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A 64 KW Concentrating Photovoltaics Applications Test Center

Volume 1 - Final Report

MASTER

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Kaman Sciences Corp.**

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A 64 KW CONCENTRATOR
PHOTOVOLTAICS APPLICATION TEST CENTER, ²

FINAL REPORT

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1.0 INTRODUCTION AND SUMMARY

Kaman Sciences Corporation has designed a 64 KW Concentrating Photovoltaic Applications Test Center (APTEC) for the U.S. Department of Energy under Contract Number ET-78-C-04-4278. The APTEC employs a combined concentrating photovoltaic array in a total energy system application for load sharing the electric and thermal demands of a large computer center with the interfaced electric and natural gas utility.

The photovoltaic array is composed of two-axis tracking heliostats of Fresnel lens concentrating, silicon solar cell modules. The modules are cooled with a fluid which transfers heat to a ground coupled heat sink/storage unit for subsequent use in meeting the computer center's thermal load demand.

The combined photovoltaic power system shares basic components - a power conditioning unit, batteries and thermal conditioning equipment - with the electric and natural gas utility service, improving the computer center's operating availability time and displacing a portion of the fossil fuel required to power the computer center with solar energy.

1.1 Conceptual System Design and Analysis

The basic system design concept is based on providing power with enhanced reliability to a computing center which is very sensitive to transients in its electric power service and which relies heavily on a constant supply of chilled water for cooling. This concept philosophy stems from projections of near term national electric grid capacity shortages and the "loss of utility service" costs to computer centers in the form of reduced operating revenues and increased nonproductive labor costs.

The basic combined photovoltaic concentrator system designed to enhance the reliability of power for the computer center is shown in Figure 1. The major overall system equipment components, loads, electric utility interface and their relationship are shown.

1.1.1 Basic Photovoltaic Power System Design

Point focusing Fresnel lenses are employed to concentrate direct normal solar radiation on 3 inch diameter silicon cells mounted in a fluid cooled absorber. Eight cells, each with its individual lens, are mounted on a linear fluid cooled absorber tube to form a module. Each module is equipped with its own bypass diode to protect the cells from back biased current flows resulting from partial shading in the series string, and from maximum intensity lightning illuminations.

Fifty three modules (424 cells) are mounted on a hydraulic powered, two-axis tracking, tower mounted platform called a heliostat. The heliostat has its own tracking controller, hydraulic power system, hydraulic ram tracking actuators, fluid cooling system, lightning elimination protection, dc manual disconnect switch, blocking diode, surge arrestor, operating controls, and safety detrack control.

The 848 cells in two heliostats are connected in series to provide an average array bus operating voltage of 428 Vdc.

The array design for this system is a new design. The heliostat design keystone is the 15" x 15" Swedlow lens with a 32X geometric concentration ratio which has been developed by Swedlow, Inc. under separate contract to Sandia Laboratories.

The projected annual array electric efficiency is 11.23%, with a projected array thermal efficiency of 60%. The array has

FIGURE 1 BASIC PHOTOVOLTAIC APTEC SYSTEM SCHEMATIC

a dry weight of 22,401 pounds per heliostat, with a prototype cost of \$371.62 per square meter of aperture. The combined cost per peak watt (electric plus thermal capacity) is \$.45 based on the above efficiencies and cost. Reallocated cost per peak watt, based on electric capacity being 13.6% of the total array energy capacity and thermal capacity being 86.4%, is \$.06 per peak electric watt and \$.39 per peak thermal watt. Upgraded structural designs based on performance data gained from transducers on an operating heliostat are anticipated to reduce heliostat structure weight (and cost) 40% to 60%.

The power conditioning unit is an off-the-shelf redundant uninterruptible power supply (UPS) unit. Its rated capacity is 250 KVA per bay with two bays. Both bays and an integral 250 KVA static interrupt switch are employed to serve the critical and noncritical load during normal commercial power conditions. When the commercial power supply suffers either a brownout or a blackout, the noncritical load automatically disconnects from the UPS, and the critical load is carried without interruption for up to two hours by the battery connected to the UPS inverter, and to the photovoltaic arrays when the sun is shining.

The battery consists of 187 cells with lead-calcium plates. It has an operating discharge voltage of from 421 Vdc down to 290 Vdc. The battery is off-the-shelf, and is of the type normally used for switch gear and UPS service. The battery will have a twenty year life for this application based on four deep discharges and twenty shallow discharges each year.

The thermal energy system is designed to maintain a constant average cell operating temperature of 140°F in the array to stabilize the array dc voltage at a constant operating level. The thermal system is designed so that the coolant fluid pumps always operate at maximum efficiency under constant flow and constant head. The thermal energy from the array is placed in ground

coupled hot storage when the arrays operate. The energy in hot storage is moved by Templifier™ (heat pump)/absorption equipment and placed in ground coupled cold storage at night. The computing center equipment is cooled from the cold storage. The ground coupled storage has the characteristic of a large capacity "thermal flywheel" that operates within a specific temperature band.

Therminol 60™ is the heat transfer fluid used to cool the arrays. This is a commercially available permanent fluid that won't boil, freeze, corrode the cooling system, or conduct electricity.

1.1.2 Characteristics of the Computer Center Load

The electric power load consists of critical and noncritical loads.

The critical load consists of the computer center equipment and support facilities that operate 24 hours a day seven days a week, at the application site. A power outage or transient quality problem interrupts computer operation and causes the computer to lose all information stored in the mainframe. Thus, when a power outage or quality problem occurs, the outage time plus the time to replace the data lost causes a loss of operating revenue, and results in costly data flow lapses to computer center users. The cooling of the mainframe with chilled water, the removal of heat rejected into the surrounding space by the primary peripherals, and the lighting requirements in the operating spaces also constitute services necessary for uninterrupted operation of the computer center.

The noncritical load consists of equipment and supporting space services that will not cause a loss of operating revenue when there is a power outage or loss of space conditioning services.

The only cost incurred in this area by utility services interruption is the cost of nonproductive personnel during the outage time.

Many computer centers are now employing uninterruptible power supplies (UPS) equipped with batteries to eliminate power service adequacy and reliability problems. The growing UPS market - which is now 17 years old - demonstrates that the benefits of employing an UPS to serve the critical load in computer centers exceed the cost of owning and operating the UPS.

Employing cold storage as a part of the critical load energy service system package is a new concept unique to this application.

KSC performed design studies for the system application and the system components based on two types of load, the computer center load and a manufacturing plant load. The computer center was selected as the sole load for this system application during the design study for the following reasons:

- The computer center will naturally share basic components (such as the UPS) with the photovoltaic arrays and the utility services in a functional manner within the integrated system, while the manufacturing load would not,
- The computer center load's demand and energy use is constant while the manufacturing load cycles with normal working hours - thus the computer center load has a lower cost per kilowatt hour of energy for balance of system costs than the manufacturing load [by a factor of the ratio of manufacturing plant annual load factor to computer center annual load factor $\left(\frac{.34}{.87}\right)$].

- The computer center employs all of the electric and thermal energy from the photovoltaic concentrators thus earning a maximum energy demand credit, full electric energy cost credit, and full natural gas cost credit from the displaced utility services. This concept eliminates the need - such as occurs from the cyclical manufacturing plant load - to backfeed excess electric power generated by the arrays on nonworking days into the utility grid where this excess energy can only earn a portion of the value of the fuel saved, thereby, in that network,
- The cost of connecting both the manufacturing and computer loads to the photovoltaic concentrator system in lieu of the superior load would exceed the benefits gained.

1.2 Load Definition

The load to be connected to the power conditioning unit in this system is shown in Table I. UPS conversion losses are included as a part of the critical load.

This load demand, power factor, and energy data were obtained from historical utility data and confirmed by monitoring the voltage, amperage, and integrated KVA's with recording instruments during September and October of 1978. This confirmed data is the source of the demand data shown. The Array Support load data is the demand and energy from the array design studies.

2.0 DETAIL SYSTEM COMPONENT DESIGNS

The following sections detail the design studies and basic performance criteria for the major equipment components in the Concentrator Photovoltaic APTEC.

TABLE I. PHOTOVOLTAIC CONCENTRATOR SYSTEM LOAD DEMAND

Load Category	Undiversified Demand KVA	Power Factor	Undiversified Demand KW	Diversified Demand KW	Annual Electric KVAH	Energy Thermal 10 ⁶ BTU
Critical Load	219	.86	255	225	1,162,899	5,108
Non-Critical Load	<u>107</u>	<u>.90</u>	<u>119</u>	<u>115</u>	<u>637,720</u>	—
total Power conditioning Unit Load	326	.87	374	340	1,800,618	
Array Support in <u>Critical Load</u>	26	.79	33	27	<u>54,607</u>	<u>—</u>
Total Energy					1,800,618	5,108

2.1 Power Conditioning Unit

The confirmed demand data of Table I were used to define the load carrying capability of the power conditioning unit for the design study, and analysis, which led to the selection of the UPS equipment. The power conditioning unit characteristics establishes design requirements for the photovoltaic array because of the "voltage-window" through which array power must pass to serve the load.

The following categories of power conditioning units were researched as a first step of the power conditioning unit selection process:

- Power conditioning equipment designs ready for upscaled development,
- Power conditioning equipment in the developmental stage,
- Off-the-shelf uninterruptible power supply (UPS) equipment.

This research resulted in the decision to employ commercially available UPS equipment for the power conditioning unit in this system for the following reasons:

- UPS equipment is available from several capable manufacturers where UPS product capability, operating life, and reliability is proven,
- The design features and operational characteristics of some of the available UPS systems are compatible with employing photovoltaic concentrator arrays as an additional power source for serving a load,

- Some of the available UPS equipment integrates the battery into load service and services the battery in a manner which precludes the requirement for additional battery support and control equipment when the UPS is integrated into the photovoltaic concentrator system.

Four separate UPS systems and their manufacturers were evaluated for this system. The above reasons for employing UPS equipment became the requirements to be met by the manufacturers in the evaluation.

2.1.1 Power Conditioning Unit Characteristics

The power conditioning equipment selected for this system is the General Electric Redundant UPS system. This unit basically consists of the rectifier-inverter arrangement shown in Figure 1. A redundant UPS has two bays - each equipped with a rectifier, inverter, battery interface, and complete switching and controls. It is also equipped with a static interrupt switch that transfers commercial power around the UPS to the load if both bays of the UPS malfunction at the same time.

Each bay of the redundant UPS unit selected for this system has a nameplate capacity of 250 KVA to match the demand of the diversified Critical Load (225 KW). The UPS bays normally operate in parallel and share the connected load. Under normal conditions the total UPS capacity is 500 KVA. When there is a malfunction in one of the UPS bays, the connected load must be reduced to the capacity of one bay. In the event of a malfunction in either one or both bays of the UPS, the noncritical load service selector switch bypasses the UPS providing commercial power to the non-critical load directly. If both bays of the UPS fail simultaneously, the static interrupt switch bypasses them and commercial

power serves the critical load directly. In this arrangement, the static interrupt switch has a capacity of 250 KVA for the sake of economy.

The UPS unit receives electricity from the commercial power source, the photovoltaic concentrator arrays, or the batteries. During normal operation, commercial power (208V-3 ϕ -60 Hz) enters the rectifiers in the UPS and is converted to 421 Vdc which is impressed on the bus between the rectifier and the inverter. The dc power then carries the batteries on float - or charges them when required - and passes through the inverter where it is converted to a regulated 208V-3 ϕ -60 Hz power service for the connected load.

Whenever the photovoltaic arrays are operating and producing an array bus voltage in excess of 421 Vdc, the arrays load share with commercial power to serve the load connected to the inverters. When this load sharing occurs, the cells in the array strings automatically maximum power track. There is a blocking diode in the array bus where it enters the UPS unit to prevent back biasing the array bus from the 421 Vdc UPS bus when the arrays are not functioning or not producing an array bus voltage at or above 421 Vdc. The 421 Vdc UPS bus cannot accept an array bus voltage greater than 435 Vdc - the UPS unit is equipped with an automatic array bus disconnect switch which opens any time the array bus voltage exceeds 435 Vdc. Control scenarios for maintaining the array bus voltage at the desired level are described in the control discussion. See Section 2.5.1, Photovoltaic Concentrator String and Basic Control Requirements, for a summary of array/dc power source load sharing experimentation.

When there is a commercial power outage or unacceptable power quality, the batteries carry the critical load so long as the battery bus voltage is above 290 Vdc. If the arrays are

operational when the batteries are carrying the critical load through the inverter, the arrays will load share with the batteries to extend the battery load support time, or reduce the depth of battery discharge in a given discharge cycle. When the arrays and battery load share, the voltage window for the arrays is expanded to a lower bus voltage equal to or greater than the declining battery bus voltage during the discharge cycle down to a minimum of 290 Vdc.

The rectifier-inverter bus voltage characteristics in the UPS, particularly the requirement that the array bus voltage be maintained within a voltage window of 421 Vdc to 435 Vdc, establish the requirements for photovoltaic array series string design. The array series strings must be designed to generate a voltage within this range; it is a basic constraint dictated by the chosen UPS.

This photovoltaic power system/UPS application is very similar to any computer center UPS application where two batteries are floated off the rectifier-inverter dc bus. The only difference being the photovoltaic arrays load sharing - through a limited voltage window - the connected load with commercial power. In-depth testing was conducted to demonstrate that this load sharing does occur. These tests, results, and conclusions are discussed in Section 2.5.1, Photovoltaic Concentrator String and Basic Control Requirements Definitions, and presented in detail in Appendix A.

2.1.2 Projected Uninterruptible Power Supply Performance

Table II shows the key selection criteria and certified performance specifications for the UPS system.

TABLE II
UPS KEY SELECTION CRITERIA AND CERTIFIED
PERFORMANCE SPECIFICATIONS

The program calculates UPS input/output power, with no battery recharge. Contact Steve Peak for any problems concerning usage. Enter your module data by using up to 9 digits with decimal point after each question mark.

Enter your basic KVA unit chosen, 360. or 426	360.
Enter your load KVA, do not exceed s curve rating	250.
Enter your load power factor, lag to unity only	.90
Enter your load voltage line to line, at nominal	208.
Enter your rectifier voltage line to line, at nominal	208.

Output per cent load = 100.0
Output line to line volts = 208.0
Output line current = 693.9
Output PF = .90
Output KVA = 250.0
Output KW = 225.0

Rec input per cent volts	=	110.0	100.0	90.0	85.0
Rec input line to line volts	=	228.8	208.0	187.2	176.8
Rec input current	=	866.2	866.2	866.2	866.2
Rec input PF	=	.74 lag	.81 lag	.90 lag	.96 lag
Rec input KVA	=	343.3	312.0	280.8	265.2
Rec input KW	=	253.4	253.4	253.4	253.4
DC volts	=	421.0	421.0	421.0	421.0
DC current	=	580.9	580.9	580.9	580.9
DC KW	=	244.6	244.6	244.6	244.6

Output per cent load = 125.0
Output line to line volts = 208.0
Output line current = 867.4
Output PF = .90
Output KVA = 312.5
Output KW = 281.2

Rec input per cent volts	=	110.0	100.0	90.0	85.0
Rec input line to line volts	=	228.8	208.0	187.2	176.8
Rec input current	=	1100.6	1100.6	1100.6	1113.9
Rec input PF	=	.74 lag	.82 lag	.91 lag	.95 lag
Rec input KVA	=	436.2	396.5	356.9	341.1
Rec input KW	=	323.7	323.7	323.7	323.7
DC volts	=	421.0	421.0	421.0	416.0
DC current	=	738.2	738.2	738.2	747.1
DC KW	=	310.8	310.8	310.8	310.8

Output per cent load = 150.0
 Output line to line volts = 208.0
 Output line current = 1040.9
 Output PF = .90
 Output KVA = 375.0
 Output KW = 337.5

Rec input per cent volts	=	110.0	100.0	90.0	85.0
Rec input line to line volts	=	228.8	208.0	187.2	176.8
Rec input current	=	1320.8	1320.8	1320.8	1359.5
Rec input PF	=	.74 lag	.82 lag	.91 lag	.93 lag
Rec input KVA	=	523.4	475.8	428.2	416.3
Rec input KW	=	388.5	388.5	388.5	388.5
DC volts	=	421.0	421.0	421.0	409.0
DC current	=	885.8	885.8	885.8	911.8
DC KW	=	372.9	372.9	372.9	372.9

The program calculates UPS input/output power, with battery recharge. Contact Steve Peak for any problems concerning usage. Enter your module data by using up to 9 digits with decimal point after each question mark.

Enter your basic KVA unit chose, 360. or 426.	360.
Enter your load KVA, do not exceed s curve rating	250.
Enter your load power factor, lag to unity only	.90
Enter your load voltage line to line, at nominal	208.
Enter your rectifier voltage line to line, at nominal	208.

The inverter load conditions for calculating battery recharge are:

Output line to line volts = 208.0
 Output line current = 693.9
 Output PF = .90
 Output KVA = 250.0
 Output KW = 225.0

The battery conditions during discharge are:

KW (constant) = 244.6
 Final current = 843.3
 Average current = 799.9

The conditions at initial recharge are:

DC volts = 374.0
 DC battery recharge current = 92.0
 DC inverter current = 653.9
 DC current total = 745.9
 DC KW total = 279.0

Rec input per cent volts	=	110.0	100.0	90.0	85.0
Rec input line to line volts	=	228.8	208.8	187.2	176.8
Rec input current limit setting	=	1112.2	1112.2	1112.2	1112.2
Rec input curr, bat rechg part	=	137.2	137.2	137.2	137.2
Rec input curr, inverter part	=	975.0	975.0	975.0	975.0
Rec input PF	=	.66 lag	.72 lag	.80 lag	.85 lag
Rec input KVA	=	440.7	400.7	360.6	340.6
Rec input KW	=	289.1	289.1	289.1	289.1
Minimum permissible rec input current limit setting	=	1049.6			
Maximum permissible rec input current limit setting	=	1516.4			

When optimal C/L is used, the rec input C/L setting reduces to $(N-1)/N$ times 1112.2 amps.

The temporary rec input C/L setting for supplying a 125% inverter overload for 20 minutes is 1245.6 amps.

When optimal C/L is used, this setting reduces to $(N-1)/N$ times 1112.2 amps plus 133.5 amps.

The temporary rec input C/L setting for supplying a 150% inverter overload for 10 seconds is 1512.5 amps.

When optimal C/L is used, this setting reduces to $(N-1)/N$ times 1112.2 amps plus 400.4 amps.

2.2 Photovoltaic Concentrator

The point focusing, two axis tracking concentrator was selected for development and use in this system as the result of a design study performed by Sandia Laboratories centering on the energy collection capabilities of various concentrator types, and on the practical aspects of manufacturing, owning, operating, and maintaining the various types of concentrators. Table III presents the concentrator performance data reviewed.

Table IV shows the design team's evaluation of the deciding factors bearing on the practical aspects of manufacturing, owning, operating, and maintaining various types of photovoltaic concentrators. These opinions are supported by the interested manufacturers.

The Fresnel lens equipped, two axis tracking concentrator was selected for development and use in this system because it has an indicated superior performance capability, and because - in the opinion of those responsible for designing and building the concentrator for this system - this concentrator has superior practicality.

The 32X and 125X geometric concentration ratio Fresnel lenses under development by Swedlow, Inc. for Sandia Laboratories were selected for use as the keystone of the detailed concentrator

TABLE III. CONCENTRATOR PERFORMANCE COMPARISON⁽¹⁾

Concentrator Type	Concentration Ratio (CR)	Average Daily Collection (KW-HR/M ² -Day)		
		Albuquerque, NM	Omaha, NB	Blue Hill, MA
E-W CPC, Periodic Seasonal Adjustment				
CR = 3	3	5.29	3.43	3.14
CR = 5	5	5.00	3.14	2.94
CR = 7	7	4.71	2.94	2.84
CR = 10	10	4.31	2.75	2.55
E-W Parabolic Cylinder, 1 Axis Tracking	10-100	5.44	3.47	3.20
N-S Parabolic Cylinder, 1 Axis Tracking	10-100	5.92	3.63	3.62
Polar Axis Parabolic Cylinder, Latitude Tilt, 1 Axis Tracking	10-100	6.67	4.20	4.06
Vertical Axis Rotation, Parabolic Cylinder Latitude Tilt, 1 Axis Tracking	10-100	6.65	4.18	4.05
Fresnel Lens, 2 Axis Tracking	100-1000	6.99	4.41	4.24

(1) E. L. Burgess, Sandia Laboratories, Photovoltaic Concentrator Specifications and Near Term Performance Specifications, Presented at Photovoltaic Systems and Applications Workshop, December 13-15, 1977, Reston, Virginia.

TABLE IV. EVALUATION OF FACTORS BEARING ON THE PRACTICAL ASPECTS OF MANUFACTURING,
OWNING, OPERATING, AND MAINTAINING THE VARIOUS TYPES OF CONCENTRATORS

Concentrator Type	Focusing Surface Life	Field Workability	Cost Reduction Potential	Heavy Industry Interest Level	Maintainability Parts Availability
CPS Seasonal Adjustment	Fair	Questioned	Questioned	Low	Questioned
Parabolic Cylinder	Questioned	Good	Good	Medium	Fair
Fresnel Lens - Two Axis Tracking	Good	Good	Good	High	Good

physical design due to their practical aspects and advanced state of development.

2.3 Fresnel Lens

The 32X Fresnel lenses developed by Swedlow, Inc. under DoE contract managed by Sandia Laboratories have a completed fabrication process and tooling development and were selected as the primary lens component of the concentrator for this system. Accelerated weathering tests have been completed, and the results on abrasion resistant coated lenses indicate that the lenses and the coating should provide a twenty year life. Further tests employing a new lens testing system demonstrate that design objectives are being met on first article lenses.

Eight lenses mounted in the prototype module are now undergoing further performance and durability testing at Sandia Labs. The results of the first prototype module tests may be reviewed in Appendix E.

2.3.1 Projected Lens Performance and Efficiency

The first article lenses demonstrate the following losses of direct normal radiation as it strikes the top of the lens and passes through.

• Sun's energy within photovoltaic device utilization band incident on Fresnel lens	100%
• Reflection losses at first surface	[4%]
• Reflection losses due to facet angles at second surface	[6%]
• Absorption and scattering and other losses in usable energy band up to	<u>[3%]</u>
• Achievable energy at photovoltaic assembly cover glass	87%
• Additional loss in first article device due to poor tooling	<u>[5%]</u>
• First article optical efficiency in usable energy band	82%

Swedlow is continually improving their tooling methods and broadening sources for tooling which will result in higher efficiency lens. Kaman believes that half of the losses from poor tooling can be eliminated by the time the lenses for this type system go into sustained production. A minimum overall optical efficiency of 84.5% in the usable energy band for the Fresnel lenses is expected.

2.4 Photovoltaic Concentrator Cell

Both silicon and GaAs cells were reviewed for possible use in this system. Silicon cells were selected for their compatibility with the available Fresnel lens capabilities, the expanding production base existing in the nation today, and the visible progress with improving cell efficiencies.

ARCO Solar, Inc. silicon concentrator cells were selected because of their standing in the rating process which considered the following requirements:

- Flat panel and concentrator 3" round cells available,
- Manufacturing technique and planning flexibility,
- Raw material resource development and crystal production capability planned,
- Team compatibility,
- A demonstrated long term management plan,
- Flexibility for product standardization and integration into concentrator.

2.4.1 Cell Development

ARCO Solar, Inc. has a continual and significant concentrator cell improvement program targeted at eventually achieving a 35%

cell efficiency. The first generation cell employed a vacuum mask method for depositing the silicon grids. ARCO Solar has now completed development of second and third generation cells which can be manufactured on the same production line equipment. The second generation cell is a 3" diameter round cell with a radial grid pattern deposited in a dry photoresist process which produces a high degree of grid uniformity and dimensional accuracy. The internal quantum efficiency for a range of spectral stimulation is shown in Figure 2.

The 3" diameter cell is specifically designed for use with the Swedlow 32X concentration ratio lens developed under contract to Sandia Laboratories.

FIGURE 2. SPECTORAL RESPONSE OF ARCO CELL

The second generation cell - when produced in quantity - will be produced at an overhead burdened cost of \$2.60 per cell, or \$.205/watt expressed in 1978 dollars. KSC anticipates a fair return on the investment and working capital, adjusted for tax, to be 34%, which will result in a \$.24/watt selling price for these cells.

The third generation cell will be cut from 4" diameter wafers manufactured with the same process that is used for the second generation cells. These cells will be square - 3.4 cm x 3.4 cm - for use with the 125X geometric concentration lens now under development by Swedlow, Inc. under contract to Sandia Laboratories. They can be marketed for a price under \$.10/watt (1978 dollars) when produced in quantity.

The Swedlow lenses - both 32X and 125X - will be available at a price under \$.03 per watt (1978 dollars) when manufactured in quantity.

The second generation cell was selected for use in the concentrators for these reasons:

- Thermal stresses in the cell mount increase as the concentration ratio increases, and operating experience and design proof should be accomplished starting with the lower concentration ratio,
- The 32X Swedlow lens is further along in the development process than the 125X lens so the probability of unforeseen problems is much less with the 32X lens in a field operational process.

2.4.2 Cell Mount

The cell mount developed for this system is a universal design - it will accommodate a maximum cell size of 3" diameter. The cell mount is designed for use with a spot focusing lens. Special attention - in the form of testing and analysis - has been given to the design of the contact rings for this cell mount to prevent thermally stressing the cell. The design employed provides the following features for long and reliable cell life:

- A highly flexible 10 mil copper mesh inner contact device for attachment to the cell - it transmits no stress to the cell itself during thermal variations due to high flexibility,
- Sufficient metal area in the copper mesh which is soldered to a copper conductor ring of sufficient conducting area to carry the current away from the cell and out of the cell mount with very negligible power loss.

Accurate control of cell operating temperature to stabilize the operating voltage of the photovoltaic arrays is an essential feature for this system because of the UPS voltage window.

The cell mount is actively cooled with Therminol 60™. This fluid is employed because of its desirable performance and physical properties, which are as follows:

- Totally noncorrosive,
- Does not conduct electricity,
- Temperature use range of from -50°F to 600°F,
- No long term heat transfer surface fouling problems,
- The fluid is permanent when used in a closed system with an inert gas expansion cushion.

Comments regarding safety requirements for employing this fluid are presented in Section 3.0, Environmental Assessment.

Figure 3 shows the physical arrangement of the cell mount with the performance characteristics of the overall assembly.

Notes

1. Electrical Isolation 3000V
2. Cell-contact ring/semiunrestrained-silicon gel on top and silicon gel impregnated disc
3. Gel dams and gel provide long-term sealing against moisture and other atmospheric contaminants

PERFORMANCE CHARACTERISTICS (140°F CELL)

I_{DN} KW/M ²	Maximum Power Electric Energy Watts	Thermal Energy to Coolant BTU/Hr	V_{OC} V	I_{SC} A	Fluid ΔT Across Heat Exchanger °F	Fluid to Cell ΔT °F
1	12.7	358	.6	26	1.95	4.3
.9	11.4	322	.6	24	1.76	3.9
.8	10.2	287	.6	22	1.56	3.4
.7	8.9	250	.6	19.7	1.37	3.0
.6	7.6	215	.6	17.3	1.17	2.6
.5	6.4	179	.6	12.5	.98	2.1

FIGURE 3. CELL MOUNT PHYSICAL ARRANGEMENT AND PERFORMANCE CHARACTERISTICS

Figures 4, 5, 6, 7, and 8 show photographs of the prototype cell mount. The alumina disc is impregnated with silicon gel after it is fired. The silicon gel provides a full contact bedding between the cell bottom with attached copper mesh and the alumina disc. The gel also provides a full contact between the alumina disc and the top of the heat exchanger.

The Therminol 60™ flows through the holes in the aluminum heat exchanger with turbulent flow to achieve the high heat exchange rate required. The cell mount is designed so that the cell assembly can be removed from the top of the aluminum heat exchanger without leaking the heat transfer fluid. The heat exchanger is flanged to the flow tube with a gasketed joint held in place by shoulders on the studs that pass up through the cell assembly and the steel clamp ring. The clamp ring is held in place by nuts screwed on the top of the studs.

2.4.3 Cell and Cell Assembly Performance and Durability Testing

The in plant testing of the encapsulated cells has been completed and the following calculated performance was exceeded in these tests at a cell temperature of 140°F.

Cell Illumination	Efficiency at Max Power	V_{oc}	I_{sc}
30 to 12 suns	13.7%	.6	22.6
10 suns	13.5%	.6	7.53
7 suns	13.0%	.585	5.27
3 suns	12.6%	.57	2.25

The cell assembly is designed to have a 20 to 30 year life in the cell mount designed to hold it. The moisture imperviousness of the silicon gel in the cell assembly remains to be proven for this duration. Environmental tests are being performed on standard cell assemblies and Glyptol™ edge coated cell assemblies

FIGURE 4. ABSORBER TUBE CAVITY FOR HEAT EXCHANGER CELL MOUNT
AND CELL INTERCONNECT TERMINAL BLOCKS

FIGURE 5. CELL MOUNT HEAT EXCHANGER INSTALLATION

FIGURE 6. CELL MOUNT HEAT EXCHANGER IN-PLACE AND CELL INTERCONNECT TERMINAL BLOCKS

FIGURE 7. ENCAPSULATED CELL ASSEMBLY IN-PLACE

FIGURE 8. COVER GLASS, CLAMP RING, AND WIRING IN-PLACE - CELL MOUNTED

to explore this area. Another sensitive area being explored is the affect ultraviolet radiation has on the silicon gel between the cell and the cover glass.

The cell assemblies have been installed in the prototype module and are at Sandia Laboratories undergoing performance and environmental survivability testing at this time.

Comments on current test results may be reviewed in Appendix E.

2.5 Module

A module consists of 8 cell mounts on a linear flow tube. The flow tube is the structural strongback of the lens alignment structure. Figure 9 shows the module assembly with its outline dimensions.

FIGURE 9. PHOTOVOLTAIC CONCENTRATOR MODULE

The physical factors that determined the overall maximum possible length of the module were the permitted hauling width of 12'0" on the nation's highways and railroads, and the allowable cell temperature variation in a module. The modules should be

completely shop fabricated, assembled, and mounted in subarray sections to minimize field erection work requirements.

The lenses are mounted in frames, and these frames are mounted on the sheet metal sides and ends of the module assembly; thus, the concentrated sunlight occurs in a nonaccessible space that is completely enclosed. The cell assemblies are inside this enclosure for protection and separation from the elements. The module employs individual lenses for each cell to avoid lens fatigue resulting from structural flexing in the array structures that could occur with multiple lens castings. Figure 10 shows a photograph of the assembled prototype module.

The driving performance factor which, in fact, determined the overall length of the module was the identification of the simplest module circuit design that provides adequate cell protection during varying illumination conditions and transients so that the protective cell circuitry would be integral to the module.

The module circuitry design was achieved through analysis employing the NET II modeling procedure developed by BDM Corporation under contract to Sandia Laboratories. This analysis procedure considered the following failure mechanisms:

- Overheating of the cell or soldered connections on the cell,
- Reverse bias over-voltage on the cell causing damage to the cell junction.

In this work, a provisional circuit design was modeled at three separate levels - the individual cell, an individual module with 8 cells, and the entire array constructed of these modules. A copy of the NET II analysis may be reviewed in Appendix B.

FIGURE 10. PHOTOVOLTAIC CONCENTRATOR PROTOTYPE MODULE

This analysis confirmed the design criteria for 8 cells per module with a bypass diode in each 8 cell module. Here are the key conclusions of this analysis work:

- The maximum reverse bias voltage on any cell in the 8 cell module is limited to between 4.7 and 5.6 volts due to shadow transients, and 7.3 volts under worst case lightning illumination transient conditions when a bypass diode is placed around no more than 8 cells in series.
- The lightning conditions used to generate the 7.3 volt reverse bias represent an extreme combination of reverse bias, with distance to lightning strike (10 meters), and amplitude of lightning stroke (200 KA).
- A lightning elimination system which precludes the worst case strike was designed (see Section 2.9).
- The maximum reverse bias voltage on an individual cell is limited to 5 volts by the characteristics of the bypass diodes and the lightning elimination system.
- The analysis of the individual cell and its mount confirmed the adequacy of the cell mount design to protect the cell from overheating under any shadowing or lightning illumination transient conditions.
- The analysis demonstrated a maximum temperature rise of 8°C (14.4°F) above coolant temperature would occur with a bypass diode around each 8 cell module due to combined thermal absorption of illumination power and reverse biased electric power.

Figure 11 shows the intra and intermodule circuit arrangement with the modular bypass diodes, and the performance characteristics for one module, and Figure 12 is a photograph of the prototype module wiring.

2.5.1 Photovoltaic Concentrator String and Basic Control Requirements Definitions

The array string contains the number of cells connected in series required to allow the string to operate within the dc voltage window at the dc bus between the rectifier and inverter in the power conditioning unit. This window has an upper limit of 435 Vdc and a lower limit of 421 Vdc (or the battery bus voltage during a commercial power outage). See Section 2.1.1, Power Conditioning Unit Characteristics.

The design criteria for a maximum cell to power conditioning unit conductor voltage drop of 3% (operating at rated capacity) was established as an achievable and cost effective goal in the electric dc power system design for operating this system to gain experience and for accommodating more efficient cells as they become available. The cost of the heavier conductors is \$3000 more than the cost of conductors for a 6% voltage drop. However, this cost is more than recovered in an energy savings with a future value of more than \$3600. More detailed analysis of the electric wiring and components design may be reviewed in Appendix I, Electrical Components and Controls Study.

The number of cells wired into a series string for this system is 848 cells, or 106 modules calculated as follows:

$$\text{No of Cells} = \frac{\frac{435\text{V} + 421\text{V}}{2}}{(1-.03)(.52\text{V})} = 848 \text{ cells}$$

$$\text{No. Modules} = \frac{848 \text{ cells}}{8 \text{ cells/module}} = 106 \text{ modules}$$

PHYSICAL ARRANGEMENT

Note:

THE BYPASS DIODES ARE PROTECTIVE DEVICES CONNECTED IN PARALLEL WITH THE MODULE SERVED, AND THEY ONLY CONDUCT CURRENT WHEN THERE IS A FAULTY CELL WITHIN THEIR MODULE CIRCUIT; AT WHICH TIME THE MODULE END POLARITY REVERSES FROM THAT SHOWN.

PERFORMANCE CHARACTERISTICS OF 1 MODULE

I_{DN} KW/M ²	Maximum Power Electric Energy Watts	Thermal Energy to Coolant BTU/Hr	V_{OC}	I_{SC}	Fluid ΔT Across Module °F	Fluid to Cell ΔT °F
1	101.6	2864	4.8	26	15.60	4.3
.9	91.2	2576	4.8	24	14.08	3.9
.8	81.6	2296	4.8	22	12.48	3.4
.7	71.2	2000	4.8	19.7	10.96	3.0
.6	60.8	1720	4.8	17.3	9.36	2.6
.5	51.2	1432	4.8	12.5	7.84	2.1

FIGURE 11. MODULE CIRCUITRY PHYSICAL ARRANGEMENT AND MODULE PERFORMANCE CHARACTERISTICS

FIGURE 12. PROTOTYPE MODULE WIRING

This calculation simply divides the average power conditioning unit window voltage by the product of the cell to power conditioning unit conductor efficiency and the average cell maximum power point voltage (.52) at an on-lens illumination level of $.75 \text{ KW/M}^2$ - the average and most available I_{DN} for the application site. Figure 13 shows the power curves for a string employing 848 averaged ARCO 3" diameter 32X cells operating at several illumination intensities as the power would be measured at the power conditioning unit window. It is expected that real string performance will fall close to the line sloped downward and to the right in the region of expected maximum power points. This is due to predominant cell performance characteristics and decreasing conductance losses with decreasing power.

The overall system design provides for variations in mass produced silicon cells and cell to power conditioning unit conductor loss under varying illuminations.

There must be a means for controlling the string voltage to assure that the power from the photovoltaic power system passes through the power conditioning unit's voltage window. This means of control is provided by operational control fixed by design, physical control added to the design, and a combination thereof. (See Section 2.10, Functional Integrated System Control Description).

One of the main features of the conceptual design is to employ fluid cooled concentrators to first, provide fixed concentrator cell operating temperature; and second, to provide an additional economic benefit for the application of the photovoltaic concentrators through beneficial use of the thermal energy removed from them.

KSC, ARCO Solar (the cell manufacturer), and General Electric (the power conditioning unit manufacturer) have performed independent

FIGURE 13. STRING POWER CURVES AT POWER CONDITIONER

tests to confirm performance characteristics of the photovoltaic string interfaced with the power conditioning unit and to identify physical control requirements to be added to the design. The test set up and typical test results are shown in Figure 14 and may be reviewed in more detail in Appendix A. Each independent test produced identical results and led to the following conclusions:

- 1) The photovoltaic string does maximum power track load share with a regulated voltage dc power supply when the string voltage equals or exceeds the dc power supply voltage.
- 2) The photovoltaic string power output cannot exceed load connected to the UPS - because if it does the PV string will not maximum power track, it will regress on its power curve to the load's power point.

Other similar tests conducted with constant dc power source voltage and constant cell temperature, demonstrated the maximum power point migration shown in Figure 13 with variable illumination. These tests confirm that with variable illumination, constant cell temperature, and the photovoltaic string voltage marginally above the regulated power source voltage, the photovoltaic string always operated in the maximum power region of the string power curve when the load served is greater than the array capacity.

The following design requirements resulted from these tests:

- A blocking diode must be placed in the photovoltaic array power supply as it enters the General Electric UPS unit to prevent reverse power flow from the UPS back into the array,

FIGURE 14. LOAD SHARING TEST CONFIGURATION AND TEST RESULTS

- The UPS must be protected from a lightning surge from the arrays, and the UPS must be protected from overvoltage (above 435V) from the arrays.

These requirements are incorporated in the design as shown in Figure 15. Other lightning protection measures are shown in Section 2.9.

2.5.2 Special Problem: Revised Flow Tube configuration

A prototype module was built for testing along with a two axis tracking test mount (rack). The module is undergoing environmental deterioration tests at Sandia Laboratories, and the test mount is installed at the APTEC site for subsequent module testing. This test mount will be employed before the construction phase commences to test the second generation module.

When the prototype module was built, a round steel flow tube was used - see Figure 3. During the fabrication of the prototype module, ARMC0 engineers and craftsmen, and KSC engineers critiqued the design and noted improvements that could be made to reduce manufacturing costs. It was jointly decided to substitute a square or rectangular flow tube for the round flow tube because it would eliminate the following process cost problems:

- Eliminate bottom cell mount flange which is welded into the flow tube with resulting flow tube work restraint requirement,
- Eliminate the requirement for the round heat exchanger plug which is suspended into the coolant fluid and allow the substitution of

FIGURE 15. DESIGN REQUIREMENTS INCORPORATED AT THE PHOTOVOLTAIC ARRAY/UPS INTERFACE

a flat faced heat exchanger. Drilling of the 1/16" diameter fluid flow passages will be much easier on the flat face than on the round heat exchanger.

- Allow the flange studs to be resistance welded to the flow tube instead of the drilled and tapped stud holes in the bottom flanges.

Figure 16 shows the basic concept of the upgraded rectangular flow tube and aluminum heat exchanger. This flow tube is interchangeable with the balance of the module as designed.

There are two areas that will be examined closely for performance during the environmental chamber tests at Sandia on the prototype module and they are

- 1) Cell encapsulation assembly - for moisture migration and unacceptable silicon gel thermal expansion and contraction pressure on the cell; and,
- 2) Adequacy of lens mount for absorbing lens expansion and contraction from moisture and thermal cycling along with any tendency of cushion and sealants to discolor the lens or otherwise change its cell structure.

The rectangular flow tube and any other indicated improvements in the cell encapsulation assembly, the lens mounting cushions and sealants resulting from the environmental test chamber tests will be employed on the APTEC heliostats.

FIGURE 16. SECOND GENERATION FLOW TUBE AND HEAT EXCHANGER

2.6 Array Structures

After the concentrator type was narrowed to the Fresnel lens two axis tracking type with a cell mount and 8 cell module design, two types of tracking mounts were developed for the module. These are the heliostat mount and the rack mount. Figure 17 shows the basic concept for each of the two types of mounts.

The vertical rotation of 10° to 85° was established as an acceptable value for any latitude in the continental United States. For the heliostat, the $\pm 108^\circ$ azimuth rotation was selected to match the minimum 85° vertical rotation on June 21st - the longest sun day of the year.

2.6.1 Comparative Performance Analysis for One Photovoltaic Concentrator String - Heliostat vs Rack Mount

The performance of a rack string and a heliostat string operating at 140°F was modeled for a typical solar radiation year of all clear days. The original ARCO cell performance was used as input.

The following radiation modeling procedure was employed to determine the "hourly binned" and total direct normal radiation (clear day) available at a particular site for one year based on the data for the 21st of each month.

- Solar declination $D = 23.5 \sin \frac{2\pi d}{365}$
where d is the number of days from vernal equinox on March 21
- Hour angle $H = 15K$
where K is the number of hours before or after solar noon

SOUTH
 TILTING
 RACK MOUNT WITH
 TURNING MODULES
 1-STRING (106 MODULES)
 VERTICAL ROTATION 10° TO 85°
 AZIMUTH ROTATION $+65^{\circ}$ TO -65°
 (SHADOW LIMITED)

TILTING AND TURNING
 HELIOSTAT W/53 MODULES
 1 STRING = 2 HELIOSTATS
 VERTICAL ROTATION 10° TO 85°
 AZIMUTH ROTATION $+108^{\circ}$ TO -108°

FIGURE 17. RACK AND HELIOSTAT DESIGN CONCEPTS FOR THE PHOTOVOLTAIC
 CONCENTRATOR APTEC

- Sun position relative to site in altitude β and azimuth ϕ angles

$$\sin \beta = \cos L \cdot \cos D \cdot \cos H + \sin L \cdot \sin D$$

$$\sin \phi = \frac{\cos D \cdot \sin H}{\cos \beta}$$

- Intensity of direct normal solar irradiation (I_{DN}) at the earth's surface at the site on a clear day

$$I_{DN} = 1.05 A (\underline{B}/\sin \beta), \text{ BTU/HR} - \text{FT}^2$$

where A = extraterrestrial irradiation, $\underline{B}$ = atmospheric extinction factor, and 1.05 is the recorded clearness index for the area of the site. Threlkeld and Jordan values for A and $\underline{B}$ were used.

The purpose of this modeling was to compare the following:

- The total annual electric and thermal energy from the rack and heliostat mounted modules,
- The monthly performance of the rack and heliostat mounted modules to determine the impact of the self-shading characteristic of the rack mounted modules.

Table V lists the comparison of rack and heliostat mounted module performance. The modeling effort conducted to project the APTEC performance may be reviewed in Appendix F.

The effectiveness of the photovoltaic concentrator is determined by the amount of energy it produces over a unit of time.

The results shown in Table V and Appendix F demonstrate that the heliostat mount is 145% more effective than the rack. The amount of energy from the heliostat mount tracks clear day solar availability on an annual basis - it generates more energy than

TABLE V. SUMMARY OF ANNUAL RACK STRING AND HELIOSTAT STRING PERFORMANCE BASED ON ALL CLEAR DAYS WITH PROTOTYPE ARCO CELL (140°F)

Month	I_{DN} (Tot Avail) (KWH)	Rack			Heliostat			Heliostat to Rack Ratio %
		I_{DN} (Avail) (KWH)	Output		I_{DN} (Avail) (KWH)	Output		
			Elec (KWH)	Thermal (BTU X 10 ⁶)		Elec (KWH)	Thermal (BTU x 10 ⁶)	
Jan	27,478	27,478	2,446	56.27	26,668	2,373	54.61	97
Feb	28,830	27,311	2,431	55.93	28,142	2,505	57.63	103
Mar	36,123	27,200	2,421	55.70	35,306	3,142	72.30	130
Apr	36,803	20,263	1,803	41.50	35,971	3,201	73.66	177
May	39,613	15,725	1,400	32.20	38,476	3,424	78.79	245
Jun	38,710	13,026	1,159	26.67	37,532	3,340	76.86	288
Jul	38,895	14,303	1,273	29.29	37,715	3,357	77.23	264
Aug	36,933	18,614	1,657	38.12	35,773	3,184	73.26	192
Sep	34,030	23,700	2,109	48.53	33,132	2,949	67.85	140
Oct	31,637	28,696	2,554	58.76	30,793	2,741	63.06	107
Nov	36,751	26,721	2,378	54.72	25,933	2,308	53.11	97
Dec	25,766	25,766	2,293	52.76	24,897	2,216	50.98	97
Annual	401,639	268,804	23,924	550.45	390,338	34,740	799.33	145

Note: A string has 848 cells in 106 modules, and prototype ARCO cell data was used.

the rack mount in significant quantities during the months of March, April, May, June, July, August, and September.

The heliostat mount was selected for exclusive use in this design because of its higher effectiveness.

2.6.2 Photovoltaic Concentrator Heliostat String Definition and On-Site Performance

The number of cells (and modules) constituting the photovoltaic concentrator string is defined in Section 2.5.1 as a function of the average of the maximum and minimum voltage accepted by the UPS from a concentrator string. There are 848 cells - or 106 modules - in string.

Mounting a string of concentrators on two heliostats was selected as the most cost effective configuration for the following reasons:

- Dynamic loading on the module mounting system is more efficient with two heliostats per string than for other quantities of heliostats per string.
- Single point mounting of the module mounting system was unmanageable for a one heliostat string.
- Control and tracking equipment unit cost per KWp was lowest for the two heliostat string (the one heliostat string excluded for the above reason).

The performance of a two heliostat string at the design site is shown in Table VI with data presented for a string equipped with the 3" diameter - 32X ARCO cell and the 3.4 cm x 3.4 cm -

TABLE VI. SUMMARY OF MONTHLY AND ANNUAL SKY COVER FACTORS, ELECTRIC ENERGY AND THERMAL ENERGY AVAILABLE TO THE LOAD EMPLOYING ONE PHOTOVOLTAIC CONCENTRATOR STRING AND THE ARCO SECOND AND THIRD GENERATION CELLS (140°F)

Month	Sky Cover Factor	3" Dia-35X Cell (2nd Gen)		3.4x3.4 cm-125X (3rd Gen)	
		Electric KWH	Thermal 10 ⁶ BTU	Electric KWH	Thermal 10 ⁶ BTU
January	.49	1,663	23.04	1,596	23.04
February	.51	1,756	24.31	1,791	24.31
March	.57	2,202	30.50	2,246	30.50
April	.60	2,244	31.08	2,288	31.08
May	.60	2,400	33.24	2,448	33.24
June	.45	2,341	32.43	2,388	32.43
July	.49	2,353	32.58	2,400	32.58
August	.47	2,231	30.91	2,276	30.91
September	.35	2,066	28.63	2,108	28.63
October	.37	1,921	26.60	1,959	26.60
November	.47	1,617	22.41	1,650	22.41
December	.45	1,553	21.57	1,584	21.51
Annual	.49	24,347	337.24	24,834	337.24

125X ARCO cell. This modeling was completed by factoring the number (1 - clearness factor) into the Table V information and interacting this I_{DN} available to the concentrator cell assemblies (for the two assemblies being examined) and the cell to UPS power loss (.97 factor) for the electric energy, and a thermal energy loss of 10% from the concentrator to the load.

The sky cover factors from the Climatic Atlas of the United States were used - they are very conservative because of the observation method employed.

The power rating of a heliostat string is as follows for $I_{DN} = 1 \text{ KW/M}^2$ with average cell temperature = 140°F:

- 32X - 3" dia. cells - 10,770 watts,
- 125X - 3.4 x 3.4 cm cells - 10,984 watts.

2.7 The Heliostat Structure and Tracking Mechanism

The heliostat structure consists of a steel tower with a dead axle mounted rotating head upon which a minimum weight box girder structure is mounted. The modules are attached - by welding - to the top stringers of the box girder frame with angle iron clips. All alignment is done in the manufacturing plant, which minimizes the probability of poor optical alignment occurring from field work. This prototype was designed using standard structural shapes, and AISC data and design methods.

Figure 18 shows the heliostat physical structure and key structural performance data. The structure has been fully analyzed using the Structural Analysis Program (SAP IV), which may be reviewed in detail in Appendix C. The moments and fiber stresses at every point in each structural member are recorded under varying live load conditions. This modeling work was performed to confirm the structural design. Strain

STRUCTURAL WEIGHT=22,401 LBS (4.1 LBS/WATT)
 OPERATING WEIGHT=25,541 LBS (4.7 LBS/WATT)
 INCLUDES WIREWAYS, WIRES, FLUIDS, HYDRAULIC
 POWER UNIT, PIPING, PUMPS, AND CONTROL'S.

POINTS OF MAXIMUM STRUCTURAL
 DEFLECTION UNDER WIND LOADING-
 MODULE MOUNT TILTED 45°.

WIND VELOCITY MPH	DEFLECTION INCHES	OPTICAL MISALIGNMENT DEGREES-MINUTES	SOLAR RADIATION LOSS (SEE FIGURE)
80	3.78	0°-52'	<1%
52	2.47	0°-34'	NONE

FIGURE 18. HELIOSTAT STRUCTURE PHYSICAL ARRANGEMENT AND
 PERFORMANCE DATA

qage data on a prototype structure would allow validation of the SAP program data and provide a set of design criteria to streamline the structural members into low cost, low weight, tapered members. Preliminary analysis indicates that streamlined design and upgraded cell performance could achieve the following performance weights:

- Structural Weight = 2.15 lb/watt - 32X Concentration,
1.83 lb/watt - 125X Concentration
- Operating Weight = 2.45 lb/watt - 32X Concentration,
2.08 lb/watt - 125X Concentration

ARMCO, Inc. has completed a manufacturing plan for the complete heliostat with piping and wiring. Under this plan, a heliostat would be shipped in 5 large sections plus 6 loose structural members. Field erection time is estimated at 120 manhours plus 16 small crane hours. The erected heliostat would then be ready for connection to the customer's field electric and fluid services.

Several foundation designs have been explored. The most economical one is a concrete cassion which will cost an estimated \$1500 or \$.30/watt.

The tracking is hydraulic powered. The hydraulic tracking system was selected over electric driven-gear train and screw tracking for the following reasons:

- Hydraulic pressure can be built up once a day during a two hour period with ample energy being stored in an accumulator to drive the heliostat through a complete daily tracking cycle,
- The hydraulic system is more reliable than other possible mechanical/electrical drives,

- The hydraulic system is more accurate, has no backlash, and is easier and more accurately controlled than other possible mechanical/electrical drives,
- The hydraulic system is fail safe - it detracks by gravity in case of a failure,
- The complete hydraulic system is mounted integrally in each heliostat.

This hydraulic system was analyzed using a reliability model developed by KSC called a "GO" model and this may be reviewed in detail in Appendix D.

2.7.1 Heliostat Assembly - Component Development

The prototype module has been fabricated and is now at Sandia Laboratories undergoing performance and environmental survivability testing at this time.

Some of the key environmental survivability factors of interest in these tests with remedial steps that will be taken if required are as follows:

- Lens compatibility with interfacing organic mounting and sealing materials
 - If any discoloration or crystalline structure changes become apparent, these materials will be changed.
- Power wiring jacketing offgasing
 - If any deleterious offgasing occurs from the cable jacket, a nylon outer jacket will be added to seal the offgasing material.

- Dust inhalation coating bottom of lens and top of cell assembly cover glass.
 - If any dust - or other air pollutant - deposits on the optics in the module it may fall off when the module is moved into a vertical position,
 - Install a vent filter to remove particulates from aspirated air,
 - Ground the lens and cell assembly coverglass to the grounded heliostat structure to neutralize any charge differential between these optical surfaces and the module metal structure,
 - Install a manual washing lance access hole in the module case for cleaning purposes.

The tracking control system is being mounted on the two axis tracking hydraulic powered module test stand at the application site. The tracking control system with hydraulics system is an integrated system employing off-the-shelf components. The purpose of the tests being made are as follows:

- Record angular velocity differentials in the vertical tracking mechanism throughout its field of movement,
- Determine the optimum tracking movement time increments required to produce maximum module performance, and the proper Mann-Russell controller set screw adjustment to produce these desired movements,
- Test the operational and safety control reliability and performance in the overall control system.

The balance of the heliostat system is an integration of off-the-shelf hardware and fluids. Two complete structural analyses of the heliostat structure have been made with a 20 psf load plus a 80 mph wind load. These analyses indicate the desirability of fish plate reinforcement of 4 I-beam structural members in the box girder structure at critical points and the addition of minor x-bracing in the tower structure. These details are being designed now and will be included in the APTEC heliostats.

The Mann-Russell Mark IV Navigational Module, a multicell, balanced bridge type electronic device was selected as the tracking controller. There is one controller on each heliostat, resulting in a controller cost of \$450 per heliostat, or \$.09 per watt. This tracking control unit was chosen from several reviewed because of off-the-shelf availability, the unit's simplicity, the price of the unit, and its applicability for integration into the hydraulic tracking system. Several offers for developing more sophisticated tracking controllers employing computerized hardware and software were rejected in favor of the Mann-Russell unit. More detailed information on this tracking control is provided in Section 2.10.1, Tracking Control System.

2.8 Concentrator Cooling and Thermal Energy Utilization

The main reasons for employing combined concentrators are as follows:

- Capture and employ the total "solar reserve" available to enhance the amount of fossil fuel replaced by the system and to realize the full economic benefit from the concentrators,

- Stabilize cell operating temperature for system controlability,
- Extend silicon cell life and reliability in the concentrator by minimizing thermal stresses caused by constantly changing cell operating temperatures,
- Provide the maximum benefit to the interfaced utility by improving their electric system load factor and releasing presently committed peaking and annual natural gas volumes from a large commercial load for higher priority uses.

The coolant fluid flow path through the heliostat and the overall system is shown in Figure 19 along with pertinent operating data.

The fluid flow through the heat exchanger that transfers heat from the cell assembly (see Figure 3) must remain in the turbulent flow region in order to properly cool the cell. This turbulent flow creates excess pumping head. A design study was performed on costs associated with array performance vs pumping head and demonstrated that maintaining turbulent flow in lieu of laminar flow had more energy benefit than cost when Therminol 60™ and the following design features are employed:

- Parallel flow through individual modules limits the pressure drop to eight cell heat exchangers in series and limits differential cell temperature to one module (see Figures 3 and 11).
- Reverse returns employed to encourage balanced flow through each module,
- No heat transfer surface fouling occurs with Therminol 60™,

VALVE A MAINTAINS CONSTANT FLOW & CONSTANT OPERATING TEMPERATURE AT MODULES.
VALVE B MAINTAINS CONSTANT FLOW/MINIMUM HEAD ON SYSTEM PUMP.

ANNUAL PUMPING POWER % OF COMBINED HELIOSTAT ENERGY = 1.27%

FIGURE 19. FLUID COOLING SYSTEM FOR THE HELIOSTAT

- Split pumping arrangement with constant flow no-throttling temperature and differential pressure control valves (A and B respectively),

If the flow velocity through the cell heat exchangers is dropped from the turbulent region to the upper laminar flow region, the annual pumping power would be reduced to 1% of array output, but the cell operating temperature ΔT across a module would double. With a .0024 Vdc drop per 1°C (1.8°F) rise in cell operating temperature, the electric output of a heliostat would drop 3% to 4% due to the increased cell operating temperature differential across the modules. The higher pumping power required to maintain turbulent flow in the cell heat exchanger is therefore the best option.

The ground coupled storage represents a large thermal flywheel - with infinite capacity so far as the heat from the heliostats and load's demand are concerned - that operates in a narrow temperature band. Stratification in the storage unit is employed to optimize operating temperatures for the cells as low as possible, and as high as possible for the load's requirements. The thermal storage provides a separation between the time and rate of thermal availability from the concentrators and the time and rate of use of the thermal energy by the thermal load.

The ground coupled storage container is filled with water. The water acts as an interim thermal storage element and as a conductor through which thermal energy moves from the heat exchanger in the storage container into the ground. When the thermal load demands energy from storage, the water from the storage unit is pumped to the load, and the ground transfers thermal energy back to the water as the water temperature drops. The ground provides the source/sink for very large amounts of thermal energy.

Figure 20 shows how the fluid cooling system for the heliostats will be interfaced with the thermal load.

The ground coupled cold storage unit is an extension of the hot storage unit - it stores the thermal energy at the condition required to serve the computer center cooling load (42°F). The cold storage unit is a more efficient place to store the thermal energy from the concentrators than the hot storage unit in this application because the temperature difference between the storage unit and ambient ground temperature is smaller. The critical cooling load is 34.5 tons per hour. The cooling COP of the absorption unit is 0.71, and the heating COP of the Templifier is 3.00. The Templifier would run 12 hours a day to handle this load, and this operation will take place at night during the utility's off peak hours. For every ton (12,000 BTUs) of cooling load served from cold storage, 1.56 KWH of off-peak commercial power will be used by the Templifier and 10,668 BTUs from the hot storage unit will be used.

2.8.1 Hot and Cold Storage Units - Component Development

This ground coupled storage technology has been under development for four years. Performance characteristics and sizing methods have been developed and documented by Kaman under DoE Contract No. EG-77-C-02-4351, and EPRI Contract RP924-1. The array/hot storage heat exchanger was selected through a modeling procedure to compare sizes, weights, capacities, etc., of heat exchangers for the purpose of optimum selection. This analysis, called FITX, may be reviewed in detail in Appendix G.

2.8.2 Hot and Cold Storage Units - Performance Testing

Two of these ground coupled storage devices have been under instrumented operation by Kaman - one for four years and another for three years. The thermal stratification characteristics and controlled ground conductance values used in this design were obtained from operational data on the two test units. The

FIGURE 20. THERMAL LOAD CONFIGURATION AND MEANS OF SERVICE AT THE APTC

conductance from the tank into the ground and from the ground into the tank is controlled by a thickness of the quartz sand around the tank. The quartz sand also isolates the tank walls from the virgin soil which could attack the tank through acid or basic minerals in the soil.

The hot storage tank should be filled with neutral water - condensate from a local power plant - to keep the fouling factor on the outside of the heat exchanger below 0.0005. Therminol 60™ is the working fluid inside the heat exchanger. The use of this fluid precludes any surface fouling. This information has been proven under four years of operating experience and reported under the above DoE contract.

2.9 Heliostat Lightning Protection and System Ground Plan

Lightning Elimination Associates (LEA) of Downey, California performed a complete design study in the area of lightning hazard and protection for this system. (This may be reviewed in Appendix H.) The necessity for the lightning hazard and protection design study surfaced in the NET II analysis of the cells, modules, and strings and in the design study centering on the power conditioning equipment. (See Section 2.5, Module.)

The objectives of this study were as follows:

- 1) A definition of the potential lightning hazards to the total photovoltaic concentrator system and associated electric apparatus to determine if the hazards warrant an investment in protective equipment,
- 2) An identification of the protective options available for each hazard identified and selection of the best options for implementation in the design,

- 3) The definition of an adequate grounding system,
- 4) Cost estimates for the recommended system.

Three potential hazards were identified as follows:

- Direct strikes to the array or close enough to a heliostat to cause an illumination stimulated voltage surge through the cells and overstress marginal cells or bypass diodes within the affected string,
- Power surges throughout the system caused by transmission line (ac or dc) strikes,
- Transients stimulated in any of the system associated transmission lines (ac or dc).

Historical data shows that, for the design site over a ten year period, 4 to 8 strikes are expected to occur in the general area of the photovoltaic concentrator system. These strikes may be all in one year or spread over ten years.

Several protection options and considerations were studied. These are the protective measures included in the design as a result of this design study:

- Install a grounded strike prevention system for each heliostat to prevent lightning strikes to any of the heliostats and the surrounding area,
- Install grounded surge arrestors in each string dc power circuit,
- Install grounded surge arrestors where the photovoltaic concentrator array bus enters the UPS,
- Install a complete grounding network system.

LEA specified the equipment and location for the hemispheric discharge arrays to be located at each heliostat, the surge eliminators, and the transient eliminators.

LEA provides a limited warranty under which all equipment they supply will be replaced at no cost should it fail at any time in the future.

The art and hardware for providing the lightning protection is well developed and widely used by electric utilities, phone companies, and microwave relay station operators. The same requirements for protection and hardware applications apply for this photovoltaic power system as applies for the above other uses.

2.10 Functional Integrated System Control Description

There are three elements to the control system which are as follows:

- Tracking control system with supporting hydraulic subsystem,
- Temperature control system,
- Power dispatching control system.

Figure 21 shows the overall system and the relationship of the above control elements to each other. Both safety and operational controls are included.

2.10.1 Tracking Control System

Each heliostat has an integral control and complete hydraulic system. The Mann-Russell Heliostat Mark IV (MR) unit is the tracking control unit. This unit has a four cell bridge balancing

FIGURE 21. FUNCTIONAL CONTROL OUTLINE

direct normal illumination sensor, a completely automatic control program, an azimuth clock drive for cloudy conditions and a manual control override.

The tracking controller activates tracking with a general illumination level of 0.04 suns in the morning and controls the movement of the hydraulic rams to keep the concentrator lenses aligned normal to the I_{DN} . The controller has an adjustable sensitivity band which will be set such that the heliostat moves when the sun leads it $0^{\circ}-7'-30''$ and will continue to move until the sun lags it by $0^{\circ}-7'-30''$. The tracking accuracy of this unit will be set to hold the heliostat within $0^{\circ}-20'$ of normal to the sun's radiation. The average speed of heliostat tracking movement is 4 angle seconds per time second in both tracking axes. But the step tracking movement is faster than this. This speed is adjustable with a set screw adjusted "pot" in the navigational module and an indexed knob on a temperature and pressure compensated hydraulic control valve (see Figure 21). This is the normal "sun shining" tracking routine. If a cloud covers the sun, a clock drive in the controller continues azimuth tracking movement at the rate of $0^{\circ}-15'-0''$ per time minute until the sun returns and the normal tracking routine commences as soon as vertical catch up occurs. Azimuth movement limit switches are mounted at azimuth ± 108 . The west limit switch is the night switch and the east limit switch is the morning ready switch. When the heliostat wakes up in the morning it azimuth tracks until the night limit switch stops it unless a detrack command occurs. When the night limit switch is hit the heliostat returns to the morning ready position. The heliostat stands up when it hits the morning ready switch and the tracking controller is reset for the next day.

If the temperature of the coolant on the modules rises above a set point (160°F), or there is a power failure to the Mann-Russell controller, the heliostat detracks - detracking

focused light off the cell mounts in the concentrator at the end of the one minute. At the end of this minute, the heliostat stops until the fault is cleared and a manual reset to normal tracking is initiated.

The hydraulic power unit consists of a surge tank, a 3/4 HP pump, and compressed gas accumulator. The hydraulic pump charges the accumulator by compressing a nitrogen gas cushion. A clock controlled circuit and the start-stop pressure actuated switches control the pump. The charged accumulator contains enough energy to drive the heliostat through a complete day's tracking cycle without recharging. The pump runs as a load managed (clock) load during commercial power off-peak time between 10 PM and 7 AM. The gas cushioned accumulator was selected in lieu of bladdered accumulators due to lower cost and freedom from bladder replacement requirements.

2.10.2 Heliostat Cooling System Control

Valve 7 (Figure 21) on each heliostat maintains the 140°F average cell temperature in each module by recirculating the coolant through the heliostat to bring the modules up to operating temperature at start up - then this valve mixes varying proportions of the fluid cooled in the hot storage unit to maintain cell operating temperature. Valve 8 acts to maintain constant differential head across pump 4. The primary function of the thermal control system is to operate the cell strings at a constant temperature to stabilize the string power curve from temperature caused variations. The secondary functions of the thermal control system are as follows:

- Minimize parasitic power use by pumps 3 and 4 by operating them constantly at their maximum efficiency without flow or head variations.

- Provide independent temperature control capabilities as an integral part of each heliostat.

The hot storage will be charged during the daytime when the arrays operate, and this stored thermal energy will be transported from hot storage to cold storage at night by the Templifier™ - absorption package. This operation is clock controlled with temperature limit go/no-go switches in both the hot and cold storage units. This is a further load management load factor improving feature for the interfaced electric utility.

2.10.3 Power Dispatching Control

This area is the heart of the photovoltaic concentrator system. The control of the power dispatching in the system is designed to be self-regulating and as simple as possible.

The key system characteristics around which the power dispatching controls function are:

- The critical load has a continuous demand and this demand is always larger than the electric generating capacity of the arrays,
- The arrays automatically maximum power track and load share with commercial power in serving the load and/or charging the batteries so long as the array bus is between 421 Vdc and 435 Vdc at the power conditioning unit.
- The batteries float off the UPS 421 V bus and stand ready to serve the critical load when there is a commercial power adequacy or quality problem.

Figure 22 is a wiring schematic of the integrated power system, and shows the elements of power dispatching control including both operational and safety controls.

2.10.3.1 Array Control.

The individual heliostats respond to direct radiation and supply power to the load in tandem as series strings - up to their maximum power capacity. Simply stated, the operational philosophy is "when the sun shows the power flows". The controls at the heliostats and the string bus, with their functions, are as follows:

- Bypass diodes - cell protection, see Section 2.5, Module,
- Manual disconnect - disconnects a heliostat from other power sources for maintenance and worker safety,
- Surge arrestors - lightning surge eliminator and start up string voltage controller combined in the same housing,
- String bus blocking diodes - primary purpose is to prevent any one string from being back biased by other strings and the secondary purpose is as a backup for the array bus diode in case it shorts.

The most difficult control problem is how to get the array power through the UPS 421 Vdc to 435 dc window. Open circuit voltage of the strings with 1 or more suns on the cell is 508 volts. At lower illumination levels, the string maximum power point, adjusted for transmission losses, can have a voltage below 421 volts dc. Figure 23 diagrams the problem. When the string is illuminated, Voc increases from 0 (A) to some value

FIGURE 22. POWER DISPATCHING CONTROL SCHEMATIC

FIGURE 23. LOW INTENSITY ILLUMINATION
POWER CYCLING PROBLEM

in the UPS voltage window (B), current flows through array bus diode, voltage drops towards maximum power point and current flow stops (due to array bus diode) (C) and the process repeats with a rapid (nanosecond) frequency due to the blocking diode characteristics.

The solution is to place a temporary resistance load on the system, which is not voltage limited for startup, so that the power from the arrays is presented to the UPS in the voltage window at a stable condition. Figure 24 shows this temporary load in the form of a resistor, R-1, at each heliostat.

When a heliostat is illuminated and the V_{oc} approaches 435 Vdc, R-1 is switched into the circuit - see Figure 24A. When both heliostats in the string are illuminated both R-1's (one at each heliostat) are in the circuit and held there for a set time - see Figure 24B.

Thus, the array power is brought into the UPS voltage window by a temporary load, then transferred to the UPS by first

FIGURE 24. TEMPORARY STARTUP LOAD IN CIRCUIT AND MAXIMUM POWER POINT TRACKS

load sharing excess power and then transferred fully as time delays drop the temporary load in the strings. The R-1 load will be 2.5 KW each.

2.10.3.2 UPS Control

The arrays automatically load share, when their voltage is proper, with commercial power (or the battery) to furnish the demand requirement of the load through the UPS. The UPS system has a complete internal series of operational and safety controls, alarms, and annunciators.

2.11 Battery

The capacity criteria for the battery is that it will support the nameplate rating capacity (250 KVA) of one bay of the UPS for two hours on consecutive days. Thus, a two hour battery support for the critical load is established. This time requirement is the minimum load support duration required to earn a demand credit on the commercial power system. The battery service could be either workday daily deep cycling or interruptible commercial power support. Either type of service can earn a demand credit with no equity differential.

The interfaced electric utility views the battery and UPS equipment with the overall photovoltaic system as a new type of load management device for their system which has the following benefits:

- The overall photovoltaic concentrator - UPS - battery - thermal system will improve the annual electric load factor of the load for their electric system based on critical time peak load,

- The battery is a utility load management device which helps solve commercial power adequacy and reliability problems for a critical load sensitive class of customer when used on an interruptible service basis,
- Handled properly, this type of load management device is a valid hedge against future generating plant capacity additions,
- The service the battery provides in supporting a critical load during power outages and transient conditions is an added value.

Two types of off-the-shelf batteries were reviewed in detail for use in this system; switchgear and UPS type, and transit type batteries. Some of the key final battery review points for these types of batteries are shown in Table VII.

The LCY-37 battery was chosen for this system for the following reasons:

- 1) Proven UPS application record,
- 2) Its more favorable performance and cost in utility managed interruptible service.

The battery storage subsystem for this APTEC design consists of 187 cells in polycarbonate containers with an operating voltage range of 290 volts dc to 421 Vdc with electrolyte, thermoplastic cell covers, microporous separators, spun polypropylene mat retainers, two electrolyte withdrawal tubes per cell, 0.63" sediment space, 6-1" square posts per cell with copper inserts, and acid resistant sintered ceramic (controlled porosity) flame arrestor on each cell.

TABLE VII. SUMMARY OF FINAL BATTERY REVIEW KEY POINTS

Battery Type	Switch Gear and UPS	Transit
Plate Material	Lead Calcium	Lead Calcium
C&D Model No.	LCY-37	CDQ-19
Number of Cells	187	330
Ftcat Voltage dc	421	421
Discharge Cutoff Voltage dc	290	290
250 KVA Load Support Time	2 Hours	2 Hours
Short Circuit Amps	25,560	26,000
Type of Service Recommended	Interruptible	Interruptible
Number of Discharge Cycles Over Life	260	3,000
Expected Battery Life for Service	20 Years	5 Years
Container	Flame Resistance - Polycarbonate	Flame Resistance - Marlex
Total Wet Weight	78,540 lb	90,090 lb
UPS Compability	Excellent & Proven	No Experience

Under conditions of four deep discharges per year and up to twenty (20) one minute discharges per year the battery should have a twenty year life with a capacity capability of not less than 95% of the original capacity capability at the end of twenty years of use. The short circuit amps of the battery should be 26,000 amps.

The battery would continuously supply a 250 KVA load for a two hour duration with a minimum recharge time of 48 hours between discharges.

The battery should be installed in a temperature controlled environment - properly ventilated - to maintain a battery temperature between 72°F and 80°F.

2.11.1 Projected Battery Efficiency

Under the battery operating strategy for this system as prescribed above, the batteries are expected to show an annual efficiency η_B of 98% calculated as follows:

$$\eta_B = \frac{\text{annual power out of battery}}{\text{annual power into battery}} \times 100$$

The battery has demonstrated that during the twentieth year of service in the operating strategy employed in this system - the discharge capacity is 95% that of the new battery.

2.12 Photovoltaic Concentrator Array Definition and Annual Load Percentage

The new heliostat mounted photovoltaic concentrator array design developed under this contract is the key feature of this system. There are five strings of heliostat mounted photovoltaic concentrators (10 heliostats) in this system design.

The percent of annual load met by this system with the five string array is shown in Table VIII.

2.12.1 Annual Array Efficiency Calculation

Annual electric efficiency (η_E), annual thermal efficiency (η_T), and combined annual efficiency (η_{ET}) are presented based on overall optical, cell, and thermal efficiencies as follows:

- η_E

$$\eta_E = \frac{I_{DN \text{ ANNUAL}} \times \eta_L \times \eta_{CA} \times \eta_C \times \eta_T \times 100}{I_{DN \text{ ANNUAL}}}$$

$$= .845 \times .137 \times .99 \times .98 \times 100 = 11.23\%$$

(η_T is a thermal variation factor which allows for temperature rise from module inlet to outlet.)

where η_L = lens efficiency = 84.5%, see Section 2.3.1

η_{CA} = cell assembly efficiency = 13.7%, see Section 2.4.3 based on an average annual I_{DN} on the lens of .75 suns

η_C = heliostat conductor efficiency = 99%,
1/3 of the conductor loss allowed the cell to UPS wiring system design.

- η_T

$$\eta_T = \frac{I_{DN \text{ ANNUAL}} \times \eta_{LT} \times (1 - \eta_E) \times \eta_{CR} \times 100}{I_{DN \text{ ANNUAL}}}$$

$$= .87 \times .8877 \times .78 \times 100 = 60\%$$

where η_{LT} = lens efficiency adjusted for longer wave length energy not included in L
for calculating η_E

TABLE VIII. PERCENTAGE OF ANNUAL LOAD MET BY THE FIVE STRING ARRAY

Type of Load and Array Capacity	Annual Electric Power		Annual Thermal Energy at Hot Storage Unit** 10 ⁶ BTU
	Demand KW	Energy KWH	
*Critical Electric Load	225	1,162,898	—
Noncritical Electric Load	115	637,720	—
Critical Thermal Load	—	—	3,405
Total Annual Load	340	1,800,618	3,405
Five String Array Output	54	121,735	1,686
Array Output % of Annual Load	16%	7%	50%

*Includes array support parasitic power (See Table I).

**Hot storage thermal energy for templier = Annual Thermal

$$\text{Load (5108 x 10}^6 \text{ BTU)} \times \frac{(\text{COP}_{\text{TEMPLIFIER}} - 1)}{\text{COP}_{\text{TEMPLIFIER}}} \text{ or } \frac{2}{3} = 3405 \times 10^6 \text{ BTU}$$

η_{CR} = thermal efficiency resulting from conductive and, convective, and radiation losses from the absorber tube and piping.

• η_{ET}

$$\eta_{ET} = \frac{I_{DN \text{ ANNUAL}} \frac{\eta_E + \eta_I}{100}}{I_{DN \text{ ANNUAL}}} \times 100$$

$$= 11.23 + 60 = 71.23\%$$

As the electrical efficiency of the cell assemblies increase for future heliostats, the thermal efficiency will decrease in a linear manner due to the decreased value of $(1-\eta_E)$.

2.12.2 Array Material Cost

The array material cost expressed in dollars per meter is derived and shown in the following list. The quantities shown were derived from material takeoffs from the heliostat drawings.

The cost per square meter of aperture is \$371.62. The peak watt capacities used in Table IX are based on the data shown in Section 2.4.3.

2.12.3 The Cost of Energy from Utility-Owned Solar Electric System

The level busbar energy costs shown here are derived from the following cost per watt of system cost with 11.22% efficient arrays for systems A and B (described in Table X) using the A&B nomographs from Figure 25, $CR = 1$.

TABLE IX

MATERIAL AND COST LIST FOR ONE HELIOSTAT UNIT WITH 61.55 SQUARE METERS OF APERTURE
AND 6.9 KW PEAK ELECTRIC CAPACITY AT $I_{DN} = 1$ KW/SQUARE METER, PLLS 43.8 KW
THERMAL PEAK CAPACITY

Material Class	Material Use in Heliostat	Quantity	Unit Cost	Total Cost
Aluminum-Extruded	Lens Mount-Frames	881 lbs	\$.85	\$ 749
-Cast	Cell Mount-Heat Exchangers	159 lbs	.85	135
Steel-Structural	Module	1478 lbs	.38	562
	Box Girder	6171 lbs	.38	2,345
	Tower w/Rotating Head Complete	3462 lbs	.38	1,316
Sheet	Module	1533 lbs	.25	383
	Tower	100 lbs	.25	25
	Hydraulic Syst.	1183 lbs	.25	296
	Bus Ducts	480 lbs	.25	120
-Linkages	Hydraulic System and Bearings	1078 lbs	4.00	4,312
-Misc Parts	Piping	2820 lbs	.50	1,410
Motors	Hydraulic Pump	15 lbs	3.00	45
	Coolant Fluid Pump	48 lbs	3.00	144
Alumina	Alumina Discs	40.5 lbs	15.00	608
Copper	Wiring (Noncell Interconnect)	841 lbs	1.70	1,430
Plastics Acrylic	Lenses	1248 lbs	.90	1,124
Cells & Interconnections	Cell Assemblies w/Interconnections 424 lbs	19,275 cm ²	.25	4,819
Hydraulic Fluid	Hydraulic System 640	80 gals	1.30	104
Therminol 60	Coolant Fluid 2500 lbs	313 gals	7.50	2,348
Tracking Controller	Mann Russel Unit 15 lbs	1 ea	450.00	450
PVC Insulators		424 lbs	.35	148
TOTALS	Wet Weight	25,541 lbs	Cost	\$22,873

Cost per peak watt electric - \$3.31

Cost per peak watt thermal - \$.52

Combined cost per peak watt electric plus thermal - \$.45

Reallocated cost per peak watt - electric 13.6% of capacity \$.06/Wp combined

thermal 86.4% of capacity \$.39/Wp combined

• Cost Per Watt Derivation:

System Component	System A Costs	System B Costs
Array	\$3.31	\$2.75
Power Conditioning & Battery	1.16	1.16
Hot & Cold Storage	.72	—
Installation Allowance	<u>1.51</u>	<u>.59</u>
Total Cost/KWp	\$6.70	\$4.50
<u>BBEC</u>	\$.054	\$.072

2.13 Key System Economic Tradeoff Study

An economic tradeoff study was made employing the Required Revenue Methodology for ERDA/EPRI Evaluations to confirm that the most feasible system configuration selection has been made for this system design. This study is summarized in Table X and presented in detail in Appendix J.

TABLE X. SYSTEM CONFIGURATIONS FOR REQUIRED REVENUE COST TRADEOFF STUDY

<u>System Components</u>	<u>Systems</u>			
Concentrator Arrays	A	B	C	D
Active - Fluid Cooled	•		•	•
Passive - Air Cooled		•		
Power Conditioner - UPS	•	•	•	•
Battery Storage	•	•		•
Hot Storage	•			
Templifier/Absorption Combination	•			
Steam Generator in Lieu of Hot Storage and Templifier/Absorption			•	•
Average Array Operating Temperature °F	140	140	240	240

The results of this study - presented in nomograph form to show level busbar energy cost sensitivity to increased overall cell efficiency and resulting system cost expressed in dollar per array KWp - are shown in Figure 25.

FIGURE 24. COST COMPARISONS FOR VARIOUS SYSTEM CONFIGURATIONS

The key points demonstrated by this study are

- 1) The economic superiority of the system configuration proposed over other configurations;
and,
- 2) The importance of striving to achieve future cell efficiency increases to reduce the level busbar energy cost from the system.

Systems C and D are identical except for the storage battery which is not included in C. The costs of the storage battery are reflected in higher busbar energy cost for system D. This particular modeling process does not allow credit for the traditional utility plant costs that the batteries displace. When this cost displacement is allowed, system D becomes slightly more favorable than system C, but remains less favorable than system A, the system designed for this Concentrator Photovoltaics APTEC.

3.0 ENVIRONMENTAL ASSESSMENT

Two areas of importance were identified and addressed during the APTEC design. They fall under the Clean Air and Clean Water Acts of the National Environmental Protection Act.

3.1 Clean Air Act Impact

The photovoltaic power system reduces the amount of combustion products discharged into the air by providing part of the energy to serve the computer center load, replacing some of the commercial power and natural gas that now serves it.

The heat rate of the electric utility base load plant that serves the computer center is 9700 BTU/KWH - which means one pound of coal is combusted for each KWH consumed in the computer

center. The conversion efficiency of the boiler that generates steam for the thermal load is 50%. Based on the information shown in Tables I and VIII, the annual net energy savings and reduction of combustion product air pollution is shown in Table XI.

TABLE XI. ANNUAL REDUCTION OF AIR POLLUTION BY COMBUSTION PRODUCTS FROM THE FIVE STRING ARRAY PHOTOVOLTAIC POWER SYSTEM

Type of Energy Saved	Annual Quantity	Annual Combustion Product Reduction	Type of Fuel Conserved
Electric Energy	67,128 KWH	34 Tons	Coal
Thermal Energy	1.686×10^6 BTU	169 Tons	Natural Gas

The heat transfer fluid (Therminol™ 60) is an aromatic ether. The vapors from this fluid have a pungent sweet odor and are unpleasant to the senses. These vapors are nontoxic based on the manufacturer's biological test data. Possible air contamination from this fluid has been minimized through the system design. The fluid system is entirely outside the buildings, and is in a closed system designed in accordance with ANSI B31.1, Code for Pressure Piping. Except for the heliostat piping and a pump station, this fluid system is all underground.

It is concluded that the photovoltaic power system complies with the requirements of the Colorado Clean Air Act. Its operation will result in an improvement in air quality in the region of the application site through the reduction of combustion products discharged into the air in the process of providing energy to operate the computer center.

3.2 Clean Water Act Impact

There are two items of concern in the photovoltaic power system relating to the provisions of the Colorado Clean Water Act. First is the possible stream flow pollution that could

result from a battery accident resulting in an electrolyte spill; second is the possible ground water pollution that could result from an array coolant system leak of Therminol 60™.

The system's design provides for the location of the batteries on racks in an enclosed ventilated room in the basement equipment room, which has a floor drain connected to the municipal wastewater system. The battery will contain 1720 gallons of electrolyte. The primary clarifier connected to the inlet works at the wastewater treatment plant has a continuous process volume of 7,500,000 gallons. If there were an electrolyte spill in the battery room, the maximum electrolyte concentration that could result in the wastewater treatment plant primary clarifier is 229 parts per million. The operators of this plant state that they would accept the electrolyte as influent and would incur no damage to their plant or process from it, and that no adverse impact would occur from the processed electrolyte in the plant's effluent.

The heat transfer fluid is biodegradable. There are no potable water wells within a radius of 5 miles from the application site. The application site has an alluvial fill on top of shale bedrock which slopes downward to the southeast, and surfaces in the bed of a creek, 1.5 miles from the application site. The creek has a continual flow from mountain runoff and receives the effluent from a military installation - 5 miles upstream of the application site. It receives the effluent flow of the municipal wastewater plant 7 miles south of the application site after the confluence with a larger creek. The combined ground water supply to the southeast with eventual relief and the aeration action of the surface flow (ranging from a minimum of 50 second feet to flood stage of over 100,000 second feet) would provide dilution and breakdown of any spilled or leaked heat transfer fluid into its nontoxic and environmentally acceptable compounds and elements. This precludes

environmental insult. The photovoltaic power system complies with the requirements of the Colorado Clean Water Act.

4.0 INSTITUTIONAL SITUATIONS

The key institutional activities of the APTEC design have centered in the areas of utility interface, building codes and future insurance costs, and land use matters involving zoning.

4.1 Compatibility With Interfaced Utility

The City of Colorado Springs, Department of Public Utilities is the interfaced utility. This utility provides both electric and natural gas service to the application site. Both this municipal utility and a privately owned utility, Public Service Company of Colorado, were participants in the APTEC design. The city's utility owns and operates its own generation, transmission, and distribution system for electric power. These utilities support each other with power generation from one system into the other on a cooperative basis. Both utilities obtain the natural gas they resell to their customers from Colorado Interstate Gas Company. Types of electric and thermal energy load management and fossil fuel conservation are matters of keen interest to both utilities.

Both organizations played key roles in guiding the photovoltaic system design to a compatible interface. These utilities have a common interest in the photovoltaic power system, and that is the cost, adequacy, and reliability of service to all their customers. The following benefits are achieved with the photovoltaic power system for the utilities and their customers:

- The batteries are of the type suitable to and sized for employing the critical and noncritical load as load management devices on the utilities' electric networks on an interruptible service basis,

- The overall photovoltaic power system will conserve a significant amount of fossil fuel while improving the load factor of the critical and noncritical load on the utilities' system,
- The thermal portion of the system substitutes coal and solar energy for natural gas to satisfy the thermal energy requirements of the computer center,
- Having the overall photovoltaic power system as a load management device connected into the regional power grid can make a valuable future contribution to controlling the cost, adequacy, and reliability of service to all the customers on the grid as the technology gains acceptance and expanded use.

There is a foreseeable future generation capacity shortage in the application site's region, and a shortage is predicted nationally.

The interfaced utilities should remain active in the APTEC installation to provide support in the following areas:

- Preparation of requests for the granting of cost tracking rates and tariffs for interruptible electric power service to the photovoltaic power system supported critical and noncritical load,
- Preparation of supporting documentation containing projected utility cost of service data and economic information directed at demonstrating the cost of service savings realized through the photovoltaic power system which, if made available through the

granting of the rate and tariff requested, would provide sufficient unsubsidized incentive to encourage more widespread use of these renewable energy systems,

- Submission of request and documentation, at the proper time, to the Public Utilities Commission the jurisdictional regulatory agencies required to order and effect the rate and tariff requested.

4.2 Building Code, Land Zoning, and Insurability

There are two prerequisites that must be satisfied for a building permit to be issued for the installation of the photovoltaic power system at the applications site. These requirements are as follows:

- 1) The system installation must comply with the application site's zoning - Planned Industrial Park II (PIPII) - and related land use designation; and,
- 2) The system and its installation designs must comply with the applicable codes employed by the Regional Building Department.

The entire system and its installation have been designed in compliance with the applicable codes which are as follows:

- Uniform Building Code,
- National Electric Code,
- Uniform Mechanical Code,
- Code for Pressure Piping - ANSI B31.1,
- ASME Boiler Code - Section VIII, Pressure Vessels.

Completion of these two steps assures the granting of building permit for the project when application is made by the project's General Contractor.

A representative of the insurance industry's fire prevention and electric code application group was called in and reviewed the dc wiring design and the design of the battery installation. His recommendations were included in the designs to provide assurance that no unusual insurance costs will result from the system and its installation at the application site.

5.0 OPERATIONS AND EVALUATION (OPEL) PLAN

A plan was developed to operate and evaluate a prototype APTEC designed and built in accordance with Sections 1.0 and 2.0. The OPEL plan is to be two years in duration and is the engineering test for the newly developed arrays. The purpose of the work in the OPEL plan is to gain operating experience with the photovoltaic concentrator system and to apply this experience to product improvement engineering for development items. Successful completion of the product improvement engineering will provide integrated mass production designs for an improved performance low cost combined photovoltaic concentrator integrated system for specific applications. The types of applications most suited for this system are high load factor electric loads combined with year round thermal energy loads employing fluid temperatures of from 42°F up to low pressure steam or medium temperature water with a maximum temperature of 230°F.

The steps constituting the product development engineering are outlined in the following tasks.

5.1 OPEL Plan Task Breakdown

This task breakdown outlines the engineering field tests and resulting product improvement engineering that will occur in the OPEL plan. The types of data to be collected are summarized as follows:

- Uniform Data Requirements (UDR)
 - Soft data, recorded in logs and reported regularly,
 - Transducer data, input to an On-site Data Acquisition System (ODAS) for reduction at a Data Reduction Center (DRC),
- Cost of Service Data
 - Electric KW, KWH, and where applicable load factor, power factor, and capacity factor recorded on magnetic tape in 15 minute intervals for reduction into PUC required format,
 - Thermal energy time and quantity of generation and use,
- Heliostat Structural Performance Data
 - Strain gage data, will be input to the ODAS for retrieval from mag tape to validate SAP model work and for structural design improvement,
 - Thermocouples, provides working temperatures at certain strain gages,
 - Hydraulic ram pressures will be recorded for optimizing hydraulic system working pressure range to minimize parasitic power use.

5.1.1 Uniform Data Requirements

A smooth flow of operational information in the form of transducer data will be provided to the data reduction center, and this data will also be used for on-site performance evaluations.

Soft data will be recorded in logs and on ledgers, and reported in Monthly Technical Progress Letter Reports and a Final Report.

5.1.1.1 Transducer Data

Figure 26 is a system schematic showing the location of all Uniform Data Requirements (UDR) transducers and other instruments. Table XII summarizes the UDR transducers and structural instruments.

This data will be fed into the ODAS along with the structural strain gage and related thermocouple outputs in properly conditioned signals.

5.1.1.2 Soft Data

The soft data requirements are divided into construction phase and OPEL phase elements. The construction phase elements are summarized as follows:

- Site Description System Schematics, and System Descriptive Parameters
 - During the day to day supervision of the project, a change log will be maintained, i.e., document the changes made, reasons for the changes, and a summary of the cost reduction or increase resulting from the change.

FIGURE 26.. SYSTEM SCHEMATIC WITH UNIFORM DATA REQUIREMENT TRANSDUCERS AND OTHER INSTRUMENTS

NOTES:

- 1.) See Table XXIII for descriptions of all transducer symbols.
- 2.) Numbers in () are for data point identification.
- 3.) Δ denotes cost-of-service study data points.

TABLE XII. TRANSDUCER SUMMARY FOR UNIFORM DATA REQUIREMENTS AND STRUCTURAL EVALUATION

Symbol	Measurement	Manufacturer	Part No.	Output Signal	Signal Conversion	Signal to ODAS Analog Digital	% Accuracy
Uniform Data Requirements
ac Voltage	American Aerospace Cont. Inc.	108	5VDC F.S.	None	Analog	2.0% F.S.
dc Voltage	Dale	RH-50-4.5K	5VDC F.S.	Resistive Divider	Analog	2.0% F.S.
ac current	AAC Inc.	1003AM3	5VDC F.S.	None	Analog	2.0% F.S.
dc Current	American Aerospace Cont. Inc.	913A	5VDC F.S.	None	Analog	1.0% F.S.
Subfield							
Array							
Battery Ch & Disch.							
	ac Power	AAC Inc.	416A	5VDC F.S.	None	Analog	2.0% F.S.
	dc Power	AAC Inc.	401	250MVDC F.S.	None	Analog	2.5% F.S.
Temperature-Cell	Hy-Cal	RTS-64-A-100-3-480-X-1	0-5V	Bridge/DC Excitation	Analog	0.05% F.S.
Temperature-Fluid	Hy-Cal	RTS-36-A-100-C8-3-H-6X1	0-5V	Bridge/DC Excitation	Analog	0.1% F.S.
Fluid Flow	Fisher-Porter	50DP-2-2-1X-B-B	5 V.F.S.	Sq. Root Extractor	Analog	0.8% F.S.
Structural Evaluation							
Strain Gage
BLH	FAED-25-1256	30 MV	Bridge Amplifier	Analog	Accuracy Determined by Installa- tion Cali- bration
		BLH	FNWFB6-50-12	60 MV	Bridge-Amplifier	Analog	
		BLH	FABW-25-1256	30 MV	Bridge-Amplifier	Analog
Temperature	Hy-Cal	RTS-61-A-100-3-480-X1	0-5V	Bridge/DC Excitation	Analog	0.05% F.S.
On/Off Relay	P&B	KRP-11AC	0&5V	Bias Supply	Analog	N/A
Hydraulic Pressure	Consolidated Controls	41SG30	0-5V	None	Analog	0.5% F.S.

- The final as-built drawings will be made from the change log. The final "as-built" layout drawings, a complete list of the installed photovoltaic equipment, a definition of the purpose of the application, the descriptive system parameters, the start-up test reports, and the break-in test reports will all be included in a Final Report. The "as-built" drawings will include a system schematic.
- Purchased Equipment Costs; Capital and Construction Costs
 - The actual cost of the direct procurement items and site construction costs will be kept on cost ledgers. The ledgers will be kept current including costs of changes. Capital costs will be accounted on a separate ledger. The summary of these ledgers will be included in the Final Report.
- Construction Schedule and Safety
 - A daily job log will be maintained during the construction phase. This log will summarize the work completed, men and equipment working, materials received, tests completed, and losses or gains in schedule by activity.
 - Items regarding safety conditions and safety design requirements that arise during the construction phase.

- Environmental Considerations

The Environmental Assessment and institutional issues discussed in Sections 3.0 and 4.0 will be reviewed during the OPEL phase. Any deviations from the conditions anticipated or the appearance of any unanticipated impacts will be documented and reported.

- Utility Interface

The work discussed in Section 4.1, Compatibility with the Interfaced Utility, will be continued in the OPEL phase. It is anticipated that the PUC will issue an order operating the experimental, interruptible - cost tracking rate and tariff for electric power service to the photovoltaic power system supported critical and noncritical load either on the receipt of cost of service proof or pending receipt of this data. The instrumentation required to produce cost of service data will be installed and placed in operation during the construction phase.

The instrumentation which provides the cost of service study technical data on magnetic tape is discussed in Section 5.1.2.

- Inverter Output Harmonic Content

The certified performance specifications for the UPS show the harmonic content of the inverter output will be a 5% total harmonic distortion with a single harmonic distortion of 3%. The inverter section of the UPS Power Module is scanned by the internal UPS annunciator package. The inverter oscillator is monitored

continuously for out of tolerance or failure. When either of these events occur, an alarm sounds and the event is hard copy reported by the UPS Logiccenter. The status of the harmonic output of the inverters will be recorded and reported on at six month intervals. Any out-of-specification harmonic conditions will be reported when they occur in the Monthly Technical Progress Letter Reports.

5.1.2 Cost of Service Instrumentation

The OPEL Plan calls for the installation, operation, and translation of the data from the cost of service (COS) instrumentation. The data will be translated into the format required to support the application to the PUC for granting the interruptible - cost tracking rate and tariff for commercial electric power service to the photovoltaic power system supported critical and noncritical load.

A formal request will be prepared and filed with the PUC for the special rate and tariff for electric power service to the critical and noncritical load supported by the photovoltaic power system.

5.1.2.1 Cost of Service Data Instrumentation Specification

The electrical instrumentation complies with the following generic classifications:

- Load demand (KW) and power factor at 15 minute intervals continuously,
- Cumulative load energy use (KWH),

- The source of the energy that serves the load, i.e., commercial, photovoltaic, battery, with the demand (and power factor for commercial) at 15 minute intervals and cumulative energy use (this required for both ac and dc metering equipment).

Because this is a combined photovoltaic power system and electric load factor adjustment occurs in part through the thermal subsystem by load management, the amount of thermal energy from the arrays and to the load are significant cost of service data items, too. The location of the thermal instrumentation required to support the request for the granting of the electric rate and tariff is shown in Figure 26.

The existing gas rate and tariff at the APTEC site is a customer cost/commodity cost rate and tariff which is very suitable for providing economic incentives for the combined photovoltaic power system.

Electric Load research meter packages will be employed as follows to comply with the traditions and requirements of the PUC for this type of work:

- AC metering and recording,
 - Westinghouse Type WR31 Load Research Packages with WR34 recorders,
- DC metering and recording,
 - Scientific Columbus Model 6268 dc Watt transducers coupled with Westinghouse WR34 Recorders,

- Load Research Meter Data Translation,
 - This data will be translated into PUC required format using a Westinghouse WLT-40 Programmable Translation System.

The thermal data recording equipment will consist of totalizing strip chart recording meters equal to Bailey or Fisher Porter flow/ Δt integrating BTU metering systems.

5.1.3 Heliostat Structure Engineering Test and Development Engineering

Strain gage, thermocouple, and hydraulic ram transducer data will be summarized and used to validate the SAP IV projected structural performance data. The validated structural performance data will be used to design a low cost, improved performance heliostat structure in the development engineering work.

A manufacturing study for mass producing the improved heliostat design resulting in a recommended manufacturing process for the heliostat and associated mass production costs will be developed using this data.

5.1.3.1 Heliostat Structural Performance Transducers Specification

A total of 238 strain gages and 12 thermocouples will be placed on one heliostat structure at the locations shown in Figures 27 and 28. The strain gage locations are selected to measure bending moments, axial loads, torques, and shear stresses at the key points in structural members and joints required to validate the SAP IV model data.

Note: 6 STRAIN GAGES LOCATED IN
OPERATING HEAD ASSEMBLY

TOWER MODEL COMPUTER PLOT

T - Tower
a - top
d - side
e - weld

Total Tower 88

FIGURE 27. STRAIN GAGE LOCATION ON HELIOSTAT
TOWER

FIGURE 28. STRAIN GAGE LOCATIONS IN UPPER ARRAY STRUCTURE

Key: M - Mainframe (59)	a - Top
B - Box Beams (30)	b - Bottom
P - Module Flow Tubes (45)	c - Top and Bottom
O - Aligned Axially	d - Side
X - 45° Angle	e - Weld
TC - Thermocouples	

Table XIII shows the strain gage allocation that is planned.

TABLE XIII. STRAIN GAGE ALLOCATION IN THE HELIOSTAT STRUCTURE

Structural Member	Strain Gage Measurement - Number of		
	Strain Gages Bending Moments & Axial Loads	Torque	Joints (Welds)
Module Flow Tubes	19	—	26
Module Support Members	12	18	—
Cantilevered Box Struct. Memb.	13	2	44
Operating Head W/Dead Axle	8	4	4
Tower	<u>8</u>	<u>4</u>	<u>26</u>
TOTALS	60	28	150

The thermocouple locations are shown in Figure 27.

It is planned that the thermocouples will report directly to the ODAS, and the strain gages will report to the ODAS through individual signal conditioners to provide dynamic structural data.

Four pressure transducers, one on each port of each hydraulic cylinder on the heliostat will report to the ODAS. Thus, dynamic and static loading on the hydraulic cylinders will be obtained to optimize the hydraulic power system pressure settings to minimize hydraulic pump demand and energy use. This data will also be used to be sure the smallest and least expensive hydraulic rams possible are used in the streamlined heliostat design.

5.1.4 Land Zoning

A formal request will be filed for permanent zoning of the strip of land where the heliostats are to be installed. This request will be for the granting of permanent zoning for this

land. The zoning classification sought will be either "Solar Power Corridor, or PIP II Solar Power Corridor, Restricted".

5.1.5 Erection, Startup, Operation, and Maintenance Manuals

Complete instruction manuals covering erection, startup, operation, and maintenance manuals for the heliostat assembly will be prepared under the OPEL plan.

5.1.6 Social Acceptance

Briefings to interested members of the public and to organizations will be prepared and presented. The Photovoltaic Power System will be available for guided tours on an appointment basis, and a short briefing will be given to each tour. The briefing will cover the Federal Photovoltaic Program Goals, the PRDA 0035 Program activities, general system information and performance capabilities.

The Photovoltaic Power System Graphic Panel Board, Figure 29, will be maintained in public view in the main reception area at the Application Site. A professional brochure will be prepared and made available at the briefings. This brochure will contain the same general information as covered in the briefing. The brochure will contain a "tear off" comment form, and visitors will be asked to leave their comments at the APTEC after the briefings.

The comments received will be consolidated and used to measure social acceptance. A summary of these comments and conclusions regarding social mood and acceptance of photovoltaic technology will be reported monthly and in the Final Report.

FIGURE 29. PHOTOVOLTAIC POWER SYSTEM GRAPHIC DISPLAY (PVPSGD)

5.1.7 Reporting

Complete reporting services will be provided for the OPEL plan consisting of Hot Line Reports, Technical Progress Letters, Draft Final Report and Final Report.

5.1.7.1 Hot Line Reports

The hot line report will be employed when it is desired to expedite communication of significant technical developments, critical problems, and emergency situations to the Government.

5.1.7.2 Technical Progress Letter Reports

This informal technical report will be submitted monthly containing project results for dissemination to government agencies and others during the OPEL phase. Formal test reports will be submitted as they become available as an enclosure to these monthly reports.

5.1.7.3 Draft Final Report and Final Report

A draft final report will be submitted to DoE for review, and resubmitted in final form 90 days after the end of the OPEL phase.

5.2 System Operations, Project Data, and Information Flow Responsibilities

Figure 30 shows the sources of data, the way it will be communicated, where it will be processed, and the end use planned for the data.

The APTEC Engineering Team will be responsible for maintaining the mainstream communications flow.

FIGURE 30. OPEL PHASE AND RELATED ACTIVITY PLAN

A system operator will exist in the APTEC project team. He will be responsible for operating and maintaining the system. The diagnostic data and the operationally oriented soft data will flow to him. He will employ the diagnostic data from the system to monitor system performance and to identify developing problems. He will be responsible for keeping and making all operationally oriented entries in the soft data logs. He will report directly to the project manager throughout the term of the OPEL Phase.

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