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Design Description of the Tangaye Village Photovoltaic Power System

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ACRONYMS AND ABBREVIATIONS

AID	Agency for International Development
CB	circuit breaker
CR	control relay
DCR	duty cycle regulator
DOD	depth-of-discharge
DP	drum programmer
I/C	instrumentation and control
JPL	Jet Propulsion Laboratory
LeRC	Lewis Research Center
NASA	National Aeronautics and Space Administration
NOTC	time delay contacts
PV	photovoltaic
R	run relay
SOC	state-of-charge
SSR	solid-state relay
TR	time delay relay

SUMMARY

This report describes the engineering design of a stand-alone photovoltaic (PV)-powered grain mill and water pump for the village of Tangaye, Upper Volta. The PV system is part of a project funded by the United States Agency for International Development and implemented by the National Aeronautics and Space Administration, Lewis Research Center. The purpose of the project is twofold: (1) to study the socio-economic effects of reducing the time required by women in rural areas for drawing water and grinding grain and (2) to demonstrate the suitability of photovoltaic technology for use in rural areas by people of limited technical training.

The PV system consists of a 1.8-kW (peak) solar cell array, 540 ampere-hours of battery storage, instrumentation, automatic controls, and a data collection and storage system. The PV system is situated near an improved village well and supplies d.c. power to a grain mill and a water pump. The array is located in a fenced area and the mill, battery, instruments, controls, and data system are in a mill building. A water storage tank is located near the well. The system employs automatic controls which provide battery charge regulation and system over- and under-voltage protection.

This report includes descriptions of the engineering design of the system and of the load that it serves; a discussion of PV array and battery sizing methodology; descriptions of the mechanical and electrical designs including the array, battery, controls, and instrumentation; and a discussion of the safety features. The system became operational on March 1, 1979.

INTRODUCTION

In 1976, the U.S. Agency for International Development (AID) initiated a program entitled "Studies of Energy Needs in the Food System." The overall goal of that program was to improve the quality of life and productivity of small farmers in rural areas of developing countries. As part of this activity, a project was initiated in 1979, in the remote village of Tangaye, Upper Volta, to demonstrate the potential for use of photovoltaic (PV) solar cells as a power source for common village tasks, with special emphasis on women's tasks. The load devices selected for the project were a grain grinder and a water pump. A PV system was chosen as the power source because of its potential high reliability and low maintenance requirements. AID provided funding for hardware and software associated with the PV system, the grain grinder and water pump, and a socioeconomic (baseline and impact) study. The National Aeronautics and Space Administration (NASA) Lewis Research Center (LeRC) was assigned responsibility for system design, development, deployment, and evaluation. The responsibilities of the Government of Upper Volta, Office of Rural Development included organizing a village cooperative to manage the mill. The villagers of Tangaye contributed the site preparation, a mill building, and the labor to aid in the installation of the photovoltaic system, mill, and water pump. Tangaye residents also operate the mill, maintain the system, and keep daily records of the system operation.

The village of Tangaye, with a population of more than 2900, is located approximately 190 km east of Ouagadougou on the main road linking Ouagadougou and Fada-N' Gourma at approximately 12° N. latitude and 0° longitude (Figure 1). The populated area is 6 to 8 kilometers in diameter, although the geographic limits of the village extend over a greater area. The primary crops are red and white sorghum, millet, rice, corn, beans, potatoes, peanuts, sesame, soybeans, manioc, and cotton. The villagers also raise cattle, sheep, goats, donkeys, horses, pigs, and poultry.

Each season is marked by extremes in availability of water. The dry season is characterized by high temperatures, hot winds at the beginning of the season, and low humidity. The earth is baked dry and the lack of green plants is reflected in the villagers' diet. March and April mark the height of the dry season. The rainy season generally begins at the end of April and continues through November.

Site preparation, including construction of the mill building and fabrication and installation of the water storage tank, was accomplished in the fall of 1978. System installation began on January 16, 1979, and was completed on February 28, 1979. During this period, LeRC personnel provided orientation and instruction to those villagers selected to be responsible for system operation. This process included instruction in system operation, maintenance, data acquisition, trouble shooting, and minor repair.

System operation began on March 1, 1979, under the management of a village cooperative (groupment); daily and monthly records of data, inspection, and maintenance are sent periodically to LeRC for analysis. In mid-1981, Government of Upper Volta personnel assumed full responsibility for monitoring and maintaining the Tangaye system. NASA-LeRC will provide technical support for the project until March of 1983.

This report describes the engineering design of the PV system and includes load profiles and load descriptions. An explanation of the sizing methodology; descriptions of the mechanical and electrical designs as well as of the array, battery, controls, instrumentation, and distribution system; and a discussion of safety features are also presented.

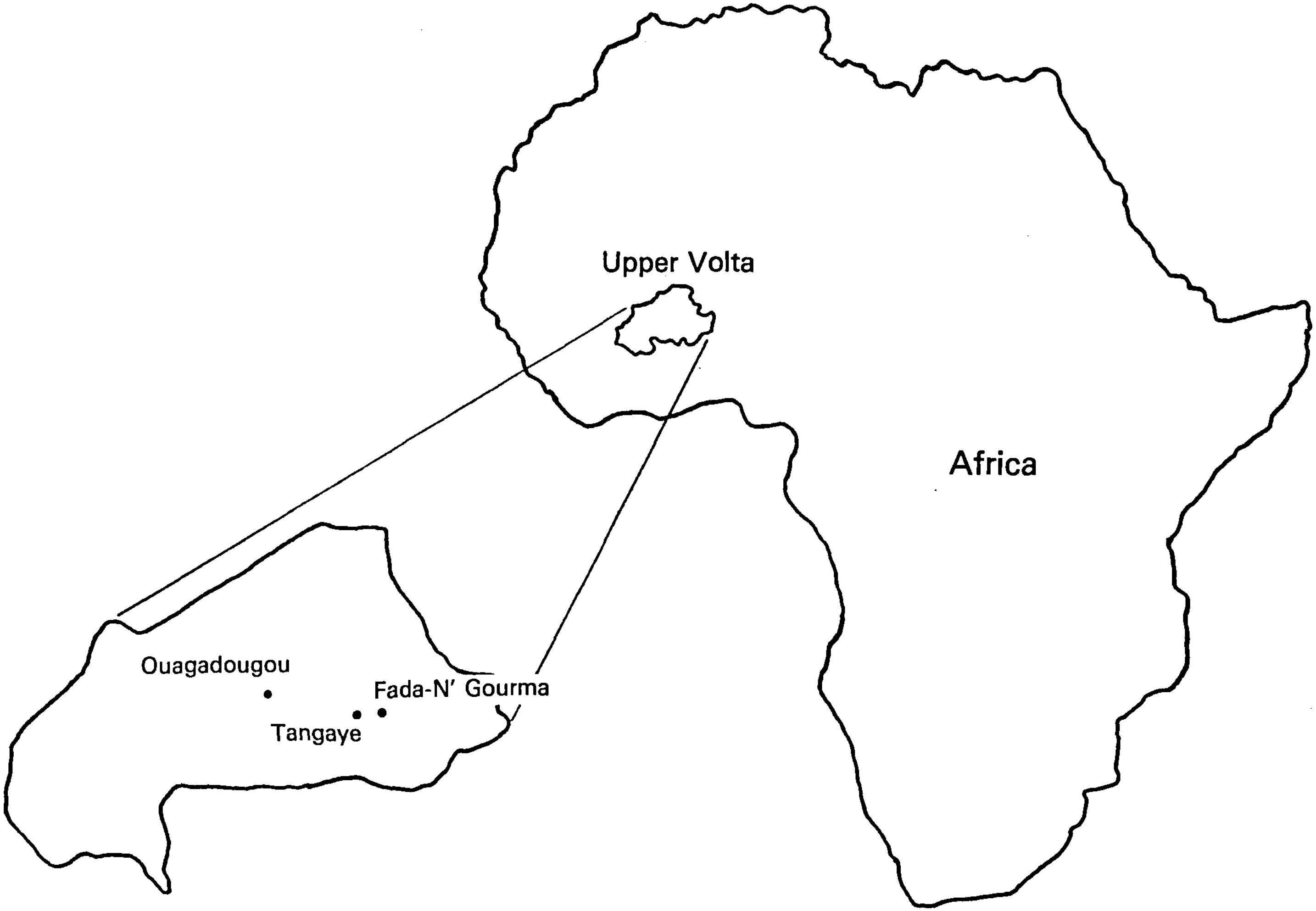

Figure 1. Location of Project

SYSTEM DESCRIPTION

The Tangaye PV system is a small, limited-energy, self-contained, automatically controlled, 120-V(d.c.) electrical power system consisting of a 12-panel PV array, lead-calcium storage batteries, instrumentation and controls housed in the mill building, and a 120-V(d.c.) electrical distribution system to power the mill and the pump motors and the mill room lights.

A block diagram of the PV power system and its associated loads is shown in Figure 2. The exact location of the PV array, water storage tank, and mill building was determined by mutual agreement of AID, NASA-LeRC, and Tangaye village officials (Figures 3 and 4).

The 1.8-kW (peak) PV array consists of three rows of four panels each mounted to steel frames and anchored into the ground in trenches backfilled with rocks and earth. Each panel consists of a string of eight PV modules wired in series to produce a nominal 120 V. The 12 panels are wired in parallel to form a 1.8-kW_{pk} array. The panels are set at a fixed tilt angle of 11° to maximize the array output on an annual basis. Power for the 12-V(d.c.) instrument and control system is provided by a separate 112-watt (peak) PV array consisting of six modules wired in parallel to produce about 15 V at 7 amperes and located at the southwest corner of the main PV array. These arrays are enclosed within an industrial-type, chain-link fence. The array panels and supporting structure are designed to withstand winds of 150 km/hour.

The electrical storage system is located in a vented room within the mill building and consists of the 120-V main battery and the 12-V instrumentation and control (I/C) battery. The 120-V main battery consists of 55 cells rated at 540 ampere-hours each. The 12-V I/C battery is a locally obtained, industrial-type battery rated at approximately 200 ampere-hours.

The I/C system provides system voltage and battery charge regulation, over- and under-voltage protection, pump and mill control, and instrumentation and data logging facilities. The I/C system, located in the mill building (Figure 5), consists of the instrument panel (Figure 6), the control panel (Figure 7), and the DAT-3 datalogger (Figure 8). The I/C system receives its power from the 12-V I/C battery and array.

The system voltage and battery charge controls provide for sequentially disconnecting and connecting individual main PV array strings to control system bus voltage and to regulate battery charge. The over- and under-voltage protection controls provide a backup to the system voltage and battery charge regulation controls by disconnecting the entire main PV array from the system bus in the event bus voltage exceeds a preset maximum or by disconnecting the loads if the bus voltage falls below a preset minimum. The under-voltage protection prevents damage to the battery from excessive battery discharge in the event of array failure or excessive use of the mill and pump.

Data from the I/C system are collected in two ways: (1) daily and monthly observation of meters and equipment, recorded by hand on prepared data sheets (Figures 9 and 10), and (2) automatically by the datalogger. The datalogger cassette is removed and replaced biweekly. The completed data cassettes and copies of all completed data sheets are taken to the U.S. AID office in Ouagadougou and from there forwarded to NASA-LeRC for review and analysis.

The water pump (Figure 11) is a Jensen Model 11W5A positive displacement pump, driven by an Applied Motors, 1/4-hp, 120-V(d.c.) permanent magnet motor. Water is delivered through an underground line to a water storage tank (Figure 12) with a capacity of about 6000 liters (approximately 1580 U.S. gallons). Water is drawn from the tank by the villagers by using a manifold pipe and five spring-loaded faucets.

The pump consists of a pump cylinder and a piston with the cylinder water intake located about 2 feet above the bottom of the well, and a gear box and a motor at the top of the well. The cylinder is supported from the gear box by an interconnecting drop pipe. The gear box drives the pump piston by means of a push rod. A water level sensor switch, located in the well about 1 foot above the cylinder water intake, stops the pump when the well water level falls below its set point. This low-level cut-off prevents damage to the pump from pumping the well dry. A second water level sensor in the storage tank controls normal operation of the pump by automatically starting the pump motor when the water level in the tank is low and stopping it when the tank is full. There is provision for hand drawing (dipping) of water if the pump is inoperable (Figure 13).

The original grain mill was a C.S. Bell Co. No. 60 burr plate mill driven by an Applied Motors, 1-hp, 120-V(d.c.) permanent magnet motor. This type of mill was selected because it is low in cost and is in common use in the area. The system was designed for 8 hours per day operation, 7 days per week. Daily operating time was controlled by an automatic clock timer. Although the mill operated satisfactorily, the wear rate of the burr plates was much greater than anticipated, and in fact, the villagers desire for very fine flour resulted in extremely high wear rates on other parts of the mill as well. Within 3 months after the system became operational, one mill had worn out completely, and a replacement was heading rapidly for the same demise.

Once the problem became apparent, the burr mill was replaced by a C.S. Bell Co. No. 10 bottom discharge hammermill (Figure 14), driven by an Applied Motors, 3-hp, 120-V(d.c.) permanent magnet motor and having a throughput, for comparable fineness, of from two to five times that of the burr mill. However, because the hammermill requires three times as much power as the burr mill, the cumulative milling time has been limited to 5 hours per day, 4 days per week. Following the installation of the hammermill, the automatic clock timer was damaged and disconnected. Milling time restrictions are now manually controlled by the mill operator.

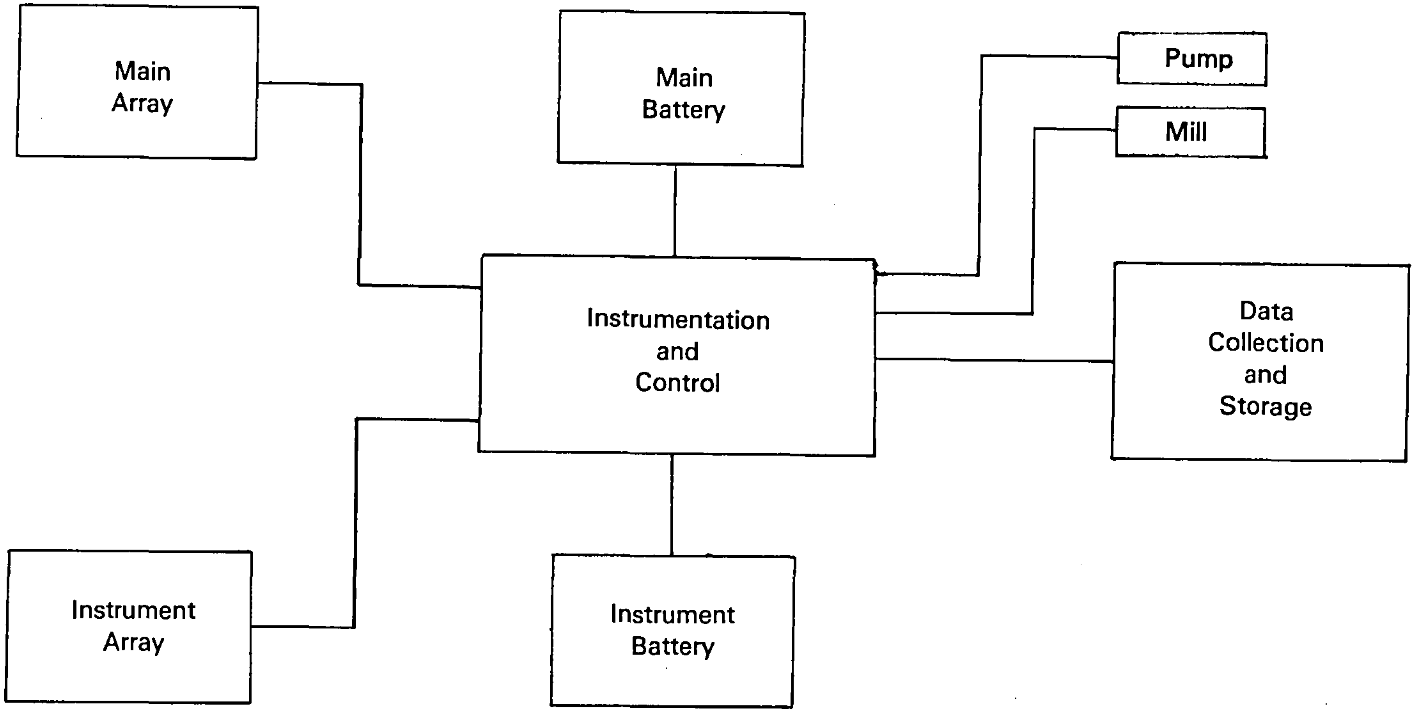

Figure 2. Simplified Block Diagram

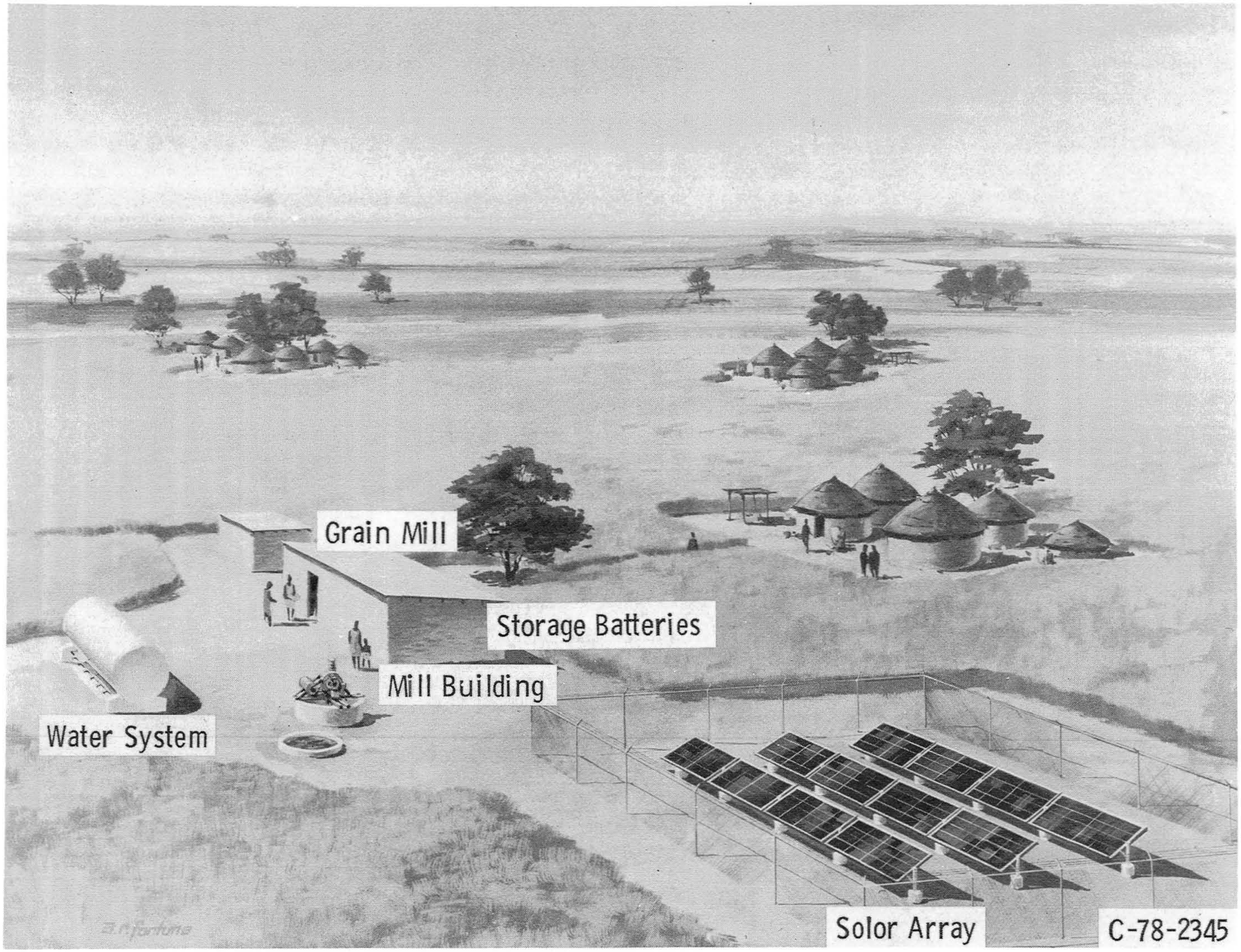

Figure 3. - Tangaye solar system.

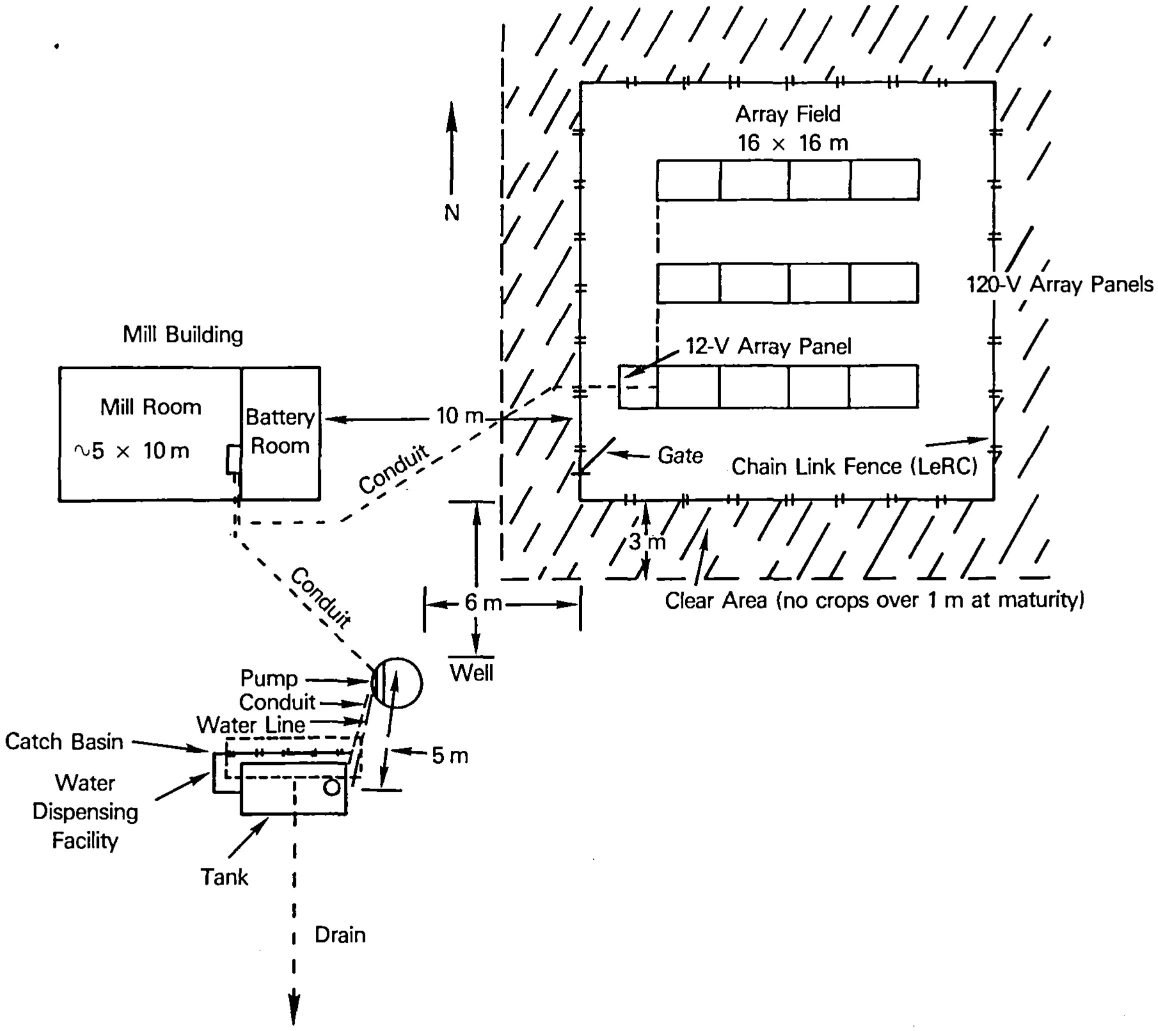

Figure 4. Tangaye Site Layout

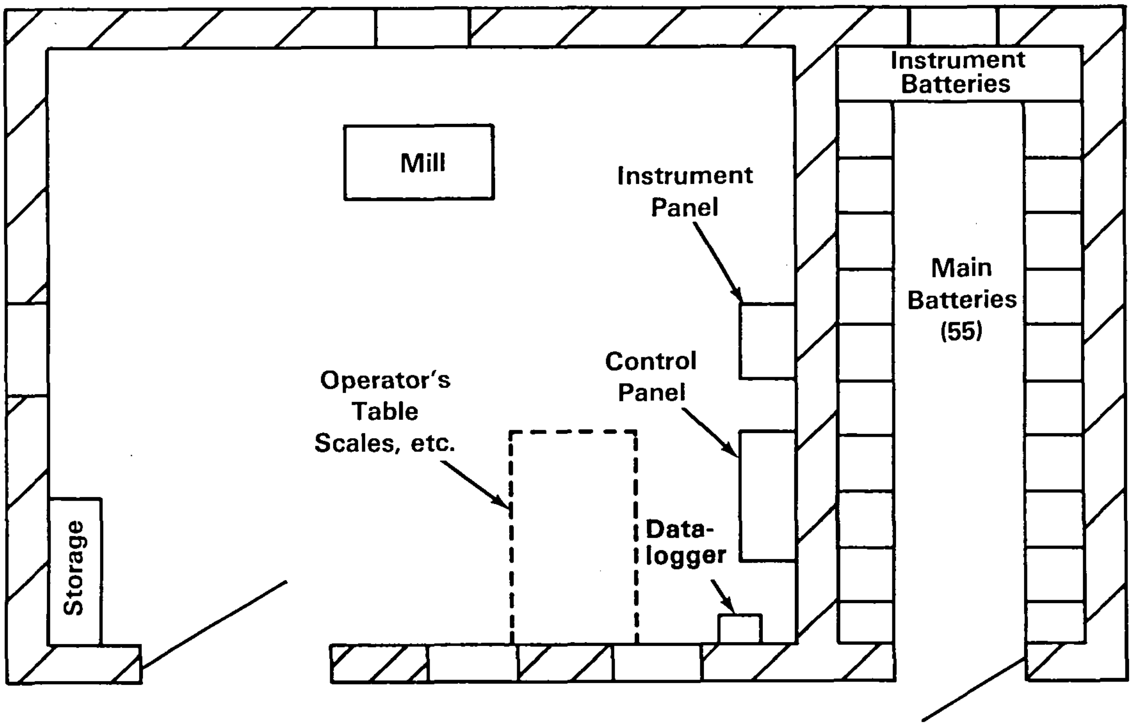

Figure 5. Mill Building

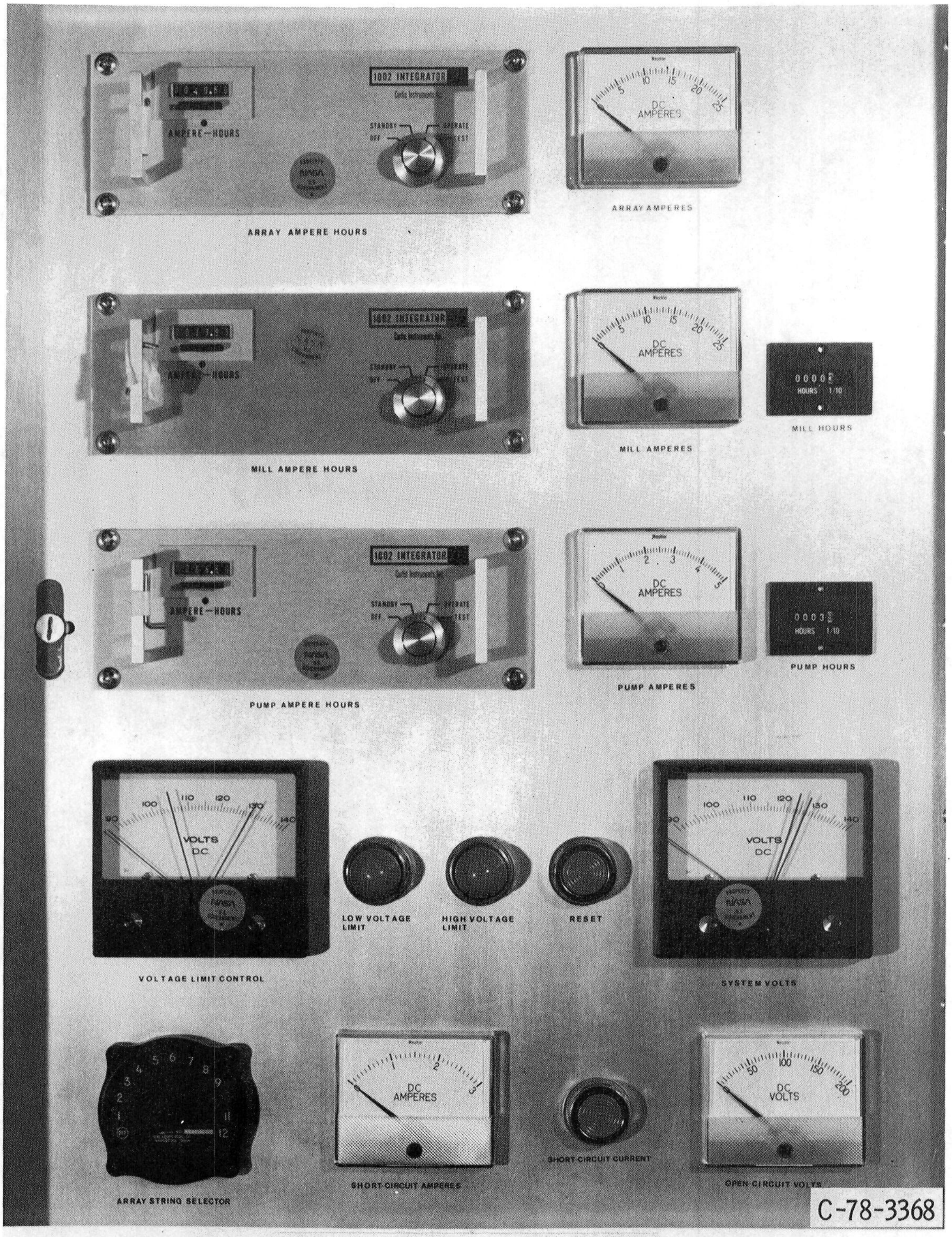

Figure 6. - Instrument panel.

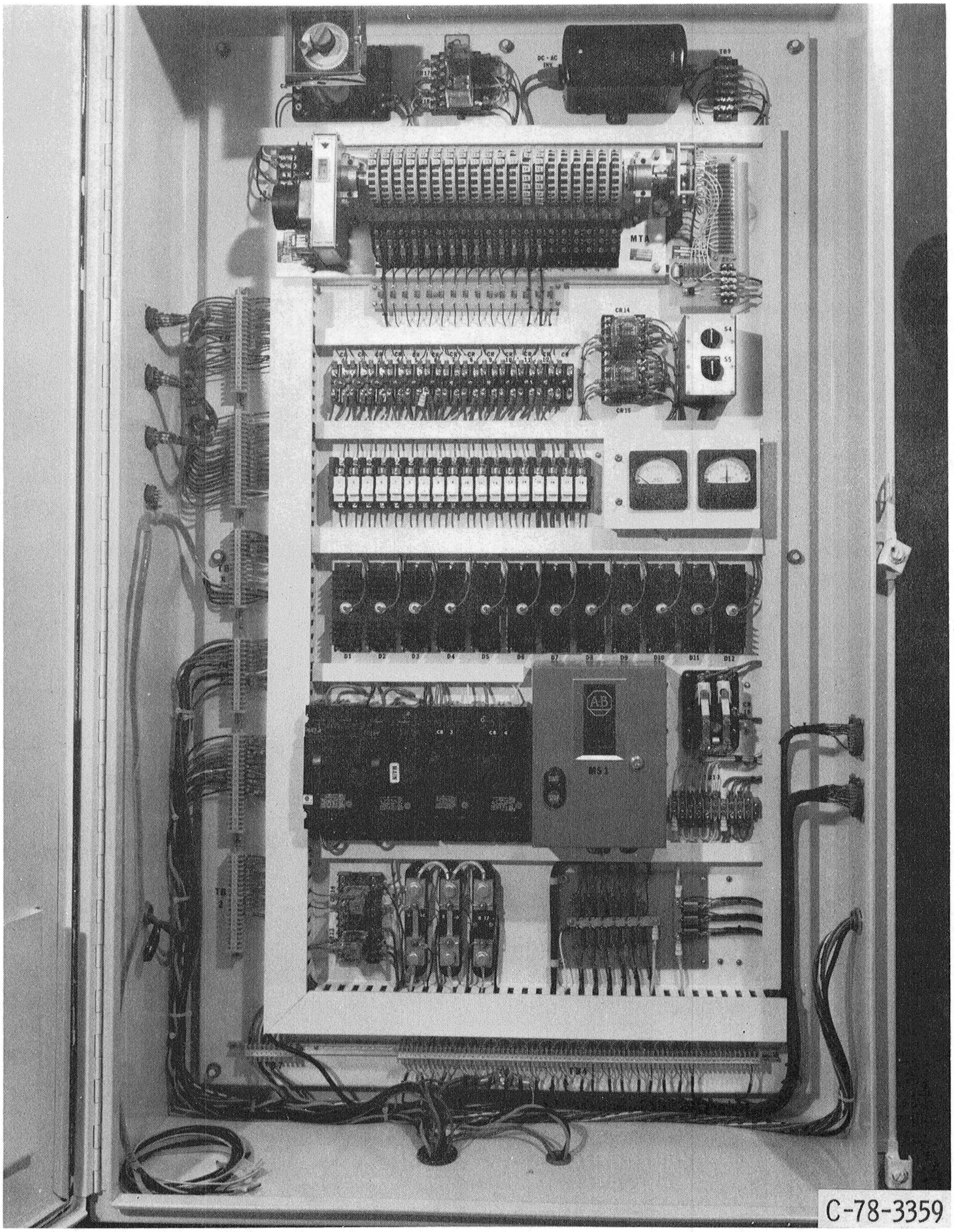

Figure 7. - Control panel.

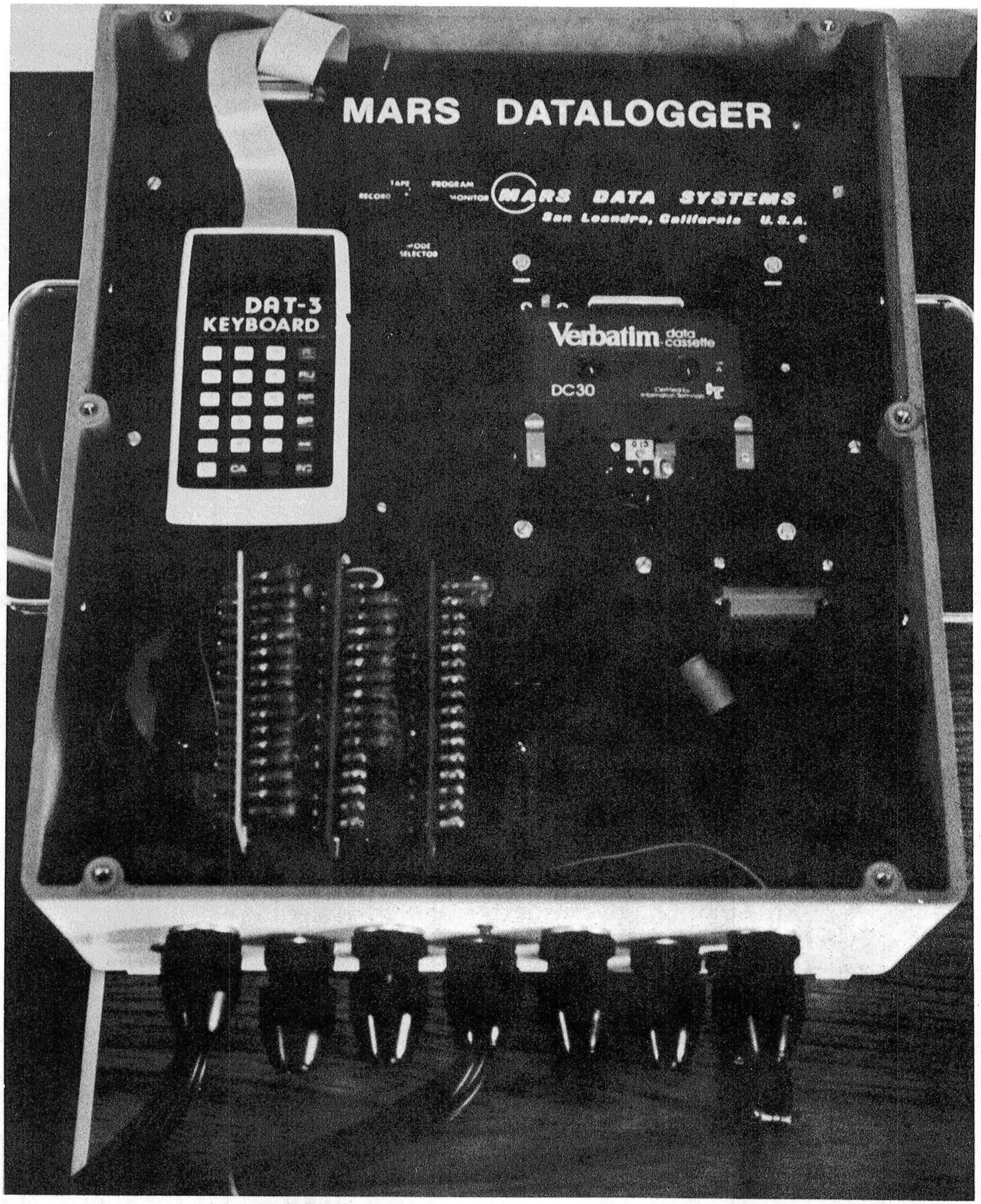

Figure 8. - DAT-3 Datalogger.

RECORD JOURNALIER TANGAYE

LeRC 04/30/79

Journee de la semaine		Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Nom								
Date								
Heure								
(1) Array Ampere-Hours								
(2) Array Amperes								
(3) Mill Ampere-Hours								
(4) Mill Amperes								
(5) Mill Hours								
(6) Pump Ampere-Hours								
(7) Pump Amperes								
(8) Pump Hours								
Voltage Limit Control	(9) Low Limit							
	(10) Volts							
	(11) High Limit							
System Volts	(12) Low Limit							
	(13) Volts							
	(14) High Limit							
Temperature								
Compteur d'Eau								
Reservoir d'Eau								
Temps								
Heures de fermeture								
Temps restant sur le Moulin								
Module thermistor								
Ambient thermistor								
Bande								
(15) 12 Volt Voltage								
(16) 12 Volt Current								
12 volt amp hour meter								
Number of DC lights on								
Total Poids								

Figure 9. Equipment Recording Sheet

Date ________________
Time ________________
Name ________________

Tangaye
Array String Data

String #	Open Circuit Voltage	Short Circuit Current
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Figure 10. Array String Data Form

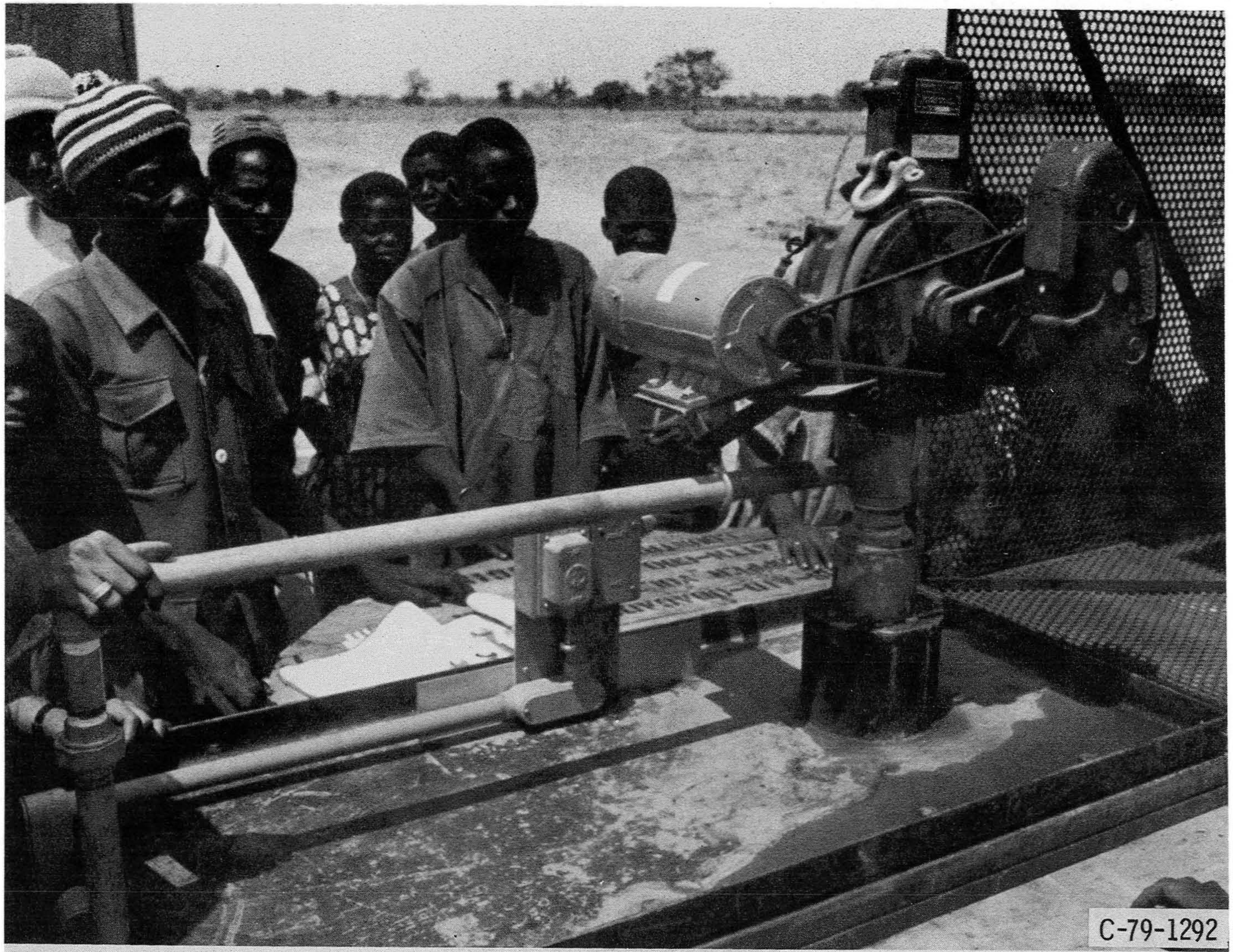

Figure 11. - Water pump.

Figure 12. - Water storage tank.

Figure 13. - Pump and facility for drawing water by hand.

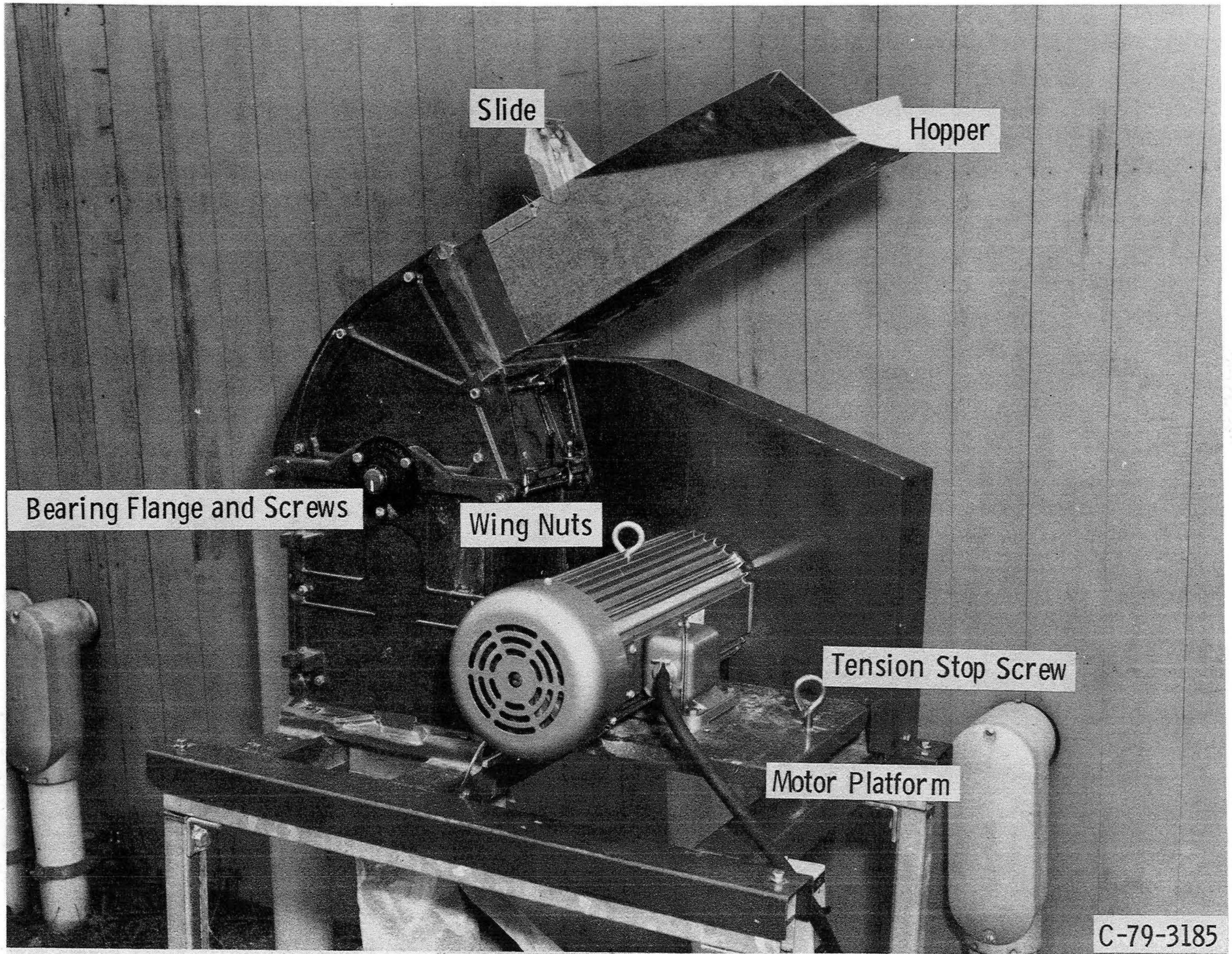

Figure 14. - Hammermill.

SYSTEM DESIGN

LOADS AND LOAD PROFILES

General

The size of the PV system was determined primarily by the U.S. AID funding availability. A total of $110,000 was provided by AID for hardware, software, shipping, and technical mointoring as shown in Table 1. During a site visit in February 1978, the recovery rate of the well was found to be about 5000 liters per day. Based on the above, the system design parameters were determined to be:

- Grain - 320 kilograms of flour per day (serving approximately 640 people)
- Water - 5000 liters per day (serving approximately 500 people)

Due to funding limitations, it was clear from the outset that the PV system would not meet all the needs of all the villagers.

Grain Mill

The original burr mill (C.S. Bell Company No. 60) was programmed to operate a maximum of 8 hours, cumulative, each day. The mill was powered by an Applied Motors, 120-V(d.c.), 1-hp permanent magnet motor which required 7 amperes of electric current. For load analysis, this mill was considered to operate continually for two 4-hour periods with a 2-hour interruption at noon. Grinding characteristics for Upper Volta grain, using very fine burr plates, are:

Grain	Once Ground (kg/hr)	Twice Ground (kg/hr)
Sorgho	92	53
Millet	84	49
Maize	59	49

This mill was operated by an automatic clock timing unit which limited the cumulative operation each day to the 8 hours. The mill was equipped with a belt guard and hopper screen for safety purposes. This mill has been replaced with a larger, more efficient, hammermill that is powered by an Applied Motors, 3-hp, 120-V(d.c.) permanent magnet motor and is operated for a maximum of 5 hours per day for 4 days per week. These time restrictions are maintained by the mill operator and the automatic clock timing unit is not used.

The original load analysis, using the 1-hp motor at 7 amperes, produced an electrical demand of 392 ampere-hours per week (7 amperes x 8 hours/day x 7 days/week). The new installation, with its operating schedule, produces an electrical demand of 300 to 360 ampere-hours per week (15 to 18 amperes x 5 hours/day x 4 days/week).

Water Pump

The existing well was tested for delivery rate by the Ministry of Rural Development of the Upper Volta Government; these measurements were later verified by measurements conducted by LeRC. The pump and well characteristics are shown in Figure 15. For load analysis, the pump was assumed to operate to the capacity of the well, 5000 liters/day. This assumption was based on the villagers' probable use of this well/pump and storage tank rather than hand-drawn water from other wells, thus saving both time and effort. Thus, the pump would be operating an estimated 3.43 hours per day, 7 days per week, requiring 2.5 amperes, producing an electrical demand of 8.58 ampere-hours per day or 60 ampere-hours per week. The pump operation was assumed to occur during two periods each day. The storage tank has a volume of 5.97 m^3 and is provided with five 15-mm valves with provision for hose attachments (Figure 16).

Instrumentation and Control System

The I/C system is powered completely separately from the main PV system and does not affect the load analysis for the main PV system. The I/C system operates from a 12-V battery which is charged by an independent 16-V PV panel, consisting of six modules wired in parallel, producing 7 amperes under full sun conditions.

Combined Load Profile

The load profile for the water pump and grain mill for each day of the year are given in Table 2.

Table 1. Cost Breakdown for Upper Volta Solar Cell Power System Demonstration Project*

Solar Cell Power System (1.785 kW peak + 72 W_{peak} spares)		
Solar cell modules and spares (100 modules)	$33,600	
Structure, wiring, other materials, tests, and assembly	4,120	
Batteries (57 battery cells) and racks	5,160	
Controls, instruments, and assembly	8,200	
		$51,080
Loads		
Water pump, motor, mount, and plumbing	980	
Grain grinder, motor, and starter	1,450	
Spare grinder, additional grinder, and pump parts	750	
		3,180
Water Tank and Distribution System	(1,900)**	
Instruction Manual and Translation		5,000
Shipping		4,600
Tools and Supplies		1,000
Travel		17,000
Contract Administration (DCAS)		620
Engineering Drawings and Documentation		6,000
LeRC Manpower (0.4 per year)		
Technical monitoring during system operation (FY 1979)		15,600
Contingency		5,920
TOTAL		$110,000

**Cost estimates based on June 1978 information.*

**AID providing separate funds for local procurement in Ouagadougou to LeRC specifications (Ref: AID Project Identification Document, Project No. 686-0234, March 11, 1978, which was part of William D. Roseborough's Trip Report).

- Pump: Jensen 11W5A, Positive Displacement Pumping Rate 1457 liter/hour
- Motor: ¼-hp, 120-V(d.c.) Permanent Magnet
- Controls: Tank Shut Off When Full
  Well Shut Off When Empty
- Well Characteristics
  - Recovery Rate
    Government of Upper Volta Estimate, 5000 liter/day
    LeRC Measured, 4800 liter/day
  - Water in Well January 1978, 6900 liters
  - Pumping Time, 3½ hours for 5000 liters
- Safety: Belt and Weight Guard

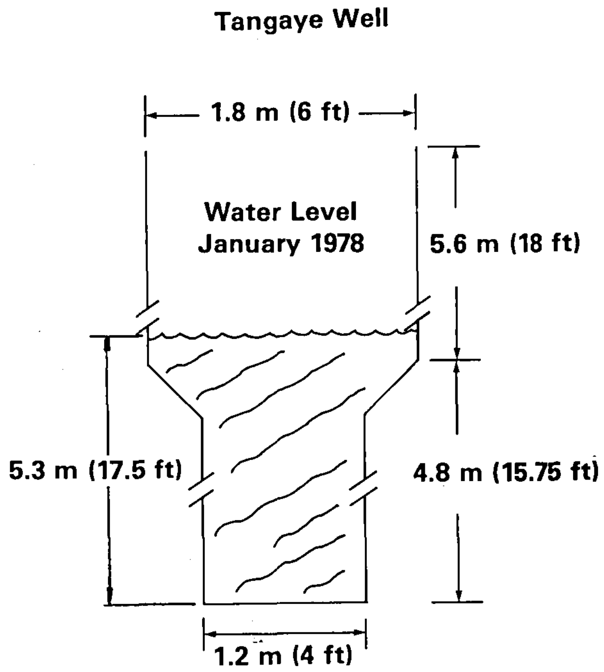

Figure 15. Tangaye Pump and Well Characteristics

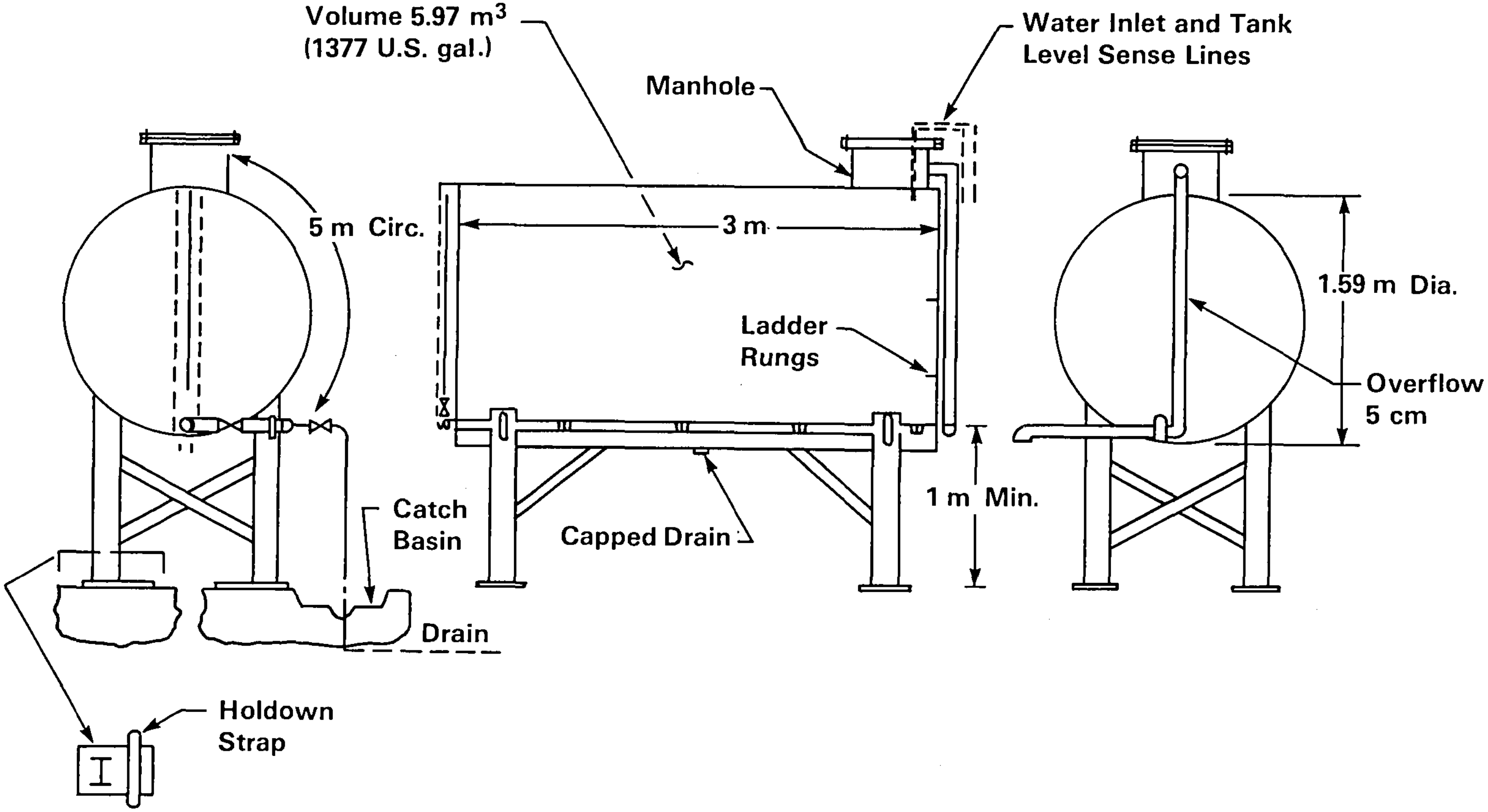

Figure 16. Water Storage and Dispensing Facility

Table 2. Water Pump and Grain Mill Load Profiles

Hour	Water Pump (ampere)	Grain Mill (ampere)	Combined Load (ampere)
7:00 (a.m.)	0.00	0.00	0.00
8:00	2.50	0.00	2.50
9:00	1.79	7.00	8.79
10:00	0.00	7.00	7.00
11:00	0.00	7.00	7.00
12:00	0.00	7.00	7.00
1:00 (p.m.)	0.00	0.00	0.00
2:00	0.00	0.00	0.00
3:00	0.00	7.00	7.00
4:00	0.00	7.00	7.00
5:00	0.00	7.00	7.00
6:00	2.50	7.00	9.50
7:00	1.79	0.00	1.79
8:00 (p.m.) to 7:00 (a.m.)	0.00	0.00	0.00
Total Ampere-Hours Per Day	8.58	56.00	64.58

PHOTOVOLTAIC (PV) ARRAY AND BATTERY SIZING

General

The PV system sizing method used to determine the PV array size (kW_{pk}) and battery capacity of the Tangaye system was developed by LeRC and consists of four separate steps:

- Identification of system voltage and a determination of hourly load profile for 1 day each month;
- Determination of the number of series battery cells required;
- Determination of PV cell operating voltage and the required number of series cells in an array string; and
- Use of a computerized array output calculation and system simulation program which is used to determine the number of parallel PV strings in the PV array and the battery capacity.

Load Profile

A pivotal factor in the continuous annual operation of any PV system is the battery depth-of-discharge (DOD) during periods of maximum load and/or minimum insolation. A typical hourly load profile for 1 day for each month thus provides the designer with a realistic basis from which to calculate battery DOD. The details of the Tangaye load profile, as discussed above, were incorporated in the PV system sizing simulation program which is described below.

Voltage Determination

To ensure long life and reliable operation of the two nominal 120-V(d.c.) motors, the system voltage is controlled at upper and lower limits of 130 V and 105 V, respectively.

Number of Series PV Cells

PV cell temperature is an important factor in PV array sizing because it affects the number of series cells required to satisfy system voltage requirements. The Tangaye PV array was designed to operate near maximum power output in the dry season to provide enough energy to ensure battery recharge prior to the next rainy season and to provide a reserve to pump water up to the capacity of the well. Because cell maximum power voltage decreases with increasing temperature at the rate of approximately 2.0 mV/°C/cell, with a concomitant decrease in cell output power, cell temperatures must be considered to avoid serious power output shortfalls during the rainy season.

Cell operating temperature can be estimated from the expression

$$T_{cell} = T_{air} + 0.3\ L$$

where L = insolation in mW/cm^2.
T = temperature °C.

For Tangaye, average daytime dry season temperatures are at or above 37°C (99°F) (Table 3) and average insolation was assumed to be 80 mW/cm^2; thus, cell operating temperature was calculated to be approximately 61°C.

Cell maximum power voltage at 61°C is obtained from the expression

$$V_{T2} = V_{T1} - 2.0\ mV/°C/cell(T_2 - T_1).$$

For the 42-series cell Solarex Model 9200J module used for this project, maximum power voltage at 28°C is 19.15 V, on the basis of LeRC measurements, and at 61°C is 16.38 V.

The nominal system bus bar voltage for this system was selected as 120 V(d.c.), primarily to minimize distribution line wire size and I^2R losses while at the same time providing for the use of standard motors and other commercially available equipment. The number of series-connected PV modules required to provide a nominal 120 V(d.c.) at the system bus bar was determined to be eight from the following considerations:

8 series connected modules at 16.38 V/module		131.04 V
Less:	Blocking diode drop (@ 1 ampere)	0.80
	Wire from array to control panel (@ 1 ampere)	1.00
	Series string current measuring resistor (1.0 ohm) @ 1 ampere	1.0
	Miscellaneous contacts	0.02
		128.22 V

Description of Sizing Program

The approximate size of the Tangaye PV power system, i.e., PV array peak kilowatt rating and battery capacity, was verified by means of the LeRC computerized PV System Simulation Program. The program consists of two parts: a determination of the hourly current output for the selected PV cell at the selected site and a system simulation that compares hourly PV array output with the hourly load profile to compile a running tabulation of battery DOD.

It should be noted that the LeRC sizing is conducted on an ampere-hour basis. Thus the ampere-hour output of a single module (or a string of series connected modules) is the same as for a single cell. The ensuing discussion refers, therefore, to single cells but should be understood in the context of a string of series-connected modules. The final determination of array size in peak kilowatts is therefore the product of the number of series-connected modules/string, the number of parallel strings, and the peak power/module. The cell output calculation uses site latitude and site-specific average monthly values of insolation, sky cover, atmospheric percipitable water, and atmospheric turbidity to calculate the direct and diffuse sunlight components. These data are then combined with the characteristics of a single cell (area, efficiency, and voltage at maximum power) of the module selected for the application to determine cell output (ampere-hours) for each month and at several different PV array tilt angles. This matrix (Table 4) is then used to identify the optimum tilt angles to input into the array output calculations in the system simulation program. The number of tilt angle changes per year is based on the amount of additional array output achieved and the availability of personnel to change the tilt angle. Inspection of Table 4 indicates that two tilt angle changes per year, 3.5° for April through September and 26° for October through March, would add only 2-1/2 percent output over that for a fixed angle of 11°.

An array degradation factor can be included to account for array output reduction due to dust accumulation, encapsulation darkening, cell mismatch losses, etc. To introduce random 4-day weather cycle variability into the daily cell output profile, the average daily insolation value for each month can be randomly varied within defined limits every fourth day.

The system simulation program combines the hourly array output profile (cell profile times number of parallel strings) for each month with the composite hourly load profile for that month to determine battery DOD on an hourly basis.

Each sizing "run" is for a 16-month period to ensure that the initial condition of a fully charged battery does not mask any annual effects.

When using randomized cell output data, the 16-month simulation is run 10 times, each time with differently randomized cell output, to identify the worst-case DOD.

The output of the simulation program may be in either of two forms: a summary listing of system status at 0600 hours every 30th day from start of simulation (Figures 17 and 18) or an hourly listing for every 11th day from start of simulation (Figure 19), or both. Included with the summary listing is the value of maximum DOD in the simulation period and the run day on which it occurs.

Tangaye Sizing

The insolation and other atmospheric data used for the array output calculation are shown in Table 3. An array degradation factor of 20 percent was used, on the basis of LeRC soiling tests and the prevalence of dust in the village. The randomization limits were ±20 percent, there not being too much variability in day-to-day weather.

Table 4 shows the cell (or series string) output as a function of tilt angle and time of year. It was determined that tilt angle changes would not provide a large enough increase in array output to warrant burdening local operating personnel with these changes. The 11° tilt angle was selected for year-round use.

In a normal sizing operation, the designer is free to vary the size of the PV array and battery capacity to achieve particular technical or economic design goals. The Tangaye system sizing was somewhat constrained in that the funding allocation for the project was limited and resulted in PV modules to produce 1800 W (based on Jet Propulsion Laboratory (JPL) maximum power rating of 18.6 W/module at 100 mW/cm^2 insolation and 60°C cell temperature). In the interest of minimizing battery capacity, all of the allocation (1800 W) was used as a fixed parameter in the system sizing. The "sizing" thus reduced to calculating the appropriate battery size for a given array.

The battery cell selected for this system is from the line of 1.225 specific gravity lead-calcium grid lead-acid cells designed for high temperature operation and manufactured specifically for PV systems by the C&D Batteries Division of The Eltra Company. These cells have the advantages of low gassing resulting in low water consumption, low self-discharge, constant charge voltage over cell lifetime, large electrolyte capacity, and large individual cell capacities which eliminated the need for paralleled cells and attendant charge balancing problems.

The inputs to the system simulation program were the composite load profile shown on Table 2 and an array size of 12 series strings of Solarex 9200J modules tilted at 11° as described above. The sizing goal was to limit battery maximum DOD to 50 percent or less in the worst-case situation (vis-a-vis randomization).

Sizing Results

The results of the system simulation sizing indicated that, for the 1800-W PV array, a battery capacity of 540 ampere-hours would result in a calculated maximum DOD of approximately 30 percent, which would tend to ensure long battery life. The 540-ampere-hour cells selected for this system can be installed and serviced without the use of auxiliary equipment such as hoists.

The results of the system simulation sizing for the original design condition, with a 540-ampere-hour battery, are shown in Figures 17 and 18. Note that the worst-case maximum DOD of 30 percent occurs on run day 247 which corresponds to September 4 based on a simulation start day of Julian day 1 (January 1). Figure 19 is an hourly listing for run days 243 (August 31) and 254 (September 11) from this simulation and gives the reader some insight into the hourly status shortly before and after maximum DOD occurs. A computer projected main battery state-of-charge annual profile is shown in Figure 20.

Number of Series Battery Cells

The number of series battery cells required is determined from such considerations as manufacturer's recommended float voltage and maximum and minimum voltage limitations of the various loads.

Battery manufacturer's recommended float voltage varies with temperature at the rate of -2.8 mV/°F/cell, i.e., lower float voltages at higher temperatures (Figure 21). Battery temperatures at Tangaye were estimated to average from 80° to 90°F. The corresponding float voltage is approximately 2.35 to 2.38 V/cell.

Instantaneous system voltage for the Tangaye system is influenced by battery state-of-charge and charge or discharge current. As was shown in the system simulation, with the onset of the rainy season and decreasing array output, the battery will gradually discharge until seasonal insolation again increases to the extent that average daily array output exceeds the average daily loads. Because the battery would be in a discharged condition during the rainy season, and, therefore, well below maximum float voltage for high temperature operation, the lower float voltage becomes the critical factor in determining the number of series battery cells. Thus, the number of series battery cells needed to satisfy the high temperature voltage constraint was

$$\frac{130\text{ V (nominal maximum system voltage)}}{2.35\text{ V/cell (90°F float voltage)}} = 55\text{ cells}$$

System minimum voltage was determined from the discharge voltage at the 500-hour rate and at 50 percent DOD. The manufacturer's recommended value for these conditions was approximately 1.95 V/cell. Thus for 55 series cells, the system minimum voltage would be approximately 107 V, the approximate minimum allowable for the operation of the motors.

Table 3. Meteorological Data for Tangaye System

Latitude: 12°

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cloud Cover*	0.54	0.51	0.68	0.74	0.74	0.72	0.81	0.82	0.77	0.61	0.48	0.57
Insolation (Langlies)	483	548	557	548	529	528	475	453	478	521	501	461
Precipitable Water (cm)**	1.08	0.97	0.99	1.24	1.50	1.75	2.80	2.74	2.50	1.69	1.00	1.19
Turbidity Coefficient	0.500	0.500	0.600	0.729	0.729	0.729	0.800	0.849	0.800	0.700	0.650	0.700
Ambient Temperature (°C)***												
Maximum	34	37	40	40	38	35	33	31	32	36	37	35
Minimum	16	18	22	25	27	24	23	22	22	23	21	16

*Cloud-cover and insolation data for town of Fada-N' Gourma, Upper Volta.

**Precipitable water and turbidity not available for Tangaye area; data for Sells, Arizona, which was judged to be similar to Tangaye.

***Temperature data for the town of Ouagadougou, Upper Volta.

Table 4. Estimated Solar Cell Performance for Tangaye System
(single cell (string) output (amp-hr per month))

Tilt Angle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.5	239	242	269	253	252	242	228	220	225	255	239	227
11.0	252	251	272	250	244	232	219	214	225	260	250	239
18.5	261	255	270	243	232	219	207	206	221	262	258	247
26.0	266	256	265	232	217	202	193	194	215	260	261	252
33.5	267	253	256	218	199	183	175	180	205	254	261	254
41.0	265	246	244	201	178	162	156	164	192	245	257	252
48.5	258	236	228	182	155	138	134	145	176	232	249	246
56.0	248	223	208	160	131	114	112	124	158	216	238	237
63.5	234	206	186	135	105	89	88	102	138	197	223	224
71.0	217	186	162	110	79	65	65	78	116	175	205	208
78.5	197	164	135	83	55	47	45	55	93	151	184	190
86.0	174	139	107	57	42	42	39	35	68	125	161	169

Run Day	Hour	Year Day	Array (Amps)	Load (Amps)	Depth of Discharge	Surplus	30-Day Surplus
1	6	1	0.0	0.00	0.00	0.0	0.0
31	6	31	0.0	0.00	0.02	0.0	496.7
61	6	61	0.0	0.00	0.03	0.0	641.6
91	6	91	0.6	0.00	0.03	0.0	660.6
121	6	121	0.9	0.00	0.03	0.0	490.6
151	6	151	1.0	0.00	0.02	0.0	435.0
181	6	181	0.8	0.00	0.05	0.0	177.0
211	6	211	0.7	0.00	0.03	0.0	165.3
241	6	241	0.3	0.00	0.25	0.0	6.7
271	6	271	0.5	0.00	0.02	0.0	249.6
301	6	301	0.0	0.00	0.02	0.0	404.7
331	6	331	0.0	0.00	0.02	0.0	333.6
361	6	361	0.0	0.00	0.03	0.0	352.1
391	6	26	0.0	0.00	0.03	0.0	411.5
421	6	56	0.0	0.00	0.02	0.0	685.6
451	6	86	0.0	0.00	0.03	0.0	650.4
481	6	116	0.6	0.00	0.02	0.0	449.6

Maximum Depth of Discharge = 0.30 Occurred on Run Day #247

Figure 17. Sample Output of Computer Simulation Program — Data Sample (worst-case randomization)

Run Day	Hour	Year Day	Array (Amps)	Load (Amps)	Depth of Discharge	Surplus	30-Day Surplus
1	6	1	0.0	0.00	0.00	0.0	0.0
31	6	31	0.0	0.00	0.03	0.0	491.5
61	6	61	0.0	0.00	0.02	0.0	710.1
91	6	91	0.5	0.00	0.02	0.0	651.3
121	6	121	0.9	0.00	0.02	0.0	509.0
151	6	151	0.9	0.00	0.02	0.0	360.7
181	6	181	1.0	0.00	0.02	0.0	319.4
211	6	211	0.9	0.00	0.03	0.0	131.6
241	6	241	0.4	0.00	0.03	0.0	87.1
271	6	271	0.5	0.00	0.03	0.0	249.9
301	6	301	0.0	0.00	0.02	0.0	516.7
331	6	331	0.0	0.00	0.02	0.0	543.7
361	6	361	0.0	0.00	0.03	0.0	378.6
391	6	26	0.0	0.00	0.03	0.0	456.1
421	6	56	0.0	0.00	0.02	0.0	671.3
451	6	86	0.0	0.00	0.02	0.0	661.1
481	6	116	0.5	0.00	0.02	0.0	532.8

Maximum Depth of Discharge = 0.03 Occurred on Run Day #214

Figure 18. Sample Output of Computer Simulation Program — Data Sample Every 30th Day (no randomization)

Run Day	Hour	Year Day	Array (Amps)	Load (Amps)	Depth of Discharge	Surplus	30-Day Surplus
243	1	243	0.0	0.00	0.28	0.0	0.0
243	2	243	0.0	0.00	0.28	0.0	0.0
243	3	243	0.0	0.00	0.28	0.0	0.0
243	4	243	0.0	0.00	0.28	0.0	0.0
243	5	243	0.0	0.00	0.28	0.0	0.0
243	6	243	0.3	0.00	0.28	0.0	0.0
243	7	243	1.5	0.00	0.28	0.0	0.0
243	8	243	2.4	2.50	0.28	0.0	0.0
243	9	243	3.9	8.79	0.29	0.0	0.0
243	10	243	5.6	7.00	0.29	0.0	0.0
243	11	243	7.1	7.00	0.29	0.0	0.0
243	12	243	8.1	7.00	0.29	0.0	0.0
243	13	243	8.1	0.00	0.27	0.0	0.0
243	14	243	7.1	0.00	0.26	0.0	0.0
243	15	243	5.6	7.00	0.26	0.0	0.0
243	16	243	3.9	7.00	0.27	0.0	0.0
243	17	243	2.4	7.00	0.28	0.0	0.0
243	18	243	1.5	9.50	0.29	0.0	0.0
243	19	243	0.3	1.79	0.30	0.0	0.0
243	20	243	0.0	0.00	0.30	0.0	0.0
243	21	243	0.0	0.00	0.30	0.0	0.0
243	22	243	0.0	0.00	0.30	0.0	0.0
243	23	243	0.0	0.00	0.30	0.0	0.0
243	24	243	0.0	0.00	0.30	0.0	0.0
254	1	254	0.0	0.00	0.10	0.0	0.0
254	2	254	0.0	0.00	0.10	0.0	0.0
254	3	254	0.0	0.00	0.10	0.0	0.0
254	4	254	0.0	0.00	0.10	0.0	0.0
254	5	254	0.0	0.00	0.10	0.0	0.0
254	6	254	0.5	0.00	0.09	0.0	0.0
254	7	254	2.1	0.00	0.09	0.0	0.0
254	8	254	3.3	2.50	0.09	0.0	0.0
254	9	254	5.3	8.79	0.10	0.0	0.0
254	10	254	7.6	7.00	0.09	0.0	0.0
254	11	254	9.6	7.00	0.09	0.0	0.0
254	12	254	10.9	7.00	0.08	0.0	0.0
254	13	254	10.9	0.00	0.06	0.0	0.0
254	14	254	9.6	0.00	0.05	0.0	0.0
254	15	254	7.6	7.00	0.04	0.0	0.0
254	16	254	5.3	7.00	0.05	0.0	0.0
254	17	254	3.3	7.00	0.05	0.0	0.0
254	18	254	2.1	9.50	0.07	0.0	0.0
254	19	254	0.5	1.79	0.07	0.0	0.0
254	20	254	0.0	0.00	0.07	0.0	0.0
254	21	254	0.0	0.00	0.07	0.0	0.0
254	22	254	0.0	0.00	0.07	0.0	0.0
254	23	254	0.0	0.00	0.07	0.0	0.0
254	24	254	0.0	0.00	0.07	0.0	0.0

Figure 19. Sample Output of Computer Simulation Program — Detailed Summary for August 31 and September 11 (worst-case randomization)

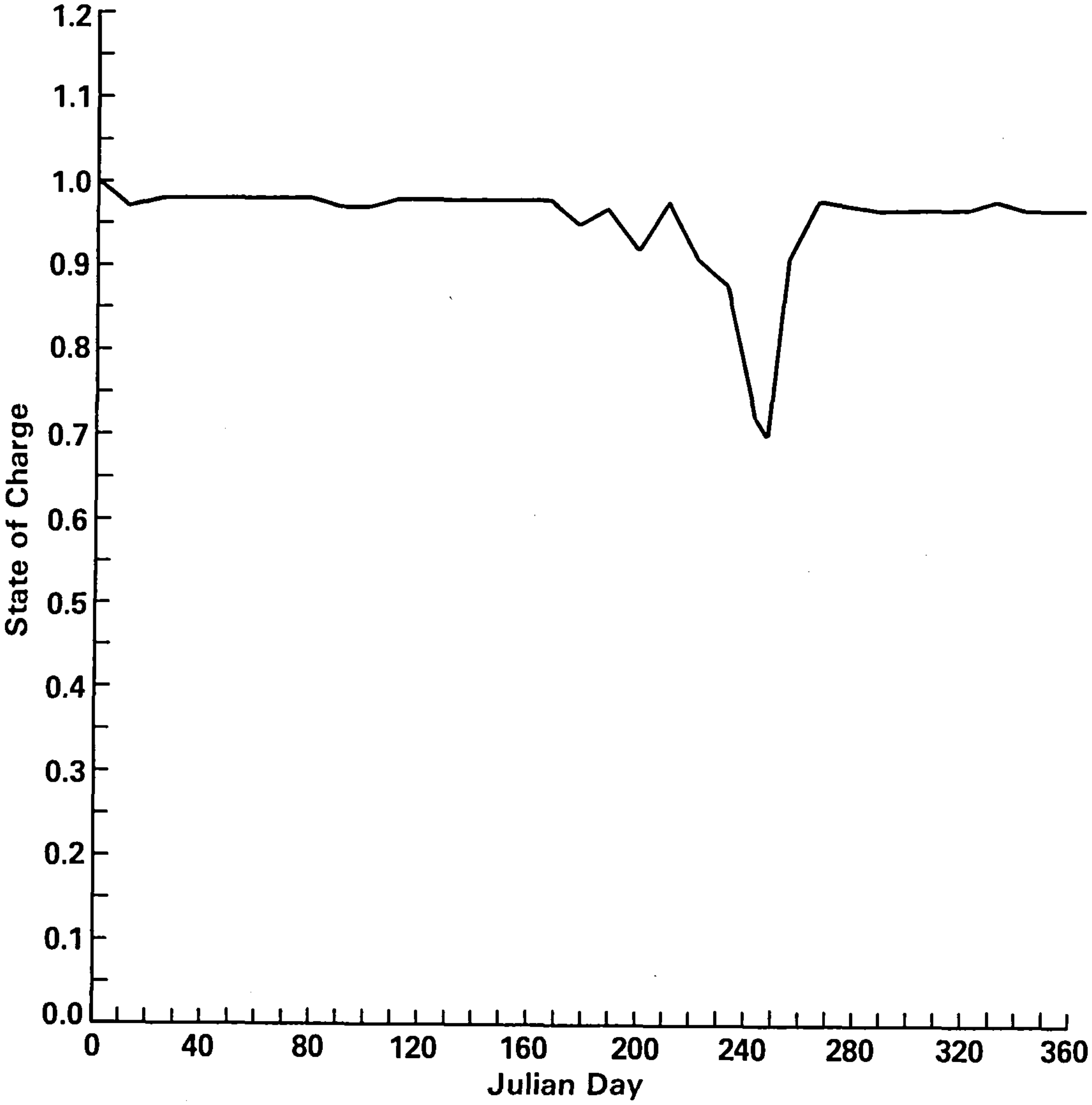

Figure 20. Tangaye Battery Predicted State of Charge (worst-case randomizations)

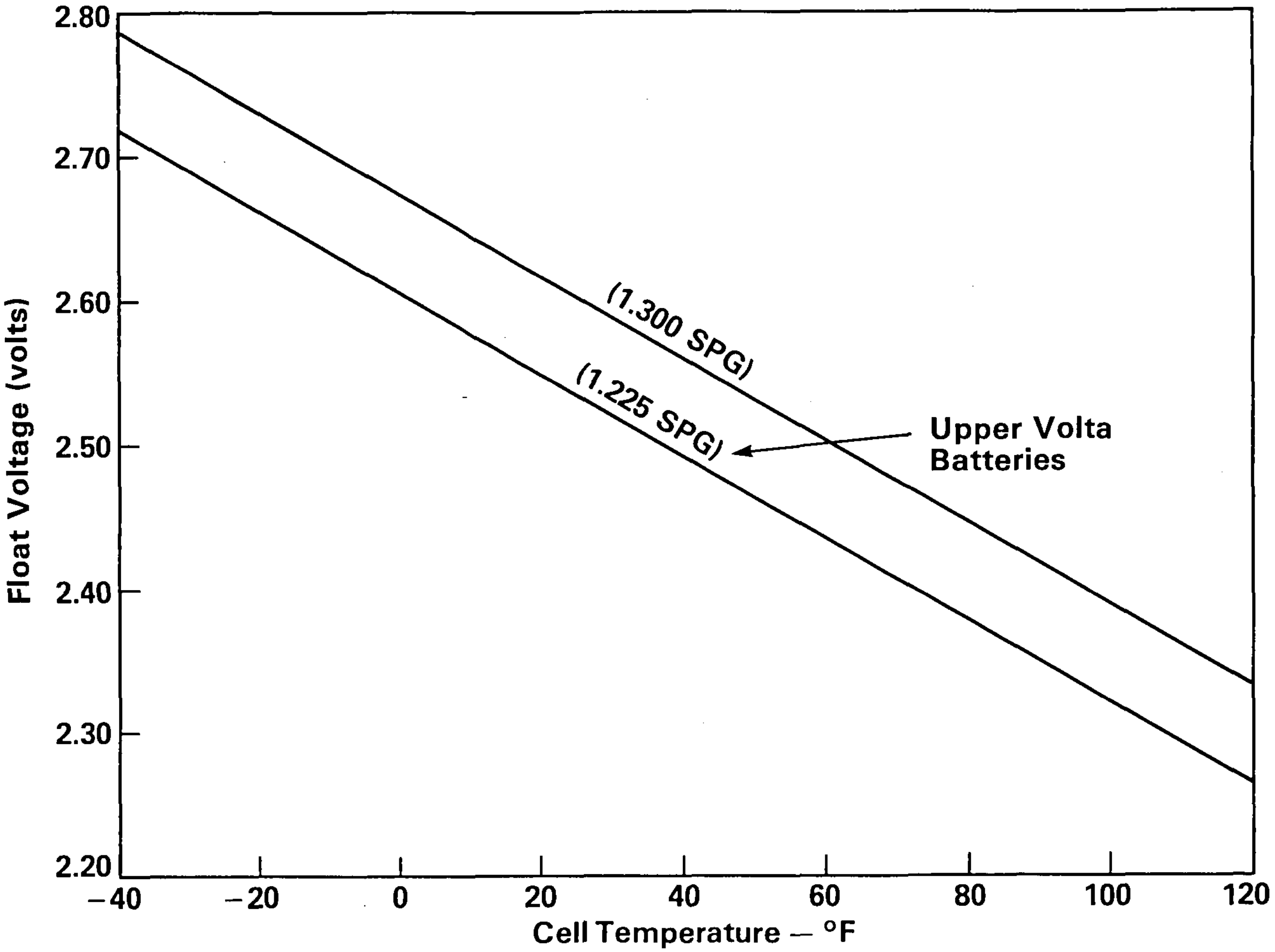

Figure 21. Recommended Float Voltage for Photovoltaic Cells at Various Temperatures (typical for lead-acid, calcium batteries)

MECHANICAL DESIGNS

Site Layout

The village, located on the main road between Ouagadougou and Niamey, Niger, is about 190 km east of the capital city of Ouagadougou or approximately 40 km west of Fada-N' Gourma, Upper Volta (Figure 1). The selections of the specific well to be used for the pump installation and of the site location for the PV array and mill building in the village were made jointly by personnel from the Upper Volta Office of Regional Development Engineering Offices, the village chief and his men's council, AID, and NASA-LeRC. The PV system layout is shown in Figure 4 and Drawing No. CF 56518.*

Array

The main array consists of 12 panels arranged in 3 rows of 4 panels each. The I/C array consists of one panel located at the southwest corner of the main array at the west end of the first row. The 16- x 16-m array area is bounded by a 5-ft, commercial-grade, chain-link fence. Access to the area is gained through a 4-ft gate at the southwest corner of the area. The gate is kept locked for security reasons. A cleared area (no vegetation over 1 m at maturity) is maintained around the fenced area for a width of 3 m.

The array structure is shown in Drawing No. CF 56519. The panel frames and supporting structure are designed to resist the aerodynamic loads from a 150-km/hr wind. These structures are made up of

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*Referenced drawings are all contained in Appendix A.

preformed "superstrut" components with bolted fabrication. The panels were assembled in Cleveland, Ohio, by a NASA-LeRC contractor. This design was employed to minimize the onsite fabrication and assembly time and to eliminate the need for specialized work skills at Tangaye. This array design is adaptable to many array site soil conditions. Where the soil permits, the structure may be installed in trenches and soil or riprap fill used for stability. In rocky conditions, the structure can be installed on the surface and can be bolted down or weighted down with rocks. The design was kept simple and direct to facilitate construction and maintenance and the possibility of module replacement. Tilt angle of the panels is fixed at 11° from the horizontal to maximize the annual output.

Mill Building

LeRC provided the basic size and layout sketches for the mill building to AID; AID was responsible for the preparation of the plans and specifications and for providing the materials and labor from local sources. The building is a one-story, 5- x 10-m structure with two separate rooms, a mill room, and a battery room (Figure 5 and Drawing CF 56518). The mill room contains the grain grinding mill, the instrument panel, the control panel, the data logger, and storage. For safety, the instrument panel and the control panel are locked with access only to authorized personnel. The battery room is vented and locked with access only to authorized personnel.

Water Pump

The water pump (Figure 22) and supporting structure rests on the existing concrete head wall structure of the well. The pumping system installation is shown in Drawing No. CF 56520 and details in Drawings Nos. CF 56521 through 56523. These structures are largely made up of preformed "superstrut" components with bolted fabrication as with the array structures described previously. The safety cage, which completely covers the pump and motor on its support mount and bolts to the pump mount, is removable to provide access for the periodic inspections and maintenance of the pump unit. A wood cover was fabricated to cover the well all around the pump mount to provide protection against debris entering the well. This cover is removable so that hand drawing of water is possible in the event of a pump failure.

All structural parts as shown on the drawings were fabricated at LeRC and assembled to ensure proper fit. The pump installation was then disassembled, crated, and shipped to Tangaye. The pump system installation "A" frame, Drawing CF 56523, was temporarily installed on the pump platform and drip pan to facilitate lowering the 3-in. pipe string into the well casing. The "A" frame is stored in a warehouse in the event that the pipe string should require removal or replacement.

Water Tank

As with the mill building, LeRC provided sketches for the water tank to AID; AID assumed responsibility for having the tank fabricated in Ouagadougou (Figure 12). The tank provides storage for about 6000 liters of water, has five dispensing valves on a manifold, an overflow pipe, and an access manhole for mounting of the fill line and pump control float level switch.

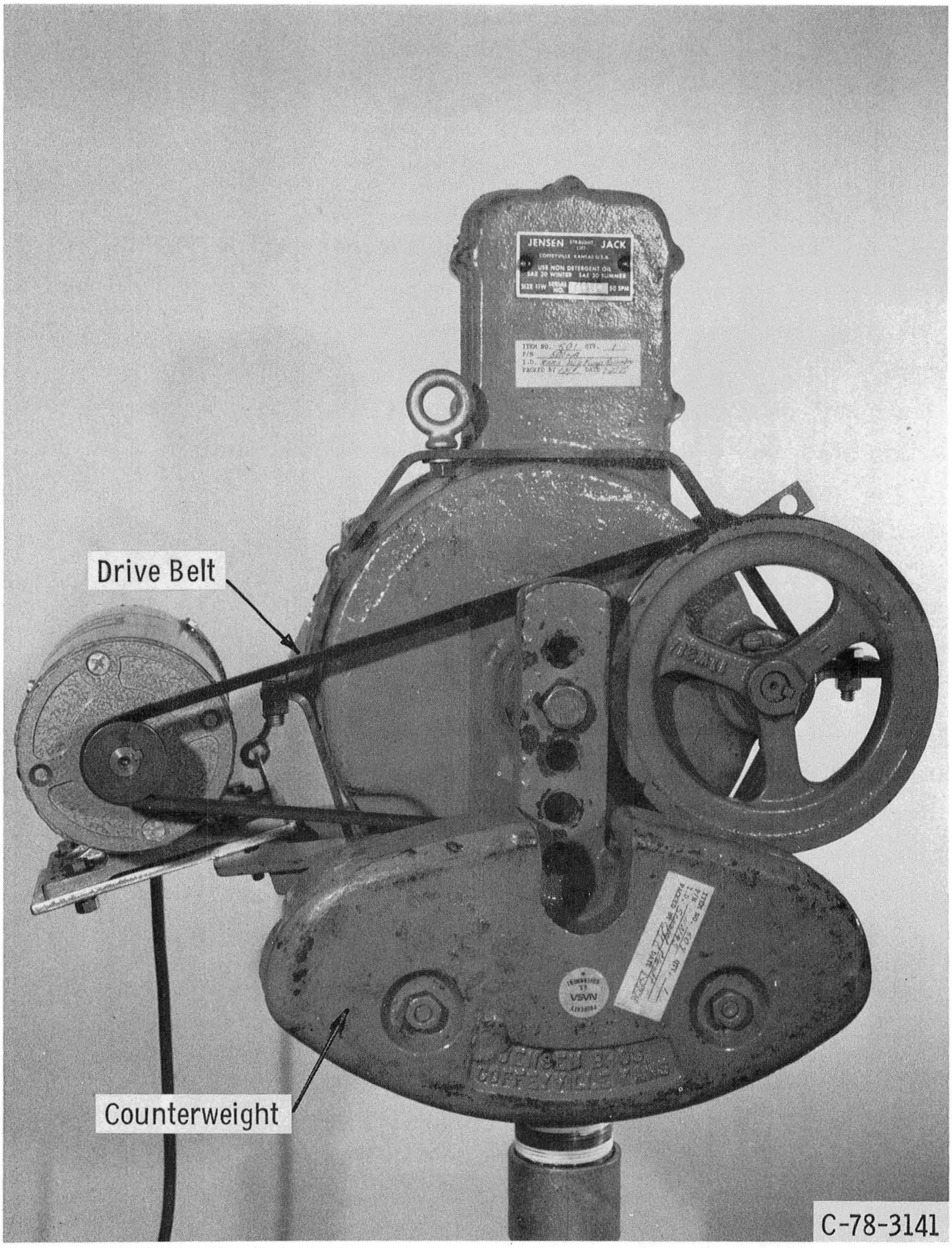

Figure 22. - Water pump and motor (rear view, cage removed).

ELECTRICAL DESIGNS

General

The electrical system is described in the previous section on system description and the following individual sections cover the array, battery, and instrumentation and control. The electrical system drawings and schematics are contained in Drawings No. CF 56524 through CF 56528.*

Arrays

The 96 Solarex Model 9200J PV modules in the PV main array are arranged in 12 panels of 8 modules each (Figure 23). The eight modules in each panel are connected in series to form a nominal 120-V string. The details of the panel wire harness are shown in Figure 24. Power from each panel is routed to a junction box at the end of each row and then cabled underground into the control panel. Note that there is a disconnect plug in the center of each harness in addition to the disconnect plug which connects the panel to the system cabling. When both plugs are disconnected, the array panel is segmented into four groups of two series-connected modules each. The maximum open circuit voltage of a panel is thus reduced to less than 50 V, a commonly accepted maximum safe d.c. voltage.

The complete circuit for each main array panel is shown in Figure 25 and Drawing CF 56524. Except for the panels, all of the other array circuit elements are in the control panel. A fuse-switch is used

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*Referenced drawings are all contained in Appendix A.

to isolate each string for testing and repair. The diodes serve to prevent battery discharge through the strings at night. The relays are solid-state relays (SSRs) used for array string switching in conjunction with the system voltage control. The 1.0-ohm resistor in each string is used in conjunction with the DAT-3 to monitor individual string currents.

The total array output is carried by the 30-ampere circuit breaker CB1. CB1 is a shunt trip circuit breaker and can be actuated in four ways: (1) manually when being used to disconnect the array during maintenance operations in the control panel, (2) automatically in conjunction with overvoltage conditions (see controls discussion), (3) remotely by the system emergency OFF switch, and (4) automatically from an over-current condition (very unlikely from array output).

The array is protected from lightning by an extensive grounding circuit. The frame of each module is connected to a separate ground harness (Figure 26), which is attached to the array panel frame and support structure. The support structures are in turn connected to a No. 8 ground wire buried about 15 inches below grade (Drawing CF 56518). There are four 3/4-in. x 8-ft grounding rods located at the corners of the ground system. In addition, the ground wire is connected to the pump installation and the water tank, and also serves as the ground point for the control panel.

Each of the 12 strings is controlled by one of the solid-state relays, CR1 through CR12. These relays are switched on or off by action of the duty cycle regulator (DCR) or the drum programmer (DP) discussed in the section on controls below. Individual string voltage and current are measured by means of voltmeter (V2) and ammeter (A2) by means of selector switch S1; these will be discussed in more detail in the section on instrumentation below.

The six Solarex Model 9200 J PV modules in the instrumentation and control (I/C) array are located in one panel and wired in parallel to produce about 16 V and 7 amperes (in full sun) to maintain the charge on the I/C battery. The I/C array is identified as "12-V Array" and the individual modules as P-13 through P-18 (Figure 27 and Drawing CF 56525). As with the 120-V system, except for the six module panel wiring, all other I/C array circuit elements are in the control panel. A fuse is included to isolate the I/C array from the 12-V bus and each module is protected against battery discharge through the modules at night by means of diodes D13 through D18. Zener diodes (DZ1 through DZ6) are used to limit the voltage from each panel and thus protect the I/C battery and circuits. The I/C array panel is connected to the grounding circuit for lightning protection. The I/C system voltage and current are measured by a voltmeter (V3) and ammeter (A5).

Batteries

The main battery consists of the 55 series-connected C&D model KCPSD-7 cells rated at 540 ampere-hours each. The cells and other associated circuit components are shown in Figure 28 and Drawing CF 56524.

The main battery is protected by two 30-ampere circuit breakers, CB2 and CB5. Circuit breaker CB2 is a shunt trip circuit breaker which is actuated by the voltage limit control and the system emergency OFF switch. CB5a and CB5b isolate the main battery from the system bus when both CB1 and CB2 are open.

The I/C battery consists of a 12-V industrial battery rated at about 200 ampere-hours (Figure 29 and Drawing CF 56525) and provides the electrical power for the I/C system. The I/C battery is protected by fuse switch F19. As stated above in the discussion of the I/C array, system voltage and current are measured by voltmeter (V3) and ammeter (A5). Battery charge is maintained by means of the I/C array.

Controls

The control subsystem has three controls: system voltage regulation and battery charge control, over- and under-voltage protection, and pump and mill controls. System voltage regulation and battery charge control are accomplished by array string switching. Two separate voltage controls provide additional system reliability. One control uses a drum programmer (DP) electromechanical device to control voltage and the other control is an all-electronic duty cycle regulator (DCR). The controls are independent and selectable by the local operator. The overvoltage controls disconnect the PV array in the event the voltage control fails. The under-voltage controls disconnect the loads to prevent excessive battery discharge in the event of loss of array power or excessive load use. The pump controls consist of a water level sensor in the water storage tank to start and stop the pump and a water level sensor in the well to stop the pump when the well water level drops below the pump intake. The mill controls consist of interlock switches and an optional time control to limit daily operating time.

Array and Battery Control

In the DCR control mode, the duty cycle regulator controls the system voltage and the charge current delivered to the system bus from the main solar array. The six DCRs connect or disconnect pairs of array strings by means of solid-state relays CR1 through CR12. If the 120-V bus voltage is below 124 V, the DCRs connect all of the strings to the bus to get the maximum current from the array to charge the battery. If the voltage is above 134 V, the DCRs disconnect all the strings, thereby removing all array current. If the system voltage is between these two levels, the DCRs connect and disconnect the strings periodically (with a time constant of approximately 5 seconds) to vary the average current from the array to the battery. If the voltage is in the low portion of this range, each of the DCRs connects its two strings for a greater length of time than it disconnects these during a cycle to give a high average array current. If the voltage is in the higher portion of this range, each DCR disconnects its two strings longer than it connects them during a cycle, therefore reducing the average array current. The average "ON" time for each pair of array strings continuously varies as the voltage varies.

The DCRs are adjusted to cycle over the same voltage range, but each may have a slightly different duty cycle frequency that is determined by the components of each DCR; this results in an apparent random operation of the DCRs. A red light on each DCR is used to indicate operation of the DCR. When the light on a particular DCR is ON, the corresponding two solid-state relays disconnect the two strings turning the strings OFF. When the light is OFF, the relays connect the two strings or turn them ON. Therefore, when the battery voltage is above 134 V (when it is close to fully charged), all of the DCR lights will be ON. When the battery voltage is below 124 V, all of the DCR lights will be OFF.

The duty cycle regulators, the primary means of system control, are enabled by putting the regulator selector switch S4 in the duty cycle (DC) position. When S4 is placed in the DC position, control of the array output is given to the DCRs by the following actions:

a. Contacts B3 and B4 of S4 are opened, removing the ground (lead 088) from CR1 through CR12; this prohibits control by contacts DP1 through DP12 of the drum programmer. The DCRs activate relays CR1 through CR12 by grounding them through DCR leads T3 and T2.

b. Contacts B1 and B2 of S4 are closed, applying 12 V to the six DCRs and to CR18 through diode D37 and the drum programmer contacts DP14. The action of CR18 is to step the drum programmer to position 1 which opens contact DP14.

The drum programmer, the secondary means of system control, is activated by placing S4 in the DP position. This removes voltage from the DCRs, connects the ground to CR1 through CR12, and applies 12 V to the circuits of CR17 and CR18. In this configuration, the DP subsystem performs the same functions as the DCR subsystem. In either control mode, the array current and voltage may be monitored by A1 and V1, respectively.

To understand the drum programmer operation, the reader must understand the way the DP interfaces with the other control subsystem elements. Figure 30 is a reproduction and elaboration of the drum programmer schedule shown in Drawing CF 56525. Rather than describe in detail each of the various control circuits (most of which are understandable by readers familiar with electromechanical controls), only those aspects or features of the controls which cannot be readily understood from the schematics are described below. For these descriptions, references will be to the electrical schematics of Drawings CF 56524 and CF 56525.

1. The meter relay contacts are in the "normal" position when the value of the parameter being sensed is between the high and low limit settings and when 12-V power is applied to the meter relay.

2. Whenever possible, control relays were designed to function in the unenergized mode so as to conserve energy. However, relays in safety-related circuits operate normally in the energized mode so as to fail-safe in the event of loss of power.

3. The control subsystem incorporates an over- and undervoltage protection feature which protects the system in the event the normal controls fail. Overvoltage protection prevents damage to controls, battery, and loads. Undervoltage protection circuits use normally energized relays CR14 and CR15 and meter relay V1a to actuate circuit breakers CB1 and CB2. V1a (Hi) contacts de-energize CR14 which trips CB1, disconnecting the PV array from the main bus. V1a (Lo) contacts de-energize CR15 which trips CB2 and disconnects all 120-V loads. An emergency shut-off button, PB7, de-energizes both CR14 and CR15 tripping both CB1 (PV array) and CB2 (loads). When CR14 and CR15 are both de-energized, CB5 is also tripped to isolate the main battery from the system 120-V(d.c.) bus.

4. The DP uses a 120-V, 60-Hz stepping motor and stepping interval timer. The inverter which inverts 12 V(d.c.) to 120 V(a.c.) requires a regulated 12-V input in order to provide a 117- to 120-V(a.c.) output to the stepping motor and the stepping timer (CA timer); this is provided by the 12-V regulator.

5. The CA timer regulates the stepping rate of the drum programmer. It has adjustable contact-open and contact-close time periods which are set to provide a stepping rate of one step every 3 seconds.

6. Both the DP and the DCRs are connected to the I/C battery/array through F15, protecting the I/C power source from overloads in either subsystem. The 12-V(d.c.) regulator and thus the d.c.-to-a.c. inverter are disconnected from the power except when either CR17 or CR18 is energized; this conserves I/C battery power.

Load Controls

The mill motor 120-V(d.c.) control and power circuits are shown on Drawing CF 56524. The 12-V(d.c.) mill timer control circuit is shown on Drawing CF 56525 and in Figure 31. The mill motor can be manually started by pushing PB5 (Drawing CF 56524) when:

1. +12 V is present at CR20, closing contacts 3 and 4;
2. Relay CR13 is not energized (switch S3, the mill operation mode switch, is normally set to "by-pass" position, removing power from CR13);
3. The mill cover switch, a safety device, is closed;
4. The STOP push button, PB4, is not activated. This button is colocated with the START push button, PB5, in a box mounted on a mill support frame;
5. The STOP button, PB6, mounted in the motor starter box (MS1) is not activated;
6. The selector switch in MS1 is in the AUTO position; and
7. CB5, CB2, CB3, and the disconnect switch and two fuses in MS1 are closed.

When these conditions are satisfied, pushing the START button energizes relay CR19. One pair of CR19 contacts by-pass the START button contacts and at the same time, the time delay relay (TR) is energized. One pair of contacts of relay TR close, energizing the start relay, S. Contacts of the start relay, MS1-5, close, applying power to the motor through a starting resistor, RES. This resistor limits the starting current to the motor. A few seconds after the motor starts, the time delay contacts (NOTC) of the TR relay close, energizing the run relay, R. Three sets of normally open contacts of the R relay close, connecting:

- A bypass around the NOTC contact, latching the R Relay;
- A bypass around the starting resistor, applying full voltage to the motor; and
- Power to the run light, N.

One set of normally closed contacts of the R relay open, deactivating the TR relay.

The motor can be stopped in many ways; usually by pushing either PB4 or PB6. An elapsed time indicator, ET-1, accumulates the time that the mill operates.

The original mill control circuit included a mill timer (Figure 31). As previously discussed, this timer is not used with the current 3-hp powered mill. Note mill bypass switch, S3: it is currently set in the Bypass position and the mill is operated manually.

Circuit overcurrent protection for the mill motor circuit is provided by:

- Overload contact in the motor starter MS1, which opens the motor control circuit.

- Overload contact in switch MW1 located on the mill stand. This overload should be the first to open in the event of an overload condition. It can be reset by turning the MW1 toggle switch to OFF and back to ON.
- Overload contact built into the motor, which will open the motor control circuit if the motor overheats.
- CB3, a 30-ampere circuit breaker.
- A 30-ampere fuse in MS1.

The mill building light, MILL LIGHT, is a standard fluorescent fixture and 120-V(a.c.) fluorescent lamp with a special inverter-ballast which transforms the 120 V(d.c.) to 120 V(a.c.), 23 kHz. The light is connected to the 120-V(d.c.) bus through a wall switch and fuse F14.

The water pump motor, MTR2, is a 1/4-hp permanent magnet motor. The pump motor turns ON and OFF automatically depending on the water level in the well and in the water storage tank. The 120-V(d.c.) power circuit for the water pump is shown in Figure 32. The 12-V(d.c.) control circuit is shown in Figure 33.

Note in Figure 33 that the control circuits are powered by the 12-V instrumentation supply. The water pump and mill motor control circuits are interlocked to the 12-V supply to prevent operation of the loads in case the instrumentation battery is too low. Opening fuse switch F17 will remove the 12-V power from both mill and pump motor control circuits and will disable both the mill and the pump motors.

With the pump bypass switch, S2, in the NORMAL position, the control of the pump operation is automatic. Pressure-sensitive switch PS2 in the well is a normally open switch. Its contacts will close only if water pressure on the diaphragm is sufficient to force the switch closed. PS2 prevents pump operation when there is less than 3 feet of water in the well. Thus, with a sufficient supply of water in the well, the contacts will be closed.

Pressure switch PS1 in the storage tank is a normally closed switch. With a low water level in the tank, the contacts will be closed, energizing the pump control relay CR21 in the pump control circuit (Drawing CF 56525). After sufficient water is in the tank, pressure on the diaphragm of PS1 will cause the contacts to open, removing power from CR21. The bypass switch, S2, is intended to be used only for test purposes.

As shown in Figure 32, when relay CR21 contacts are closed and circuit breaker CB4 is closed, relay CR16 in the pump power circuit (Drawing CF 56524) is energized. The contacts of CR16 apply power to the water pump motor through the manual switch MW2, located in the protective cage of the motor.

Overload protection is provided for the pump motor by:

- CB4, a 15-ampere circuit breaker;
- A switch, MW2, located on the pump frame (Figure 11); and
- Overload contacts built into the motor. These contacts will open automatically if the motor overheats, opening the pump control circuit, and will close when the motor cools.

Instrumentation

Most of the instrumentation is for diagnostic purposes for this experimental system and would not be required for the operation of a similar system. All instrumentation for the system is mounted on the instrument panel, except for the 12-V system meters and the mill timer which are in the control panel, and a remote mill current meter mounted near the mill. The three cables (item 22 in Figure 34) on the left wall of the control panel enclosure interconnect the control panel and the instrument panel. The instrument panel face contains the various instrument components identified in Figure 35. A rear view of the panel is provided in Figure 36. An overview of the function of the instruments is given below.

- Meter Relay - The meter relay is a special type of meter, with internal relays which can control other circuits.

  The meter relay contacts are in the "normal" position when the value of the parameter being sensed is between the high and low limit settings and when 12-V power is applied to the meter relay.

  Whenever possible, control relays were designed to function in the unenergized mode so as to conserve energy. However, relays in safety-related circuits operate normally in the energized mode so as to fail-safe in the event of loss of power.

  The limit set points for the meters of this system have been chosen carefully and set at the time of installation.

- Elapsed Time Indicator - This device has built-in electronic timing circuits which advance a mechanical counter whenever the device is powered. The indicator is connected in parallel with the unit whose operating time is to be measured so that the time is incremented whenever power is applied to the unit.

- Ampere-Hour Meter - The ampere-hour meters integrate current flow. Voltage from a precision resistor shunt charges a capacitor. When the capacitor is charged to a predetermined level, it triggers a circuit which discharges the capacitor and indexes the counter wheel to register 0.01 ampere-hours.

The DAT-3 automatic datalogger monitors selected system parameters (Figure 37). Generally, it uses the same sensors as the panel meters. Measurements are taken automatically every 20 seconds and recorded on cassette tape once an hour, on the hour. The average, maximum, and/or minimum value for the preceding hour and/or the instantaneous value on the hour may be selected for recording by a software program in the DAT-3. The tapes are changed every 2 weeks and sent to LeRC for computer reduction of the data.

Information sampled and recorded by the data logger is as follows:

- Current from each string of the main array;
- Total array current;

- Main battery current, charging or discharging;
- Mill motor current;
- Pump motor current;
- Instrument array current;
- Instrument battery current, charging or discharging;
- Instrument battery voltage;
- Main battery voltage;
- Position of the drum programmer;
- Temperature of the main array; and
- Ambient temperature.

A separate battery and battery charger operated from the 12-V(d.c.) I/C bus furnish the power to the data logger; these are internal, within the case of the data logger. Protection is provided from overcurrent by Fuse F16, shown in Figure 38.

Cabling

All cabling from the arrays to the control panel in the mill building, from the control panel to the pump motor at the well, and to the pressure-sensitive switches in the water storage/dispensing tank is buried underground in PVC conduit (Figure 4 and Drawing CF 56518). Appropriate PVC fittings, couplings, adapters, and moulded junction boxes were used.

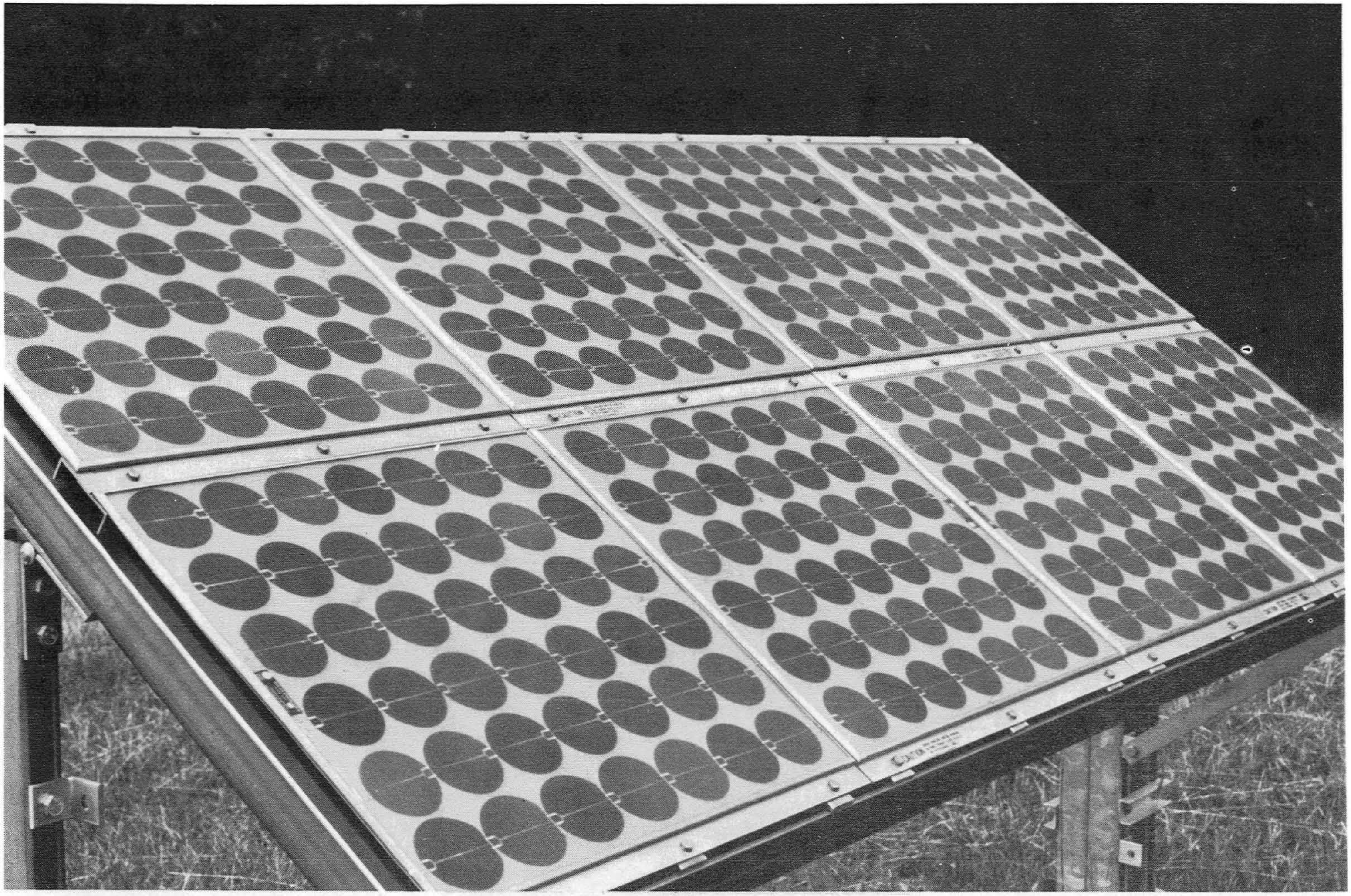


Figure 23. 8-Module PV Panel.

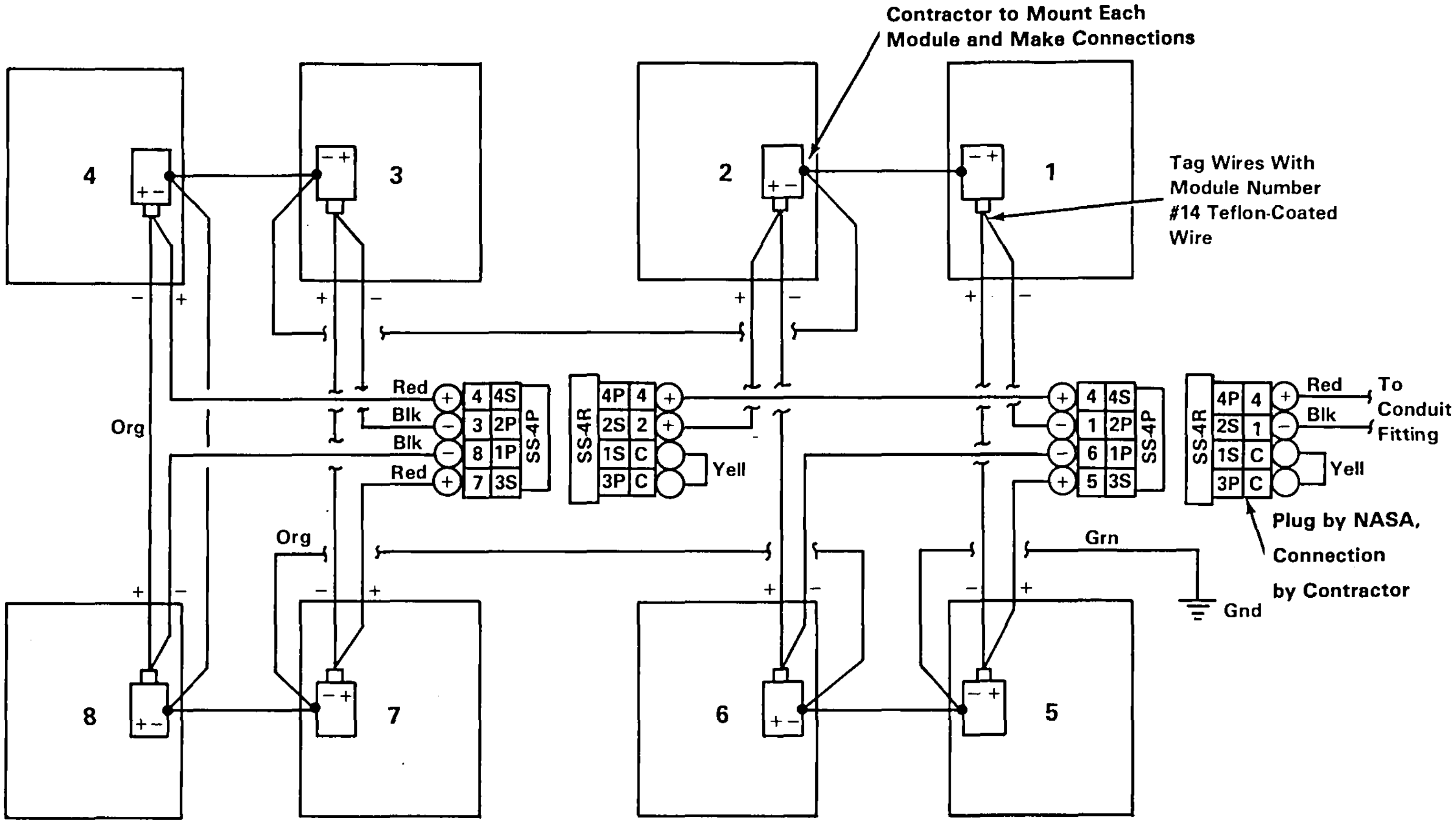


Figure 24. 120-V Panel Wiring Diagram

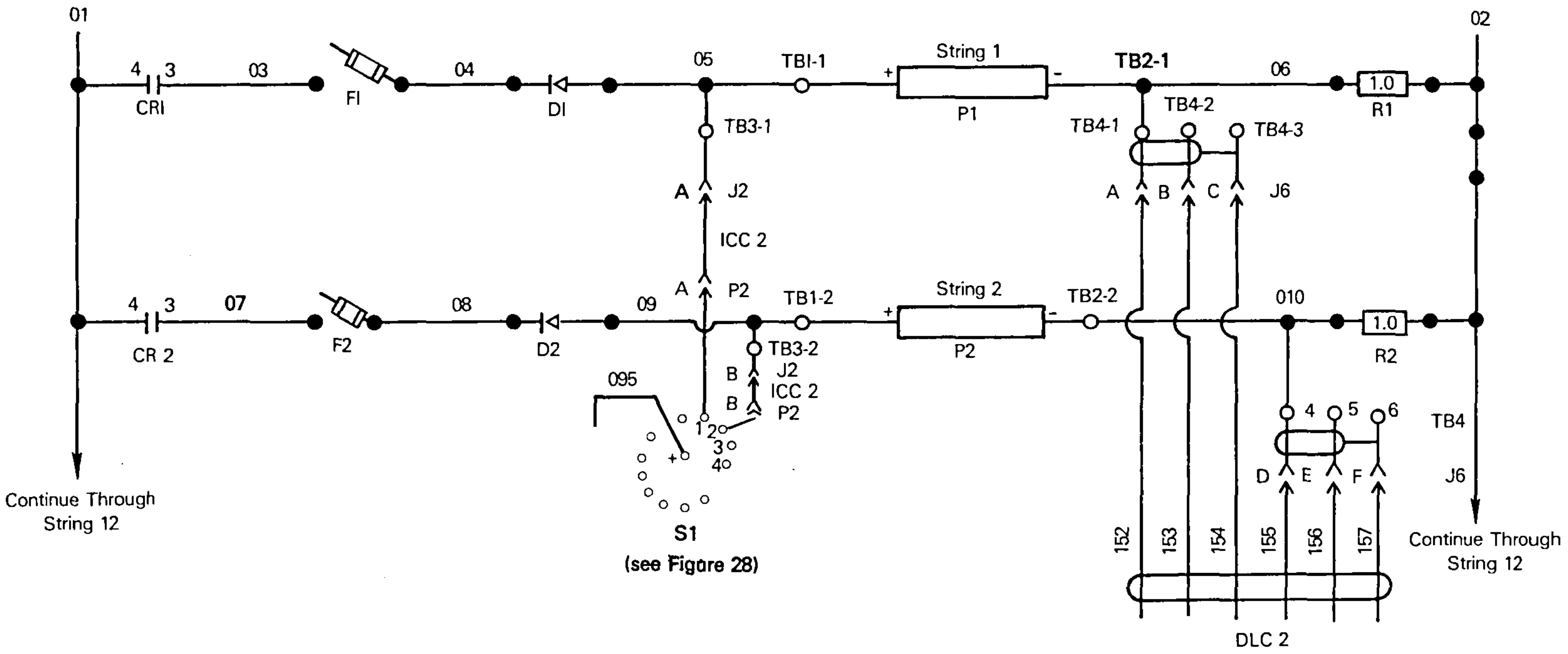


Figure 25. Main Array Circuit

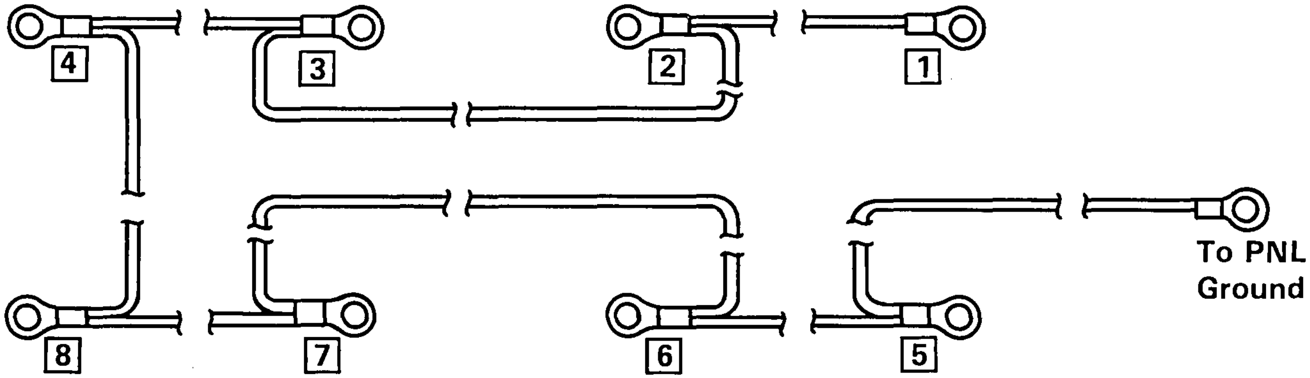


Figure 26. Ground Harness Assembly for 120-V Panel

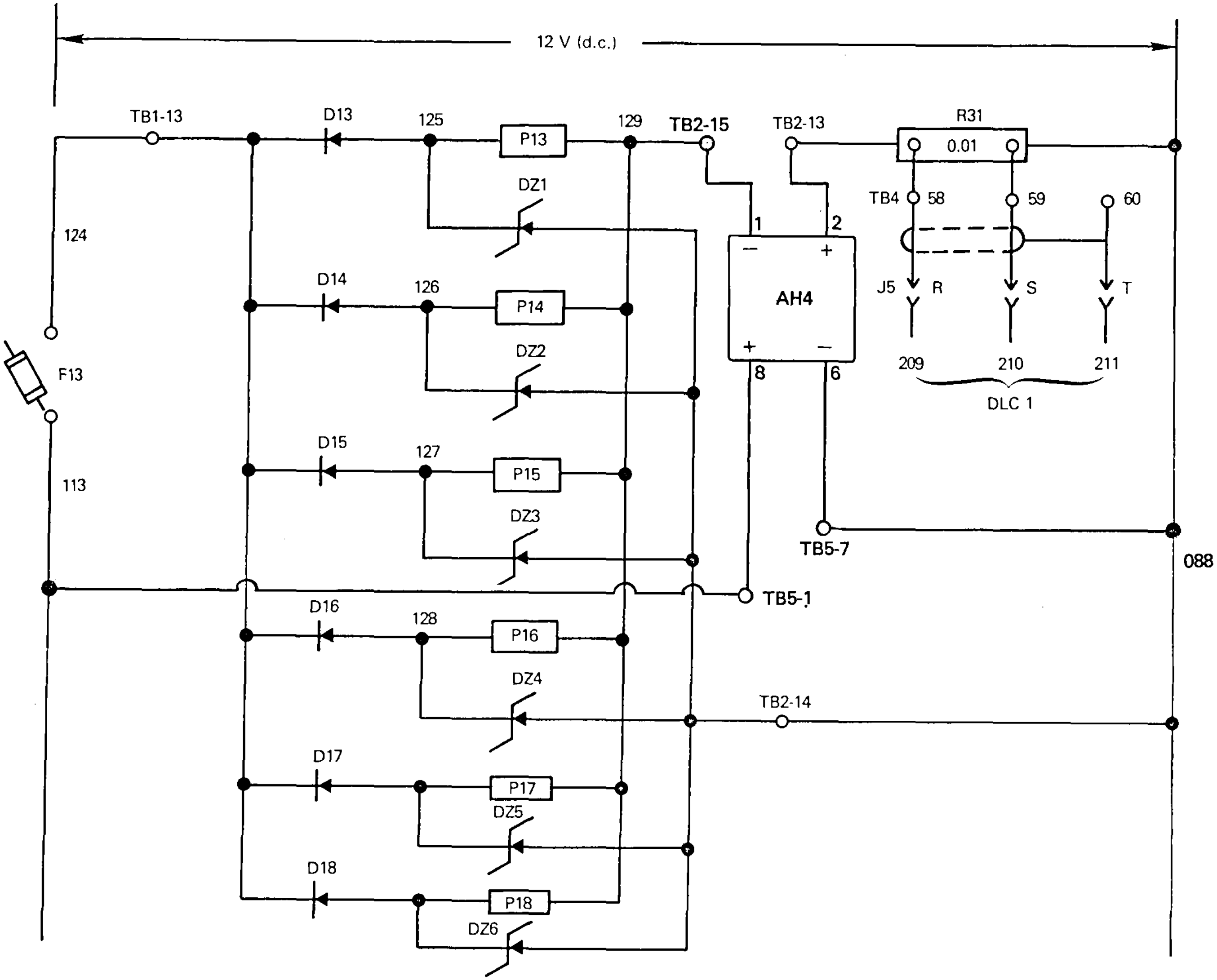


Figure 27. 12-V Array Schematic

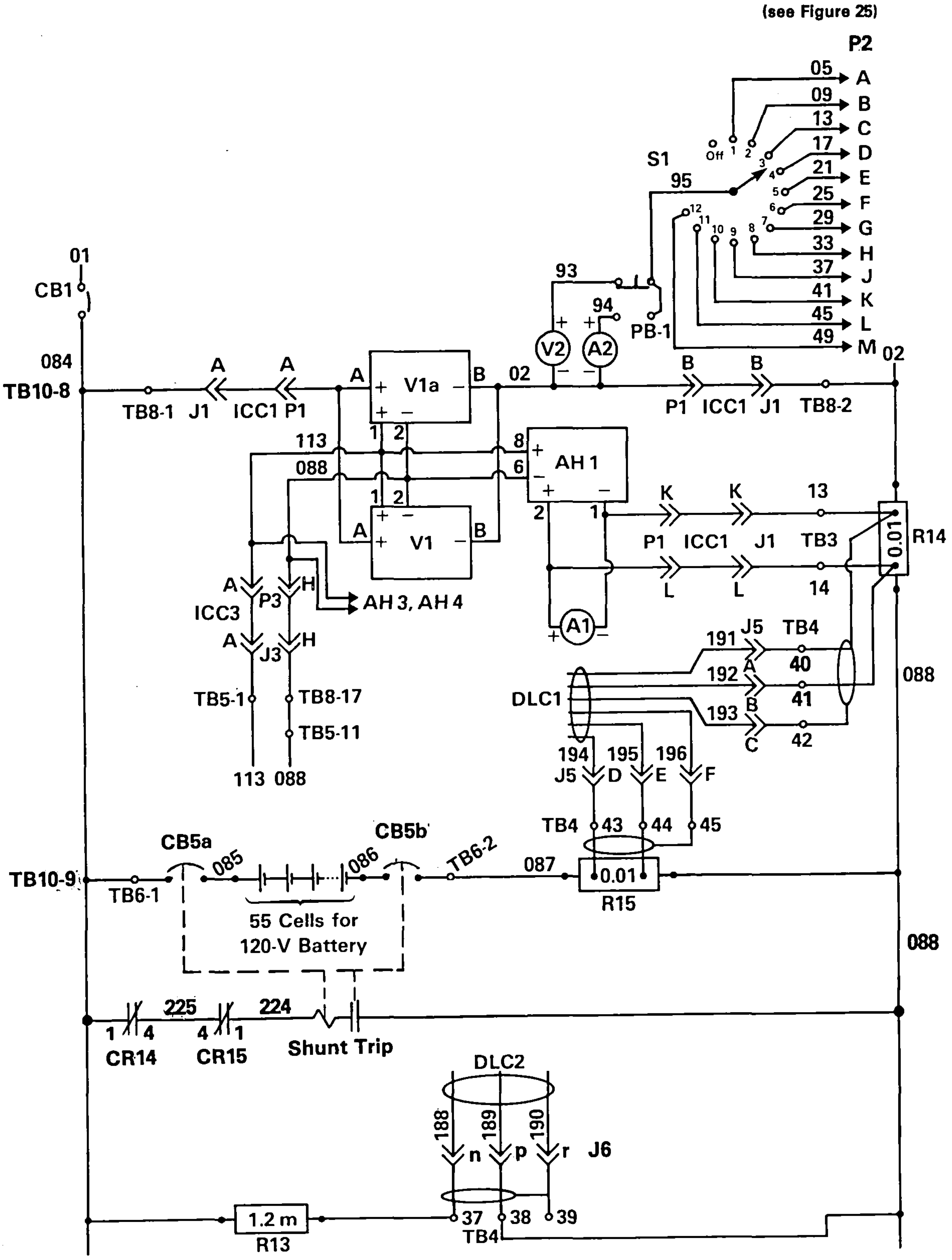


Figure 28. Main Battery Circuit

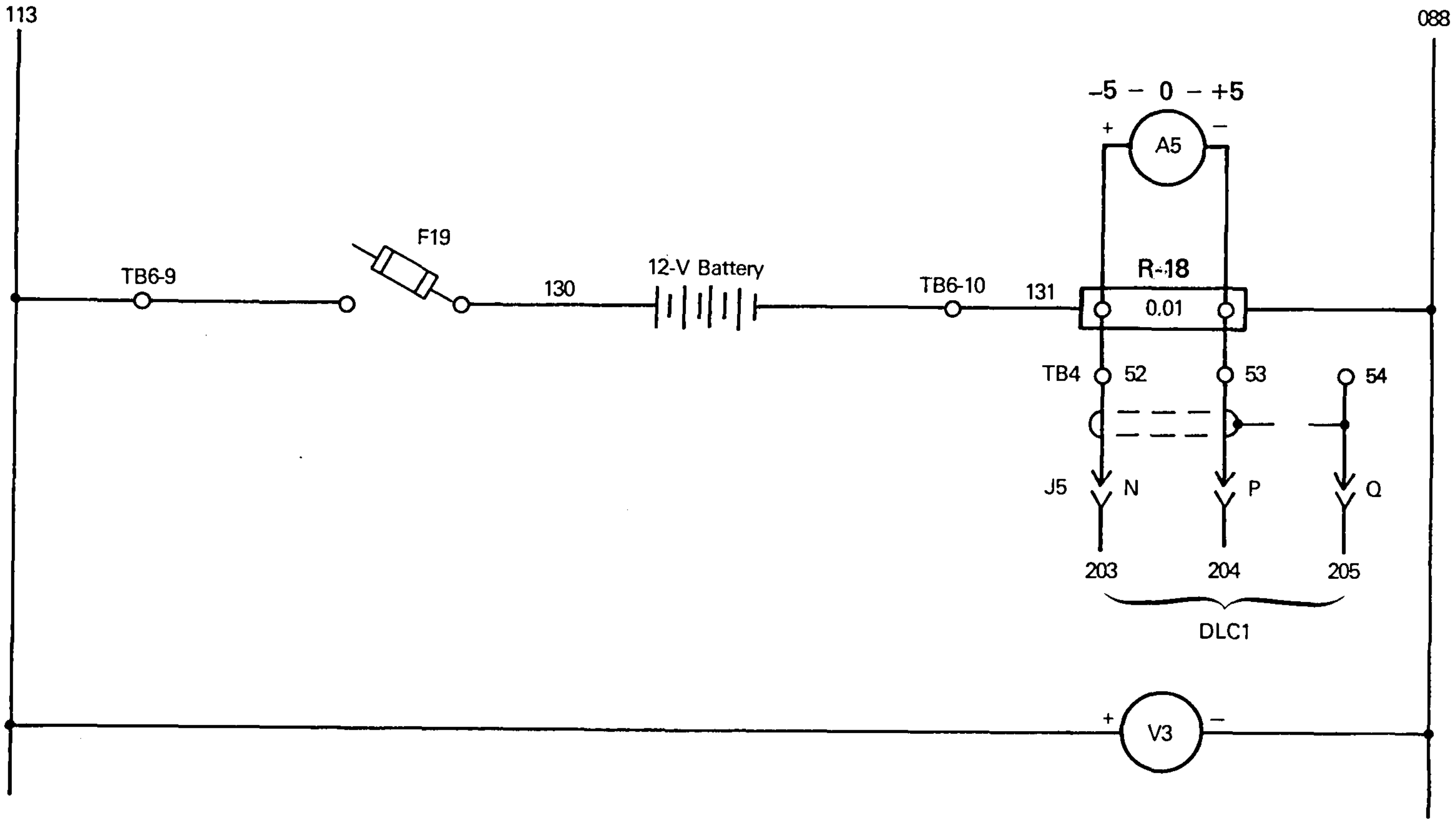


Figure 29. 12-V(d.c.) Battery Circuit

All Strings Switched On

All Strings Switched Off

		Step Position of Drum																								
		24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
String #1	(CR1)												X	X	X	X	X	X	X	X	X	X	X	X	o	
#2	(CR2)												X	X	X	X	X	X	X	X	X	X	X	o	o	
#3	(CR3)												X	X	X	X	X	X	X	X	X	X	o	o	o	
#4	(CR4)												X	X	X	X	X	X	X	X	X	o	o	o	o	
#5	(CR5)												X	X	X	X	X	X	X	X	o	o	o	o	o	
#6	(CR6)												X	X	X	X	X	X	X	o	o	o	o	o	o	
#7	(CR7)												X	X	X	X	X	X	o	o	o	o	o	o	o	
#8	(CR8)												X	X	X	X	X	o	o	o	o	o	o	o	o	
#9	(CR9)												X	X	X	X	o	o	o	o	o	o	o	o	o	
#10	(CR10)												X	X	X	o	o	o	o	o	o	o	o	o	o	
#11	(CR11)												X	X	o	o	o	o	o	o	o	o	o	o	o	
#12	(CR12)												X	o	o	o	o	o	o	o	o	o	o	o	o	
DP Limit	UP												o	X	X	X	X	X	X	X	X	X	X	X	X	
	DN												X	X	X	X	X	X	X	X	X	X	X	X	o	

Load Switches on Step Switches Open "0" Close "X"

Opens Circuit to DP Up Command to Prevent 360° Rotation

Opens Circuit to DP Down Command to Prevent 360° Rotation

Figure 30. Drum Programmer Schedule

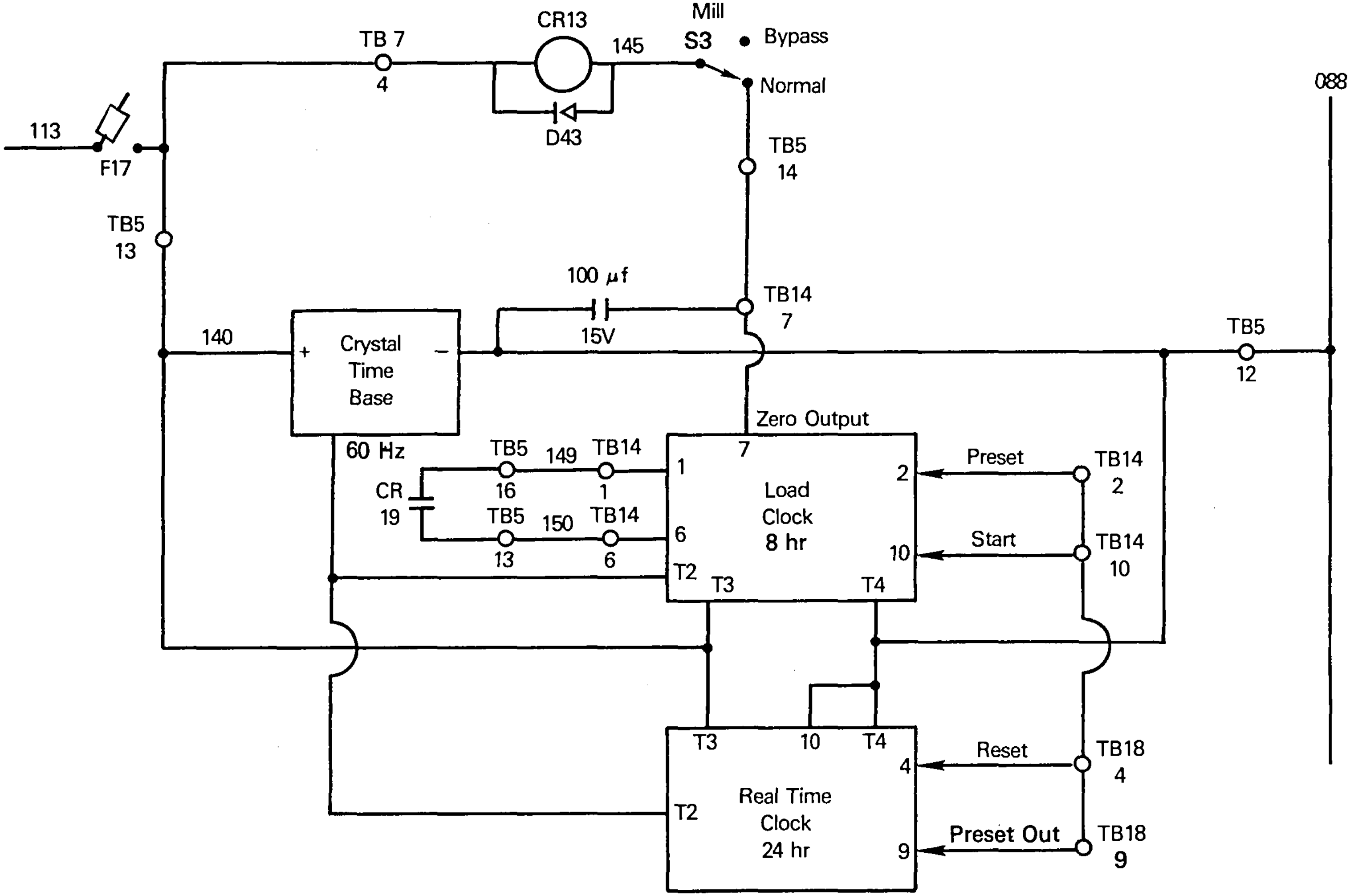


Figure 31. Mill Timer

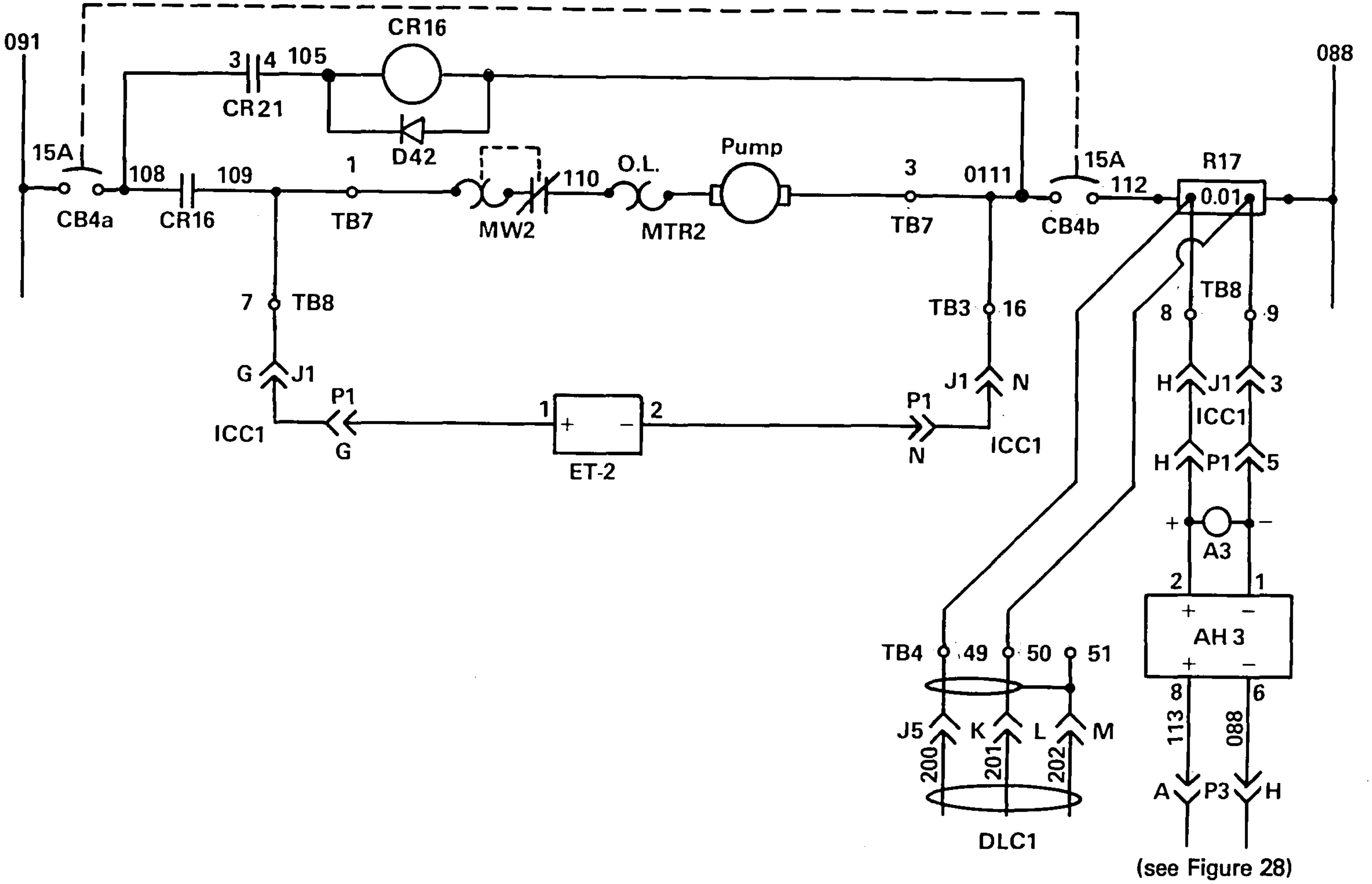


Figure 32. Water Pump Power Circuit

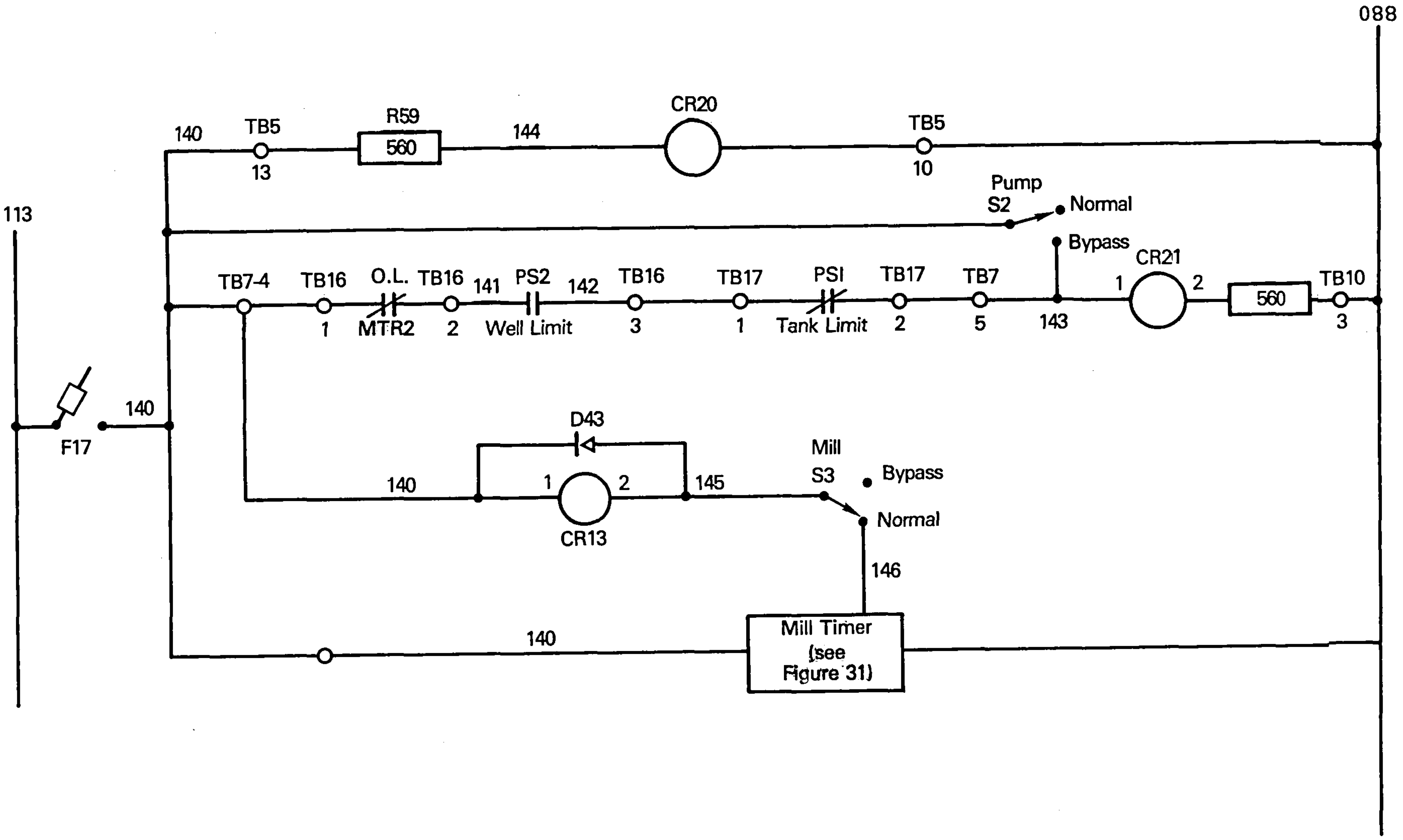


Figure 33. Load Controllers

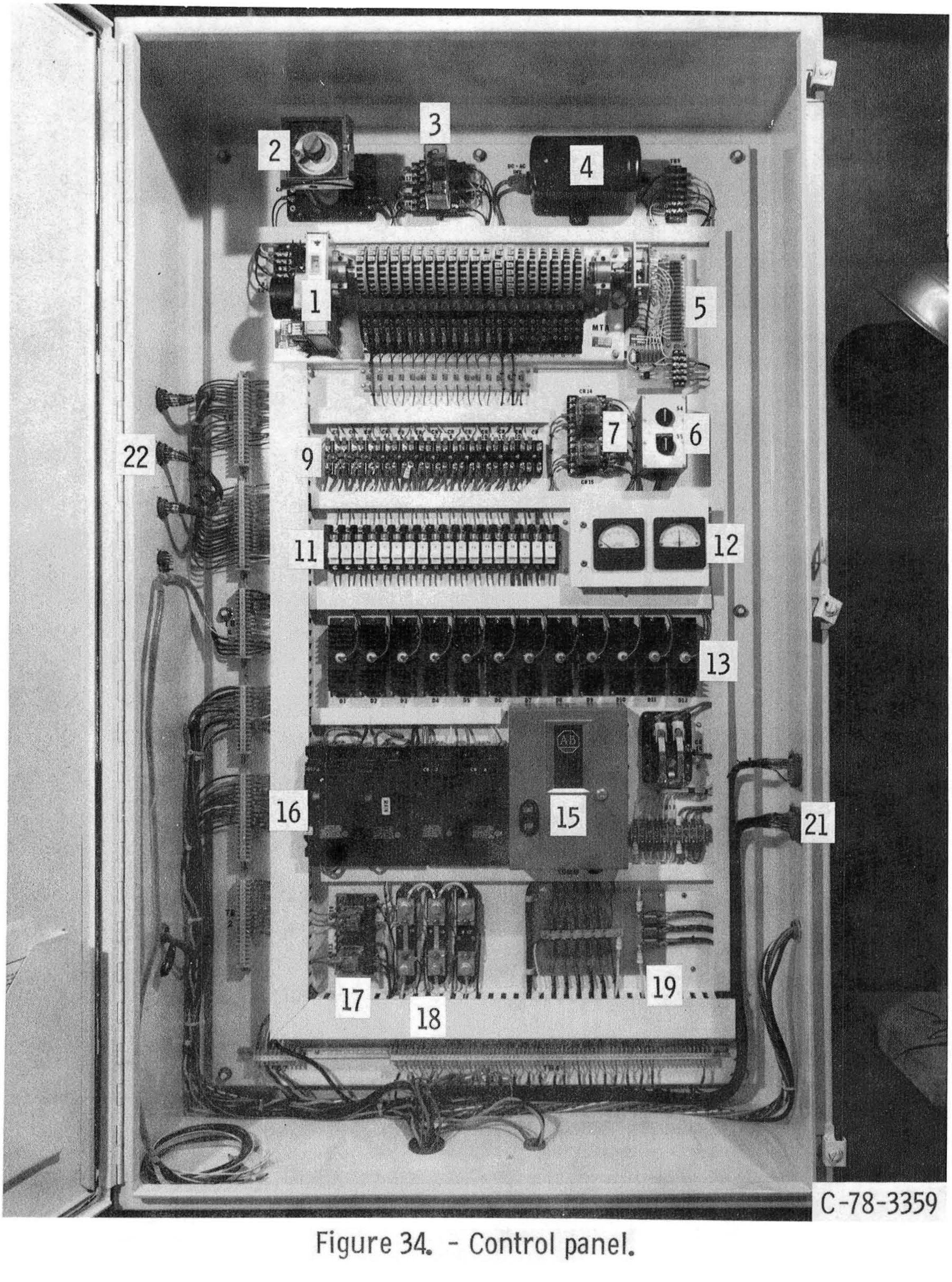


Figure 34. - Control panel.

Item	Identity
1	Drum Programmer
2	Drum Programmer Timer (CA)
3	Drum Programmer Control Relays (CR17, CR18)
4	d.c.-to-a.c. Inverter
5	Position Signal Resistors (R23—R47)
6	Drum Programmer/Duty Cycle Regulator Control Switches (S4, S5)
7	High/Low Voltage Alarm Relays
8	Dropping Resistors for Solid-State Relays (not shown in photo)
9	Solid-State Relays (CR1—CR12)
10	Duty Cycle Regulator (not shown in photo)
11	Fuse Switches (F1—F18)
12	12-V(d.c.) Ammeter, Voltmeter
13	Main Array Blocking Diodes (D1—D12)
14	Starter for Mill Motor (MS1) (not shown in photo)
15	Relay for Water Pump Motor (CR16)
16	Circuit Breakers (CB1—CB4)
17	Relays for Mill Timer (CR13, CR19)
18	Shunts for Ampere Hour Meters (R14, R16, R17)
19	Current Monitor Resistors for Main Array (R1—R12) and Main Battery (R15) Instrument Battery (R18), Instrument Array (R31)
20	Mill Timer (not shown in photo)
21	Connectors for Datalogger for Cables DLC1 and DLC2
22	Connectors for Instrument Panel for Cables ICC1, ICC2, and ICC3

Figure 34. Control Panel (continued)

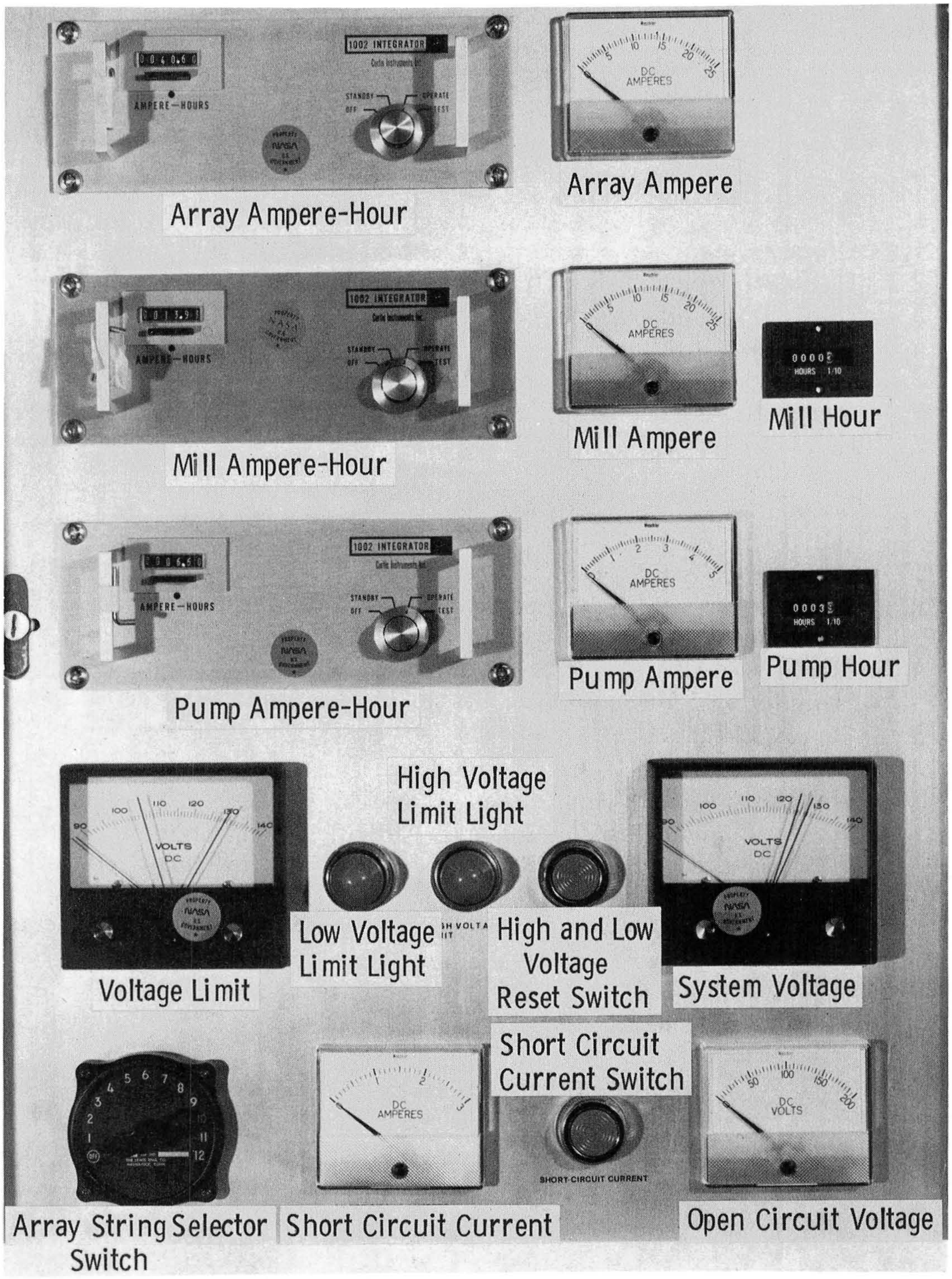


Figure 35. - Instrument panel (front).

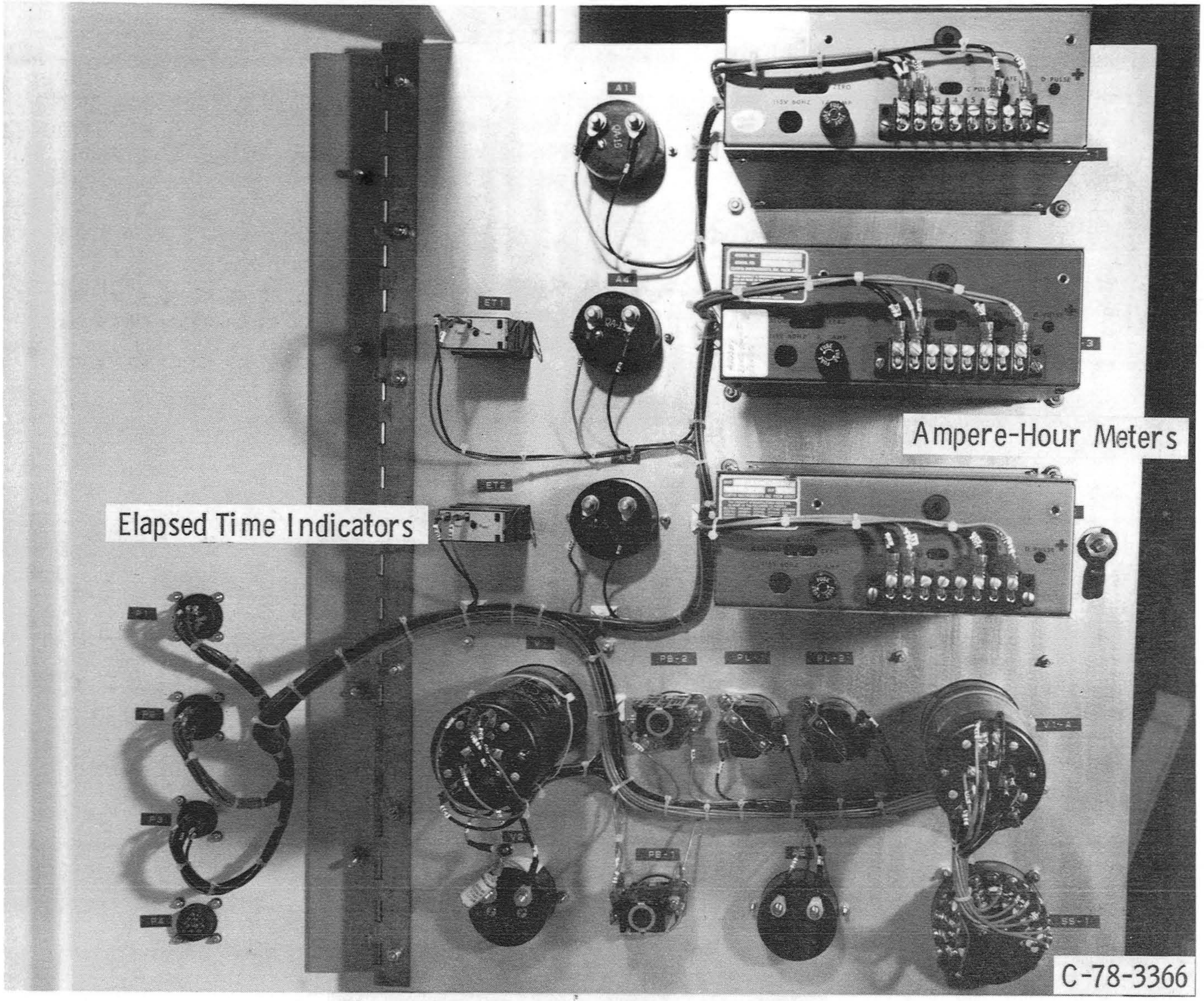


Figure 36. - Instrument panel (rear).

Function	Range
Array Current	0 - 25 A
Array Current (average)	0 - 25 A
System Volt	0 - 200 V
System Volt (maximum)	0 - 200 V
System Volt (minimum)	0 - 200 V
Main Battery Current	-20 - +20 A
Main Battery Current (average	-20 - +20 A
Main Battery Current (maximum)	-20 - +20 A
Main Battery Current (minimum)	-20 - +20 A
Instrument Array Current	0 - 10 A
Instrument Array Current (average)	0 - 10 A
Instrument Volt	0 - 20 V
Instrument Battery Current	-10 - +10 A
Instrument Battery Current (average)	-10 - +10 A
Pump Motor Current	0 - 5 A
Pump Motor Current (average)	0 - 5 A
Mill Motor Current	0 - 25 A
Mill Motor Current (average)	0 - 25 A
Mill Motor Current (maximum)	0 - 25 A
Step Switch Position	0 - 25
Array Temperature	0 - 100 mV
Air Temperature	0 - 100 mV
Array String 1 Current	0 - 2 A
Array String 2 Current	0 - 2 A
Array String 3 Current	0 - 2 A
Array String 4 Current	0 - 2 A
Array String 5 Current	0 - 2 A
Array String 6 Current	0 - 2 A
Array String 7 Current	0 - 2 A
Array String 8 Current	0 - 2 A
Array String 9 Current	0 - 2 A
Array String 10 Current	0 - 2 A
Array String 11 Current	0 - 2 A
Array String 12 Current	0 - 2 A

Figure 37. Typical Data List for the DAT-3

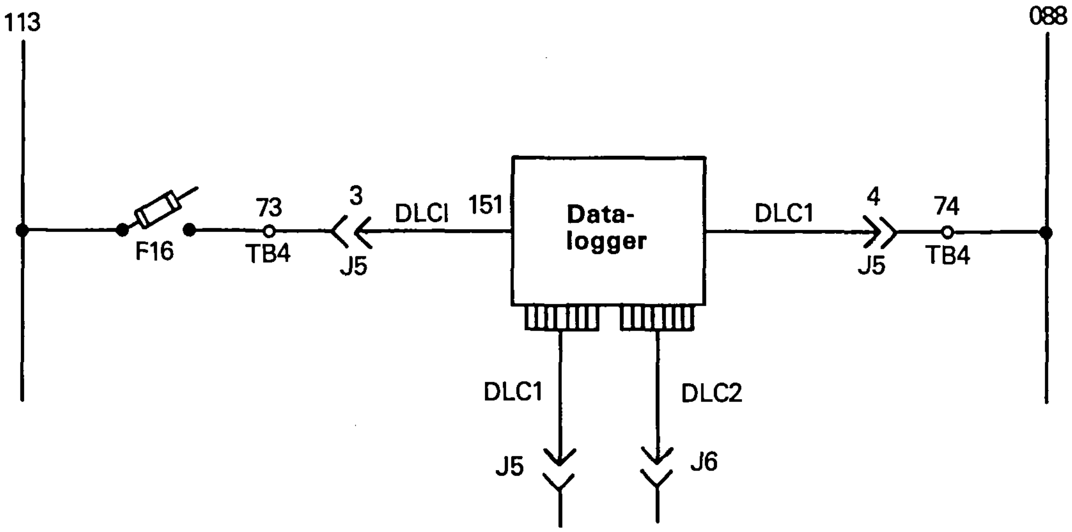


Figure 38. Datalogger Circuit

SAFETY

Throughout the design and installation of this system, safety for the user--operational and maintenance as well as installation personnel--was of utmost concern. All areas of access needed for operation or maintenance are locked. Only authorized, properly trained people are allowed access to the array field, battery room, control and instrument panels, and water pump protective cage. All electrical connections are made in special junction boxes or within otherwise secured areas with no access to the wires or switches by the villagers. The battery room is vented and completely separate from the grinding room and is provided with eye-flush bottles, and protective clothing is available to be used when maintaining the batteries.

In addition to providing all of the physical safety features indicated throughout the text and summarized below, LeRC provided detailed instruction and training of the operating and maintenance personnel which emphasized safety practices and policies.

Summary of Safety Features

- Array -
  - Locked fence area
  - Wash only after sunset
  - High-voltage caution signs
  - Electrical disconnects within the array field (for maintenance purposes)
- Battery -
  - Locked room
  - Room ventilation
  - Gloves/apron/mask
  - Eye wash
- Mill -
  - Belt and pulley guard
  - Hopper screen
  - On/off control on mill
  - Electrical interlock for motor on mill cover

- Pump - Belt/pulley/counter-weight guard
  On/off control at pump

- System - Overvoltage - array disconnect
  Under voltage - load disconnect
  All wires in conduit
  Electrical grounding system
  Circuit breakers or fuses (all circuits)
  Emergency shut-off button (to isolate all parts of the system in an emergency)

CONCLUDING REMARKS

This experimental system demonstrates the technical and operational feasibility of a small, stand-alone, photovoltaic power system for remote applications in developing countries and thus fulfills the technical objectives of the project. The first 2 years of field operation at Tangaye have yielded valuable experience relative to the design and use of PV systems in a rural environment. Details of the operational experience may be found in Operational Performance of the Photovoltaic Powered Grain Mill and Water Pump at Tangaye, Upper Volta, by James E. Martz, Anthony F. Ratajczak, and Richard DeLombard, TM-82767. Some system design observations generated during this time period are discussed below.

The module and structure designs provide for easy replacement of failed modules. Although the solar cells are high technology items, they are packaged in a module which can be replaced by local personnel with an ease and confidence which belies the ultimate sophistication of the device.

The PV system modularity design provides for ease of system expansion. Because of the modularity of the system design, particularly in the array structure, the system can be easily increased or decreased in size to meet changing energy requirements. This change of capability was demonstrated by a doubling in size of the Tangaye PV array in the spring of 1981 to meet increased milling requirements.

The array structure design allows for assembly and installation by local personnel. The system installation demonstrated that an array structure designed for partial onsite assembly can be assembled and installed by villagers. At Tangaye, villagers assembled and installed the PV array support structure following training by LeRC personnel.

Electromechanical and electronic control subsystems have complementary advantages and disadvantages. The electromechanical subsystem has a higher probability of parts failure than the electronic subsystem, but has the advantage of two modes of backup operation: semi-automatic and completely manual. The electronic subsystem is, conversely, less susceptible to failure, but is considerably more difficult to work around if failure does occur. The electronic subsystem has, however, sufficient redundancy so that a failure of one of the control modules disrupts operation from only 17 percent of the PV array. The two control subsystems provided continuous PV system control despite minor problems in both subsystems. In particular, the station keepers understand the electromechanical subsystem well enough to use it in both the semi-automatic and manual modes. The manual mode was used, for example, when a component failure interrupted automatic operation of that subsystem and during a period when the electronic subsystem was physically removed from the system for design modifications.

The mill timer designed to limit mill operation to 8 hours per day was found to be unnecessary. Although the timer functioned properly during all tests at LeRC, soon after installation in Tangaye it began to function erratically and eventually had to be disconnected. In place of the automatic controls, LeRC personnel taught the station keepers to calculate the daily PV array/combined loads energy balance and to determine the number of hours of milling time available the next day. This manual method of mill time determination is actually superior to the "fixed-time" timer because it allows increased mill time during periods of high insolation and, conversely, reduced mill time during the cloudy season, thus lessening the risk of excessive battery discharge. The station keepers learned quickly to manage the system energy and have been managing it since March 1979. This manual energy management proved especially useful when the photovoltaic modules began failing and the PV array output began decreasing. The result of this experience with manual energy management is that automatic load-limiting controls such as the timer are no longer considered necessary.

Although LeRC designs anticipated a concrete floor in the battery room of the mill and battery building, a shortage of cement and assurances that a native tamped earth floor would support the main battery resulted in the battery racks being placed on the prepared earth floor. During the 1980 rainy season, the local water table rose to within 18 inches of the ground level and the battery racks started to lean over with attendant risk of damage to the battery cells and injury to maintenance personnel. Local AID personnel, with help from the station keepers, provided emergency shoring. As a result of this experience, the battery room floor was concreted in May 1981.

The burr mill selected originally for this system, although capable of grinding flour of satisfactory fineness, is not suitable for such a production operation because of the high component wear rates imposed on the mill when fine flour is being produced and to the high noise levels associated with such production. The hammermill was determined to be superior in all respects. (Since the introduction of the hammermill at Tangaye in 1979, hammermills are now being sold commerically in Ouagadougou.)

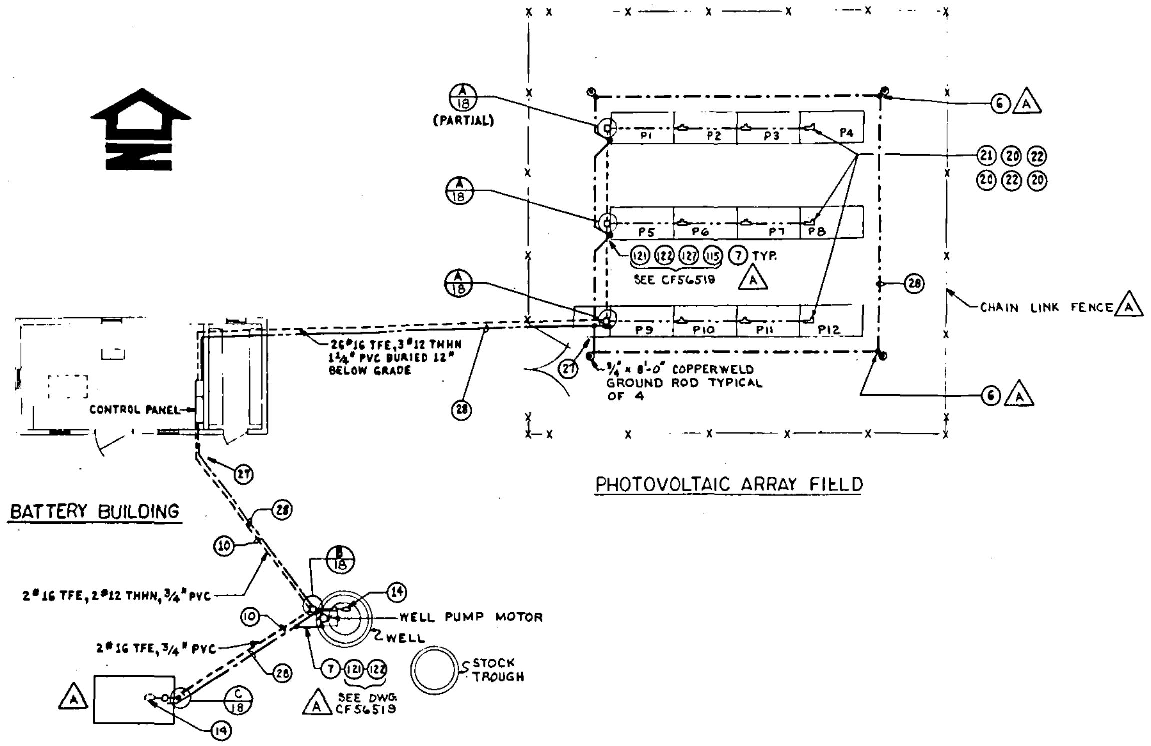
The pumping subsystem has functioned essentially trouble free. The only problems experienced with the pumping subsystem have been due to leakage of water into the well limit switch and leaking packing glands on the pump drive rod stuffing box. The well and storage tank limit switches were replaced with nonsubmersible switches and the stuffing box seals were replaced. Except for these problems, the pump has operated trouble free during the first 2 years.

The station keepers have been able to effect mechanical repairs to the mill and have proven to be rather adept at improvising fixes when, for instance, spare parts for the burr mill were expended. Repairing (not replacing) electrical devices is still beyond their sphere of understanding and experience.

Overall, the system has been on line 97 percent of the time, has ground approximately 55 metric tons of grain (49 metric tons with the hammermill and an estimated 6 metric tons with the burr mill), and has pumped 5500 cubic meters of water while generating 3800 kilowatt hours of electricity.

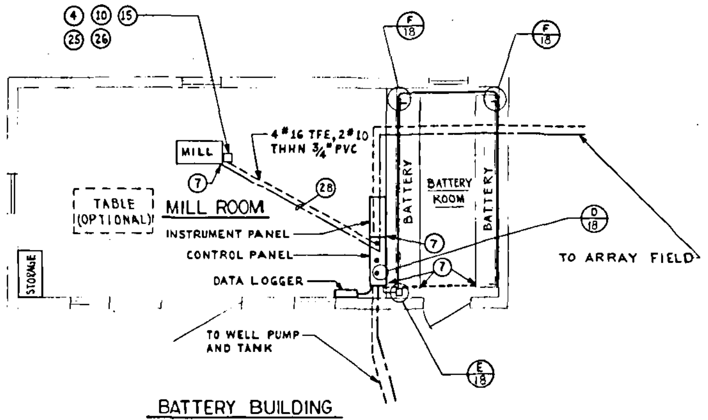
APPENDIX A

DESIGN DRAWINGS
NASA-LeRC DRAWING NUMBERS CF 56518 THROUGH CF 56528



SITE OF PHOTOVOLTAIC ARRAY FIELD AND EQUIPMENT

SCALE: ⅛" = 1'-0"
(APPROX 1 : 100)



BATTERY BUILDING

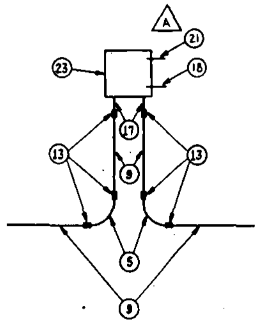
SCALE: ¼" = 1'-0"

NOTES

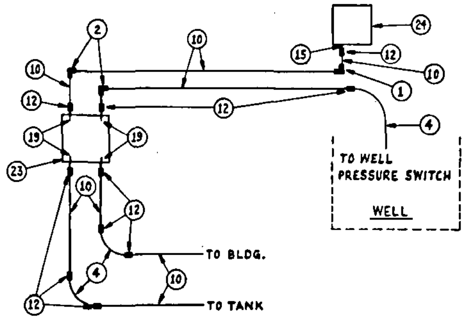
1. BLANK GROMMETS TO BE ALTERED BY DRILLING TWO (2) ⅛ DIA. THRU HOLES ¼" APART LOCATED SYMMETRICALLY ABOUT THE CENTERLINE.

MATERIAL LIST

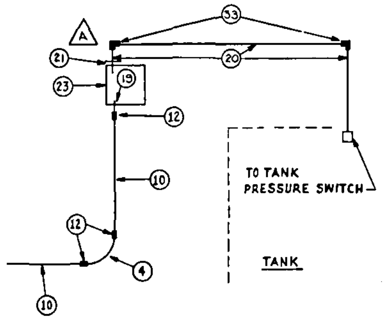
ITEM Nº	DESCRIPTION	REQ
1	CARLON-¾" PVC ACCESS FITTING E985ELR	1
2	CARLON-¾" PVC ACCESS FITTING E986ELB	4
3	CARLON-¾" PVC ACCESS FITTING E983ET	2
4	CARLON-¾" PVC-90° ELBOW, PART Nº E780E	10
5	CARLON-1¼" PVC-90° ELBOW, PART Nº E780G	7
6	CLAMP 5999-00-951-2943	4
7	TERMINAL 5940-00-840-6355	5
8	TEFLON TAPE, ANTI-SEIZING, ½" WIDE x 3 MIL THICK	AS REQ'D
9	CARLON-1¼" PVC CONDUIT, TYPE 40 PART Nº 49009	123 FT.
10	CARLON-¾" PVC CONDUIT, TYPE 40 PART Nº 49007	143 FT.
11	CARLON-CEMENT, QUART ZIP'LICATOR PART Nº VC9952	1
12	CARLON-¾" PVC CONDUIT COUPLING PART Nº E940E	29
13	CARLON-1¼" PVC CONDUIT COUPLING PART Nº E940G	20
14	PRESSURE SWITCH, MICRO-DIAPHRAGM TYPE, WEIL PUMP CO.	2
15	CARLON-¾" PVC TERMINAL ADAPTER PART Nº E943E	6
16	CARLON-1¼" PVC TERMINAL ADAPTER PART Nº E943G	1
17	CARLON-1¼" PVC BOX ADAPTER E996G	5
18	CARLON-½" PVC BOX ADAPTER E996D	4
19	CARLON-¾" PVC BOX ADAPTER E996E	8
20	CONDUIT-½" THINWALL 5975-00-178-1216	90 FT.
21	BOX CONNECTOR-½" THINWALL 5975-00-100-8721	3
22	CONDUIT OUTLET "T" ½" THINWALL 5975-00-839-5320	6
23	CARLON-PVC MOLDED JUNCTION BOX 6"x6"x4" PART Nº E987R	6
24	CONDUIT OUTLET-2 GANG 5975-00-042-9940	1
25	SWITCH ENCLOSURE GE-2940BC202A	1
26	MOTOR STARTER 6110-00-500-3175	2
27	SPLICE 5940-00-228-7912	4
28	WIRE #8 6145-00-286-9406	294 FT.
29	BATTERIES C & D KCPSD-7	
30	BATTERIES C & D 3DCPSD-5	
31	MOTOR APPLIED CAT. Nº SR5324-2805-568	
32	MOTOR APPLIED CAT. Nº SR3632-2806-488	
33	½" E.M.T. ACCESS FITTING	



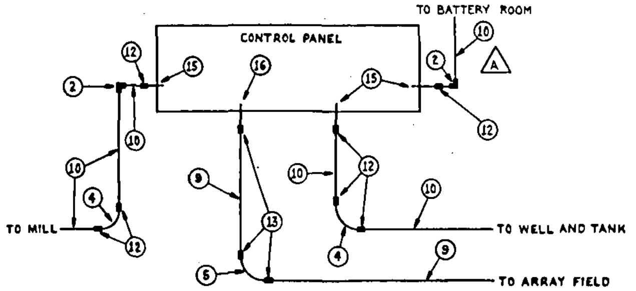
DETAIL A/18
(TYP.)
(ELIMINATE ONE LEG ON PARTIAL)
NO SCALE



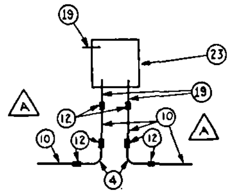
DETAIL B/18
NO SCALE



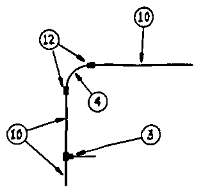
DETAIL C/18
NO SCALE



DETAIL D/18
NO SCALE



DETAIL E/18
NO SCALE



DETAIL F/18
(TYP.)
NO SCALE

SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF. 1323)	GSR CVA 1-28-81

REVISIONS

DESIGN CONTRACTOR
Snider
RIDGE ROAD
ROCKY RIVER, OHIO 44116
9/20/78 DD LM MF MF

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

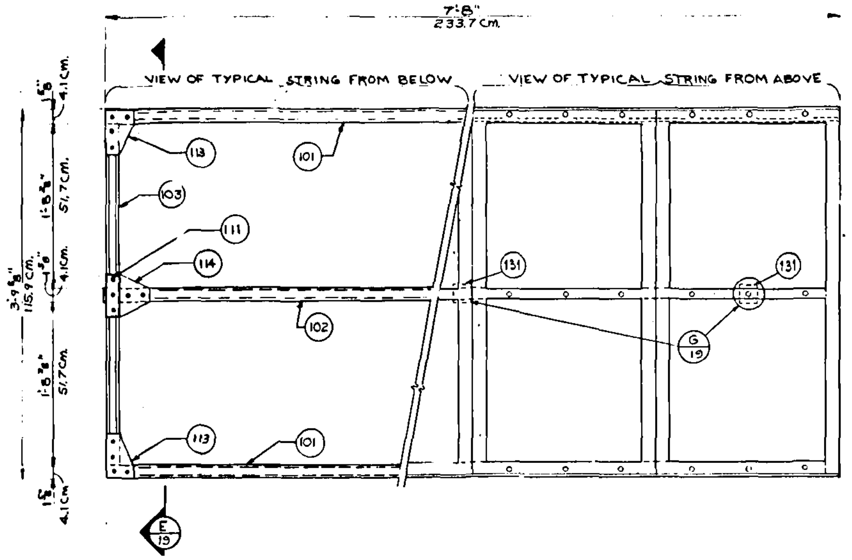
DR.	CK. RFP	D. SUP.
DES.	D. ENG. JEM	D.P. ENG.
D.S. HD.	D.B. CH.	D. DIV.
R. ENG.	R.S. HD.	R. DIV.

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

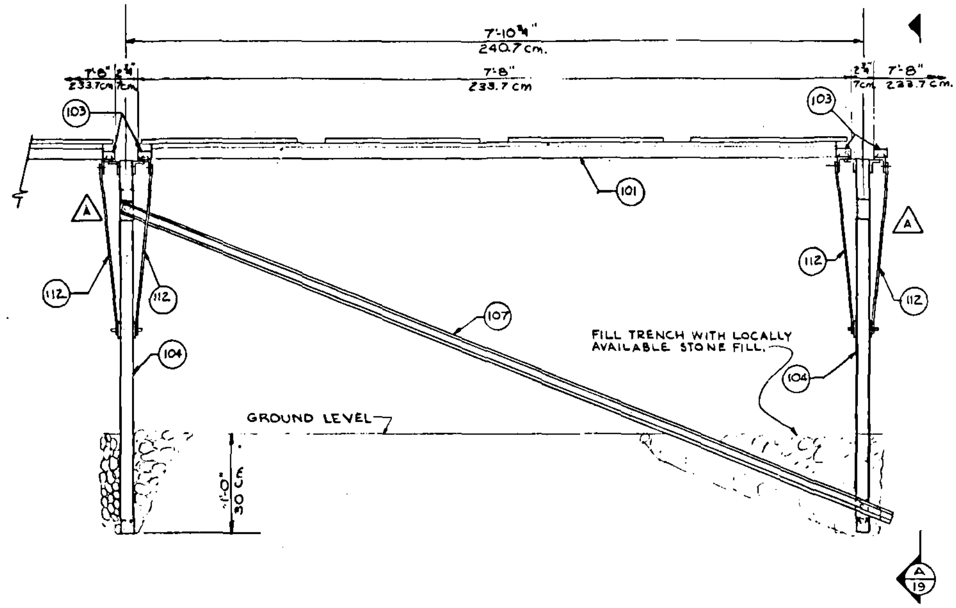
PHOTOVOLTAIC POWER SYSTEM DEMONSTRATON
TANGAYE, UPPER VOLTA, AFRICA

PLANS AND DETAILS

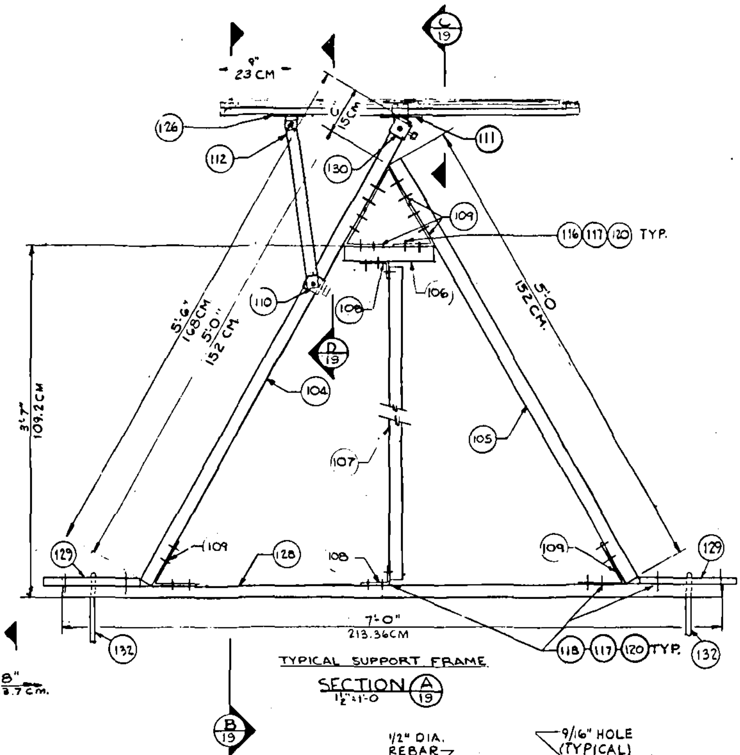
SCALE: AS NOTED
REFERENCE
CF56518
ELECTRICAL
OFFICIAL DATE 1-15-79



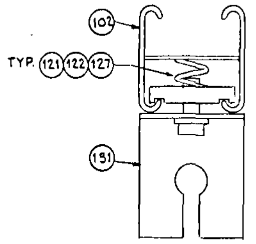
PLAN VIEW OF TYPICAL MODULE FRAME
1/2"=1'-0



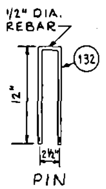
SECTION B/19
1/2"=1'-0



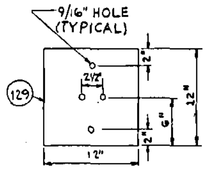
TYPICAL SUPPORT FRAME
SECTION A/19
1/2"=1'-0



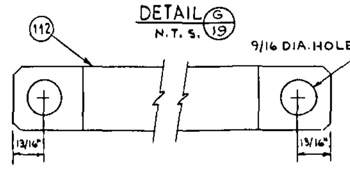
DETAIL G/19
N.T.S.



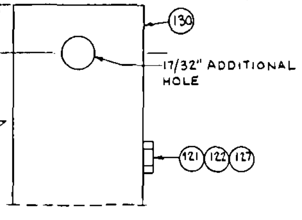
PIN
N.T.S.



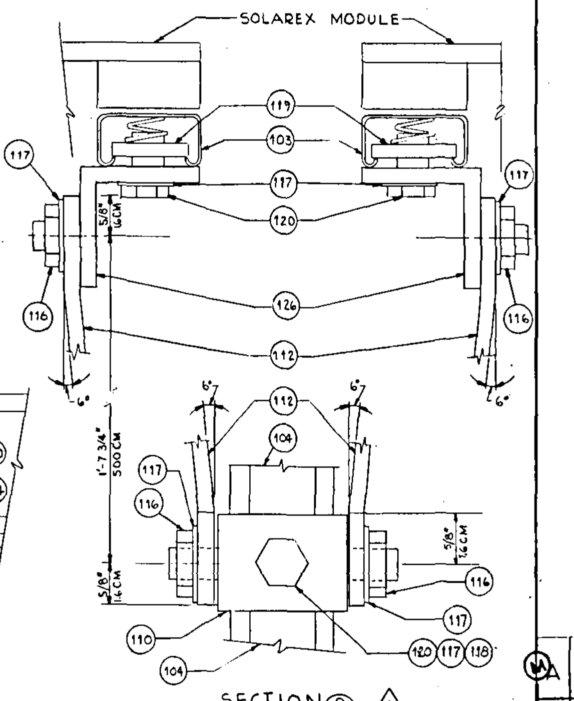
FLAT PLATE
N.T.S.



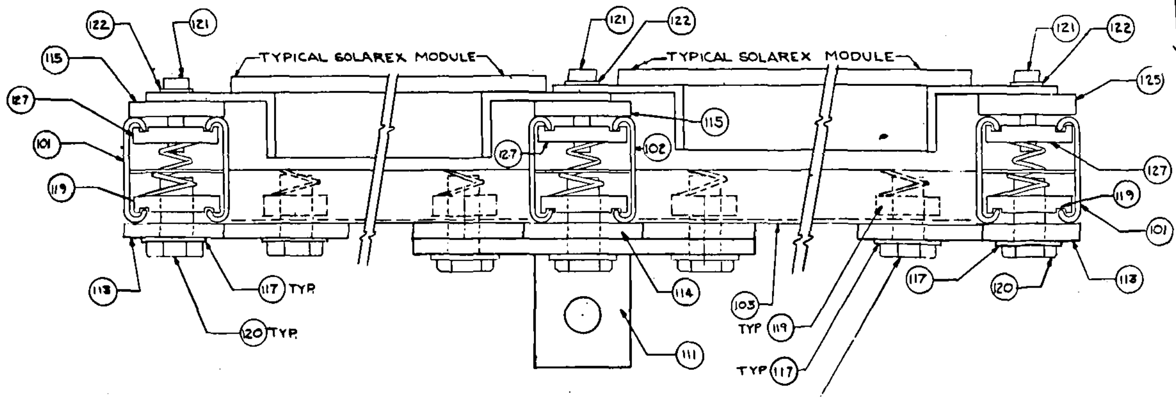
BAR A
N.T.S.



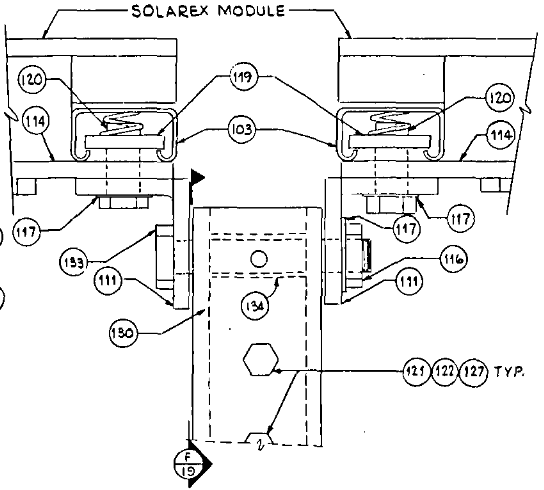
SECTION F/19



SECTION D/19 A
FULL SIZE



SECTION E/19
FULL SIZE



SECTION C/19
FULL SIZE

12" = 1'-0"
1 1/2" = 1'-0"
3" = 1'-0"
GRAPHIC SCALES

COMMERCIAL PARTS LIST

NO	DESCRIPTION	QUAN. REQD PER FRAME	TOTAL REQD	COMMENTS
101	CHANNEL-"SUPERSTRUT" No.B-1202 - 7'-8"LG	2	24	
102	CHANNEL-"SUPERSTRUT" No.B-1202 - 7'-4 3/4 ±1/16 LG	1	12	
103	CHANNEL-"SUPERSTRUT" No. B-1200-3'-6 5/8 ±1/16 LG	2	24	
104	CHANNEL-"SUPERSTRUT" No. A-1200 - 5'-6 LG	–	15	
105	CHANNEL-"SUPERSTRUT" No.A-1200 - 5'-0 LG.	–	15	
106	CHANNEL "SUPERSTRUT" No. B-1202 - 0'-10" LG	2	15	
107	CHANNEL-"SUPERSTRUT" No. A-1200 - 9'-0 LG	1	12	
108	90° ANGLE FITTING-"SUPERSTRUT" No.AB-204	2	24	
109	60° ANGLE FITTING-"SUPERSTRUT" No.X-225-4	–	57	
110	U-FITTING-"SUPERSTRUT" No. AX-264	2	30	
111	90° ANGLE FITTING-"SUPERSTRUT" No. X-263	2	24	
112	BAR-1/4 x 1 1/2 x 1'-9	2	24	
113	FLAT PLATE-"SUPERSTRUT" NO. AB-257	4	48	
114	FLAT PLATE-"SUPERSTRUT" NO. AB-261	2	24	
115	FLAT PLATE-"SUPERSTRUT" NO. AB-241-5/16	24	288	
116	1/2" HEX NUT-"SUPERSTRUT" NO. E-145	–	84	
117	1/2" -LOCK WASHER-"SUPERSTRUT" NO. E-148	–	873	
118	REGULAR SPRING NUT-"SUPERSTRUT" No.A-100-1/2	–	429	
119	SHORT SPRING NUT-"SUPERSTRUT" No.B-100-1/2"	–	408	
120	HEX HEAD CAP SCREW-1/2" x 15/16" E-142	–	873	
121	HEX HEAD CAP SCREW-1/4" x 1"	36	432	
122	1/4" LOCK WASHER-"SUPERSTRUT" NO. E-148-1/4	36	432	
123	HEX HEAD CAP SCREW-1/2" x 1 1/4" E-142			
125	FLAT PLATE FITTING-"SUPERSTRUT" No AB-291 (3/8")	12	144	
126	90° ANGLE FITTING-SUPERSTRUT NO. X 209	2	24	
127	SHORT SPRING NUT-SUPERSTRUT No. B-100-1/4"	36	432	
128	CHANNEL "SUPERSTRUT" No. A-1200-7'-0" LG	–	15	
129	FLAT PLATE 12" X 12" x 9/16"	–	30	
130	"U-FITTING-"SUPERSTRUT" NO. A-802 MODIFIED PER. DWG. CB-PVPO-124	–	15	
131	BRACKET, WIRING HARNESS-DWG CB-PVPO-117	–	24	
132	PIN	–	30	
133	HEX hd CAP SCREW 1/2" x 3"	–	15	
134	1/2" ID x 15/8" LONG SS. TUBING FOR SPACER	–	15	

NOTES:

1. ALL ITEMS IN "COMMERCIAL PARTS LIST" SHALL BE FURNISHED BY THE GOVERNMENT.
2. ALL PIECES OF MODULE FRAME TO BE SUPPLIED WITH AN "ELECTRO-CHROMATE" FINISH, INCLUDING THREADED FASTENERS.
3. ALL PIECES OF SUPPORT FRAME TO BE SUPPLIED WITH "HOT DIP AFTER FAB" FINISH.
4. ALL THREADED FASTENERS FOR SUPPORT FRAME TO BE SUPPLIED WITH "ELECTRO-CHROMATE" FINISH.

SYM.	NO.	DESCRIPTION	APP./DATE
M A		CHANGED SOLAREX MODULE ADJUSTING BRACKET ARRANGEMENT (REF. 1323)	GSR CJA 12-9-80

REVISION M

DESIGN CONTRACTOR
rider
20335 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

1079	E.S. SHR	S.E. LG
D.S. D.D	D. WRT	P.E. MF
DR.	CK. RFK	D. SUP.
DES.	D. ENG. JEM	D.P. ENG.
D.S. HD. WJJ	D. SECT. HKS	D. DIV.
R. ENG.	R.S. HD.	R. DIV.

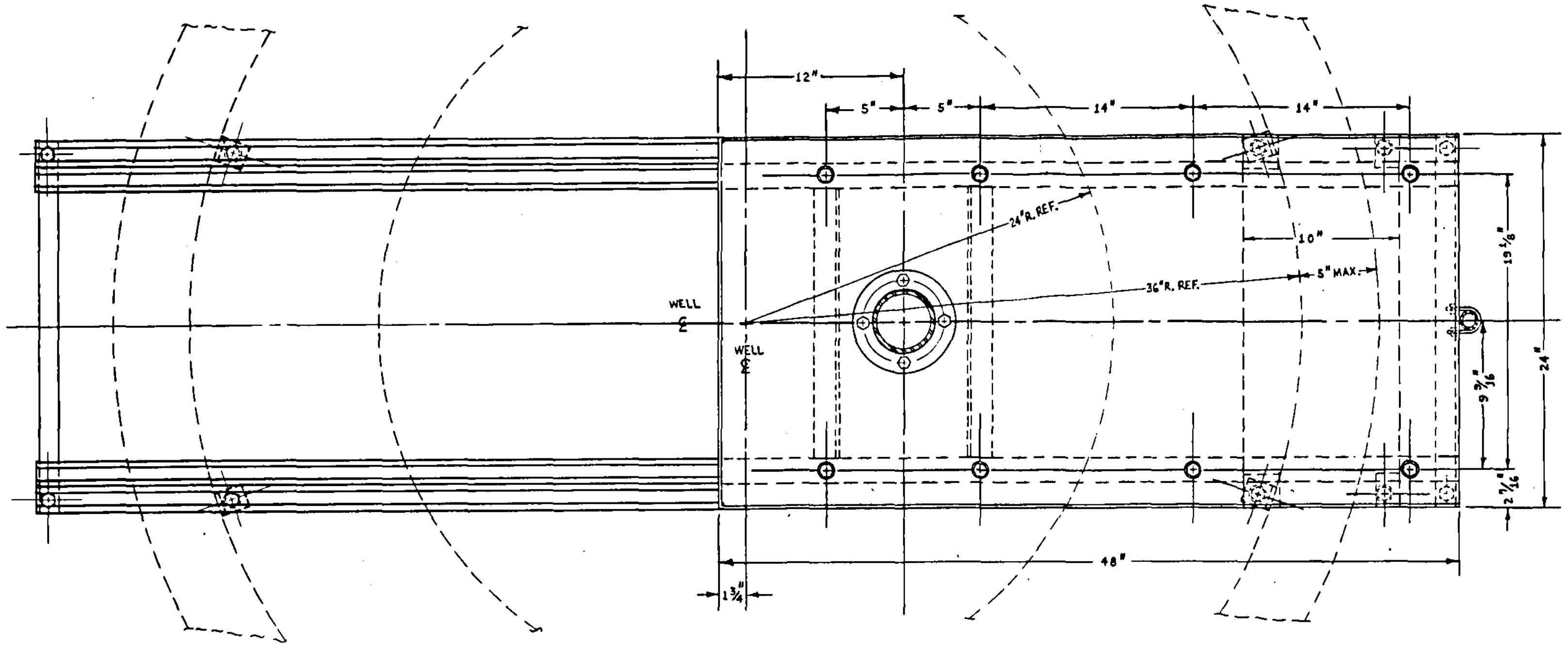
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

SUPPORT AND MODULE FRAME DETAILS

SCALE AS NOTED
REFERENCE

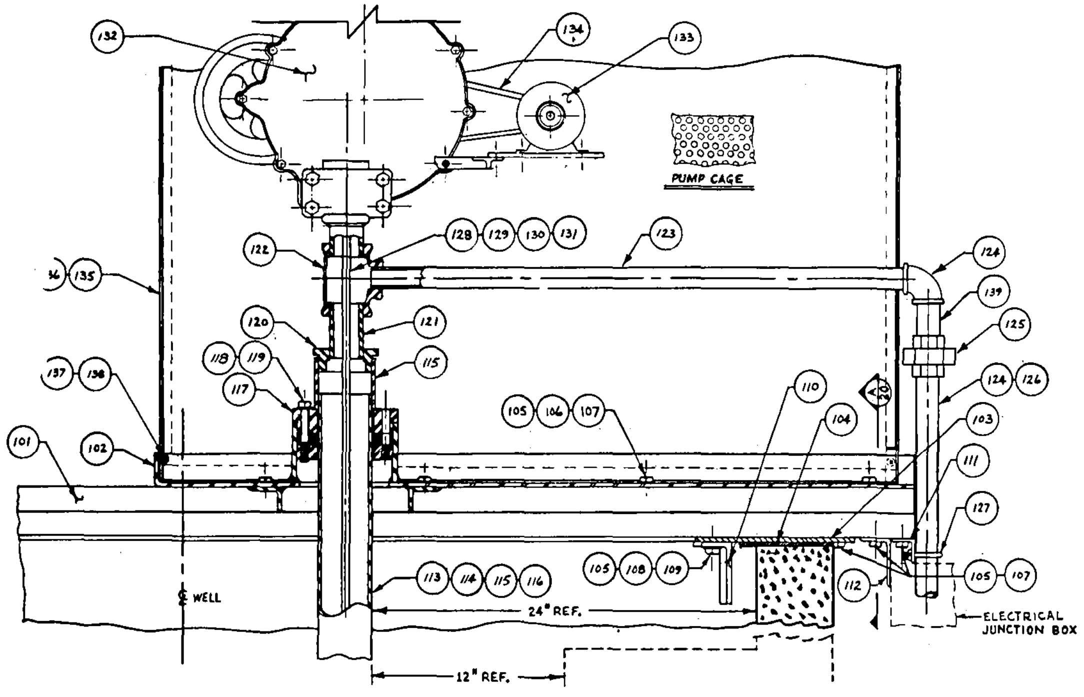
CF 56519
STRUCTURAL
OFFICIAL DATE 11-6-79



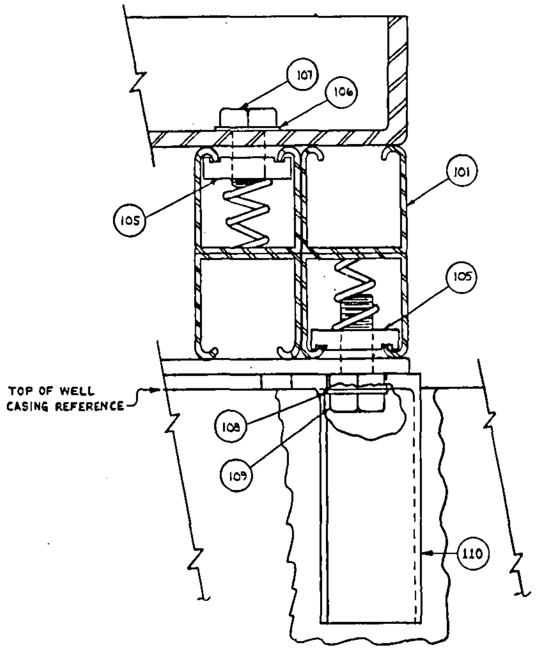
PUMP PLATFORM INSTALLATION
(PLAN VIEW - PARTIAL)
SCALE: 3" = 1'-0"

ITEM NO.	DRAWING NO.	PARTS LIST DESCRIPTION	REQ'D
101		FOUR CHANNEL - "SUPERSTRUT" NO. A-1204A 7'- 4 1/2" LG.	2
102	CF-56522	PUMP SUPPORT & DRIP PAN ASSEMBLY	1
103	CF-56522	FOOT-PLATE (ALUMINUM)	2
104	CF-56522	FOOT-PAD (RUBBER) - ADHESIVE ATTACHED TO FOOT-PLATE (ITEM 103)	2
105		SPRING NUT - "SUPERSTRUT" No. A-100 (1/2")	20
106		FLAT WASHER - "SUPERSTRUT" No. E-147 (1/2")	8
107		HEX. HD. CAP SCREW - 1/2" (13) x 1" LG.	16
108		LOCK WASHER (FOR 1/2" CAP SCREW)	4
109		HEX. HD. CAP SCREW - 1/2" (13) x 1 1/4" LG.	4
110		90° ANGLE FITTING - "SUPERSTRUT" No. AB-252-1 (1 7/8" x 3 7/8" x 1 1/2" w 1/4" Tk.)	4
111	CF-56522	PIPE SUPPORT (ALUM. ANGLE - 1 1/2" x 1 1/2" x 1/4" x 2' LG.)	1
112	CF-56522	ELECTRICAL JUNCTION BOX SUPPORT (ALUM. ANGLE - 1 1/2" x 3" x 3/16" x 2' LG.)	1
113		PUMP CYLINDER - "JENSEN" No. 652124	1
114		PUMP SCREEN (INCL. STD. 3" GALV. PIPE PLUG & 2 EA. S.S. WORM - GEAR CLAMPS)	1
115		3" PIPE COUPLING, GALV.	5
116		3" PIPE, GALV., (7'-5 1/8" LG.) THREADED BOTH ENDS	4
117	CF-56521	PUMP MOUNT & SEAL ASSEMBLY	1
118		HEX. HD. CAP SCREW - 3/8" (16) x 3" LG. (MODIFIED - THD. LTH. 1 3/4" LG.)	4
119		FLAT WASHER - 3/8"	4
120		BUSHING, 3" TO 2" (STD. PIPE), GALV.	1
121		NIPPLE, 2" x 2 1/2" LG. (STD. PIPE), GALV.	1
122		REDUCING TEE 2" x 2" x 1" STD. PIPE, GALV.	1
123		1" PIPE, GALV. (~34 1/2" LG.), THREADED BOTH ENDS, CUT FOR FIELD FIT.	1
124		90° ELBOW, 1" (STD. PIPE), GALV.	2
125		UNION, 1" (STD. PIPE), GALV.	1
126		1" PIPE, GALV. (50" LG.), THREADED BOTH ENDS	1
127		U-BOLT (FOR 1" STD. PIPE) w NUTS	2
128		JENSEN PUMP ROD, 7/16" DIA. x 5' LG. STEEL ROD, 7/16" (14) THDS., (BOTH ENDS)	6
129		PUMP ROD COUPLING NUTS, 7/16" (14) THD.	6
130		PUMP ROD JAM-NUTS, 7/16" (14) STN. ST'L.	13
131		JENSEN PUMP STUFFING BOX ROD, 7/16" DIA. x 4' LG. POLISHED STEEL, 7/16" (14) THD. (ONE END ONLY)	1
132		JENSEN JACK PUMP No. 11W5A	1
133		PUMP MOTOR, 120 VDC., "APPLIED MOTOR" P/N SR 3632-2806-46B	1
134		3/8" x 42" LG. V-BELT	1
135	CF-56522	PUMP CAGE (PROTECTOR)	1
136	CF-56522	PUMP CAGE COVER PLATE	1
137		HEX. HD. CAP SCREW - 1/4" (20) x 1" LG., S.S.	4
138		STD. NUT - 1/4" (20), S.S.	4
139		NIPPLE, 1" x 4" LG. (STD. PIPE), GALV.	1
140	CF-56521	MOUNTING PLATE	1
141	CF-56521	COMPRESSION PLATE	1
142	CF-56521	GASKET-SEAL	1

NOTES



PUMPING SYSTEM INSTALLATION
(SECTION VIEW - PARTIAL)
SCALE: 3" = 1'-0"



SECTION A/20
SCALE: FULL

1'-0"
1'-0"
GRAPHIC SCALES

SYM.	NO.	DESCRIPTION	APP./DATE
		REVISION (M)	

DESIGN CONTRACTOR
30350 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116
1/9/79
1140
E.S.
S.E. MF
D.S.
D. J.W.S.
P.E.

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............
DR.
CK. AFP
D. SUP.
DES.
D. ENG.
D.P. ENG.
D.S. HD. WJJ
D.S. CH.
D. DIV.
R. ENG.
R.S. HD.
R. DIV.

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

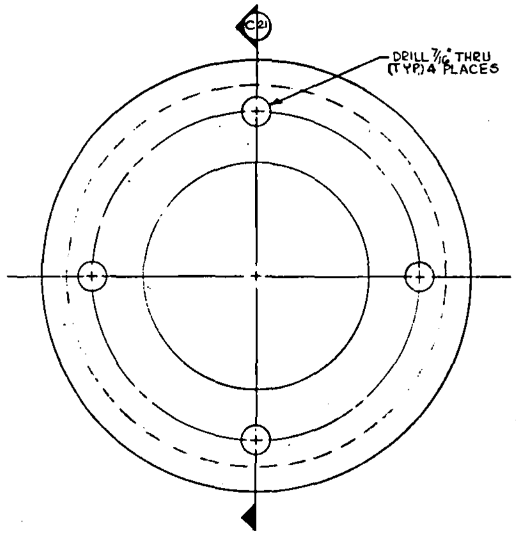
PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

PUMPING SYSTEM INSTALLATION

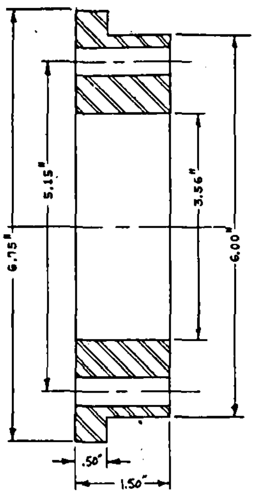
SCALE: AS NOTED
REFERENCE
CF56520
ELECTRICAL
OFFICIAL DATE 1-15-79

A - 89/90

NOTES

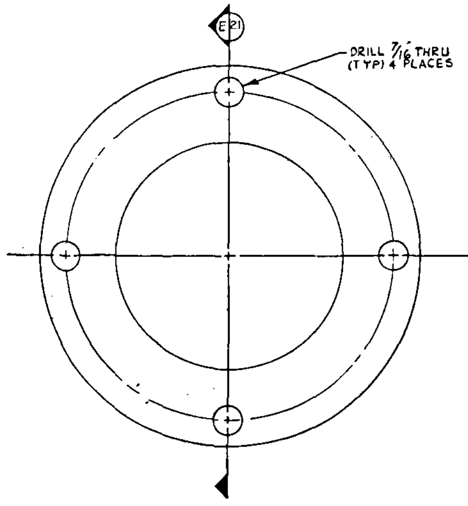


SEAL ASSEMBLY MOUNTING PLATE 140/21
SCALE: FULL SIZE
MAT'L: STEEL
REQ'D: ONE

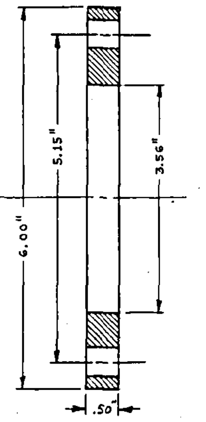


SECTION C/21
SCALE: FULL SIZE

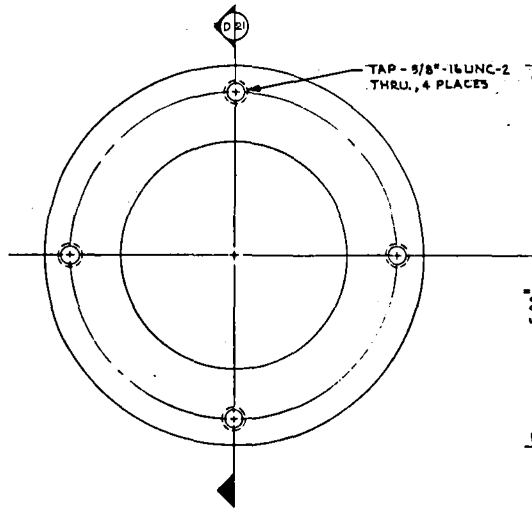
NOTE: BREAK ALL CORNERS AND SHARP EDGES 1/32"



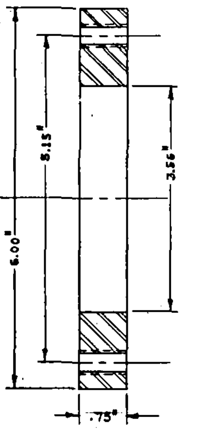
SEAL ASSEMBLY GASKET SEAL 142/21
SCALE: FULL SIZE
MAT'L: SILICON-RUBBER
REQ'D: ONE



SECTION E/21
SCALE: FULL SIZE

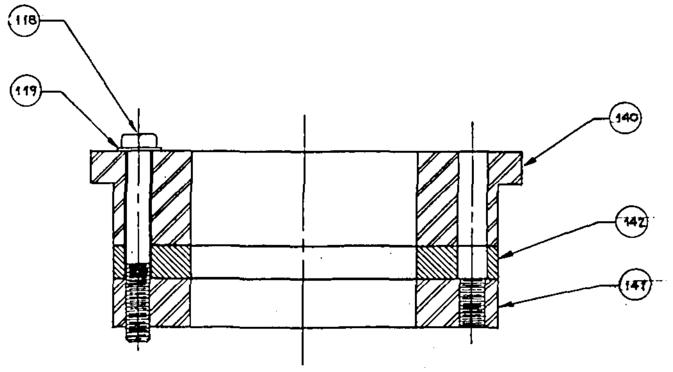


SEAL ASSEMBLY COMPRESSION PLATE 141/21
SCALE: FULL SIZE
MAT'L: STEEL
REQ'D: ONE



SECTION D/21
SCALE: FULL SIZE

NOTE: BREAK ALL CORNERS AND SHARP EDGES 1/32"



PUMP MOUNT AND SEAL ASSEMBLY 117/21
SCALE: FULL SIZE

SYM.	NO.	DESCRIPTION	APP./DATE
		REVISIONS (M)	

DESIGN CONTRACTOR
Snider
20335 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116
1/9/79
1140
E.S. SKA
S.E. MF
D.S.
D. J.W.S.
P.E. LJM

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

DR.	CK. AFP.	D.SUP.
DES.	D. ENG. RSD	D.P. ENG.
D.E. HR. WJL	D.E. CH. NAS	D. DIV.
R. ENG.	R.E. HD.	R. DIV. RSP

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

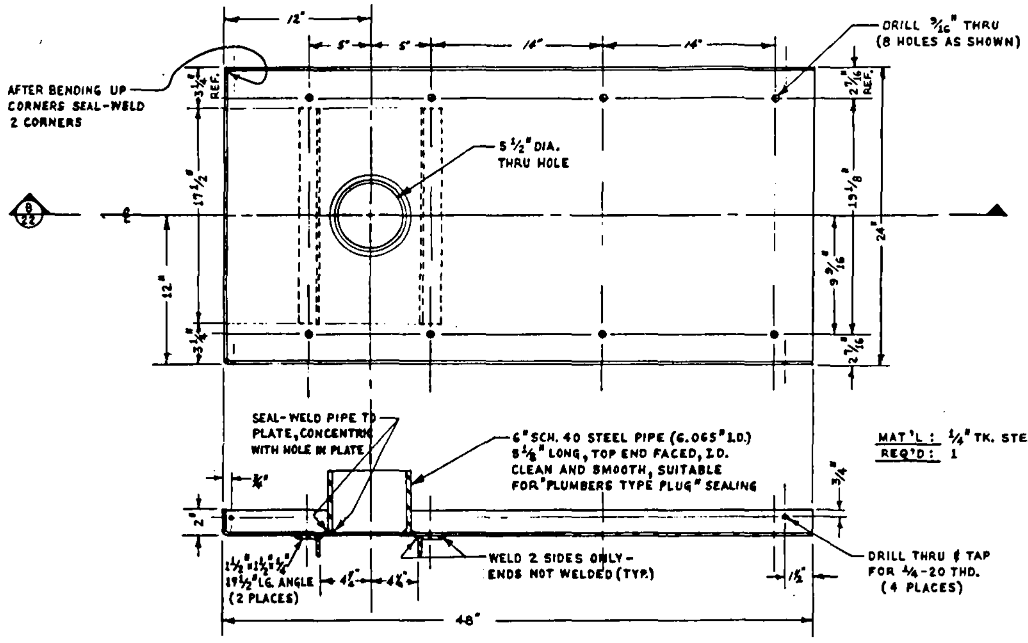
PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

PUMP MOUNT AND SEAL ASSEMBLY

SCALE: FULL SIZE
REFERENCE

CF56521
ELECTRICAL
OFFICIAL DATE 1-15-79.

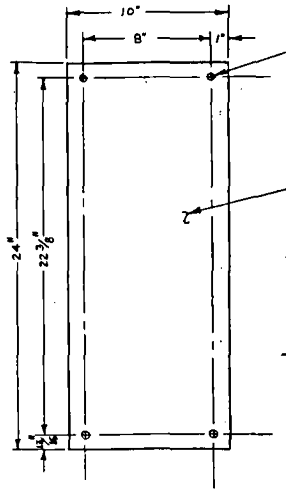
NOTES



SECTION (B/22)
SCALE : N.T.S.

MAT'L : 1/4" TK. STEEL PLATE
REQ'D : 1

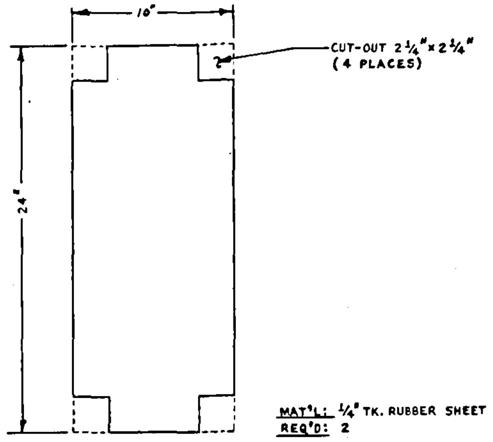
PUMP SUPPORT & DRIP PAN ASSEMBLY (102/22)
N.T.S.



NOTE: BREAK SHARP EDGES - 1/32" RAD.
BREAK CORNERS - 1/8" RAD.

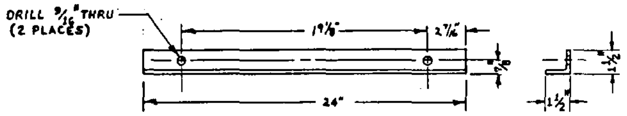
REQ'D : 2

FOOT-PLATE (103/22)
SCALE : 1/4" = 1"



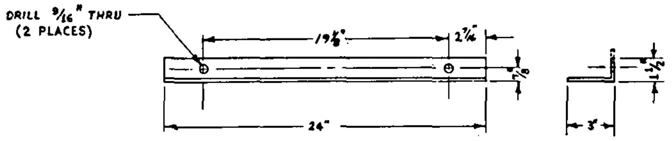
MAT'L: 1/4" TK. RUBBER SHEET
REQ'D: 2

FOOT-PAD (104/22)
SCALE: 1/4" = 1"



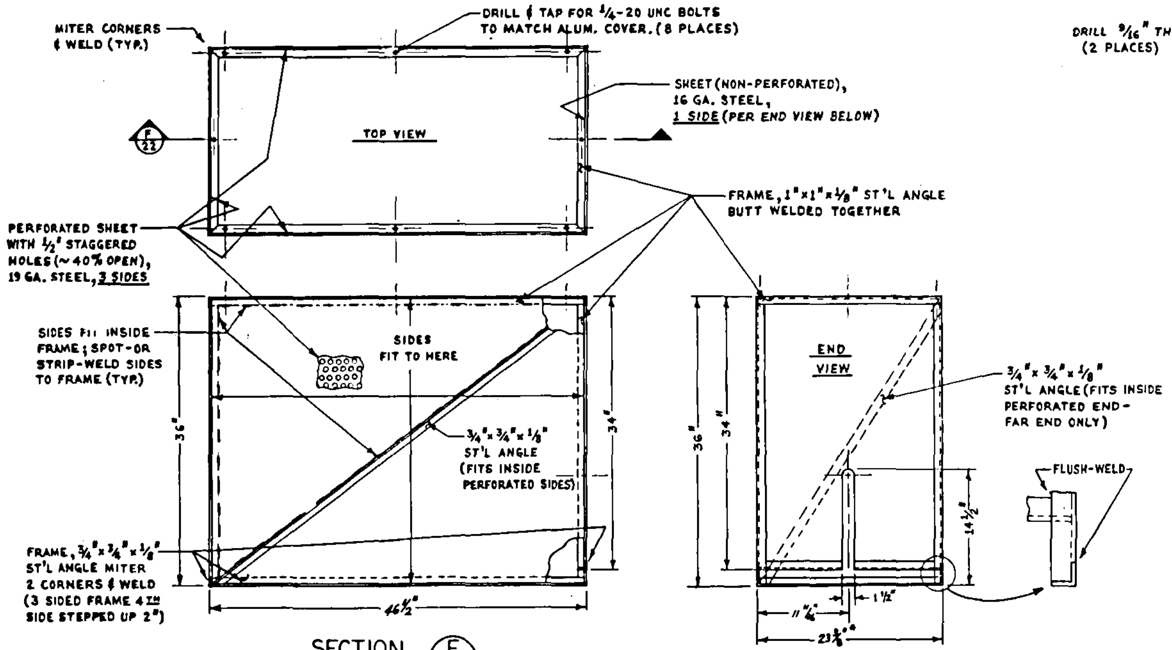
MAT'L: MAKE FROM 1 1/2" x 1 1/2" x 1/4" TK. (OR 3/16")
ALUM. ANGLE
REQ'D: 1

PIPE SUPPORT (111/22)
SCALE : 1/4" = 1"



MAT'L : MAKE FROM 2" x 3" x 3/16" TK.
ALUM. ANGLE
REQ'D: 1

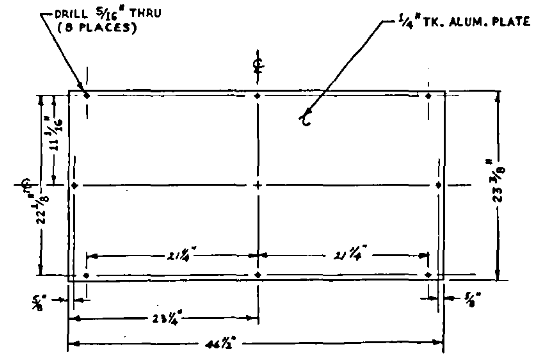
ELECTRICAL JUNCTION BOX SUPPORT (112/22)
SCALE : 1/4" = 1"



SECTION (F/22)
SCALE : 1/8" = 1"

* TO FIT INSIDE DRIP PAN

PUMP CAGE (135/22)
SCALE : 1/8" = 1"



NOTE : USE THIS PLATE AS TEMPLATE FOR DRILLING PUMP CAGE, CENTER COVER PLATE ON PUMP CAGE BEFORE DRILLING

PUMP CAGE COVER PLATE (136/22)
(1-REQ'D)
SCALE : 1/8" = 1"

SYM. | NO. | DESCRIPTION | APP./DATE
REVISIONS (M)

DESIGN CONTRACTOR
Gilbert/Commonwealth? Rider
20220 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116
1/9/79
1140
S.E. MF
D.S.
P.E.

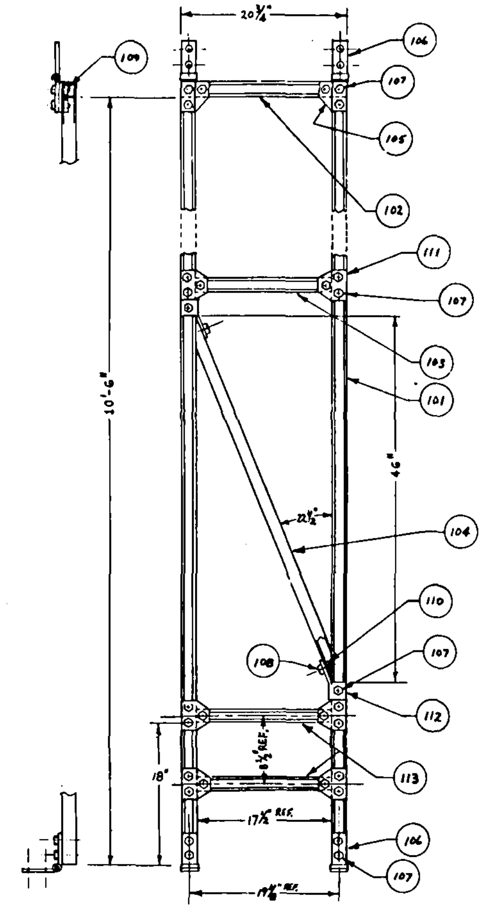
UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............
DR.
CK. AFK
D. SUP.
CHK.
U. ENG.
UP. ENG.
D.S. NO. WJJ
D.S. CH.
D. DIV.
R. ENG.
R.S. NO.
R. DIV.

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE UPPER VOLTA, AFRICA

PUMP SUPPORT, CAGE AND DETAILS

SCALE : AS NOTED
REFERENCE
CF 56522
ELECTRICAL
OFFICIAL DATE 1-15-79

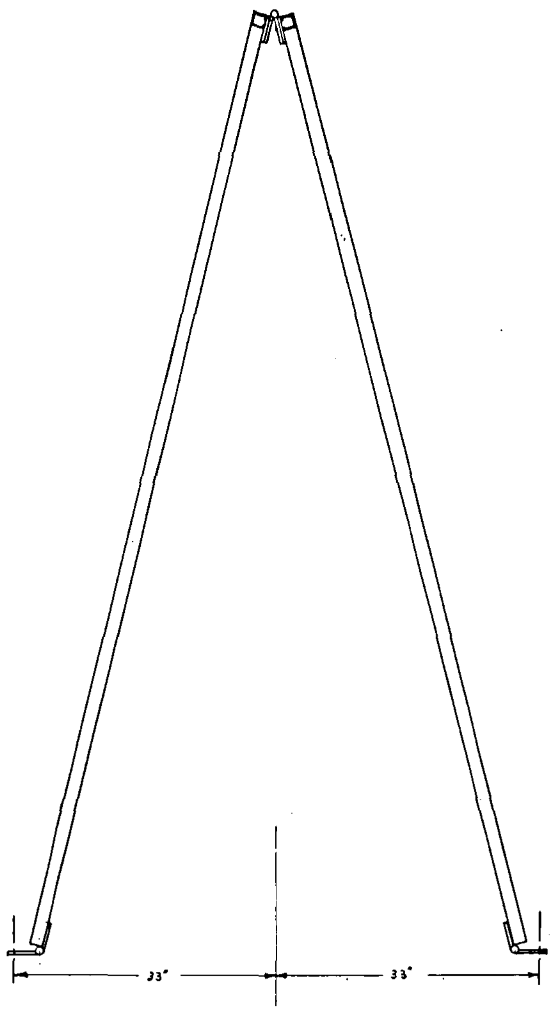


PUMP SYSTEM INSTALLATION "A" FRAME

SCALE: 1/8"=1' (1 1/2"=1')

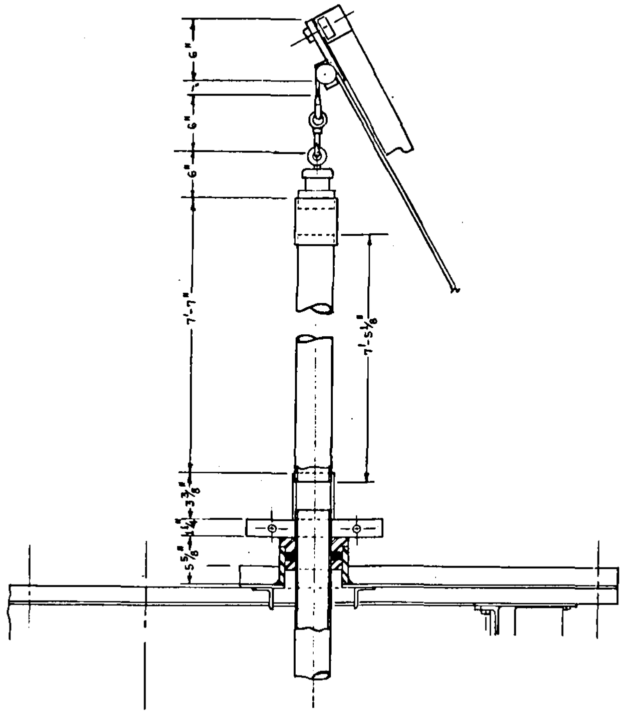
REQ'D: 2

NOTE: TWO HALVES OF "A" FRAME SHARE TOP HINGES.



PUMP SYSTEM INSTALLATION "A" FRAME

SCALE: 1/8"=1' (1 1/2"=1')



DROP PIPE INSTALLATION

N.T.S.

ITEM NO.	PART NO.	PARTS LIST (APPLIES TO THIS DWG. ONLY) DESCRIPTION	REQ'D
101		SINGLE CHANNEL - "SUPERSTRUT" No. A-1200 10'-6" LG.	4
102		SINGLE CHANNEL - "SUPERSTRUT" No. A-1200 20 3/4" LG.	2
103		SINGLE CHANNEL - "SUPERSTRUT" No. A-1200 17 1/2" LG.	3
104		SINGLE CHANNEL - "SUPERSTRUT" No. A-1200 ENDS BEVELED 22 1/2° (AS SHOWN) OVERALL LENGTH - 46"	2
105		CORNER FITTING - "SUPERSTRUT" No. AB-255	4
106		HINGE - "UNISTRUT" No. P1354	6
107		HEX. HD. CAP SCREW - 1/2" (13) x 1 1/4" LG	54
108		HEX. HD. CAP SCREW - 1/2" (13) x 1" LG.	4
109		SPRING NUT - "SUPERSTRUT" No. A-100	54
110		SPRINGLESS NUT - "SUPERSTRUT" No. AC-100	4
111		TEE FITTING - "SUPERSTRUT" No. AB-259 (or "UNISTRUT" No. P-1356)	8
112		ANGLE FITTING (22 1/2°) - "SUPERSTRUT" No. X-212-1	4
113		DOUBLE CHANNEL - "SUPERSTRUT" No. B-1402	2

NOTES

1 1/2" = 1'-0"
3" = 1'-0"

GRAPHIC SCALES

SYM.	NO.	DESCRIPTION	APP./DATE

REVISION M

DESIGN CONTRACTOR

Spider
30335 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116

1/9/79 1140
E.S. GHH
S.E. MF
D.S. WM
P.E. LJM

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES..........

DR.	CK. AFP	S. SUP.
DSN.	S. ENG.	D.P. ENG.
D.E. HD. WJJ	D.E. CH. RAJ	S. DIV.
R. ENG.	R.E. HD. AFR	R. DIV. RSP

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

PUMP SYSTEM INSTALLATION "A" FRAME

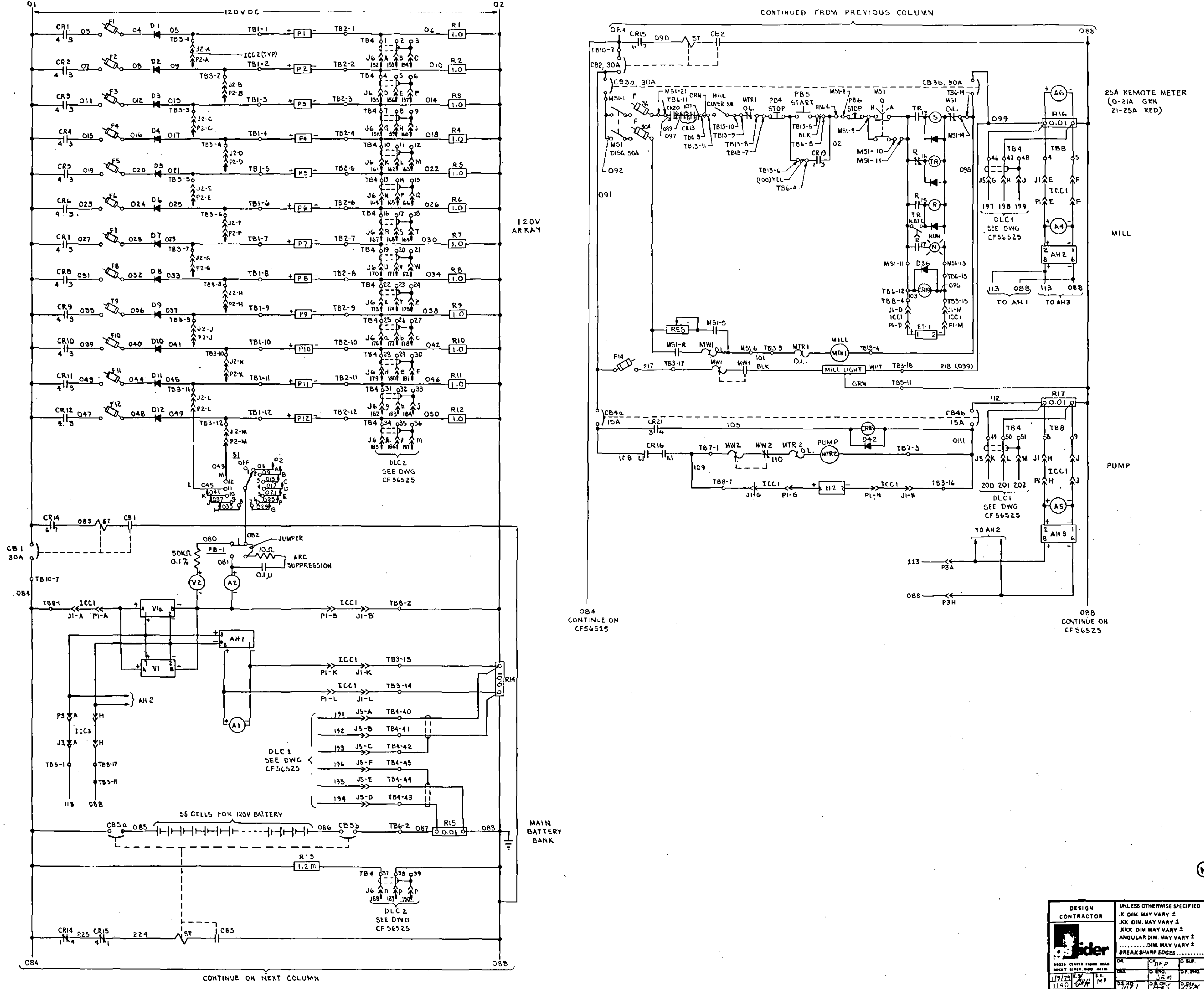
SCALE: AS NOTED

REFERENCE

CF56523

ELECTRICAL

OFFICIAL DATE 1-15-79



NOTES

SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF 1923)	GSR/ CJA 1-28-81

REVISION Ⓜ

DESIGN CONTRACTOR

20325 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116

1/9/79
1140
E.S. JHH
S.E. MF
D. PAG

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
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ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES..........

DR.
CK. TFP
D. SUP.
DES.
D. ENG. JEM
D.P. ENG.
D.S. HQ.
D.S. CH.
D. DIV.
R. ENG.
R.S. HQ.
R. DIV.

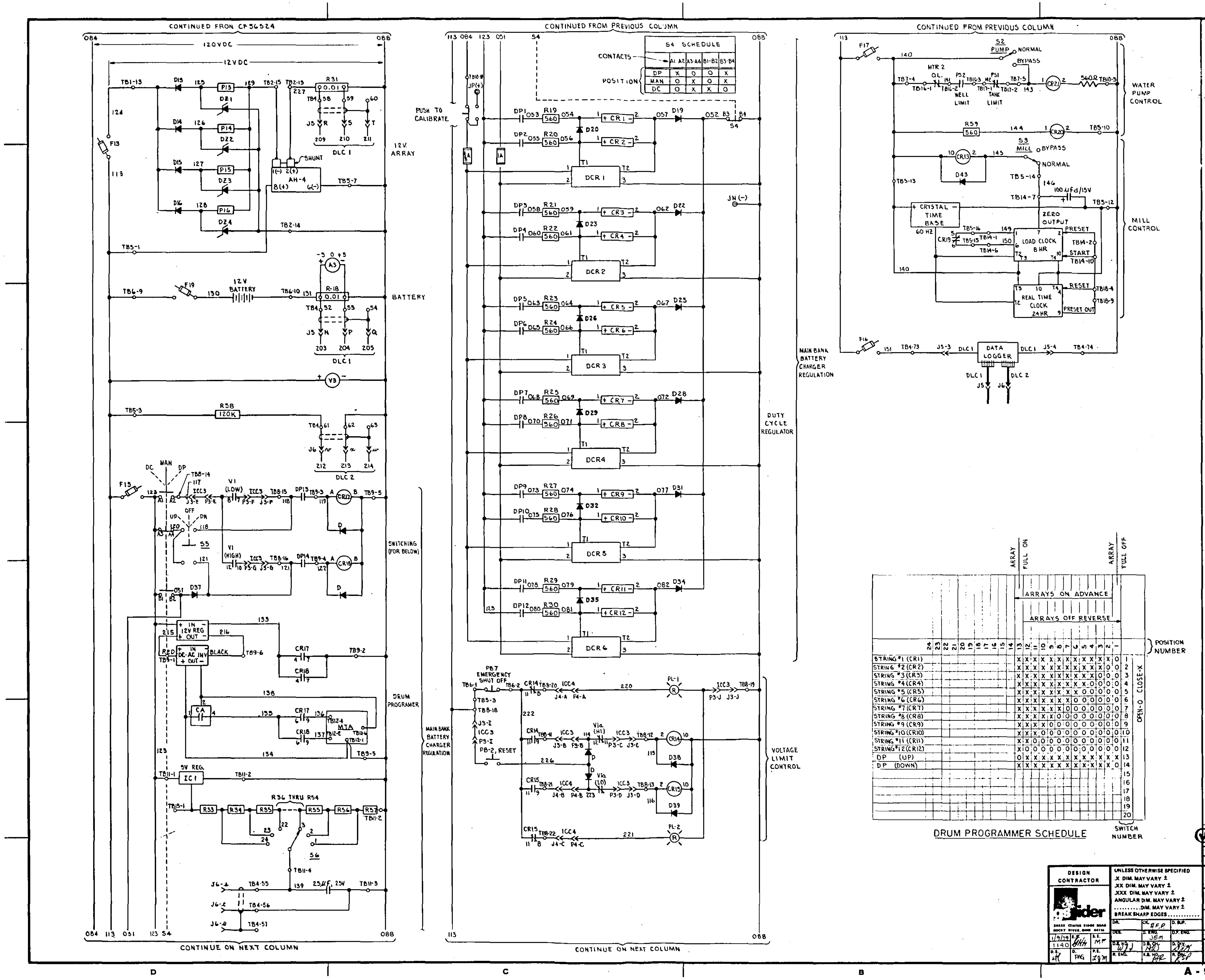
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE UPPER VOLTA, AFRICA

SCHEMATIC WIRING DIAGRAMS

SCALE: NONE
REFERENCE

CF 56524
ELECTRICAL
OFFICIAL DATE 1-15-79



S4 SCHEDULE

CONTACTS	A1-A2	A3-A4	B1-B2	B3-B4
DP	X	O	O	X
MAN	O	X	O	X
DC	O	X	X	O

POSITION

ARRAY FULL ON

ARRAY FULL OFF

ARRAYS ON ADVANCE

ARRAYS OFF REVERSE

POSITION NUMBER

	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
STRING #1 (CR1)												X	X	X	X	X	X	X	X	X	X	X	X	O	1
STRING #2 (CR2)												X	X	X	X	X	X	X	X	X	X	X	O	O	2
STRING #3 (CR3)												X	X	X	X	X	X	X	X	X	X	O	O	O	3
STRING #4 (CR4)												X	X	X	X	X	X	X	X	X	O	O	O	O	4
STRING #5 (CR5)												X	X	X	X	X	X	X	X	O	O	O	O	O	5
STRING #6 (CR6)												X	X	X	X	X	X	X	O	O	O	O	O	O	6
STRING #7 (CR7)												X	X	X	X	X	X	O	O	O	O	O	O	O	7
STRING #8 (CR8)												X	X	X	X	X	O	O	O	O	O	O	O	O	8
STRING #9 (CR9)												X	X	X	X	O	O	O	O	O	O	O	O	O	9
STRING #10 (CR10)												X	X	X	O	O	O	O	O	O	O	O	O	O	10
STRING #11 (CR11)												X	X	O	O	O	O	O	O	O	O	O	O	O	11
STRING #12 (CR12)												X	O	O	O	O	O	O	O	O	O	O	O	O	12
DP (UP)												O	X	X	X	X	X	X	X	X	X	X	X	X	13
DP (DOWN)												X	X	X	X	X	X	X	X	X	X	X	X	O	14
																									15
																									16
																									17
																									18
																									19
																									20

OPEN-O CLOSE-X

SWITCH NUMBER

DRUM PROGRAMMER SCHEDULE

NOTES

SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF 1323)	GSR/ CJA 1-28-81

REVISIONS

DESIGN CONTRACTOR

gilbert/commonwealth / Spider

20225 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
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ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

1/9/79	E.	S.E. MF
1140		
D.S.	D. PAG	P.E.
DR.	CK. AFP	D. SUP.
DES.	D. ENG. JEM	D.P. ENG.
D.S. HD. WJJ	D.B. CH.	D. DIV.
R. ENG.	R.B. HD.	R. DIV. RSP

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE UPPER VOLTA, AFRICA

SCHEMATIC WIRING DIAGRAMS

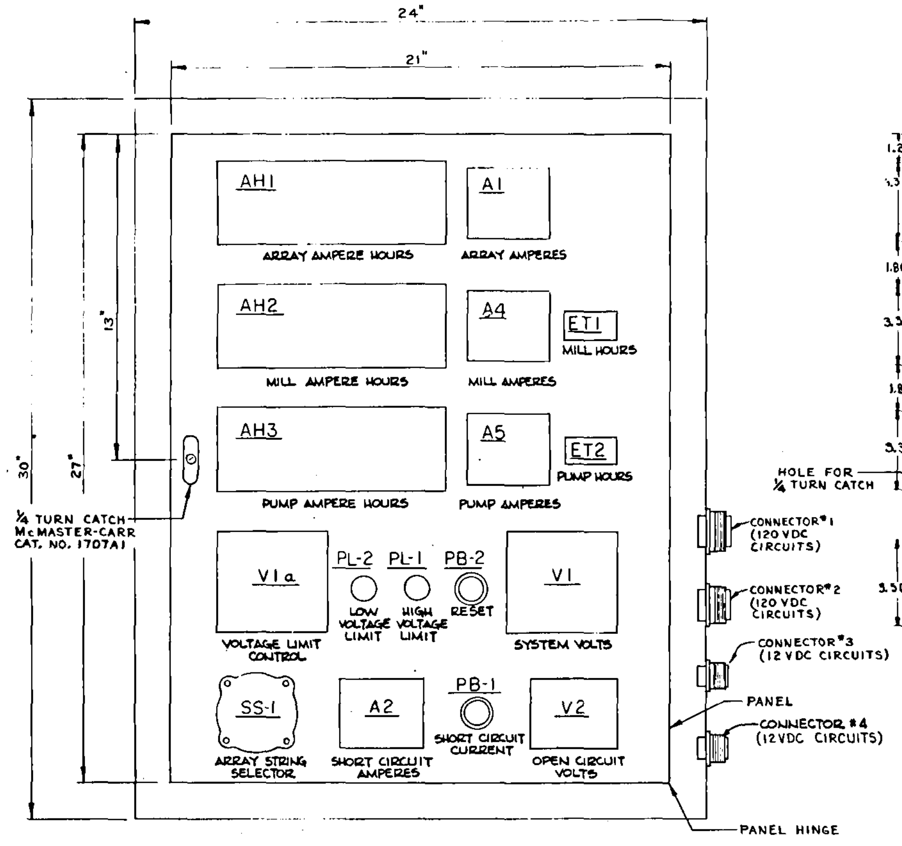
SCALE: NONE

REFERENCE

CF56525

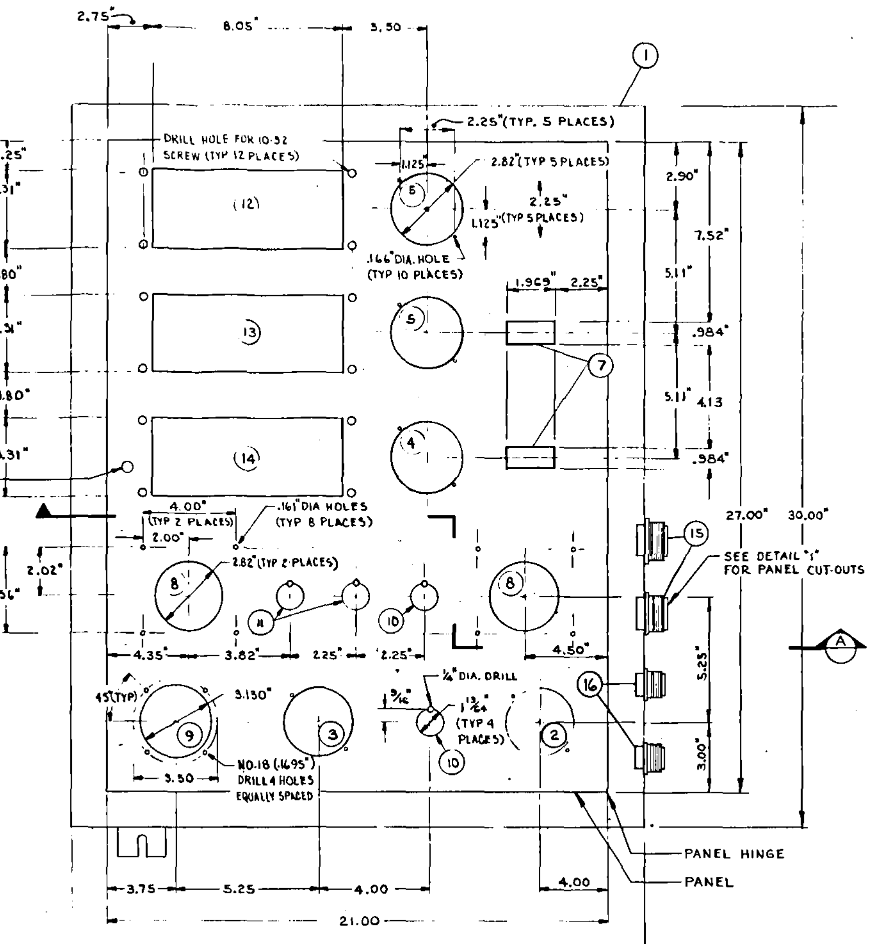
ELECTRICAL

OFFICIAL DATE 1-15-79



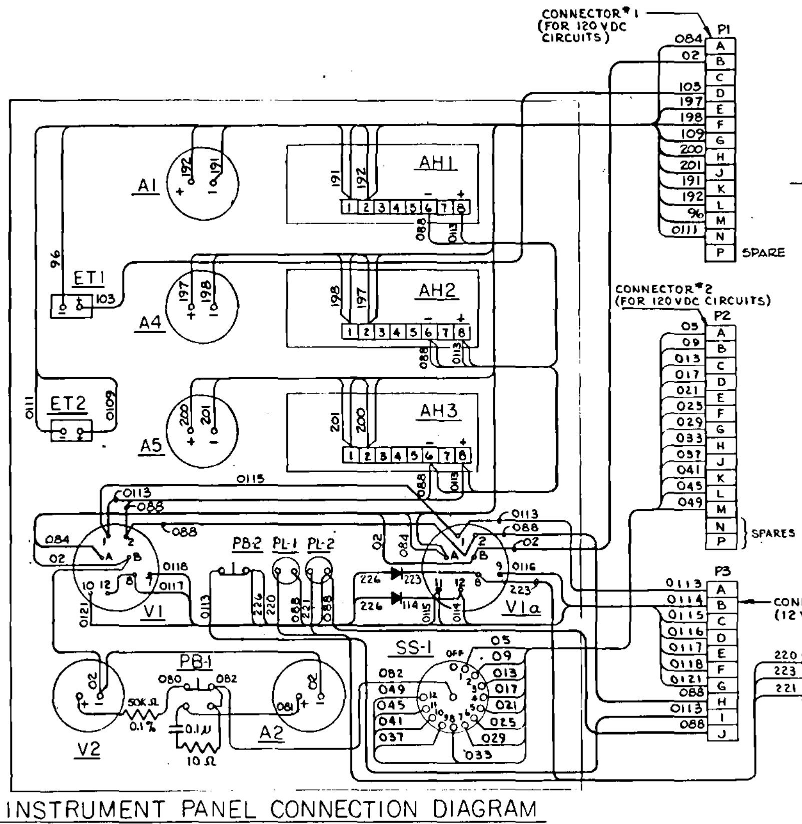
INSTRUMENT PANEL LAYOUT

(VIEW WITH DOOR OPEN SHOWING INSTRUMENT ARRANGEMENT)
NOT TO SCALE



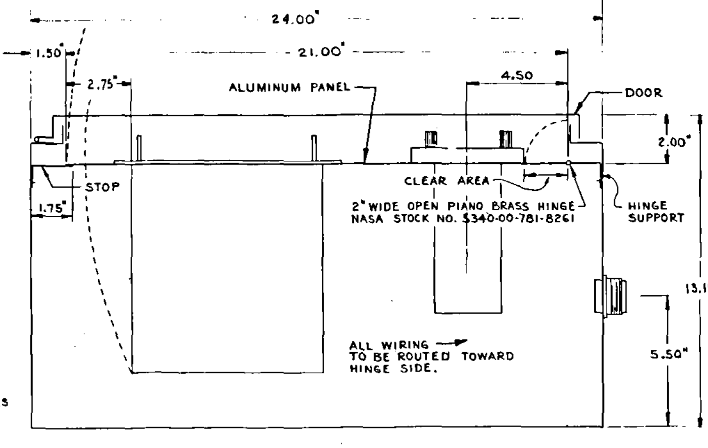
INSTRUMENT PANEL LAYOUT

(VIEW WITH DOOR OPEN SHOWING PANEL CUT-OUTS)
NOT TO SCALE



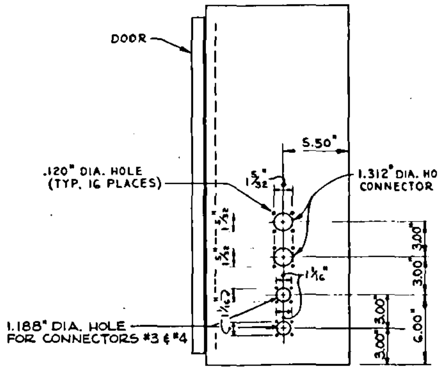
INSTRUMENT PANEL CONNECTION DIAGRAM

(VIEW LOOKING AT BACK OF PANEL)



SECTION (A/26)

NOT TO SCALE



DETAIL "I"

NOT TO SCALE

EQUIPMENT LEGEND (APPLIES TO THIS DRAWING ONLY)

SYMBOL	QUANT	DESCRIPTION
①	1	NEMA 12 ENCLOSURE 30" HIGH X 24" WIDE X 12" DEEP HOFFMAN CAT. # A-302412 LP
②	1	ANALOG PANEL METER WITH 0-200VOLTS DC RANGE; INPUT IMPEDANCE 1000 Ω/V; ± 2% ACCURACY WESCHLER GX352-606B601A22
③	1	ANALOG PANEL METER WITH 0-3 AMPS DC RANGE; ± 2% ACCURACY WESCHLER GX352-606B597A12
④	1	MILLIVOLT METER WITH 0-5 AMPS DC SCALE (100 MILLIVOLT EXTERNAL SHUNT SUPPLIED BY OTHERS) WESCHLER GX352-606B609A09
⑤	2	MILLIVOLT METER WITH 0-25 AMPS DC SCALE (100 MILLIVOLT EXTERNAL SHUNT SUPPLIED BY OTHERS) WESCHLER GX352-606B609A12
⑥		
⑦	2	ELAPSED TIME INDICATOR, 5 DIGIT, READS 9999.9 HRS., WITHOUT RESET, 120 VDC OPERATION. KESSLER-ELLIS TYPE LTH 15-20
⑧	2	COMPACK I OPTICAL INDICATING CONTROLLER WITH 90-140 VDC RANGE SUPPRESSED SCALE, DOUBLE SET POINT, 12 VDC OPERATING VOLTAGE, CONTACTS RATED FOR 12VDC OPERATION. LFE CORP. MODEL 503-K.
⑨	1	12 POINT ROTARY SELECTOR SWITCH LEWIS ENGINEERING CO. CAT. # 10S12
⑩	2	MOMENTARY CONTACT PUSHBUTTON WITH 1 N.O. & 1 N.C. CONTACT BLOCK GENERAL ELECTRIC CAT. # CR2840U201
⑪	2	PILOT LIGHT, 12 VOLT GENERAL ELECTRIC CAT. # CR2940UC 212A10 WITH RED COLOR CAP CAT. # U200H
⑫	1	D.C. POWERED DIGITAL AMP-HOUR METER CURTIS INSTRUMENTS CAT. # M/N 1002-25-2-C1-SHR-E-12VDC (CALIBRATED FOR SOLAR ARRAY USAGE)
⑬	1	D.C. POWERED DIGITAL AMP-HOUR METER CURTIS INSTRUMENTS CAT. # M/N 1002-25-2-C1-SHR-E-12VDC (CALIBRATED FOR BATTERY LOAD USAGE.)
⑭	1	D.C. POWERED DIGITAL AMP-HOUR METER CURTIS INSTRUMENTS CAT. # M/N 1002-5-2-C1-SHR-E-12VDC (CALIBRATED FOR BATTERY LOAD USAGE)
⑮	2	SOLID SHELL BOX RECEPTACLE FOR 14 #16 AWG WIRES AMPHENOL CAT. NO. MS3102R-20-27P (NASA STOCK NO. 5935-00-807-892D) CABLE CLAMP AMPHENOL CAT. NO. MS3057-12A (NASA STOCK NO. 5935-00-223-0572)
⑯	2	SOLID SHELL BOX RECEPTACLE FOR 10 #16 AWG WIRES; AMPHENOL CAT. NO. MS3102A-18-1P (NASA STOCK NO. 5935-00-173-7849) CABLE CLAMP AMPHENOL CAT. NO. MS3057-10A (NASA STOCK NO. 5935-00-809-0786.)

NOTES

SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF 1323)	GSR/ CUA 1-28-81

REVISIONS

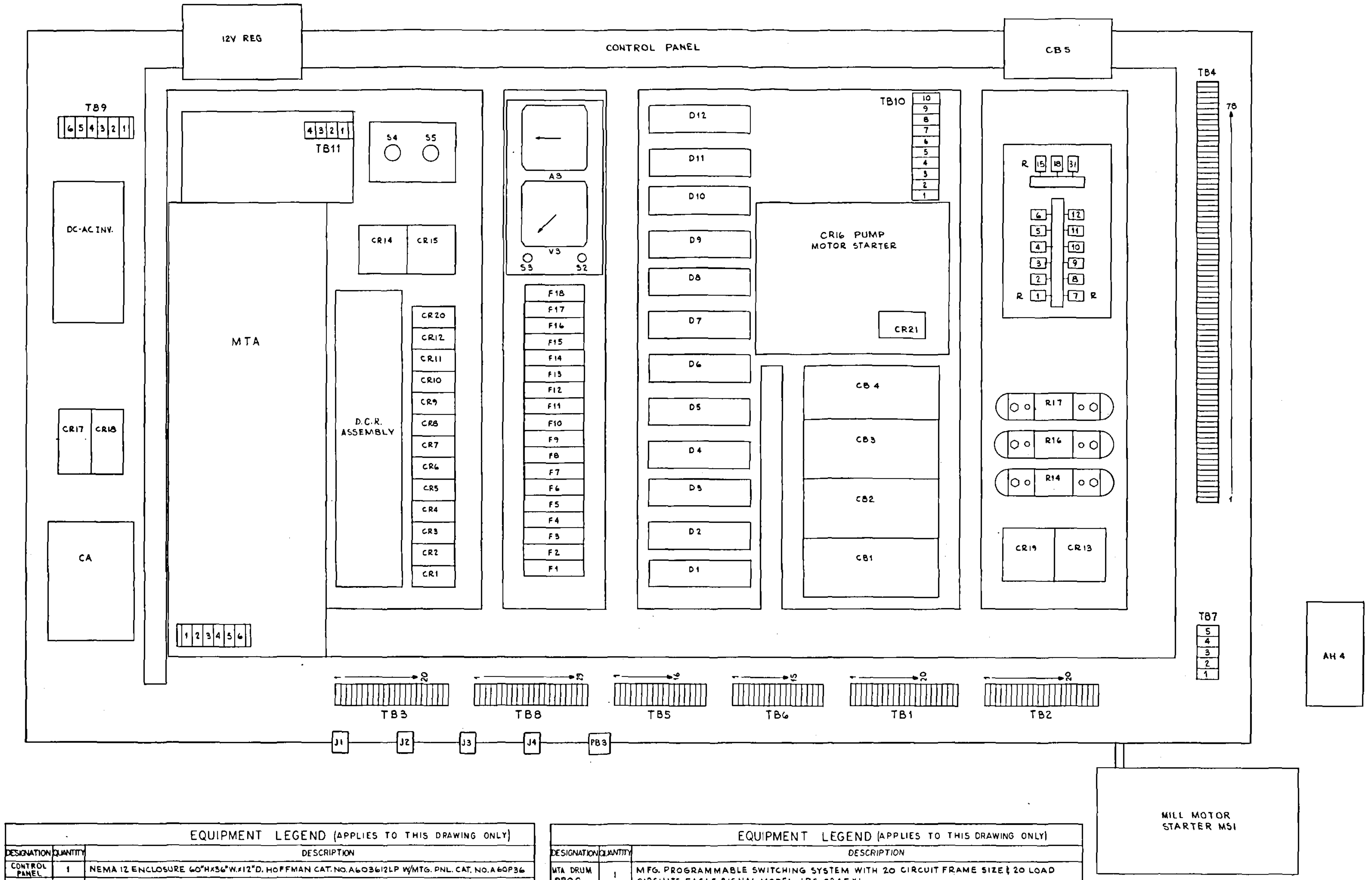
DESIGN CONTRACTOR Gilbert/Snider 20325 CENTER RIDGE ROAD ROCKY RIVER, OHIO 44116	UNLESS OTHERWISE SPECIFIED .X DIM. MAY VARY ± .XX DIM. MAY VARY ± .XXX DIM. MAY VARY ± ANGULAR DIM. MAY VARY ± ....DIM. MAY VARY ± BREAK SHARP EDGES............	NASA LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135
9/20/78 1079	C.S.	S.E. MF
D.S. D.D.	D. PAG	P.E. MF
DR.	CK. AFP	D. SUP.
DES.	D. ENG. JEM	D.F. ENG.
D.S. HD.	D.E. CH.	D. DIV.
R. ENG.	R.S. HD. AHR	R. RSP

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

INSTRUMENT PANEL LAYOUT

SCALE: NONE
REFERENCE

CF 56526
ELECTRICAL:
OFFICIAL DATE 1-16-79



EQUIPMENT LEGEND (APPLIES TO THIS DRAWING ONLY)

DESIGNATION	QUANTITY	DESCRIPTION
CONTROL PANEL	1	NEMA 12 ENCLOSURE 60"Hx36"W.x12"D. HOFFMAN CAT. NO. A603612LP W/MTG. PNL. CAT. NO. A60P36
F1 THRU F18	18	SWITCH ACTION FUSE BLOCK 30A, ACCEPTS #18 THRU. #8 WIRE BUCHANAN CAT. NO. P0312 WITH END SECTION CAT. NO. P0380 & MTG. CHANNEL CAT. NO. 63; FUSE, BUSSMAN CAT. NO.
CB1	1	30A. CIRCUIT BREAKER, 125 VDC, SINGLE POLE WITH SHUNT TRIP & 1-N.O. AUX. CONTACT G.E. CAT. NO. TED 124030 WL, TEDST12RS
CB2	1	40A. CIRCUIT BREAKER, 125 VDC, SINGLE POLE WITH SHUNT TRIP & 1 N.O. AUX. CONTACT G.E. CAT. NO. TED 124040WL, TEDST12RS
CB3	1	30A. CIRCUIT BREAKER, 250VDC, DOUBLE POLE G.E. CAT. NO. TED 124030WL
CB4	1	15A CIRCUIT BREAKER, 250VDC, DOUBLE POLE G.E. CAT. NO. TED 124015WL
CB5	1	40A CIRCUIT BREAKER, 250VDC, DOUBLE POLE WITH SHUNT TRIP & 1 N.O. AUX. CONTACT G.E. CAT. NO. TED 134040 WL, TEDST11RS
S4, S5		SELECTOR SWITCH UNIT WITH 1 N.O. & 1 N.C. CONTACT BLOCK G.E. CAT. NO. UB202A
D1 THRU D12	12	SILICON RECTIFIER, 10AMP TYPE 1N204
CR16		MOTOR STARTER ALLEN BRADELY CAT. NO. 209 BAG-1
TB1-TB6-TB8		MINIATURE TERMINAL BLOCK, ACCEPTS #30 THRU #12 WIRE BUCHANAN CAT. NO P125
TB7	1	MEDIUM DUTY TERMINAL BLOCK, ACCEPTS #22 THRU. #10 WIRE BUCHANAN CAT. P625
J1, J2	2	SOLID SHELL BOX RECEPTACLE FOR 14 #16 WIRES. AMPHENOL CAT. NO. MS3102R-20-27P (NASA STOCK NO. 5935-00-807-892D) & CABLE CLAMP AMPHENOL CAT. NO. MS3057-12 A (NASA STOCK NO. 5935-00-223-0572)
J3, J4	2	SOLID SHELL BOX RECEPTACLE FOR 10 #16 WIRES. AMPHENOL CAT. NO. MS3102A-18-1P (NASA STOCK NO. 5935-00-173-7849) & CABLE CLAMP AMPHENOL CAT. NO. MS3057-10A (NASA STOCK NO. 5935-00-809-0786)

EQUIPMENT LEGEND (APPLIES TO THIS DRAWING ONLY)

DESIGNATION	QUANTITY	DESCRIPTION
MTA DRUM PROG.	1	MFG. PROGRAMMABLE SWITCHING SYSTEM WITH 20 CIRCUIT FRAME SIZE & 20 LOAD CIRCUITS-EAGLE SIGNAL MODEL JDS-2345X1
R15, R18, R31	3	.01Ω, 10 WATT RESISTOR, 1% TOLERANCE DALE TYPE RH-10
CR1-CR12, CR20	13	SOLID STATE CONTROL RELAY, 4-10 VDC INPUT TELEDYNE CAT. NO. 603-3
CR13, CR14, CR15, CR19		GENERAL PURPOSE RELAY, 3PDT, 10AMPS, 12VDC POTTER & BRUMFIELD CAT. NO. KRP-14DG
CR17, CR18		RELAY - EAGLE SIGNAL CAT. NO. 30D2CD012
R1 - R12	12	1Ω, 10 WATT RESISTOR, 1% TOLERANCE DALE TYPE RH-10
CA	1	GW EAGLE SIGNAL CA100A61010
12V REG	1	WILMORE ELECTRIC CO. MODEL 1340
DC-AC INV	1	TERADO CORP. 12VDC TO 120VAC INVERTOR MODEL TROJAN 50-120 WITH 50-193 OSCILLATOR
R14, R16	2	HA-25-100 25AMP, 100mv METER SHUNT
R17	1	HA-5-100 5AMP, 100mv METTER SHUNT
PB3	1	GE CR2940U301
A3	1	± 5AMP DC AMMETER WESCHLER TYPE X-351 WEC 9755 EXTERNAL SHUNT 50mv
V3	1	12 VDC VOLTMETER

SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF 1323)	GSR/ CJA 1-28-81

REVISIONS Ⓜ

DESIGN CONTRACTOR
Gilbert/Snider
30433 CENTER RIDGE ROAD
ROCKY RIVER, OHIO 44116

1/9/79
1140
E.E. GHh
S.E. MF
D.S.
D. WDL
P.E.

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

DR.
CK. AFP
D. SUP.
DES.
D. ENG. JEM
D.P. ENG.
D.E. HD. WJJ
D.E. CH. HHS
D. DIV.
R. ENG.
R.S. HD.
R. DIV.

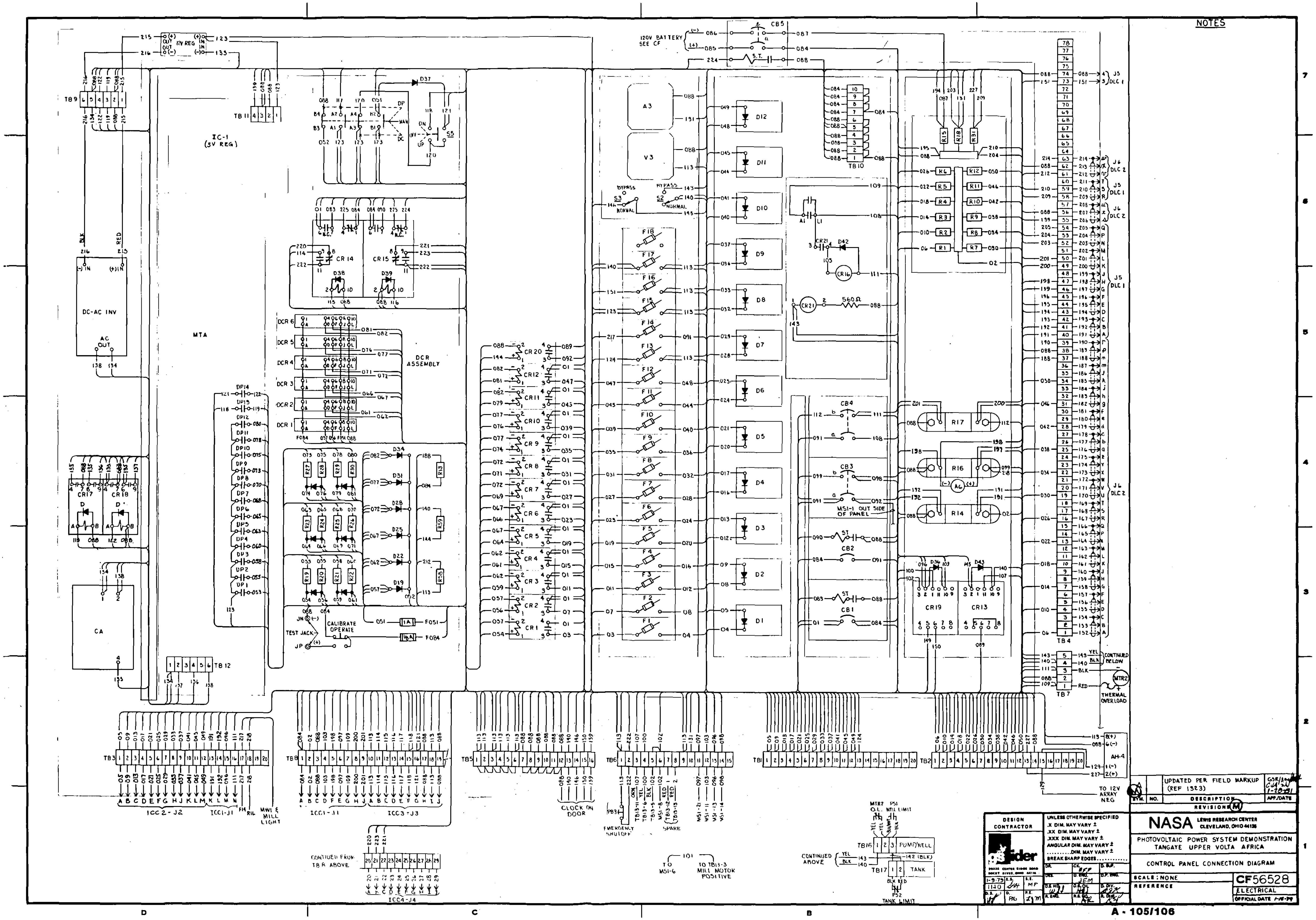
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE, UPPER VOLTA, AFRICA

CONTROL PANEL LAYOUT
AND EQUIPMENT LIST

SCALE HALF SIZE
REFERENCE

CF56527
ELECTRICAL
OFFICIAL DATE 1-15-79



SYM.	NO.	DESCRIPTION	APP./DATE
A		UPDATED PER FIELD MARKUP (REF 1323)	GSR/ CW 1-20-81

REVISIONS M

DESIGN CONTRACTOR

Sverdrup & Parcel and Associates, Inc. / Gilbert...

UNLESS OTHERWISE SPECIFIED
.X DIM. MAY VARY ±
.XX DIM. MAY VARY ±
.XXX DIM. MAY VARY ±
ANGULAR DIM. MAY VARY ±
..........DIM. MAY VARY ±
BREAK SHARP EDGES............

1-9-79	E.S.	S.E. MF
1140		
D.S.	D. PAG	P.E.

DR.	CK. RFP	D. SUP.
DES.	D. ENG. JEM	D.P. ENG.
D.S. HD. WJJ	D.E. CH.	D. DIV.
R. ENG.	R.S. CO.	R. DIV.

NASA LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135

PHOTOVOLTAIC POWER SYSTEM DEMONSTRATION
TANGAYE UPPER VOLTA AFRICA

CONTROL PANEL CONNECTION DIAGRAM

SCALE: NONE

REFERENCE

CF56528

ELECTRICAL

OFFICIAL DATE 1-18-79

APPENDIX B

MANUFACTURERS AND EQUIPMENT

(This list of manufacturers and equipment is provided for information purposes only and does not imply endorsement by the NASA-Lewis Research Center or the U.S. Agency for International Development.)

Equipment	Model	Vendor
Solar Cell Modules	9200J	Solarex Corporation 1335 Piccard Drive Rockville, MD 20850 Attn: Joseph Lindmayer (301) 948-0202
	20-10-1452 (Replacement May 1981)	Sensor Technology 21012 Lassen Street Chatsworth, CA 91311 (213) 882-4100
Array PV Panel and Panel Support Structural Material		Super Strut 802 Eisenhower Drive, North Goshen, IN 46526 (219) 533-0335
Storage Battery (lead-calcium)	LCPSA 1890	C&D Batteries Division 3043 Walton Road Plymouth Meeting, PA 19462 (215) 828-9000
Mill	Group A, Model No. 10 Bottom Discharge Hammermill	C.S. Bell Company P.O. Box 291 Tiffen, OH 44883 Attn: Ron White (419) 448-0791
	Model 120-D (Replacement May 1981)	Jacobson Machine Works 2445 Nevada Avenue Minneapolis, MN 55427 Attn: Will Donaghy

Equipment	Model	Vendor
Water Pump	11W5A	Jensen Brothers Manufacturing Company, Inc. 14th and Pacific Streets Coffeyville, KS 67337 Attn: Derrick Morris (316) 251-5700
120-V(d.c.) Permanent Magnet d.c. Motors o Water Pump (1/4-hp) SR 3632-2806-48B o Mill (3-hp) SRF 5572-3074-82 BC		Applied Motors P.O. Box 106 Rockford, IL 61125 Attn: Mr. Kyburz (815) 397-2006
Motor Starter (3-hp)	Special d.c., Reduced Voltage, 2-Step Combination WC-3211 4-6-78	Winkle Electric Company 1900 Hubbard Road Youngstown, OH 44501 Attn: J.A. Hartman (216) 744-5303
Level Switch	Level Actuated DW-1 (Replacement May 1981)	Square D Company Executive Plaza Palatine, IL 60067 (312) 397-2600
Datalogger	DAT-3	Mars Data Systems 14666 Doolittle Drive San Leandro, CA 94577 Attn: Arthur A. Loya (415) 483-7902
Programmable Drum Relay (PDR) PDR System	JDS 2345	Eagle Signal Division 736 Federal Street Industrial Controls Davenport, IA 52803 Attn: Don Morris (319) 326-8105
12V Regulator PDR Subsystem	1340	Wilmore Electronics Company P.O. Box 1329 Hillsborough, NC 27278 Attn: Chris Ely (919) 732-9351

Equipment	Model	Vendor
DC to AC Inverter PDR Subsystem 12V DC to 120V AC	TROJAN 50-120	Terado Corporation 1068 Raymond Avenue St. Paul, MN 55108 Attn: Fred Munson (612) 646-2868
AC Timer PDR Subsystem	CA100A61010	Eagle Signal Division 736 Federal Street Industrial Controls Davenport, IA 52803 Attn: Don Morris (319) 326-8105
Elapsed Time Indicator	LTH 15.10	Kessler & Ellis Products Dept EM 120 1st Avenue Atlantic Highlands, NJ 07716 Attn: Eleanor Polcsik
Ampere Hour Meter	1002	Curtis Instruments 200 Kisco Avenue Mt. Kisco, NY 10549 Attn: Rhoda McDonald (914) 666-2971
Optical Controller Meter Relay	COMPAK 1-503K	LFE Corporation 1601 Trapelo Road Waltham, MA 02154
Solid State Relay (CR1-12,20,21)	603-3	Teledyne Relays SS. Div. 12525 Daphne Avenue Hawthorne, CA 90250 (213) 777-0077
Electromechanical Relay (CR-13,15,19)	KRP 14DG	Potter & Brumfield, AMF 200G Richland Creek Drive Princeton, IN 47671 (812) 386-1000
Circuit Breakers	TED 1240	General Electric Supply Company 5605 Granger Road Cleveland, OH 44131 Attn: Mr. Hank Reich (216) 523-6441

Equipment	Model	Vendor
Ammeters	GX 352	Weschler Electric 16900 Foltz Industrial Parkway Strongsville, OH 44136 Attn: Bob Andrews (216) 238-2550
Water Meter	5/8-inch Trident 8	Neptune Water Meter Company 9200 Shelbyville Road Louisville, KY 40222 Attn: Bert Malley (502) 426-5070

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16. Abstract

This report describes the engineering design of a stand-alone photovolatic (PV)-powered grain mill and water pump for the village of Tangaye, Upper Volta. The PV system is part of a project funded by the United States Agency for International Development and implemented by the National Aeronautics and Space Administration, Lewis Research Center. The purpose of the project is twofold: (1) to study the socioeconomic effects of reducing the time required by women in rural areas for drawing water and grinding grain and (2) to demonstrate the suitability of photovolatic technology for use in rural areas by people of limited technical training. The PV system consists of a 1.8-kW (peak) solar cell array, 540 ampere-hours of battery storage, instrumentation, automatic controls, and a data collection and storage system. The PV system is situated near an improved village well and supplies d.c. power to a grain mill and a water pump. The array is located in a fenced area and the mill, battery, instruments, controls, and data system are in a mill building. A water storage tank is located near the well. The system employs automatic controls which provide battery charge regulation and system over- and under-voltage protection. This report includes descriptions of the engineering design of the system and of the load that it serves; a discussion of PV array and battery sizing methodology; descriptions of the mechanical and electrical designs including the array, battery, controls, and instrumentation; and a discussion of the safety features. The system became operational on March 1, 1979.

17. Key Words (Suggested by Author(s))

Design; Photovolatic; Power; Village

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