. The Ramsey units provide the low frequency (6 Hz) power for tracking operation (115 rpm). For stowing speed (1725 rpm), the frequency controllers are bypassed and the azimuth drive motors are placed directly on the 60 Hz power line. Since the elevation drive motors only need operate at one speed (1725 rpm), they are driven directly from the line through the power switching circuitry. To ensure that the drive system does not operate beyond normal end limits, limit

switches are provided to inhibit motor operation in the overtravel zones.

Induction motors, besides being readily available, are the simplest, most reliable and least expensive type of electric motors. The Westinghouse 1/4 hp, 230V, 60 Hz, three-phase, 1725 rpm induction motor, a proven industry standard, has been selected as the drive motor for the tracker elevation and azimuth drive systems. The design of this motor incorporates thermal protection, ball bearings and a totally enclosed non-ventilated heavy duty NEMA 56 frame to ensure high reliability in tough environments with mean-time-to-failure in excess of 30 years. These features ensure low maintenance and low mean time to repair. All motors have double-ended shafts to allow manual positioning of both the elevation and azimuth axes with a standard hand-held portable drill motor.

The transistor-transistor logic of each controller interface permits independent control of all tracker drive motors in both the forward and reverse directions. Each TAC microcomputer delivers the logic level command signals to the controller to implement elevation and azimuth position changes as determined by position feedback sensors. Signals from the interface logic circuits control gating inputs to the AC power switches that provide the three-phase power to the drive motors.

Drawing 102E225, Appendix A, shows the schematic of the logic, AC power switches, and modes of operation. The logic gates and inverters are available from Texas Instruments. The AC power switches are provided by Crydom. The AC power switches feature optical coupling at the input circuitry to provide isolation between the high voltage AC source and the low voltage digital computer signals. The internal triacs are fired at zero crossings of the AC power line to minimize RFI* noise generation. The DC power for the microcomputer, position sensors, and interface logic is provided by Standard Power Supplies.

2.4.4 Power Distribution for the Array Field

The design of the power distribution system for the purpose Westinghouse 50 KW array field utilizes standard electric utility practice and equipment with known field experience, reliability, and costs for

*Radio Frequency Interference

both equipment and installation. The proposed design results in a cost effective and reliable power distribution system.

The power distribution system consists of two distinct subsystems identified as the tracking power and DC output power systems. The tracking power system consists of the cables, circuit breakers, transformers, and switches required to provide the tracker drive and control systems with power. As shown on Drawing 102E221 included in Appendix A, tracking power is supplied from the data building where the incoming 277/480 volt grounded wye is transformed to 240 volt delta for utilization by the field tracking devices.

The tracking power distribution system is a radial circuit configuration. The two-frequency control units are wired in parallel to a single phase 240 volt source using No. 14 AWG conductor protected by a 10 amp circuit breaker. The output of each frequency control unit is wired to the control box on each group of seven (or eight) trackers using No. 14 AWG conductor. The frequency controllers provide a 6 Hz, 3 phase output which drives the azimuth motors at tracking speed. The frequency controllers will be pad mounted as shown on Drawing 650A998 in Appendix A.

Three phase, 240 volt power is wired to the control box on each tracker with each circuit wired to two or three trackers to be compatible with the trenching layout, Drawing 102E218 in Appendix A. Each of these circuits is protected by a 15 amp circuit breaker located in the tracking power distribution panel in the data building.

As shown on the trenching layout, all cables are direct buried in a three foot deep by three foot wide trench with an eight inch vertical separation between communication, tracking power, and output power cables. Soil conditions at the site are such that the excavated material is suitable for backfilling the trench. Prior to and after installing cables in the trench, the backfill material is compacted. The layout of the trenches maintains straight runs with right angle routing which allows for easy location of all cables. Cables crossing under roadways are protected by conduit for the width of the roadway.

The DC output power system consists of the cables required to transmit the power generated at each array to the DC power bus located in the data building. The system is designed to limit the voltage drop between any array and the DC power bus to 2 percent of minimum output voltage. Two No. 6 AWG conductors are installed from each array to the DC power bus where the outputs of all fifteen arrays are wired to the DC power bus in parallel.

The cables used for the power distribution system consist of coated, stranded copper conductors encapsulated in heat resistant, mechanically rugged, ethylene-propylene based insulation with a hypalon jacket which provides excellent resistance to mechanical abuse and weathering making it suitable for direct burial. The routing of the power distribution cables is specified in Drawing 650A993 in Appendix A, which identifies cable numbers, from/to points, trench numbers, wire size and approximate cable lengths.

2.4.5 System Supervisory Control

Each of the two major subsystems, the tracking arrays and the power conditioner, is controlled by its own dedicated computer. In the case of the arrays, elevation and azimuth are calculated by a minicomputer which interfaces with a microprocessor in each tracking array as described previously. The power conditioner includes its own dedicated microprocessor which controls its input and output contactors. As a result, little supervisory control is needed except to provide interfacing commands to insure that the arrays and power conditioner operate in the proper modes at the proper time.

The five major commands which will be available in the supervisory control section of the minicomputer are discussed below.

2.4.5.1 System Operate

This command enables the system to operate in the normal mode. The minicomputer drives the arrays to track the sun. When the array output is sufficiently high, the power conditioner senses it and closes its input contractor to supply power if all other conditions are proper.

Conversely, if the array output voltage drops below a certain level, the power conditioner will automatically shut down.

2.4.5.2 System Shutdown

The second command simply tells the system to shut down so that tracking ceases and the power conditioner input and output contactors remain open.

2.4.5.3 Track Without Power Conversion

The third command permits tracking but eliminates power conversion by prohibiting the power conditioner input and output contactors from closing. This command is used to conduct experiments.

2.4.5.4 Stow Arrays

The fourth command instructs the arrays to slew to the stowed position and prohibits power conversion. This command is used in the event of oncoming severe weather.

2.4.5.5 System Lockout

The fifth command prevents power conditioner cycling in event of a fault. If an overcurrent condition occurs causing the power conditioner overcurrent limit to be reached, the power conditioner will turn off and then attempt to restart. If the fault persists, the power conditioner will continue to cycle. The supervisory control will permit three such reclosing cycles and then command the power conditioner to shut down and await the attention of service personnel. This command will also activate an alarm at the utility dispatch center to call attention of the dispatcher to the need for service.

2.5 Instrumentation System

2.5.1 Types of Data Acquisition Systems Used

The instrumentation system comprises three separate data acquisition systems. A brief description of each of these together with the purpose of each one is presented in the following sections.

2.5.1.1 Solar Energy System (SES) Data Acquisition System

The tracking arrays are controlled by a Texas Instruments Type 990/10 minicomputer which has sufficient excess computational and storage capacities to serve as a data acquisition system. It will log, process and display, or print data as required.

The primary purposes of this system will be to acquire and display data during system checkout or when service is required, and to make available data to be used to evaluate system performance when special experiments are performed during Phase III.

The Texas Instruments system is completely self-contained with provision for keyboard command entry, CRT visual display, and printed copy output.

2.5.1.2 Georgia Power Company (GPC) Metering

The Georgia Power Company through the Southern Company, operates one of the largest utility data centers in the United States. The data acquired in this program will be processed at this facility which has extensive software development capability for data translational analyses.

Data will be logged using a Fairchild Power Demand Storage Unit (PDSU) which records demand and energy on magnetic tape at 15 minute intervals. The unit is capable of storing 45 days of data and includes a battery backup power supply to prevent loss of data in the event of a utility outage.

At appropriate time intervals, the data stored in the PDSU's will be transferred to cassettes using a Fairchild Portable Recording Device. The cassettes will then be dumped into a Texas Instruments terminal which interfaces with the Southern Company computer facility.

The data will be used by the Georgia Power Company during Phase III and afterward for revenue metering and dispatching purposes as well as system evaluation to be reported to DOE on an annual basis.

2.5.1.3 On-Site Data Acquisition (ODAS) System

The On-Site Data Acquisition System will be furnished by DOE and will log data independent of the other two systems. In some cases, common transducers may be used for all three systems, but operation of the solar energy system and the two previously described data systems will be unaffected by the presence or absence of the ODAS.

Data logged by the ODAS will not be processed on-site, but will be transferred via telephone lines to a national data reduction center for processing and reduction. However, raw data logged can be accessed on-site via a visual display or hard copy printer.

The ODAS will serve two basic purposes. First, it will provide data for DOE to use to evaluate the results of all PRDA 35 systems on a uniform basis. Secondly, it will provide detailed results of several special parameter measurements needed to evaluate the design of the tracking to photovoltaic arrays utilized.

2.5.2 Definitions of Parameters to be Measured

A list of parameters to be measured is provided in Table 2.5.1. Shown also in the table are the total quantity of measurement points for each parameter, the interval between parameter measurements, and which of the three data acquisition systems will record them. The ODAS will record all parameters, necessitating 278 input channels for these parameters alone.

Solar cell assembly temperatures will be measured at 38 key positions on each of two instrumented arrays. The locations of these measuring points on the instrumented arrays are shown in Figure 2.5.1.

TABLE 2.5.1

DEFINITION OF DATA ACQUISITION REQUIREMENTS

<u>Parameter</u>	<u>Total Quan.</u>	<u>Sampling Interval</u>	<u>SES</u>	<u>GPC</u>	<u>ODAS</u>
On Instrumented Arrays #1 and #2					
Series String Currents	6	10 min.			X
Lens/Cell Module Voltage	96	10			X
Solar Cell Assembly Temperature	76	30			X
Strain Gages	20	10			X
On All Arrays					
Voltage	15	10	X		X
Current	15	10	X		X
Power	15	10	X		X
Energy	15	60	X		X
On Array Field					
Voltage	1	10	X		X
Current	1	10	X		X
Power	1	10	X		X
Energy	1	60	X		X
At Power Conditioner Output					
Voltage	3	10	X		X
Current	3	10	X		X
Power	3	10	X	X	X
Energy	1	60	X	X	X
On Array Tracking Drive Circuit					
Power	1	10	X	X	X
Energy	1	60	X	X	X
GPC Demand and Energy Measurements					
Energy drawn from grid	1	15		X	X
Energy fed back to grid	1	15		X	X
Data Building load	1	15		X	X
Maintenance building load	1	15		X	X

Figure 2.5.1 Designation of thermocouple temperature measurement locations on instrumented arrays

In addition to the electrical, thermal, and mechanical parameters measured, a weather station will be furnished by DOE which will provide measurements of the eight parameters listed in Table 2.5.2. The ODAS will include input channels to log these parameters as well as the others previously discussed. Some of these weather parameters will also be included as inputs to the Solar Energy System and Georgia Power Company data acquisition system as well.

2.5.3 Soft Data

In addition to the hard or transducer data to be logged as described in the previous sections, much soft data which by nature is unquantifiable will be recorded. A list of some of these parameters is presented in Table 2.5.3. Others will be added as necessary.

TABLE 2.5.2

LISTING OF PARAMETERS TO BE MEASURED TO THE WEATHER STATION

	<u>Data Item</u>	<u>Recording Interval</u>	<u>Comments</u>
1.	Direct Normal Radiation	10 min.	Recorded during day-light hours
2.	Total Horizontal Radiation	10 min.	Same
3.	Reference Solar Cell (Short circuit current)	10 min.	Same
4.	Wind Speed/Direction	30 min.	Recorded for DOAA data base
5.	Barometric Pressure	30 min	Same
6.	Ambient Air Temperature	30 min.	Same
7.	Humidity or Dew Point	1 hour	Same
8.	Precipitation	1 hour	Same

TABLE 2.5.3
SOFT DATA PARAMETER DESCRIPTIONS

1. Site description
2. Purchased equipment costs
3. Capital and construction costs
4. Construction schedule
5. Scheduled cleaning, maintenance, calibration, and repair
6. Unscheduled cleaning, maintenance, and repair
7. System downtime
8. Equipment failures
9. Pre-operational
10. Environmental consideration
11. Utility interface
12. Safety considerations
13. System schematic
14. Inverter harmonic content
15. System description parameters

2.6 Data Building

The data building is a multi-purpose facility designed to house the master control computer, the power conditioning equipment, the house service transformer, metering equipment, protective relaying, and data recording equipment. Drawing 389D864, Appendix A, shows details of the building and a floor plan.

The house service transformer is a 15 kVA, 277/480 - 120/208 volt dry-type unit supplied from the 480 volt meter and relay cabinet via a #1/0 aluminum-conductor quadraplex underground cable. The tracking field transformer is a 15kVA, 277/480-240 volt dry-type unit wired to the incoming #1/0 cable. A fused, three-pole disconnect switch will provide the house service and tracking field transformer protection and local disconnect.

The 120/208 volt output of the house service transformer supplies the data building loads including the instrumentation systems. This circuit is metered by a three-phase four-wire wye watthour meter having a pulse generator to provide a data input to the instrumentation recorder.

The output of the tracking power transformer is connected to a 240 volt power distribution panel board having a 50 Ampere main breaker, one 10 Amp, three-pole branch circuit breaker, and six 15 Amp three-pole branch circuit breakers which provide the power to operate the trackers. A watthour meter is connected to the 240 volt bus provided with an impulse generator to provide a data input to the instrumentation recorder to monitor tracking power.

The control room contains all the equipment necessary to control and monitor the required AC and DC power systems. The operator's console contains the master control computer, operators keyboard, and CRT display of system functions. This equipment is similar to that shown in Figure 2.4.2.

The DC meter panel, Drawing 389D863 contained in Appendix A, contains meters for monitoring the current from each array, a switch selectable meter for monitoring the output voltage of each array, meters for monitoring the power delivered by each tracker, and meters for monitoring the total array buss voltage, current, and power .

The AC meter panel, shown in Drawing 389D862 contained in Appendix A, contains meters for monitoring the line-to-neutral phase voltages, phase currents, and phase power from the power conditioning equipment. The AC meter panel also contains a three-phase watthour meter for display of total energy. In addition, a wattmeter and watthour meter are provided to display the power and energy consumed by the trackers. Space is provided on the AC and DC meter panels for system power supplies and future controls and displays if required.

The DC termination panel contains terminal strips for terminating all field and control room cabling, shunts for measuring each tracker current, ranging resistors for scaling meter displays, signal transducers to interface a data acquisition system, isolation switches for array testing purposes, and total array buss for paralleling all trackers. The total array buss is connected to the power conditioner.

The AC termination panel contains the terminal strips for terminating the power conditioner output and instrumentation required for the AC meter panel. The output AC power to the utility grid is terminated within the AC termination panel.

2.7 Lightning Protection

Lightning protection is achieved by a protection system connected to a low impedance "ground field." A ground field consists of bare copper wire buried in the ground in a grid pattern to establish a low uniform impedance as shown in Appendix A, Drawing 102E218.

The lightning protection system consists of two sets of steel poles tied together with 2/0 ACSR wire strung overhead. These are connected to the ground field which dissipates any lightning surges induced in the overhead wire. Also, all circuits (AC and DC) will have varistors connected to the ground field at various key points in the system. Each tracker assembly in the array field is electrically connected to the grid through steel columns located in each array foundation.

Lightning protection for the AC output is provided primarily through the utility distribution system. Protective relaying, upon sensing the lightning fault condition, opens the substation circuit breaker or line recloser for a short time interval (30 Hz or less). The induced voltage is then dissipated through low impedance grounded lightning arrestors.

During Phase 11, Georgia Power Company will make ground resistance measurements in the immediate vicinity of the array field, and complete detail design for the lightning protection system and ground field.

3. ENVIRONMENTAL ASSESSMENT

3.1 Site Description

The proposed site of the Minola Road Concentrating Photovoltaic (MR-CPV) demonstration system is located adjacent to a Georgia Power Company (GPC) vehicle maintenance facility in DeKalb Co., GA.

As a result of construction of this facility, the site has already been altered from its natural state. The alteration included the addition of fill dirt, packing and grading for proper drainage. This work was completed in 1977.

Since all major site alterations have already been completed, it is expected that the proposed Minola Road-Solar Concentrating Photovoltaic project will have minimum impact on the environment.

3.2 Site Location

The proposed MR-CPV site consists of approximately one acre and lies in DeKalb County, GA. It is 15 miles northeast of the Hartsfield International Airport outside of Atlanta and is within five miles of the intersection of Interstate Highway 20 (I-20) and Interstate Highway 285 (I-285). It is located near the intersection of Minola Road and I-20.

3.3 Geology

The proposed site is situated in the Winder Slope District of the Midland Georgia sub-section of the Piedmont Physiographic Province. The site is located in a low seismic risk zone. The only significant impact on the geology of the site will occur during the construction of the array foundations which will expose the soil to the forces of erosion.

3.4 Soils

There are four different series of soils on the site. In general, sandy and sandy-clay loams are characteristic. The soils have low to moderate shrink-swell potentials, implying relatively stable soil conditions for foundations. The soil erosion potential and impact have already been discussed in the Geology Section of this statement.

3.5 Climate

The climate of the central section of Georgia is classified as "Subtropical-humid". There are four distinct seasons, with summer being warm and having a maximum temperature occurrence of 90°F or higher on about half the days from June through August. The average minimum temperature during the summer is 66.7°F, and the average maximum for winter is 56.8°F. Freezing conditions occur infrequently during the winter. The highest temperature recorded near the site was 108°F in 1925, and the lowest on record was -9°F in 1899. The mean annual precipitation is 51.8 inches, and the average mid-day relative humidity is 56 per cent. Data over a 16-year period taken at Griffin, Georgia, indicates a mean daily solar radiation value of 254 langleys in January and 601 langleys in May, with April through August being about the same as May. It is not expected that there will be any impact on the climate around the site.

3.6 Surface Water Hydrology

The proposed site lies within the headwaters of the Snapfinger Creek Watershed of the South River Basin. The average annual runoff in the watershed is about 1.2 cubic feet per second per square mile. During the most severe drought on record, which occurred in 1954, the minimum one-day streamflow in the vicinity of the project site was less than 0.2 cubic feet per second. The creeks in and around the site are small streams of limited capacity, mainly because they are headwaters of the drainage basin. A retention pond is located on the premises to prevent overflow from the site. Therefore, there will be minimum or no detrimental effects.

3.7 Ground Water Hydrology

The availability and quality of ground water in the Piedmont Province is complex. In general, the yield of water wells constructed to obtain their maximum yield will average about 30 gallons per minute. Extreme yields range from 0 to 500 gallons per minute. There are several producing wells on or near the Minola Road site; however, many attempts at drilling wells in certain areas, such as for single-family residential use, have not produced water in sufficient quantity and quality. Depending on the location in the aquifer from which water is taken, iron may be present and, thus, require treatment for removal. There is not expected to be any significant impact on the ground water resources of the area. However, there will be a slight decrease in the amount of recharge, due to decreased vegetation and the impervious condition of the soil in some areas of the site.

3.8 Flora

The site is cleared graded land with fill dirt. At present, it is maintained in stands of Fescue grass. The adjacent area of the proposed site is covered with varying densities of second-growth mixed pine-hardwood canopy, with pines predominating. Scattered individual trees represent ages beyond 30 years. The site does not contain any rare or endangered species.

3.9 Fauna

A faunal inventory was prepared from field observations made on the proposed site in each representative habitat and from a literature research for the habitats common to the Georgia Piedmont. Among the mammals found, the most numerous were rabbits, squirrels and cotton rats. Most birds on the site are songbirds, but there is also a dense population of quail. There are not any known endangered species present, nor is the acreage at this site likely to be designated critical habitat for any endangered species. Also, since the site is already graded, there will be little or no habitat alteration.

3.10 Archaeology and History

A preliminary survey of the site was conducted in order to determine if any archaeological or historical resources were evident on the project site, but no unique historical evidence was found on the site. There are no structures on the site at present. A preliminary survey of the site did not reveal any archaeological resources. If any such resources exist, they are probably well below the surface since fill dirt covers the original top soil. Since Georgia has been occupied for about 10,000 years, there is a possibility of archaeological resources occurring all over the state.

If anything of archaeological significance is below the surface, it would be studied and reported, in accordance with federal procedures.

3.11 Air Quality

The existing particulate and sulfur dioxide concentrations in the ambient atmosphere at the site are well below the Georgia State Air Quality Standards. There are existing emission sources within several miles of the project site, but they have a negligible effect in the vicinity of the site and are not expected to impact the MR-CPV. It is not expected that the MR-CPV facility will contribute enough particulate, sulfur dioxide, nitrogen oxides, oxidants or total hydrocarbons to make a significant change in the existing air quality. The impact of any support or spin-off industries that occur in the vicinity of the site should be negligible because of the State of Georgia's Environmental Protection Division's authority to influence the location of industries through various regulations. In particular, the State of Georgia has been delegated the authority to conduct the required program to prevent significant deterioration of air quality. Finally, with respect to mobile sources, considering the location of the proposed MR-CPV site and the existing conditions, it can be assumed that the impact of the carbon monoxide from the residents and/or employees vehicles will not produce a violation of the State carbon monoxide air quality standard.

3.12 Water Supply

Water is supplied to the site by the DeKalb County Water Commission. Water supply is abundant. Water requirements of the MR-CPV are minimal and should not cause any adverse impact on water supply in the area.

3.13 Water Quality

There is some minor potential for detrimental impact to water quality from erosion during any construction. However, the existing retention pond should mitigate this problem.

3.14 Solid Waste

All solid waste produced by MR-CPV can be handled off-site, by DeKalb County disposal facilities in the surrounding area. The plants are operated to Georgia-approved Solid Waste Management Plan. Adequate facilities are available to handle any expected increase in solid waste due to the MR-CPV. Also, DeKalb County has adequate sewage disposal facilities for the MR-CPV.

3.15 Land Use and Zoning

The site is zoned for commercial and light industrial development, by the DeKalb County Zoning Commission. The MR-CPV will comply with any land use or zoning requirements of the DeKalb County Zoning Commission.

3.16 Socio-Economic

Any evaluation of the socio-economic impact of the site must include the Atlanta metropolitan area. Atlanta is one of the most rapidly growing metropolitan complexes in the United States, and it currently serves as the hub of the entire southeastern part of the nation. The educational, technological, and cultural bases existing in the area are particularly suited for the support of the MR-CPV.

There will be a positive fiscal impact on the county and on surrounding area. The economic spin-offs MR-CPV are impossible to measure at this time, but they will have a positive fiscal impact. Any increase in population will cause a minimal increase in the demand for schools, but the net effect will be beneficial because of the increase in the tax base from the industry.

3.17 Public Safety

Police, fire protection, hospital and health services are currently available in DeKalb County. In addition, DeKalb County is supported by other resources in Atlanta, particularly in the hospital and health services area. DeKalb County also maintains a Civil Defense and Disaster Protection Program.

The development of the MR-CPV at the proposed site may have an impact on public safety - but the impact should be minimal.

3.18 Energy

Georgia Power Company distributes electricity around the site. Power lines are in existence along Minola Road, which is adjacent to the northern boundary of the site. Natural gas is supplied to the area by Atlanta Gas Light Company.

3.19 Communication

Southern Bell Telephone Company serves the DeKalb County area. Overhead service lines currently run along Minola Road.

Newspapers prominent in the area include the Atlanta Journal-Constitution and the DeKalb News Sun. The area is also served by 32 radio stations in Atlanta and two local stations in Lithonia. More than a dozen public, private and educational television stations are based in Atlanta and the surrounding area. The MR-CPV may increase the daily demand on existing communication facilities, but adequate resources are available to handle this increased demand.

3.20 Transportation

The proposed site is located proximate to I-20, a major Interstate Highway that connects the site to Atlanta and to other interstate highway networks of the Southeast. There is a direct exit from I-20 to Minola Road. Atlanta's Hartsfield International Airport is located 20 miles from the site via I-20 and I-285. This airport is the nation's second most active passenger terminal and the fifth most active air freight terminal. A small local airport is located approximately 8 miles north-east of the site. There is no anticipated adverse impact on this local airport from the MR-CPV. Rail service is provided to metro Atlanta via the main lines of Southern and L&N Railroads and their affiliate.

Georgia provides deepwater ports in Brunswick and Savannah, and inland-barge terminals in Augusta and Columbus. Savannah is the most modern port in the South Atlantic, offering more than four million square feet of warehouse space and service by more than 100 steamship lines. The Central of Georgia Railroad provides direct service to Savannah.

The impacts on transportation will occur mostly in the local area. The urbanization of site and the development of adjacent properties will lead to a substantial increase in the number of automobiles. The location of MR-CPV will have negligible impact on Hartsfield Airport during the construction state. It is conceivable that the airport will carry air cargo and passengers bound for the proposed application. But, with the airport's existing size and capacity, it is doubtful that any impact will be felt. Rail and private carriers will also realize some increase in cargo during the construction and equipping stages of the development, and the long-range impact may be significant depending on the future needs of the industrial application.

3.21 Recreation

There currently exists a large inventory of recreational facilities throughout the immediate area, the metropolitan Atlanta complex, and the State of Georgia. This includes a wide variety of professional and

collegiate sports. It is doubtful that any impact will be felt because of the MR-CPV.

3.22 Site Aesthetics

Aesthetics of a site cannot be mathematically measured or defined. Essentially, it is what a viewer sees and his response to the scene. MR-CPV site, as viewed from the highways adjacent to it, is a rather pleasant, gently rolling piedmont area with low-lying sections previously cleared for buildings, and with higher sections covered with pine stands. It is considered that the solar arrays can have minor effect on site aesthetics.

3.23 Adverse Impacts

All adverse impacts caused by the development of MR-CPV can be mitigated if laws, regulations, codes or resolutions are followed and if standard engineering precautions are taken.

Siltation and sedimentation appear in many of the environmental investigations as adverse impacts. Soils, geology, water quality, surface hydrology and fauna investigations have all identified this problem, which will result from foundation construction operations. Increased runoff and decreased infiltration of rainwater resulting from paving and building construction are related problems that contribute to sedimentation. Both can be mitigated.

It is anticipated that site and regional aesthetics will be degraded by the facility itself, by the traffic moving to and from the site, and by disposal sites in the area that will handle any solid waste.

Site preparation and construction could destroy any unknown subsurface archaeological sites, if present. However, by following federal guidelines for federal projects, losses will be prevented. The loss of plant and animal life on the site is an impact that, should be negligible and can be mitigated if it exists. However, no rare or endangered species are involved, and no species will be jeopardized by the project. Furthermore, a long-term solution, where areas that cannot be developed

are allowed through natural succession to revert to low-land hardwood forest, can result in a more productive and diverse plant and animal community without interference with research activities. The net result would be a long-term positive impact requiring little, if any, investment.

No toxic or other hazardous fluids are used in the propose MR-CPV. Therefore, there will be no spills, releases, or other discharges to the environment. Also, no air pollution problem is expected.

3.24 Irreversible and Irretrievable Commitments of Resources

Most irreversible and irretrievable commitments of resources resulting from the implementation of the project will involve natural resources occurring in other areas of the state, nation or world which will be expanded on the site. Human and financial resources will also be involved. Off-site resources include building materials (whether mineral or timber) needed to construct buildings, roads, utility lines and pipes, employee residences and offices or research equipment; fossil fuels for energy; human labor to construct the facility, to provide labor for the research project and to provide police protection and community services; and money to pay for construction, maintenance, operations, and salaries. Water used by the site will not be available to other users; it will be treated and returned to the streams. Chemicals involved in treatment will be lost. Solid waste generated on the site will be placed in landfills and may or may not be irretrievably lost.

3.25 Overall Benefit Statement

The construction of the MR-CPV at the Minola Road site and the attainment of MR-CPV objectives will produce significant socio-economic, technological and environmental benefits to the State of Georgia, the nation and the world. Short-term socio-economic benefits will accrue to the region and the state as a result of increased economic activity. Long-term environmental and technological benefits will result from the solar energy related research.

There will be less dependence on fossil fuels and, therefore, a reduction in extraction operations, as well as less flooding associated with the development of power-generation dams. Consequently, there will be less destruction of the natural environment. Technological benefits of the research are certain, the results of which may be the development of an alternative energy source for worldwide use.

APPENDIX A

**DRAWING PACKAGE
FOR
WESTINGHOUSE**

**MINOLA ROAD – CONCENTRATING PHOTOVOLTAIC
50 KILOWATT DEMONSTRATION SYSTEM**

LIST OF DRAWINGS
MR-CPV 50KW DEMO SYSTEM

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Miscellaneous Details-LCM	389D860	-	A10
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MR-CPV 50KW DEMO SYSTEM

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SPECIFICATIONS

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FOR MODULE INTERCONNECTION WIRING SEE DWG 102E218

NO	DESCRIPTION	QTY	UNIT	REMARKS
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TABLE I

GROUP NO.	PART NO.
1	712J518G01-

- 5 PRIOR TO FINAL TIGHTENING OF ITEM 9, ALIGN ITEM 6 TO ITEM 1, TO MEET DWG REQUIREMENTS.
- 6 THICKNESS OF SHIM STACK SET AT ASSEMBLY TO MEET CLEARANCE REQUIREMENTS.
- 7 VENDOR ITEMS AS SHOWN OR APPROVED EQUAL.
- 8 PURCHASE FROM OPTICAL COATING LABORATORY INC., PHOTOELECTRONICS GROUP, 15251 DON JULIAN ROAD, CITY OF INDUSTRY, CALIF 91746. OR APPROVED EQUAL.
- 9 METAL STAMP PART NO. APPROX AS SHOWN WITH .12 HIGH CHARACTERS PER P5294517-1. SEE TABLE I.

SECTION A-A
SCALE: 1/1
TYP 7 PLACES

SECTION B-B
SCALE: 1/1
TYP 2 PLACES

SECTION C-C
SCALE: 1/1
TYP 8 PLACES

SECTION D-D
SCALE: 1/1
TYP 2 PLACES

SECTION E-E
SCALE: 1/1
TYP 2 PLACES

QTY	ITEM NO.	DESCRIPTION	CODE	QTY	ITEM NO.	DESCRIPTION	CODE
4	AR	16 SHIM .250±.005 ID x .82±.06 OD					
4	4	15 SCREW, SOC HD CAP, 190-32UNF x .50 LG					
20	14	LOCK NUT	72962				
16	13	WASHER, 190 FLAT .063 THK x .734 OD					
10	12	WASHER, 190 FLAT .040 THK x .562 OD					
9	11	WASHER, 25 FLAT .063 THK x .734 OD					
3	10	SCR, STD RND HD MACH, 190-32UNF x .75 LG					
8	9	SCREW, SOC HD CAP, 190-32UNF x .62 LG					
14	8	SCREW, SOC HD SHOULDER	29440				
7	7	SCREW, SOC HD SHOULDER	29440				
2	6	CONCENTRATOR MODULE ASSY	D202325				
1	5	MODULE CONNECTION DEVICE	389D976G01-				
2	4	BRACKET	389D860H01-				
2	3	BRACKET	389D860H02-				
1	2	SUPPORT STRUCTURE	712J518G01-				
1	1	FRESNEL LENS	389D855H01-				
PARTS LIST							
UNLESS OTHERWISE SPECIFIED				CONTRACT NO. ET-78-04-4277			
TOLERANCES - DO NOT SCALE				Westinghouse Advanced Energy Systems Division			
SPL DEC SPL DEC ANGLES				Pittsburgh, Pennsylvania			
#03 #.005 #				ASSEMBLY -			
				LENS/CELL MODULE			
				MR-CPV 50KW DEMO SYSTEM			
PS 294517 IDENT				J 14683 712J518			
DWG CODE NO. 3				SCALE 1/1			

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SCALE 2/1

	5	PAINT (RUST-OLEUM)	08882	5783					
	4	PAINT (RUST-OLEUM)	08882	1069					
	3	SPACER			STL		1018		
	2	BRACKET			CRS		ASTM-A36G		
	1	BRACKET			CRS		ASTM-A36G		
	ITEM	DESCRIPTION	CODE	PART OR IDENTIFYING NO.	MATERIAL		SPECIFICATION		QTY

[illegible]

3. FINISHED ITEMS 1, 2 & 3 TO BE PAINTED WITH SINGLE COATS OF ITEMS 4 & 5 IN ACCORDANCE WITH MANUFACTURER'S INSTRUCTIONS.
2. BREAK ALL SHARP EDGES .02 R MAX. OR CHAMFER.
1. TAG IDENT PART NO. PER PS 294517-1. SEE IDENT COLUMN.

8 7 6 5 4 3 2 1

389D861		57	1	
REV		DESCRIPTION	DATE	APPROVED

1 HEAT SINK		389D861H01		ALUM		6063-T5	
QTY	REV	ITEM NO.	DESCRIPTION	CODE	IDENTITY NO.	MATERIAL	SPECIFICATION
PARTS LIST							
UNLESS OTHERWISE SPECIFIED		CONTRACT NO. XAL-72205-AL		Westinghouse Advanced Energy Systems Division			
INTERPRET DIMS PER MIL-STD-100		DATE OF ORDER		Pittsburgh, Pennsylvania			
DIM IN INCHES BASED ON 867		D. STUMPF		SOLAR CELL HEAT SINK			
TOLERANCES - DO NOT SCALE		1-14-79		LENS/CELL MODULE			
2PL DEC 3PL DEC ANGLES		1-15-79		MR-CPV 50KW DEMO SYSTEM			
±.02 ±.005 ±.2°		1-16-79		SCALE 1/1			
±.02 ±.005 ±.2°		1-17-79		WT ACTL WT CALC			
±.02 ±.005 ±.2°		1-18-79		SHEET 1 OF 1			
±.02 ±.005 ±.2°		1-19-79		DWG CODE NO. 3			
±.02 ±.005 ±.2°		1-20-79		D 14683 389D861			

8 7 6 5 4 3 2 1

A13

3890857

A

- BRUNING 40-107 27446

A

APPLICATION				REVISIONS													
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED												
REV STATUS	REV	—	—	—	—												
OF SHEETS	SHEET	1	2	3	4												
UNLESS OTHERWISE SPECIFIED INTERPRET DWG PER MIL-D-1000 DIM IN INCHES BASED ON 66°F		CONTRACT NO. XAL-72205-AL						Westinghouse Advanced Energy Systems Division Pittsburgh, Pennsylvania									
L/O		DFTM J.M. BROWN		DATE OF DWG 1-25-79		POWER DISTRIBUTION WIRING TABLE MR-CPV-50 KW DEMO SYSTEM											
		CHECKER		DESIGN <i>[Signature]</i> 1/26/79													
				DFT SUPV. <i>[Signature]</i> 1-26-79													
DWG CODE NO.						DWG SIZE A		CODE IDENT NO. 14683				DWG NO. 650A993					
		<i>P. J. Slom 1/26/79</i>		<i>[Signature] 1/26/79</i>		SCALE <i>✓</i>		REV —				SHEET 1 OF 4					
		<i>C.M. Kane 1/26/79</i>															

POWER DISTRIBUTION WIRING TABLE

CABLE NUMBER	FROM	TO	TRENCH NO.	WIRE SIZE	LENGTH (FT)
TP01	PWR. Dist. Pnl. CIR. BKR. 1	FC1	NS1, EW2	2C, #14CU	125
TP02	FC1	FC2	EW2, NS1, EW5	2C, #14CU	172
TP03	PWR. Dist. Pnl. CIR. BKR. 2	Tracker 1	NS1, EW1	3C, #12CU	100
TP04	Tracker 1	Tracker 2	EW1	3C, #12CU	58
TP05	Tracker 2	Tracker 3	EW1	3C, #12CU	58
TP06	PWR. Dist. Pnl. CIR. BKR. 3	Tracker 5	NS1, EW2	3C, #12CU	100
TP07	Tracker 5	Tracker 4	EW2	3C, #12CU	58
TP08	PWR. Dist. Pnl. CIR. BKR. 4	Tracker 6	NS1, EW3	3C, #12CU	200
TP09	Tracker 6	Tracker 7	EW3	3C, #12CU	58
TP10	Tracker 7	Tracker 8	EW3	3C, #12CU	58
TP11	PWR. Dist. Pnl. CIR. BKR. 5	Tracker 10	NS1, EW4	3C, #12CU	220
TP12	Tracker 10	Tracker 9	EW4	3C, #12CU	58
TP13	PWR. Dist. Pnl. CIR. BKR. 6	Tracker 11	NS1, EW5	3C, #10CU	300
TP14	Tracker 11	Tracker 12	EW5	3C, #10CU	58
TP15	Tracker 12	Tracker 13	EW5	3C, #10CU	58
TP16	PWR. Dist. Pnl. CIR. BKR. 7	Tracker 15	NS1, EW6	3C, #10CU	300
TP17	Tracker 15	Tracker 14	EW6	3C, #10CU	58
TP18	FC1	Tracker 1	EW2, NS1, EW1	3C, #14CU	120
TP19	FC1	Tracker 2	EW2, NS1, EW1	3C, #14CU	120
TP20	FC1	Tracker 3	EW2, NS1, EW1	3C, #14CU	170
TP21	FC1	Tracker 4	EW2	3C, #14CU	33

DWG
SIZE
A

CODE IDENT NO.
14683

DWG NO.

650A993

SCALE

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REV

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SHEET 2 of 4

POWER DISTRIBUTION WIRING TABLE (continued)

CABLE NUMBER	FROM	TO	TRENCH NO.	WIRE SIZE	LENGTH (FT)
TP22	FC1	Tracker 5	EW2	3C, #14CU	33
TP23	FC1	Tracker 6	EW2, NS1, EW3	3C, #14CU	120
TP24	FC1	Tracker 7	EW2, NS1, EW3	3C, #14CU	120
TP25	FC1	Tracker 8	EW2, NS1, EW3	3C, #14CU	170
TP26	FC2	Tracker 9	EW5, NS1, EW4	3C, #14CU	116
TP27	FC2	Tracker 10	EW5, NS1, EW4	3C, #14CU	78
TP28	FC2	Tracker 11	EW5	3C, #14CU	33
TP29	FC2	Tracker 12	EW5	3C, #14CU	33
TP30	FC2	Tracker 13	EW5	3C, #14CU	83
TP31	FC2	Tracker 14	EW5, NS1, EW6	3C, #14CU	116
TP32	FC2	Tracker 15	EW5, NS1, EW6	3C, #14CU	78
OP01	D.C. PWR. BUS	Tracker 1	NS1, EW1	2C, #6CU	100
OP02	D.C. PWR. BUS	Tracker 2	NS1, EW1	2C, #6CU	90
OP03	D.C. PWR. BUS	Tracker 3	NS1, EW1	2C, #6CU	140
OP04	D.C. PWR. BUS	Tracker 4	NS1, EW2	2C, #6CU	150
OP05	D.C. PWR. BUS	Tracker 5	NS1, EW2	2C, #6CU	100
OP06	D.C. PWR. BUS	Tracker 6	NS1, EW3	2C, #6CU	200
OP07	D.C. PWR. BUS	Tracker 7	NS1, EW3	2C, #6CU	180
OP08	D.C. PWR. BUS	Tracker 8	NS1, EW3	2C, #6CU	230
OP09	D.C. PWR. BUS	Tracker 9	NS1, EW4	2C, #6CU	210
OP10	D.C. PWR. BUS	Tracker 10	NS1, EW4	2C, #6CU	240
OP11	D.C. PWR. BUS	Tracker 11	NS1, EW5	2C, #6CU	300
OP12	D.C. PWR. BUS	Tracker 12	NS1, EW5	2C, #6CU	300
OP13	D.C. PWR. BUS	Tracker 13	NS1, EW5	2C, #6CU	350

DWG
SIZE
ACODE IDENT NO.
14683

DWG NO.

650A993

SCALE

1/2"

REV

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SHEET 3 of 4

POWER DISTRIBUTION WIRING TABLE (continued)

CABLE NUMBER	FROM	TO	TRENCH NO.	WIRE SIZE	LENGTH (FT)
OP14	D.C. PWR. BUS	Tracker 14 NS1, EW6		2C, #6CU	340
OP15	D.C. PWR. BUS	Tracker 15 NS1, EW6		2C, #6CU	300

NOTES

1. No. 14 cable to be copper, 7 strands, Okonite Okolon 112-11-2071 or approved equal.
2. No. 12 cable to be copper, 7 strands, Okonite Okolon 112-11-2101 or approved equal.
3. No. 10 cable to be copper, 7 strands, Okonite Okolon 112-11-2131 or approved equal.
4. No. 6 cable to be copper, 7 strands, Okonite Okolon 112-11-2221 or approved equal.

DWG
SIZE
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CODE IDENT NO.
14683

DWG NO.
650A993

SCALE ~

REV -

SHEET 4 of 4

RELAY LEGEND

DEV NO.	DESCRIPTION	FUNCTION
27/58	GE CO MODEL #121WV5A1A OVER-AND UNDER VOLTAGE RELAY, 55-110V TAP RANGE, 0.2/2.0A TARGET 1 SEAL-IN	TRIPS 125A C.B. AS BACK-UP TO DEVICES IN P.C. EQUIPMENT
59N	GE CO MODEL #121WV5A1A OVER-AND UNDER VOLTAGE RELAY, 16-64V TAP RANGE, 0.2/2.0A TARGET 1 SEAL-IN	OPENS P.C. MAIN CONTACTOR FOR GROUND ON 208V SIDE OF ISOLATION TRANSFORMER
81	WESTINGHOUSE STYLE #6718.287A15 TYPE KF UNDER FREQUENCY RELAY, 55-59.5 HZ, 120 V, A.C. AUXILIARY, ADJ TIME DELAY 6-30 CT, 0.2/2.0A TCS	TRIPS 125A C.B. AS BACK-UP TO DEVICES IN P.C. EQUIPMENT

REV	REV	DESCRIPTION	DATE	BY	REVISION	REVISION	REVISION
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A21

OUTPUT STATES			EFFECT ON ELEVATION ARRAY
FOR	FAST	GO #	
0	0	0	MOTORS OFF, ARRAY STOPPED
0	0	1	ARRAY MOVES REVERSE, LOW SPEED
0	1	0	MOTORS OFF, ARRAY STOPPED
0	1	1	ARRAY MOVES REVERSE, HIGH SPEED
1	0	0	MOTORS OFF, ARRAY STOPPED
1	0	1	ARRAY MOVES FORWARD, LOW SPEED
1	1	0	MOTORS OFF, ARRAY STOPPED
1	1	1	ARRAY MOVES FORWARD, HIGH SPEED

OUTPUT STATES			EFFECT ON ELEVATION ARRAY
FOR	GO #		
0	0		MOTORS OFF, ARRAY STOPPED
0	1		ARRAY MOVES REVERSE
1	0		MOTORS OFF, ARRAY STOPPED
1	1		ARRAY MOVES FORWARD

REV	REV	DESCRIPTION	DATE	BY	CHKD	DATE	BY	CHKD	DATE	BY	CHKD
1											
PARTS LIST											
MOTOR CONTROL CIRCUIT AND POWER SWITCHING - MR-CPV 50KW DEMO SYSTEM											
102E225											
14683											
102E225											
1											

A22

5. ALL CONNECTORS TO BE WATERTIGHT.
4. WIRES SECURED TO LENS/CELL MODULE USING CLIP-ON TYPE CABLE TIES.
3. WIRES SECURED TO VERTICAL MEMBERS OF TRACKER USING CABLE TIES WITH PUSH-IN TYPE MOUNTING BASE.
2. WIRES SECURED TO HORIZONTAL MEMBERS OF TRACKER WITH CABLE TIES.
1. ALL WIRE TO BE #16 COPPER CONDUCTOR, 600V D.C.

QTY	REV	DESCRIPTION	DATE	BY	CHKD	APPROVED	REVISION
1	1	WIRING DIAGRAM, MODULE INTERCONNECTION, MR-CPV 50 KW DEMO SYSTEM	10/24/77	R. H. HARRIS			
PARTS LIST WIRE: 16 AWG COPPER CONDUCTOR, 600V D.C. CABLE TIES: 1/2" X 1/2" X 1/8" POLYESTER TERMINAL BLOCKS: 1/2" X 1/2" X 1/8" POLYESTER JUNCTION BOX: 1/2" X 1/2" X 1/8" POLYESTER MODULE TERMINATION DEVICE: 1/2" X 1/2" X 1/8" POLYESTER							
WORKING DRAWING NO. 102E238 SCALE: NONE SHEET: 1 OF 1

QTY	ITEM NO.	DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE
PARTS LIST							
UNLESS OTHERWISE SPECIFIED		CONTRACT NO. XAL-72205-AL		Westinghouse Advanced Energy Systems Division Pittsburgh, Pennsylvania			
INTERPRET DWG PER MIL-D-1000 DIM. IN INCHES BASED ON 88°F		DATE OF DWG J.M. BROWN 1-25-79		DATA BUILDING			
TOLERANCES - DO NOT SCALE		DESIGN 1/11/79		MR-CPV 50KW DEMO SYSTEM			
ZPL DEC. 3PL DEC. ANGLES		CHECKED 1/16/79		DWG NO. 389D864			
Z		Z		REV. -			
Z		Z		SCALE 1/4" = 1'-0"			
Z		Z		WT. ACTL. WT. CALC. SHEET 1 OF 1			
SPECIFICATION TYPE		DWG CODE NO.		DWG NO. 389D864			
DWG CODE NO.		C.M. Lee 1/16/79		DWG NO. 389D864

QTY USED	BYT NO.	ITEM NO.	DESCRIPTION OR REMARKS	UNIT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	QTY ORDERED
PARTS LIST								
UNLESS OTHERWISE SPECIFIED				CONTRACT NO. XAL-72205-AL		Westinghouse Advanced Energy Systems Division Pittsburgh, Pennsylvania		
INTERPRET DRAW FOR MIL-STD-100 DIE IN INCHES BASED ON 80°F				DRAWN J.M. BROWN 1-23-79		FRONT PANEL LAYOUT AC METER PANEL MR-CPV 50KW DEMO SYSTEM		
TOLERANCES - DO NOT SCALE				CHECKED J.M. BROWN 1-25-79				
EPL DEC SPL DEC ANGLES				DESIGNED J.M. BROWN 1-23-79				
2 * * *				APPROVED J.M. BROWN 1-23-79				
SPECIFICATION TYPE				SCALE 1/2		BY ACTL		BY CALC
DWG CODE NO. 3				SHEET 1 OF 1

SP-5000 A 1000	GOVERNMENT SP-5000 A 1000	MADE OF PROCESS
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TOLERANCE	AUG	SPEC	PER	LA	501
DIMENSIONS IN INCHES - DO NOT SCALE DRAWING					
2ND DECIMAL TOLERANCES					
UNLESS OTHERWISE SPECIFIED					
2 PLACE	3 PLACE	ANGLES			
XX = .02	XXX = .005	± 1"			
* SYMBOLS					
V = VENDOR ITEM SEE SPECIFICATION					
CONTROL DRAWING					

[illegible]

SANDIA LAB
POWER CONTROL UNIT
SYSTEM LOGIC DIAGRAM
ED386071
22 July 4/22/78

Technical drawing of a mobile laboratory unit, showing front and side views with dimensions and labels.

Front View Labels:

- LOUVERS IN DOOR FOR AIR OUT
- 7.00 DIA AIR OUTLET
- 5.00X12.00 AIR INLET

Side View Labels:

- 3.00 Ø CONDUIT
- WIRE SIZES
 - 1) 2-250 MCM MAX FROM BATTERY 300V, 250 A
 - 2) 2-250 MCM MAX FOR BATTERY CHARGING 300V, 120 A
 - 3) 2-250 MCM MAX FROM SOLAR ARRAY 300V, 250 A
- 1.50 Ø CONDUIT OPENING
- LOAD 208V, 175A 4-#10 WIRES MAX
- UTILITY 208V, 175A 3-#10 WIRES MAX

Dimensions:

- Top: 30.00, 2-12, 30.00, 2-12, 30.00, 2-12
- Left: 30.00, 3.00 MAX
- Right: 27.16, 29.75, 41.25
- Bottom: 91.30, 2.25, 21.00, 1.00, 4.00, 7.12

AIR OUT (indicated at the bottom of the front and side views)

[illegible][illegible]

REVISIONS				
DCI	ZONE	LTR	DESCRIPTION	DATE
4/560	W/K		NEW DRWG.	1/14/78

REQ'D	PART NUMBER	DESCRIPTION	ITEM
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	DRAWN: <u>D. L. ...</u> CHECK: <u>...</u> ENG: <u>...</u> APP'D: <u>...</u> DATE: <u>...</u> FRACTIONS: <u>16</u> DECIMALS: <u>XX 1</u> ANGLES: <u>...</u> UNITS: <u>...</u>	OCLI OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 10201 San Juan Rd. - City of Industry, Calif. 91708 CONCENTRATION: <u>...</u> SIZE: <u>D</u> CODE IDENT NO: <u>...</u> DWG NO: <u>D202325</u> SCALE: <u>...</u> REV: <u>1/12</u> SHEET: <u>1</u> OF <u>1</u>	
NEXT ASSY	USED ON	APPLICATION	

4

REVISIONS					
DCN	ZONE	LTR	DESCRIPTION	DATE	APPROVE
4555		NK	NEW DRWS.	11/2/98	

Q20 NEXT DAY USED ON		APPLICATION	
100 MIL THICKNESS 100 MIL THICKNESS		100 MIL THICKNESS

REVISIONS				
DCN	ZONE	LTR	DESCRIPTION	DATE
4559		NK	NEW DRWG	11/24/76
				APPROVED
				81 1/26

2 REQ'D
1 SHOWN
1 OPPOSITE

		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		DRAWN FSW/HTT/EN 11/20/76		OCL OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 15851 Don Julian Rd. • City of Industry, Calif. 91746	
		TOLERANCES:		CHECK 50 11/24/76			
		DECIMALS .X ±		ENGR 60 11/24/76		END COVER	
		.XX ±		PROD			
		.XXX ± .010		QA			
		FRACTIONS ±		MATERIAL		SIZE	
		ANGLES ±		6061-T6 ALUM.		B	
		DO NOT SCALE DRAWING				CODE IDENT NO.	
NEXT ASSY		USED ON				DWG NO.	
APPLICATION						B-202324	
						SCALE	
						FULL	
						REV	
						NK	
						SHEET	
						1 OF 1	

APPLICATION			REVISIONS			
NEXT ASSY	USED ON	LTR	DCN	DESCRIPTION	DATE	APPROVED
			NK 4380	INITIAL RELEASE	7/24/78	(Signature)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: DECIMALS .X ± .XX ± .000 .XXX ± .015 FRACTIONS ± ANGLES ± DO NOT SCALE DRAWING	DRAWN			OCLI OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 15251 Don Julian Rd. • City of Industry, Calif. 91746-	
	CHECK	SO	7/19/78		
	ENGR	SO	7/19/78	COVER GLASS WESTINGHOUSE	
	PROD				
	QA	WJB	5-15-78		
MATERIAL	1/8" SUNADEX GLASS DIFFUSED PATTERN		SIZE A SCALE FULL	CODE IDENT NO. REV N/C	DWG NO. A-805607
			SHEET 1	OF 1	

PHOTOGRAPHIC COPY PRESS
 NUMBER NO. A-8056

APPLICATION		REVISIONS				
NEXT ASSY	USED ON	LTR	DCN	DESCRIPTION	DATE	APPROVED
		N/C	4381	INITIAL RELEASE	11/21/78	(91/1/39)

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES:

DECIMALS .X ±

.XX ±

.XXX ± .005

FRACTIONS ±

ANGLES ±

DO NOT SCALE
DRAWING

DRAWN	ES. WHITTEN	9/18/78
CHECK	SO	9/19/78
ENGR	SO	9/19/78
PROD		
QA	WILL	7-25-78

MATERIAL

OCL

OPTICAL COATING LABORATORY, INC.
PHOTOELECTRONICS GROUP

15251 Don Julian Rd. • City of Industry, Calif. 91746

CELL/SPACER ASSY
WESTINGHOUSE

SIZE
A

CODE IDENT NO.

DWG NO.

A-805609

SCALE 2:1

REV N/C

SHEET 1 OF 1

APPLICATION		REVISIONS				
NEXT ASSY	USED ON	LTR	DCN	DESCRIPTION	DATE	APPROVED
		N/C	4379	INITIAL RELEASE	1/21/78	(91/1/78)

2. SiO COATING ON BACK SURFACE
 1. SOLDER PLATE TOP OF WAFER .001 THK

NOTES:

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: DECIMALS .X ± .XX ± .XXX ± .005 FRACTIONS ± ANGLES ± DO NOT SCALE DRAWING	DRAWN	F.S. WHITTEN	9/18/78	OCLI OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 15251 Don Julian Rd. • City of Industry, Calif. 91746	
	CHECK	SO	9/19/78		
	ENGR	SO	9/14/79	SPACER WESTINGHOUSE	
	PROD				
	QA	WJH	9-15-78		
MATERIAL 015 THICK SILICON WAFER	SIZE	A		CODE IDENT NO.	DWG NO.
	SCALE	FULL		REV	N/C

APPLICATION		REVISIONS				
NEXT ASSY	USED ON	LTR	DCN	DESCRIPTION	DATE	APPROVED
		UK	4400	new	7/27/78	(128)
		A	4437	Change from .375 To .395	10/4/78	(128)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: DECIMALS .X ± .XX ± .XXX ± 0.005 FRACTIONS ± ANGLES ± DO NOT SCALE DRAWING	DRAWN	SB	7/24/78	OCLI OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 15251 Don Julian Rd. • City of Industry, Calif. 91746
	CHECK			
	ENGR	S. J. HARRISON	9/24/78	WESTINGHOUSE CONCENTRATED CELL
	PROD			
	QA			
MATERIAL		SIZE	CODE IDENT NO.	DWG NO.
Silicon Cell		A		TAA 12289
SCALE		REV	SHEET	
NONE		A	1 OF 1	

WESTINGHOUSE ELECTRIC CORPORATIONDESIGN OF WESTINGHOUSE CONCENTRATOR CELL MODULE1.0 SCOPE1.1 General

This document describes the design and construction of the Westinghouse concentrator cell module.

1.2 Function

The concentrator cell module will be part of a concentrator system to be used in a terrestrial environment to generate electrical power when exposed to concentrated sunlight.

2.0 APPLICABLE DOCUMENTS2.1 Specifications

QQ-S-571E, Amendment 2 - Solder, tin alloy; tin-lead alloy; and lead alloy.

2.2 Drawings

TAA-12289, Rev. A	Concentrator Cell, Westinghouse
A-805607	Coverglass, Westinghouse
A-805608	Spacer, Westinghouse
A-805609	Cell/Spacer Assembly, Westinghouse
B-805604	Interconnect, Westinghouse
B-202324	End Cover, Westinghouse
D-202321	Solar Cell Laydown, Westinghouse
D-202325	Concentrator Module Assembly, Westinghouse

3.0 CONSTRUCTION

This section describes the sequence of construction of the concentrator module.

- 3.1 Attach cell (Dwg. No. TAA-12289) to spacer (Dwg. No. A-805608) by solder re-flow.
- 3.2 Solder interconnect (Dwg. No. B-805604) to cell/spacer assembly (Dwg. No. 805609) to form series string (Dwg. No. D-202321).
Insert 3M No. 39 tape between N and P interconnects. Each string has 13 cells in series as shown in module assembly Dwg. No. D-202325.
- 3.3 Attach two strips of 3M No. 69 tape in the channels of the substrate for insulation.
- 3.4 Prime anodized aluminum substrate and silicon spacers with GE SS 4004.
- 3.5 Bond cell string to anodized aluminum substrate with ECCOSIL 4952.
- 3.6 Solder interconnect of end cells to binding posts as electrical terminals.
- 3.7 Prime coverglass and cells with SS 4044 primer.
- 3.8 Attach coverglass to each cell with RTV-602 to complete module assembly (Dwg. No. D-202325).
- 3.9 Attach end caps (Dwg. No. B-202324).

PRELIMINARY

WESTINGHOUSE ELECTRIC CORPORATION

SPECIFICATION FOR A CONCENTRATOR CELL MODULE

1.0 SCOPE1.1 General

This specification defines the design, construction, performance, and testing for a concentrator cell module.

1.2 Function

The concentrator cell module will be part of a concentrator system to be used in a terrestrial environment to generate electrical power when exposed to concentrated sunlight.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this specification.

2.1 Specifications

QQ-S-571E, Amendment 2 - Solder, tin alloy; tin-lead alloy; and lead alloy.

Specification for a Concentrator Solar Cell - Westinghouse dated 10-24-78.

2.2 Drawings

TAA-12289, Rev. A	Concentrator Cell, Westinghouse
A-805607	Coverglass, Westinghouse
A-805608	Spacer, Westinghouse
A-805609	Cell/Spacer Assembly, Westinghouse
B-805604	Interconnect, Westinghouse
B-202324	End Cover, Westinghouse
D-202321	Solar Cell Laydown, Westinghouse
D-202325	Concentrator Module Assembly, Westinghouse
(Westinghouse No.)	Anodized Aluminum Substrate

3.0 REQUIREMENTS

3.1 Components

3.1.1 Concentrator Solar Cell

The concentrator solar cell shall meet the requirements delineated in the specification for a concentrator solar cell and Drawing No. TAA-12289, Revision A, Westinghouse.

3.1.2 Silicon Spacer

The silicon spacer shall meet the requirements as shown in Drawing No. A-805608.

3.1.3 Coverglass

The coverglass shall meet the requirements as shown in Drawing No. A-805607.

3.1.4 Interconnect

The interconnect shall meet the requirements as shown in Drawing No. A-805604.

3.1.5 Anodized Aluminum Substrate

The anodized aluminum substrate shall meet the requirements as shown in Westinghouse Drawing No. _____.

3.2 Construction

3.2.1 The cell shall be attached to silicon spacer by solder reflow.

3.2.2 The interconnect shall be soldered to the cell/spacer assembly (Drawing No. A-805609) to form a series string. Dimensions are shown in Drawing No. D-202321 and Drawing No. D-202325.

3.2.3 A strip of 3M Tape No. 69 shall be inserted between the N and P interconnect to insulate the two parts.

3.2.4 The interconnects shall be soldered to the cell/spacer assemblies (Drawing No. A-805609) to form a series string as shown in Drawing Nos. D-202321 and D-202325.

3.2.5 Two strips of 3M Tape No. 69 shall be attached to the channels of the aluminum substrate for insulation.

3.2.6 The aluminum substrate (Drawing No. 805608) and the silicon spacers shall be primed with G.E. SS4004 primer.

- 3.2.7 The cell/spacer strings shall be bonded to the aluminum substrate with Eccosil 4952 adhesive.
- 3.2.8 Wires shall be soldered to the end cells and the terminal posts.
- 3.2.9 The active surface of the cells and the coverglasses (Drawing No. A-805607) shall be primed with G.E. 8S4004 primer.
- 3.2.10 The coverglasses shall be attached to the solar cells with RTV-602. The amount of adhesive delamination shall not exceed 10% of the cell size.
- 3.2.11 The end caps (Drawing No. B-202324) shall be attached to the module.

3.3 Electrical Performance

The conversion efficiency of the concentrator module shall be equal to or exceed TBD when mounted in the solar collector and tested in natural sunlight. The temperature of the cell string shall be maintained at TBD°C.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The supplier shall be responsible for the performance of mechanical inspection. The location and method for performing electrical test is to be negotiated.

4.2 Mechanical Inspection

4.2.1 Dimensions

Each module shall be inspected for conformance to the mechanical dimensions as shown in the module assembly, Drawing No. 202325.

4.2.2 Adhesive Delamination

Each cell/coverglass assembly shall be inspected for delamination to conform with the requirement in Paragraph 3.2.10.

4.3 Electrical Performance

The location and method to determine the electrical performance of the concentrator cell module are to be established at a later date.

5.0 PREPARATION FOR DELIVERY

The concentrator cell module shall be packaged in such a way to permit cross-country shipment either by air or by land without mechanical damage to the module.