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Plastic Heliostat and Heliostat Enclosure Analysis

Solar Systems Group
Boeing Engineering and Construction
Seattle, Washington

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

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PLASTIC HELIOSTAT AND HELIOSTAT ENCLOSURE ANALYSIS
FINAL REPORT

Prepared by
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Boeing Engineering and Construction
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Principal Investigator
M. J. Berry

Prepared for
Sandia National Laboratories
Livermore, California 94550

Contract 20-9944

Foreword

This final report was prepared to satisfy the requirements of Task B-8 of the Statement of Work of Sandia Contract 20-9944. It describes analyses, design, trade studies, heliostat and plant busbar energy cost analyses. Sandia technical management was performed by Mr. Clayton Mavis. BEC contributors were:

Program Manager	Donald Bartlett
Principal Investigator	Marc Berry
Heliostat Design	Ken Hernley
Heliostat and Power Plant Analysis	Bill Beverly

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1.0 INTRODUCTION AND SUMMARY

Boeing Engineering and Construction Company (BEC), under contract with Sandia National Laboratories, Livermore, submits herein the conceptual design and cost analysis report of an enclosed plastic heliostat for a 50-MW_e central receiver solar thermal electric power plant. This work was performed under Contract 20-9944.

The purpose of this study was to analyze the most recent design of the Boeing enclosed plastic heliostat for cost and compare results with a reference second generation glass heliostat case provided by Sandia National Laboratories, Livermore (SNLL). In addition, sensitivities of busbar energy costs to variations in capital cost (installed cost), operation and maintenance cost and overall reflectivity (ρt^2) were evaluated.

1.1 Design and Cost Overview

The conceptual design developed is shown in Figure 1-1. It consists of an overcoated polymethylmethacrylate (PMMA) film reflector membrane on a tubular aluminum support structure, thermoformed polyvinylidene fluoride (PVDF) enclosure, pedestal, drive actuator, support blower and a screw-anchor/cable tie-down system. No controls design work was performed. The tie-down system reacts wind loads (lift and drag) and up-load due to internal pressurization. Provision is made for removal and replacement of the enclosure once in the 30-year life of the plant. Manufacture of the heliostat components was planned at a central facility in Phoenix, Arizona while final assembly occurs at the power plant sites.

Costs for heliostat materials, labor, transportation, factory and site were etimated. The HELCAT code, provided by SNLL, was used to compute capital cost. SNLL provided a Second Generation reference case for comparison purposes. Figure 1-2 shows the overall installed cost comparison, as well as component cost comparisons. The greatest cost advantages of plastic heliostats are seen to lie with the reflector and drive mechanism.

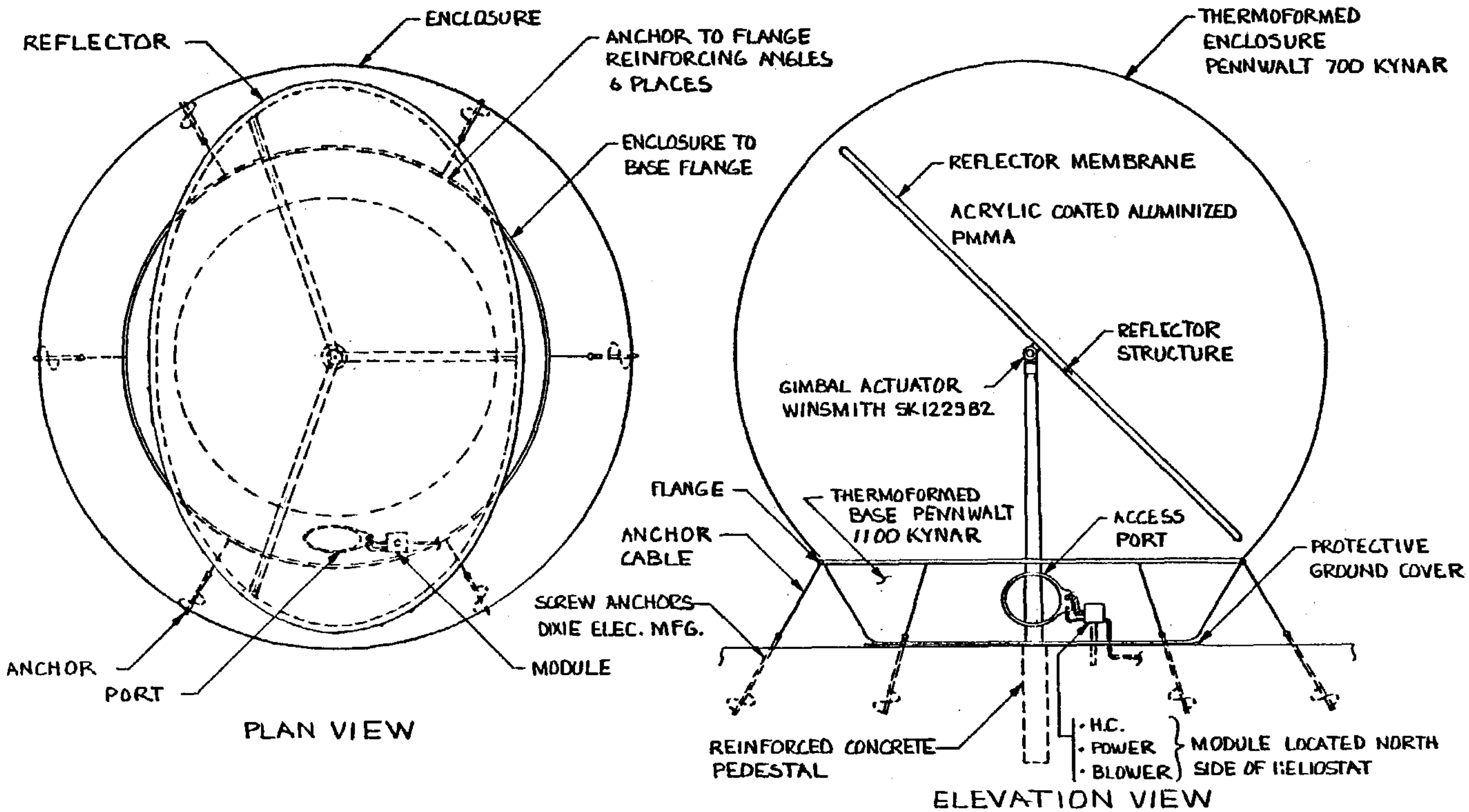


FIGURE 1-1 PLASTIC HELIOSTAT AND ENCLOSURE CONCEPT

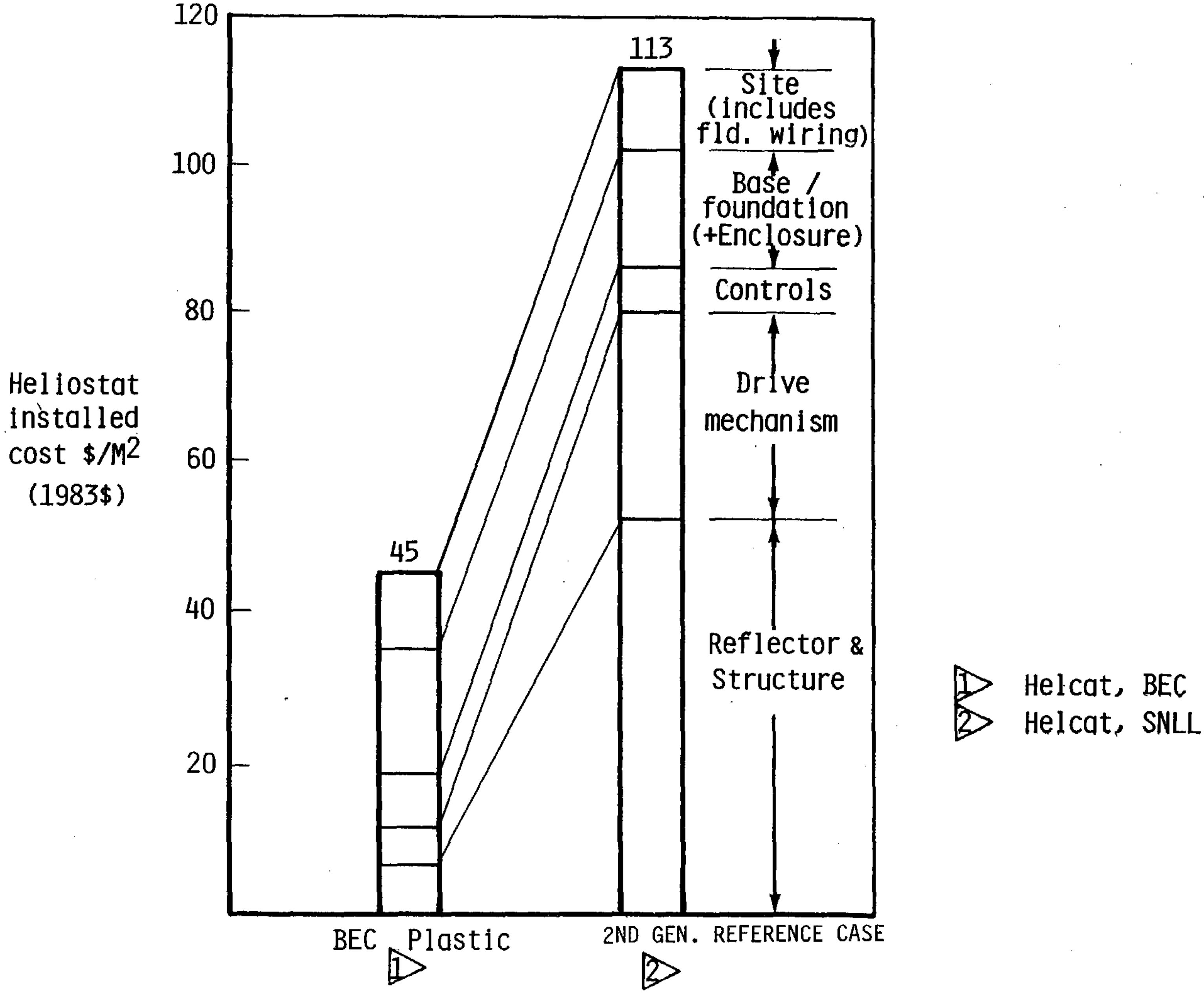


FIGURE 1-2 HELIOSTAT COST COMPARISON

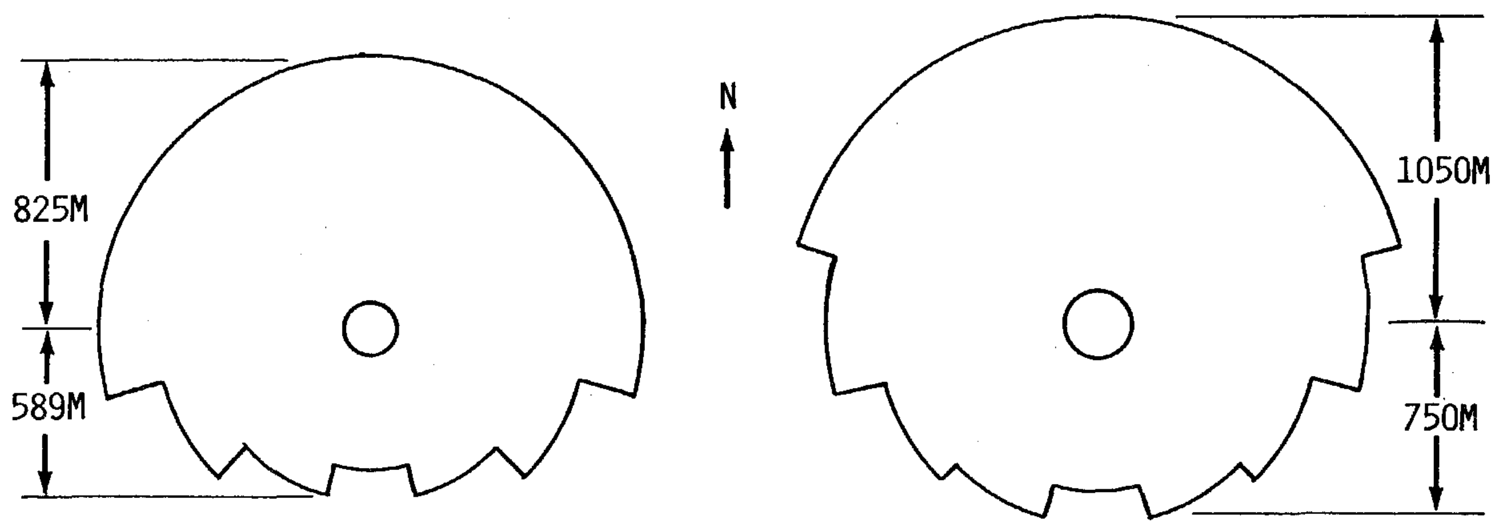
Installed cost data for the BEC plastic heliostat and the reference heliostat data for a "straw man" 50-MW_e power plant were input to DELSOL 2 (modified by SERI for enclosed heliostats). A plant was designed and busbar energy (BBEC) computed. Results are shown in Figure 1-3. In total plant terms the Second Generation heliostat cost is 15% greater than the BEC plastic heliostat. However, the heliostat accounts for only part of the BBEC costs (49% for Second Generation; 32% for BEC plastic). When Second Generation balance-of-plant costs are subtracted, one can see the BBEC attributable to heliostats. Figure 1-4 shows that the Second Generation heliostat costs are approximately 38% higher than BEC plastic heliostat costs. The added balance-of-plant costs caused by plastic heliostats, resulting from larger field and taller tower, are included in this assessment.

1.2 Conclusion

This study shows that plastic enclosed heliostats offer a significant opportunity for collector subsystem cost reduction. The Second Generation reference case heliostats are estimated to be nearly 40% more expensive. In terms of BBEC for the entire plant, use of plastic heliostats result in a 15% overall savings.

2ND GEN. REF CASE 50 MW_e FIELD

BEC PLASTIC 50 MW_e FIELD



No. of Heliostats	6609
Land area	1.96 KM^2
Tower Height	110M
Receiver Height	16.8M
Diameter	12.0M
Levelized BBEC	127 MILS/KW-HR
% Heliostat Cost	49.0%

No. of Heliostats	8018
Land Area	2.42 KM^2
Tower Height	140M
Receiver Height	17.3M
Diameter	12.0M
Levelized BBEC	110 MILS/KW-HR
% Heliostat Cost	31.7%

FIGURE 1-3 POWER PLANT COMPARISON

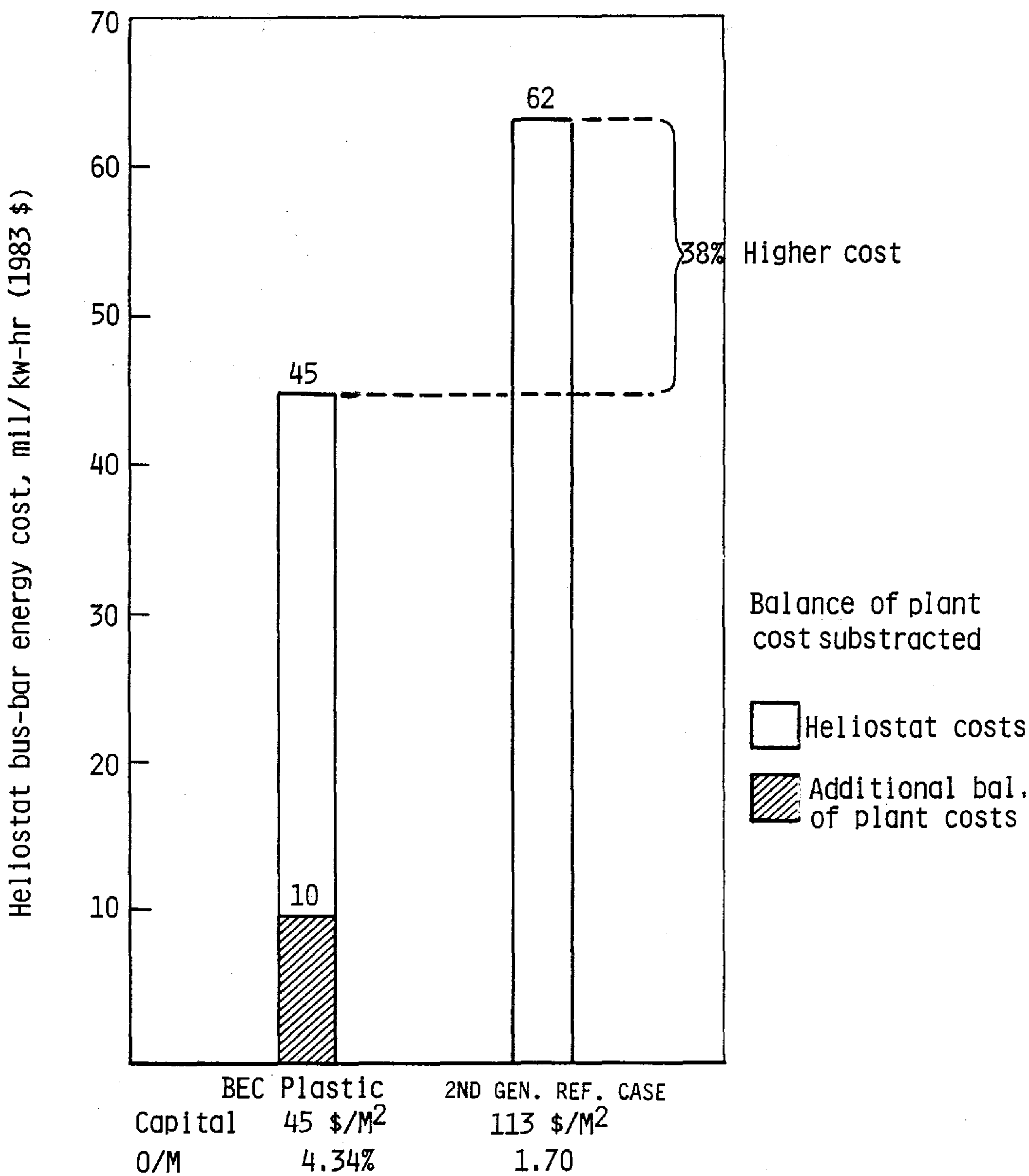


FIGURE 1-4 ENERGY COST COMPARISON

2.0 STUDY GROUND RULES

The primary objective of the study was to select a size and design optimized plastic enclosed heliostat and compare its energy costs with those of a SNLL provided Second Generation glass/steel reference case heliostat. To make the comparison consistent Sandia specified the power plant that would be the basis for both analyses. The production rate is 50,000 heliostats per year (or equivalent area). Table 2.0-1 provides the plant performance requirements and analysis assumptions. Heliostat requirements follow Second Generation specifications issued by SNLL (see section B in Appendix).

Table 2.0-1 System Requirements and Study Assumptions

- Site:

Location	Barstow, CA
Longitude	116.83°W
Latitude	34.87°N
Altitude	593m (1946 ft)
Topography	Flat, unrestricted boundaries
Annual weather factor	0.83

- Design Point:

Day	March 21, Day 81
Hour	Solar noon
Insolation	950 W/m^2
Ambient temperature	15°C (59°F)

- Insolation Profile:

Model	Meinel
Precipitable water	20mm
Relative pressure	93% of sea level
Sunshape	Limb-darkened sun
Visibility	25 km

- Receiver Subsystem:

Receiver type	Cylindrical external receiver
Working fluid	Molten salt
Absorptance	0.965
Radiation and convection loss	0.17
Flux limit	0.80 MW_t/m^2
Tower type	Concrete ($\geq$ 120m)

Table 2.0-1 System Requirements and Study Assumptions (continued)

- Electric Power Generation Subsystem:

Plant rating	50 MWe
Turbine type	Steam
Cycle efficiency	0.42 (design point)
	0.399 (off-design)
Total parasitic load fraction	0.065 (of gross output)

- Thermal Energy Storage Subsystem:

Storage medium	Molten salt
Solar multiple	1.5
Round trip efficiency	1.0

- Economic Factors:

Cost basis	1983$
Contingency	0%
Spare parts	0%
Indirect costs	16%
Capital escalation	8%
General inflation	8%
Interest during construction	10%
Years to construction start	0
Plant lifetime	30 years
Fixed charge rate	15.9%
Discount rate	9.96%
Heliostat 1st yr O&M	1.7% (glass)
Bal. of plant 1st yr O&M	1.5%
Plant factor	100%

3.0 HELIOSTAT CONCEPTUAL DESIGN

The previous plastic enclosed heliostat design was prepared by BEC in 1978 (Reference 3-1) and is shown in Figure 3-0. It was believed that redesign of the base/foundation, pedestal and drive actuator could produce additional significant cost reductions. The design presented here reflects some revisions to the previous work, but is by no means complete. The ultimate, least cost enclosed heliostat will require further design effort.

Figure 3-1 is the heliostat installation drawing. The conceptual design was prepared to a level of detail that permitted design analysis and reasonably accurate component pricing. Additional effort will be required to refine the design and produce drawings suitable for prototype fabrication.

The following paragraphs present the design by component. Some components have changed little from previous studies, others represent new, cost-saving approaches.

3.1 Performance Requirements

Design of the heliostat was based upon functional, performance, design and construction requirements derived from Sandia's general specification, A10772, from the Second Generation Heliostat Program. These requirements were allocated to each of the major elements which were to be designed; reflector, enclosure, controls, base-foundation and drive. Requirements are described in Appendix B of this volume.

3.2 Reflective Assembly

The reflective assembly consists of a bi-axially stretched reflective acrylic over-coated, aluminized polymethylmethacrylate membrane bonded to a light-weight circular aluminum frame (Figure 3-2). The overall diameter of the reflective assembly is 8.78m (28.8 ft.). This size was selected on the basis of the cost/size optimization as discussed in Section 3.7. The reflector is gravity focused by pre-tensioning the reflective membrane during

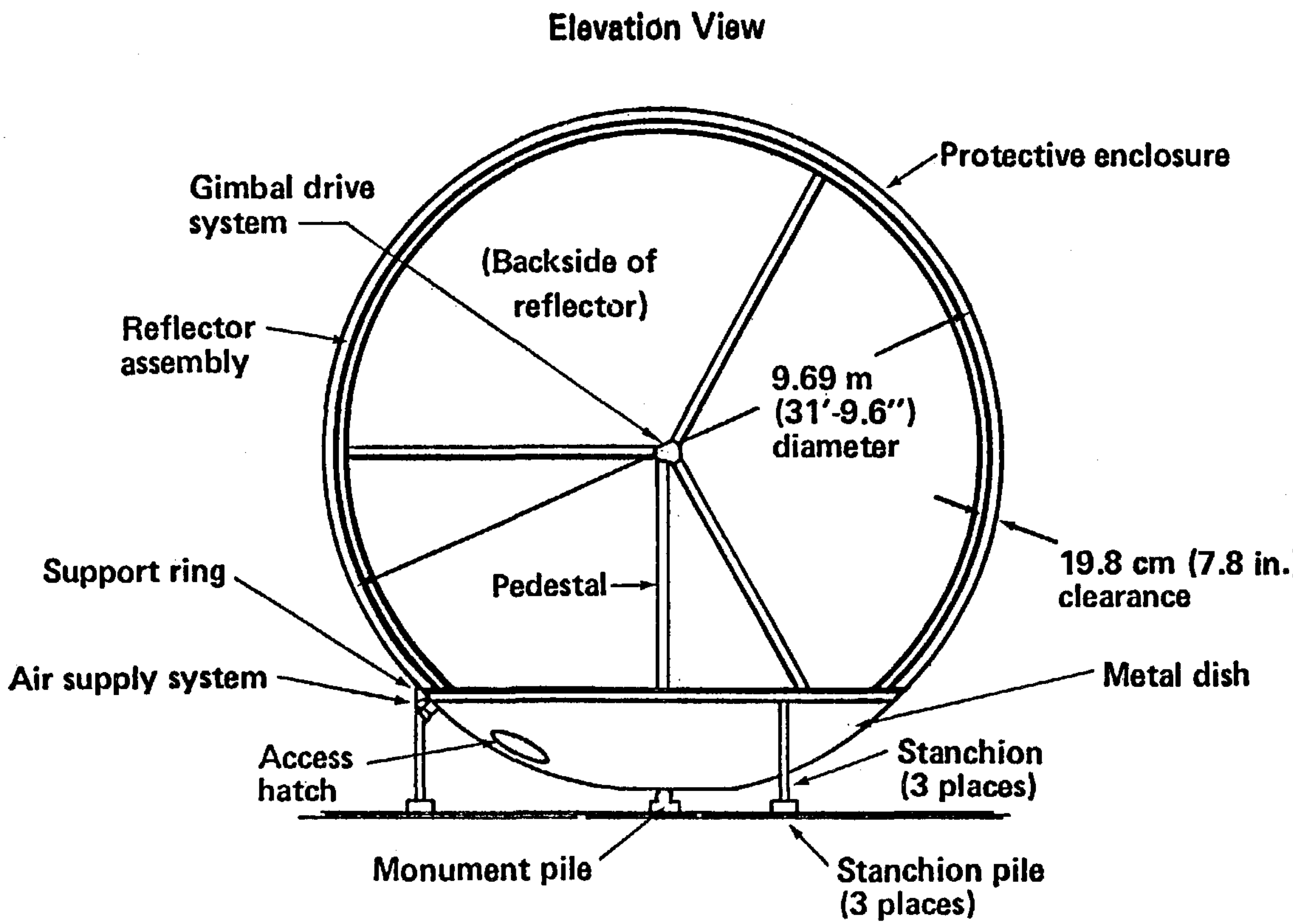
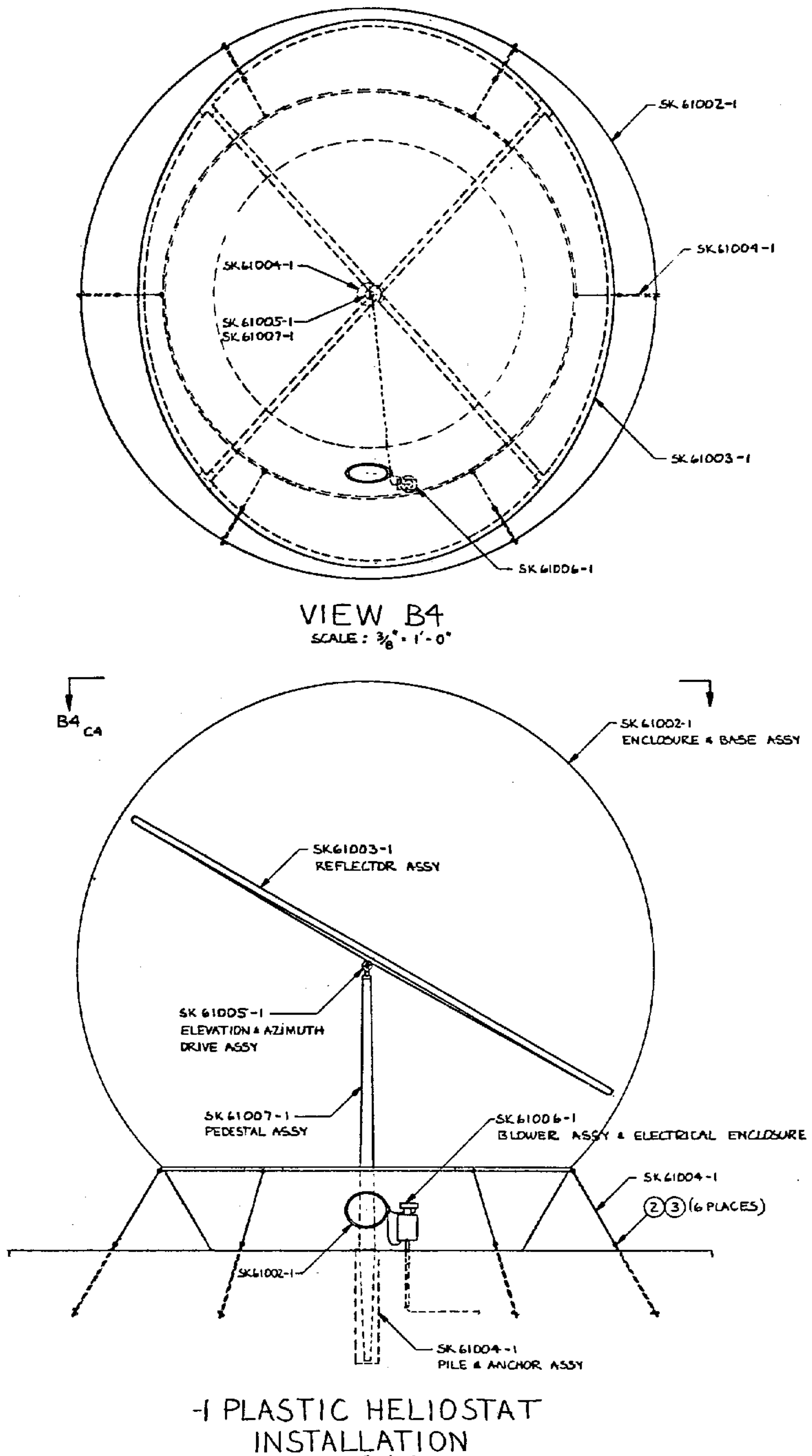


FIGURE 3-0 PREVIOUS BEC DESIGN

HOLE LOCATION FOR ⅛/32 DIAMETER RIVET
HOLE LOCATION FOR ⅛/32 DIAMETER BOLT

REVISIONS: ZONE | REV | DESCRIPTION | DATE | APPROVED



QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART NUMBER	DESCRIPTION
			1		SK61007-1 PEDESTAL ASSY
			1		SK61006-1 BLOWER ASSY & ELECTRICAL ENCLOSURE
			1		SK61005-1 AZIMUTH & ELEVATION DRIVE ASSY
			1		SK61004-1 PILE & ANCHOR ASSY
			1		SK61003-1 REFLECTOR ASSY
			1		SK 61002-1 ENCLOSURE & BASE ASSY
			6	-3	SLEEVE - COPPER 3/16" McMASTER CARR CAT. NO. 3572T30
			6	-2	THIMBLE - GALVANIZED STEEL 3/16" McMASTER CARR CAT NO 3494T12
			—	-1	PLASTIC HELIOSTAT INSTALLATION
			-1		PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES - — DECIMALS - —

USED ON —
SECT NO
CHG NO
GROUP ORG K 6100

DRAWN K. Hanley 3-3-83
CHECKED M. J. Berg 3-12-83
STRESS
ENGR K. Hanley 3-14-83
GROUP
PROJ M. J. Berg 3-14-83

BOEING
CORPORATE OFFICES SEATTLE, WA 98124

PLASTIC HELIOSTAT INSTALLATION

SIZE E | FSCM NO. 81205 | DWG NO SK61001
SCALE: NOTED | SH 1 OF 1

DWG NO SK61001 | SHEET 1 | REV

DRAWING RECORDS CLERK

FIGURE 3-1

3-8-83

D1 6007 3280 REV 4/78

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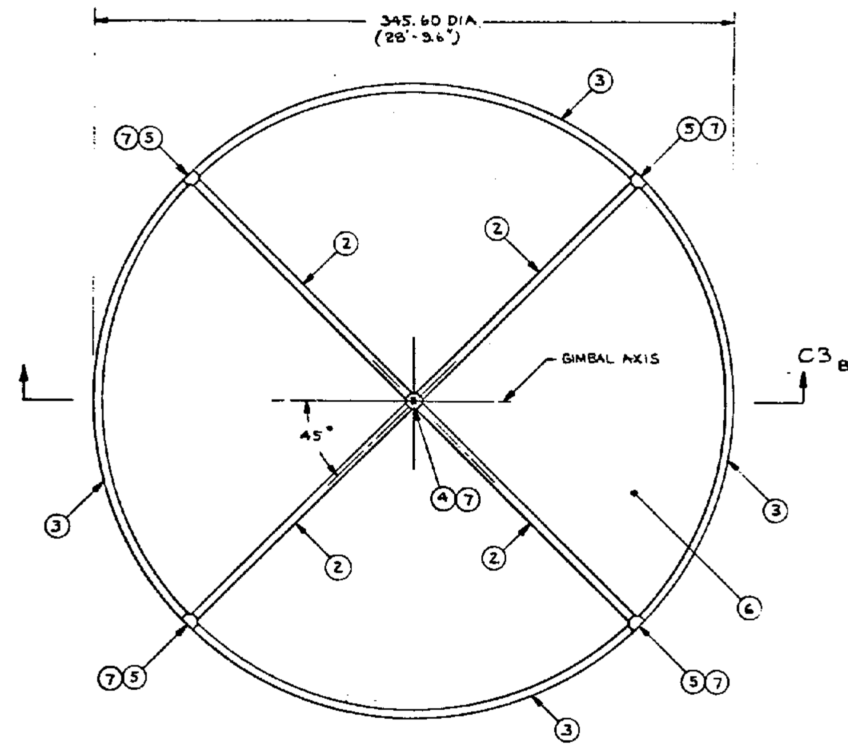
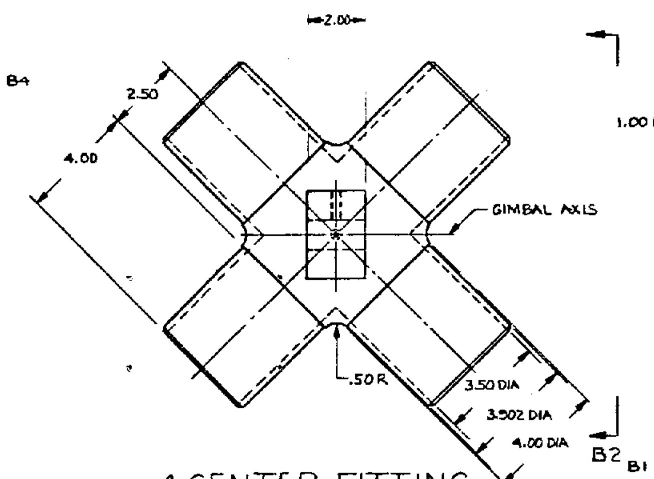
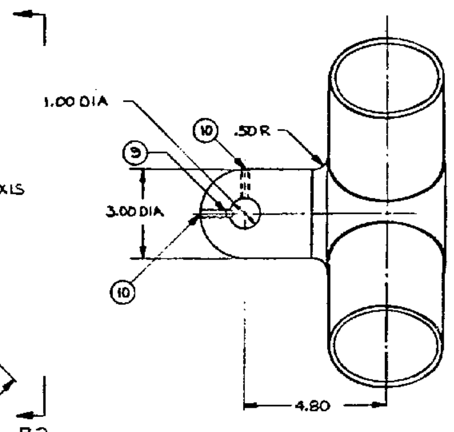
1. ACRYLIC COATED ALUMINIZED POLY METHYL METHACRYLATE FILM. BOND TO STRUCTURE WITH A RADIAL PRETENSION OF 1000 PSI.
2. EA934 A RESIN AND EA934 B HARDENER - HYSOL DIVISION THE DEXTER CORP. OLEAN N.Y. 14760
3. AEROSOL BLOWN RIGID POLYURETHANE FOAM. CAST AGAINST A FLAT TOOL SURFACE
4. MACHINE KEY BAR STOCK CAT NO 98491A150 1 McMASTER CARR P.O. BOX 54960 LOS ANGELES CA 90054 OR EQUAL.
5. HEX SOCKET ALLOY STEEL CUP POINT SET SCREW CAT NO 91375A835 McMASTER CARR P.O. BOX 54960 LOS ANGELES CA 90054 OR EQUAL.



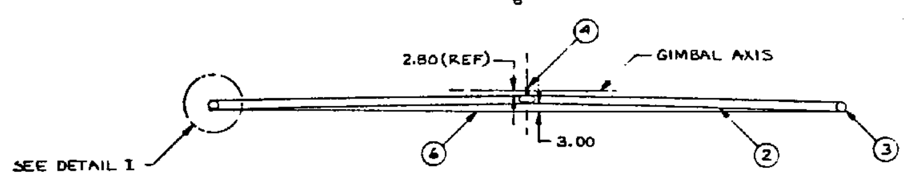
-1 REFLECTOR ASSY
SCALE: 3/8"=1'-0"



-4 CENTER FITTING
SCALE: 1/2 SIZE



VIEW B2
SCALE: 1/2 SIZE



SECTION C3
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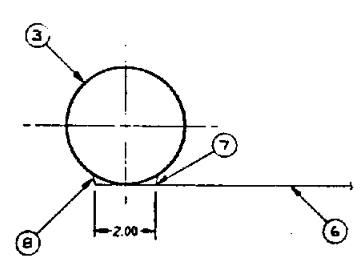
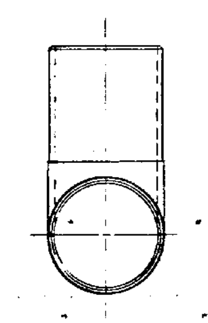
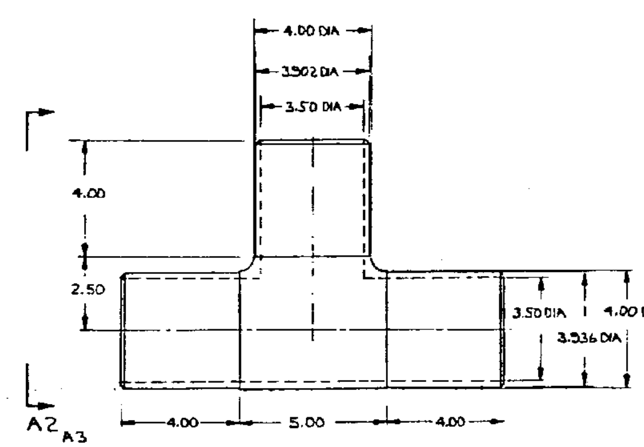


DETAIL I
SCALE: 1/2 SIZE



VIEW A3
SCALE: 1/2 SIZE



-5 RIM FITTING
SCALE: 1/2 SIZE

QTY REQD	QTY REQD	QTY REQD	QTY REQD -1	PART NUMBER	DESCRIPTION	NOTE
			2	10	SETSCREW 3/8-16UNC-2A × 1.0	5
			1	-9	KEY 5/16 × 5/16 × 2.0 STL	4
			AR	-8	FOAM - CAST POLYURETHANE	3
			AR	-7	ADHESIVE - ROOM TEMP CURE EPOXY	2
			1	-6	REFLECTIVE FILM .0035 THICK PMMA	1
			4	-5	RIM FITTING ALCOA DIE CAST ALLOY 360	
			1	-4	CENTER FITTING ALCOA DIE CAST ALLOY 360	
			4	-3	RIM TUBE 4.0 DIA × .032 × 172.2 6061 T6 AL	
			4	-2	ARM TUBE 4.0 DIA × .049 × 165.8 6061 T6 AL	
			—	-1	REFLECTOR ASSY	

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ANGLES ± 1/2° DECIMALS ± .03

USED ON SK 61001	DRAWN K Hensley	DATE 2-15-83
	CHECKED M J Berry	3-12-83
	STRESS	
SECT NO.	ENGR K Hensley	3-14-83
CHG NO.	GROUP	
GROUP ORG K 6100	PROJ M J Berry	3-14-83

BOEING
CORPORATE OFFICES SEATTLE, WA 98124

PLASTIC HELIOSTAT REFLECTOR ASSY

SIZE E | FSCM NO. 81205 | DWG NO. SK 61003
SCALE: NOTED | SH 1 OF 1

SK 61003

FIGURE 3-2

3-8-83

assembly. This process results in a controlled sag due to gravity. The controlled sag produces a parabolic reflector with a predictable focal length. The pre-tension stress level is set at different values depending upon the heliostat field zone.

3.2.1 Reflector Frame

The reflector frame consists of four circular rim segments, four T-fittings, four spokes and a center hub. The rim segments use 0.81 cm (0.032 in.) wall 10.2 cm (4.0 in.) aluminum alloy tubing while the spokes are made of 0.12 cm (0.049 in.) wall 10.2 cm (4.0 in.) aluminum alloy tubing. The T-fittings and center hub are aluminum alloy castings. Reflector frame joints are made by adhesive bonding.

3.2.2 Reflector Membrane

The reflective membrane is made by adhesive joining panels of 0.010 cm (.004 in.) thick aluminized polymethylmethacrylate film. An acrylic overcoat is provided to protect the aluminum surface from oxidation. This material was selected over previously specified metalized polyesters because of its established resistance to ultraviolet degradation. While polyester is less expensive, field testing has failed to provide any long-term weatherable polyesters.

During the course of this study four metalized film material samples were received from suppliers for evaluation. Included were:

Material	Supplier
Acrylic coated, aluminized, PMMA	3M Company
Acrylic coated, silvered, polyester	3M Company
Stainless coated, silvered, polycarbonate	Deposition Technology Inc.
Stainless coated, silvered, FEP Teflon	Deposition Technology Inc.

The 3M samples were of films currently on the market while the Deposition Technology samples were first-try lab samples. The samples were measured for specular reflectivity on the Boeing bi-directional reflectometer. The results of the measurements are shown in Figure 3-3. The results show that the silvered polyester would be preferred for its high initial reflectivity. This material demonstrates the high levels of reflectivity that can be obtained. The use of silver and the smoothness of the polyester film make the high reflectivity possible. Weatherability, however remains to be proven.

The silvered polycarbonate had high reflectivity at large cone angles but dropped off considerably at the desired small cone angles. The silvered teflon performed poorly, demonstrating the difficulties of metalized fluorocarbons. The aluminized PMMA sample had a specular reflectivity ρ_S = .86 at a cone angle of 0.14°. This material represents reflectivity that is available now and would require minimal development for heliostat application.

3.3 Drive Mechanism

The azimuth and elevation drives shown in Figure 3-4 use gearboxes specifically designed for the heliostat by the Winsmith Company. The gearbox utilizes a planetary reduction gear drive of 15376:1 gear ratio. This drive consists of two compound stages of 124:1 gear ratio each, and all components are designed for manufacturing by die cast or powdered metal procedure.

Each stage has two planet gears meshing with ring gears of identical I.D., but with a difference of 2 teeth between stationary and moving ring gear. This simplified design principle has been used successfully on a large number of applications, including the aximuth drive for the second generation heliostat drives for Boeing. The number of teeth of each stage is the same, 20 for the sun gear, 20 for the planets, 60 for the stationary ring gear, and 62 for the output ring gear. The difference is in the diametral pitch which is 24 for the first, and 16 for the second stage. Efficiency is calculated as 42% overall.

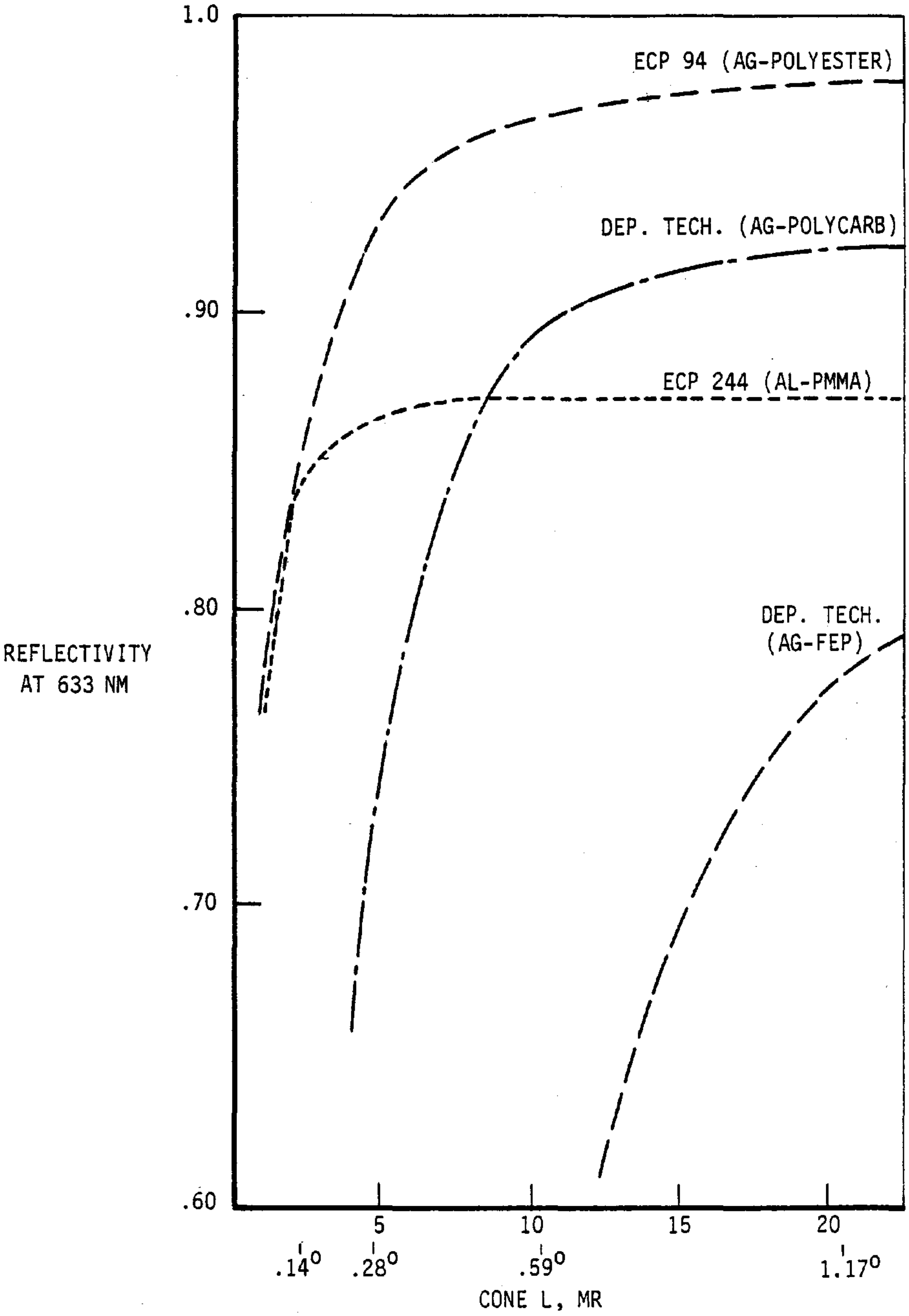


FIGURE 3-3 SAMPLE REFLECTIVITY MEASUREMENTS

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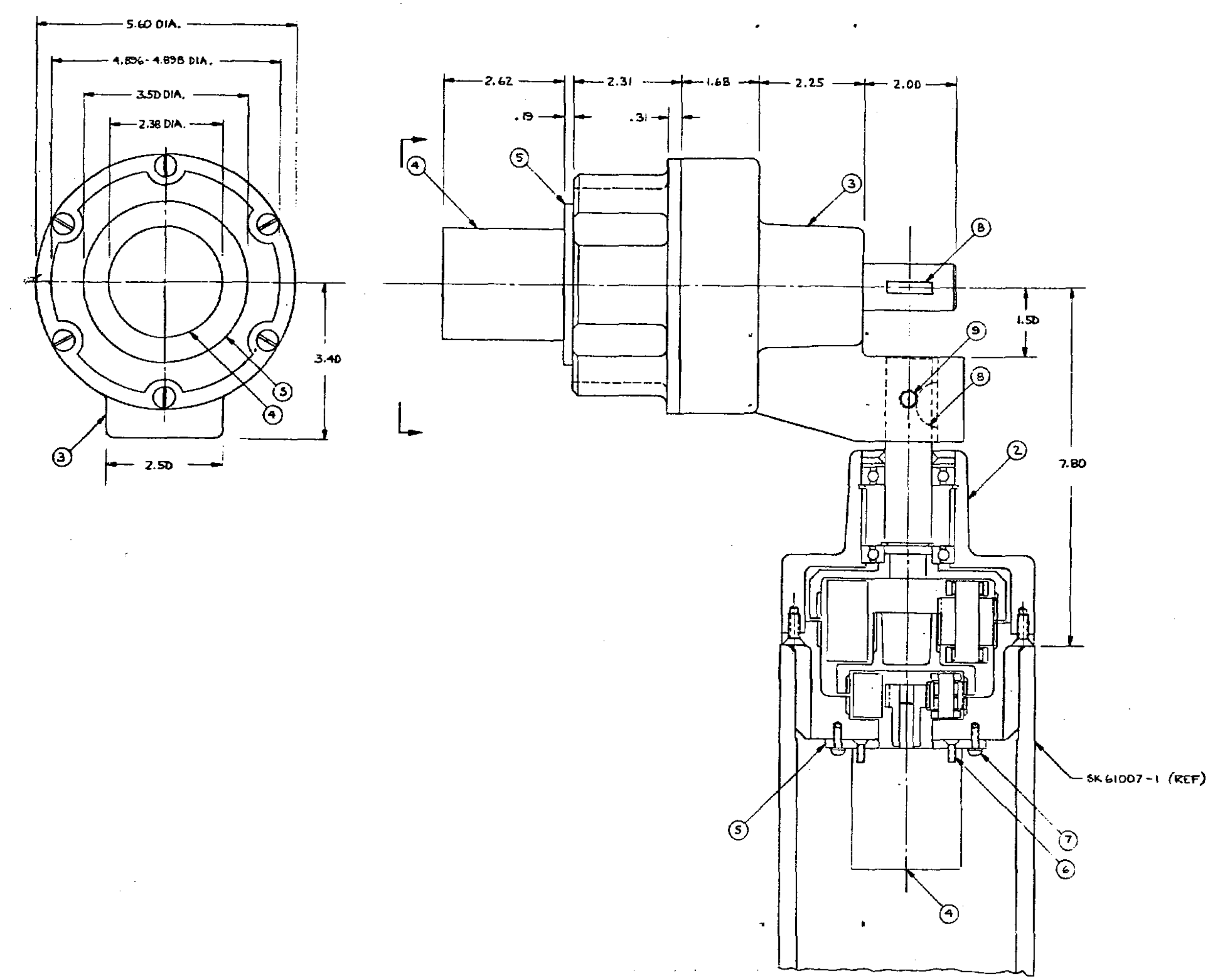
1 WINSMITH DIV. OF UMC INDUSTRIES INC. SPRINGVILLE NEW YORK 14141.

2 HURST MFG CORP. · BOX 326, PRINCETON, INDIANA, 47670

3 Mc MASTER-CARR SUPPLY CO. P.O. BOX 54960, LOS ANGELES, CA 90054



QTY REQD -3	QTY REQD -2	QTY REQD -1	PART NUMBER	DESCRIPTION	
1			-9	HEX SOCKET ALLOY STEEL CUP POINT SET SCREW 3/8-16 x 3/4 McMASTER CARR CAT NO 91375A 622	
1	1		-8	WOODRUFF KEY CARBON STEEL NO. 141 Mc MASTER CARR CAT NO 98481A190	
4	4		-7	8-32 UNC-2A x 1/2 ROUND HD PHILLIPS SCREW Mc MASTER CARR 90273D194 OR EQUIV	3
4	4		-6	8-32 UNC-2A x 1/2 FLAT HD PHILLIPS SCREW MC MASTER-CARR 90273D194 OR EQUIV	3
1	1		-5	ADAPTOR PLATE 3.75 DIA x .25 ASTM A 635 STL	
1	1		-4	AC MOTOR, 1800 RPM, HURST MB-2201	2
		1	-3	ELEVATION DRIVE, WINSMITH SK-122382-2	1
		1	-2	AZIMUTH DRIVE, WINSMITH SK-122382-1	1
		—	-1	AZIMUTH AND ELEVATION DRIVE ASSY	

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGLES ± 1/2° DECIMALS ± .03

USED ON SK 61001	DRAWN K. Hemley	DATE 2-7-83	BOEING CORPORATE OFFICES SEATTLE, WA 98124
	CHECKED M. Berm	5-12-83	
	STRESS		PLASTIC HELIOSTAT
SECT NO.	ENGR K. Hemley	3-4-83	AZIMUTH & ELEVATION DRIVE ASSY.
CHG NO.	GROUP		SIZE E · FSCM NO. 81205 · DWG NO. SK 61005
GROUP DRG K 6100	PROJ M. J. Berm	3-4-83	SCALE: FULL · SH 1 OF 1

DWG NO SK 61001

FIGURE 3-4

3-9-83

3-13 are sketches of the concepts of the trade study. Table 3-1 lists the results of the study in terms of cost, technical confidence of attachment and suitability to all terrains. A brief description of each concept follows:

Metal Dish (Figure 3-5)

This is the concept from the Prototype Heliostat Contract (Reference 3-1) which consists of a steel base dish shell which is supported by a steel tubular ring and vertical tubular steel supports. The vertical supports are connected to individual concrete, poured in place, foundations.

Concrete Ring (Figure 3-6)

The ground is excavated to provide a below grade base and access tunnel. A concentric concrete ring of sufficient mass to react pressurization and aerodynamic loads is poured in place. The enclosure is fastened to the concrete ring with metal strips and fasteners. The inside floor is lined with plastic sheeting. The pedestal is attached to a poured in place foundation.

Concrete Ring-Rebar Truss (Figure 3-7)

A concrete ring of sufficient mass to react aerodynamic loads and a pedestal foundation are poured in place. Rebar trusswork extends up from the concrete ring to support the plastic film base shell and enclosure interface.

Concrete Ring - Pipe Strut (Figure 3-8)

A concrete ring with 4 spokes of sufficient mass to react aerodyamic load is poured in place. Pipe struts connect the base ring to the plastic film base shell and enclosure interface. The pedestal mounts to the hub formed by the intersecting spokes. This design has no earth penetrations.

FIGURE 3-5 HELIOSTAT BASE FOUNDATION CONCEPT
METAL DISH

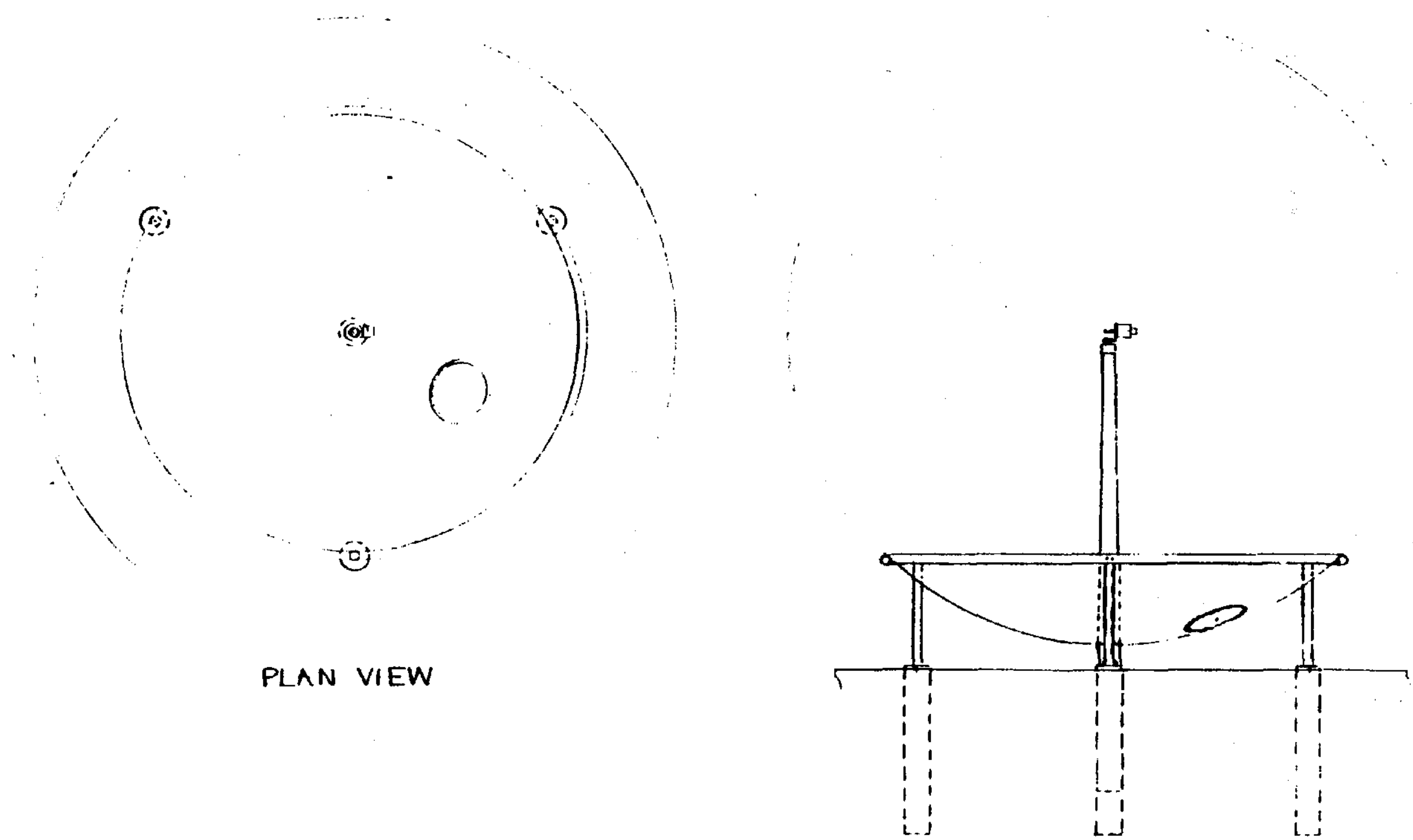
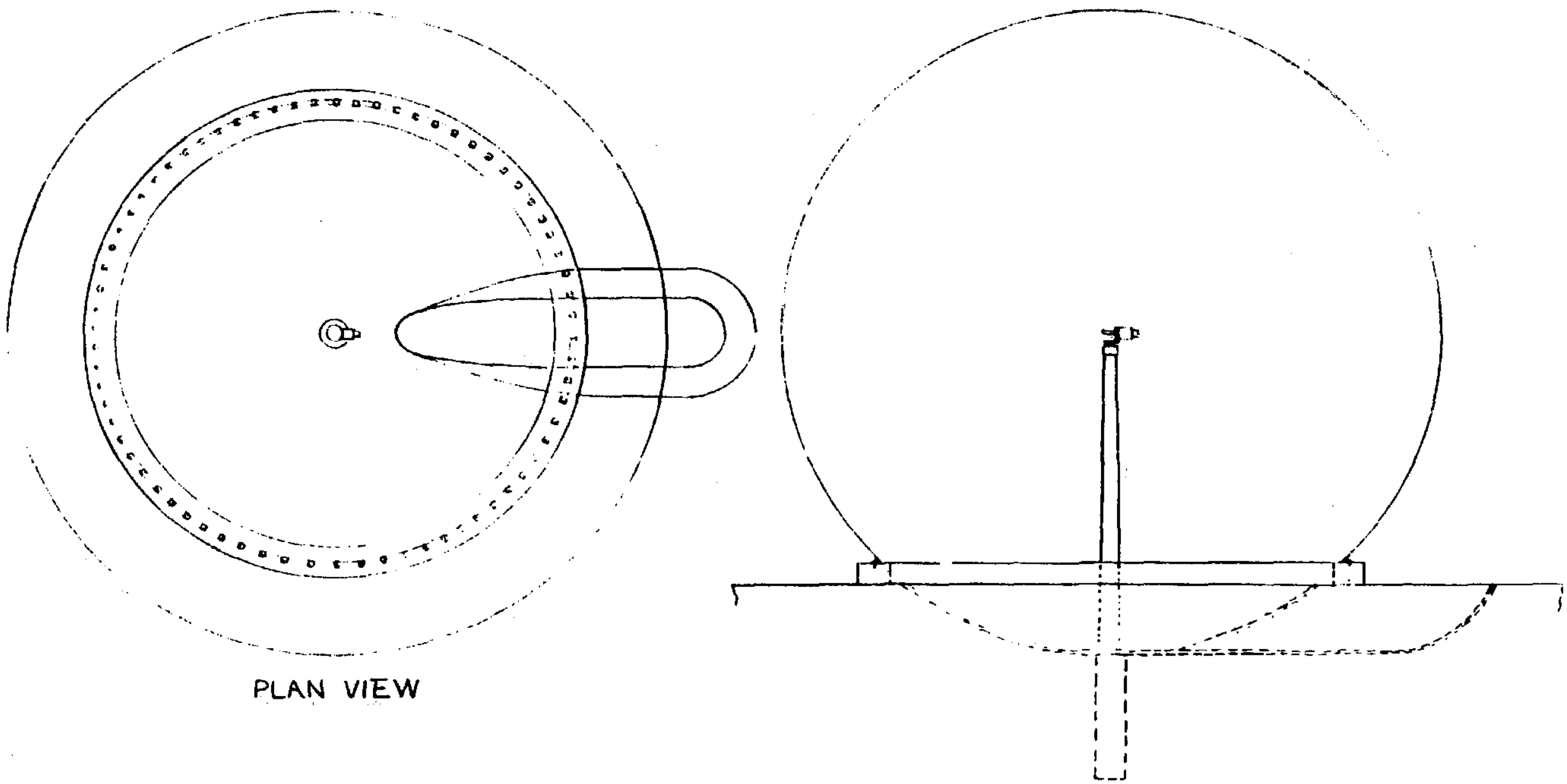


FIGURE 3-6 HELIOSTAT BASE / FOUNDATION CONCEPT
CONCRETE RING

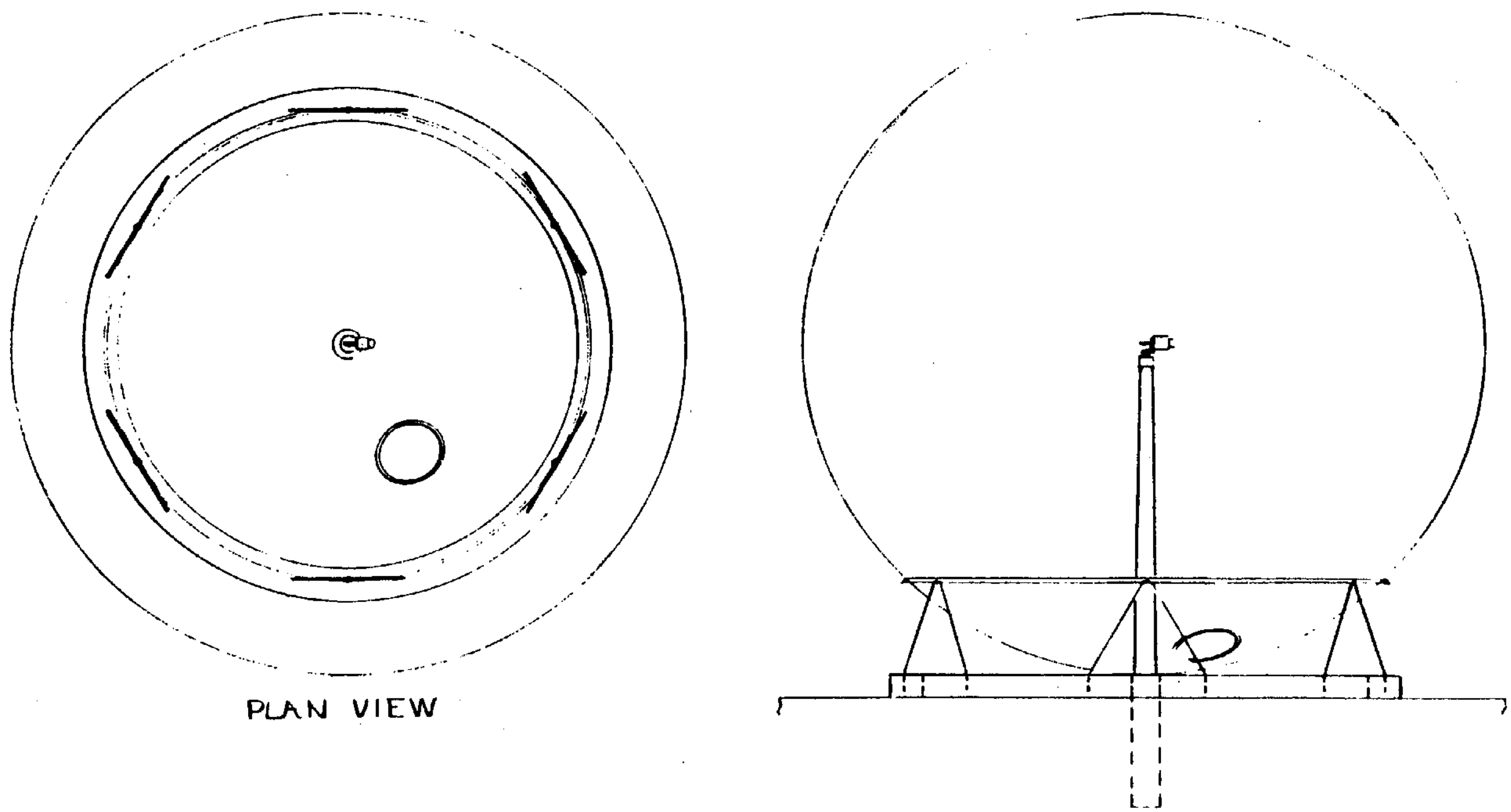


2-3-82 K HERNLEY

BOEING

NUMBER
REV LTR

FIGURE 3-7 HELIOSTAT BASE / FOUNDATION CONCEPT
CONCRETE RING - REBAR TRUSS



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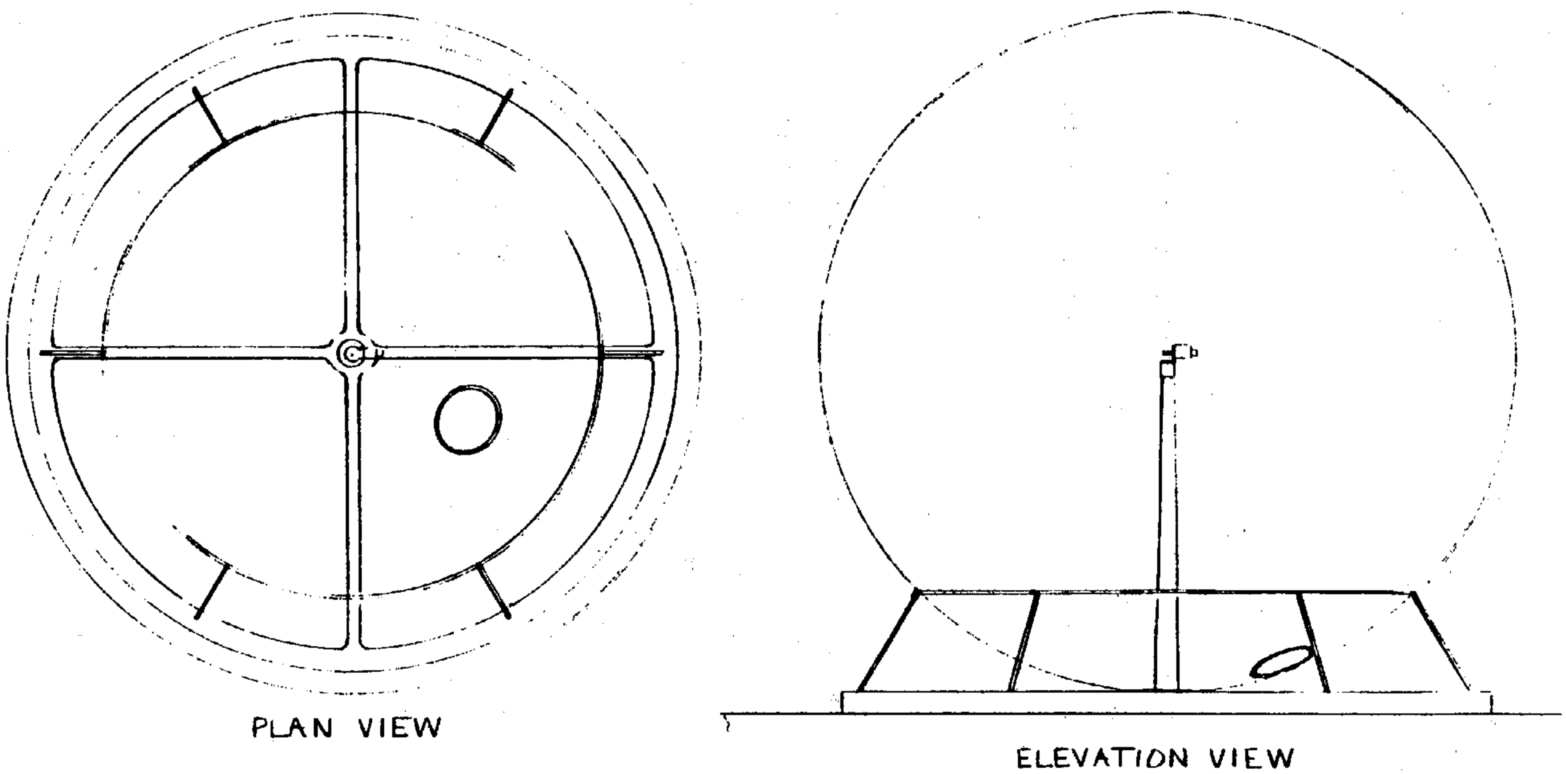
SHEET

D1 4802 8100 REV 8/71

FIGURE 3-8 HELIOSTAT BASE / FOUNDATION CONCEPT
CONCRETE RING - PIPE STRUT



2-3-83 K. HERNLEY

Concrete Cones (Figure 3-9)

Equally spaced concrete cones provide the reaction mass to aerodynamic loads. Connectors at the top of the cones fasten to the plastic film base shell/enclosure interface. The pedestal mounts to a poured in place concrete foundation.

Screw-In Anchors (Figure 3-10)

Equally spaced ground anchors are cable connected to the plastic film base/enclosure interface. The cables are pretensioned such that they retain some tension under 90 mph wind loadings. The pedestal mounts to a poured in place concrete foundation.

Overhead Cable (Figures 3-11, 3-12)

The heliostat reacts aerodynamic loads through the pedestal and an overhead wire rope cable. A plastic film base is used. Load spreading pads must be provided at top of enclosure and at intersection of base shell and pedestal. Poles capable of supporting the cable and reacting wind loads are required.

Earth-Filled Plastic (Figure 3-13)

The ground is excavated to form a cylindrical below-grade base hole and access tunnel. The cylindrical base is installed and partially backfilled with earth to provide aerodynamic reaction mass. The pedestal mounts to a poured in place concrete foundation.

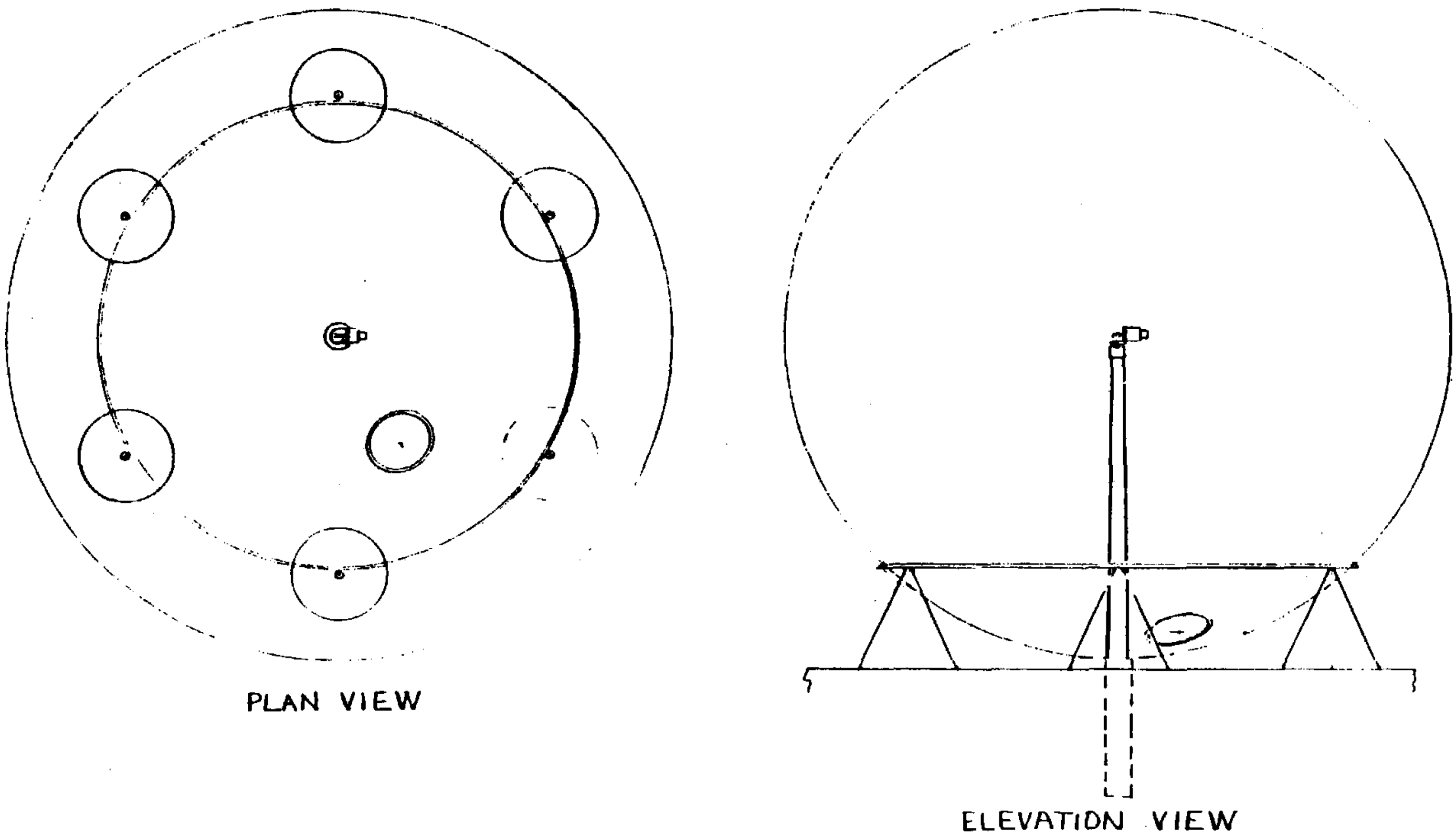
3.5.2 Selected Configuration

Examination of Table 3-1 shows the screw-in anchor concept to be the most economical. It can be seen that it's economy lies primarily in low material cost, but is also among the least labor and tooling intensive. The technique of attachment earned medium confidence as compared to the high priced steel dish and concrete ring which received high confidence. Terrain versatility was also medium compared to the totally above ground concrete ring with pipe

BOEING

NUMBER
REV LTR

FIGURE 3-9 HELIOSTAT BASE / FOUNDATION CONCEPT
CONCRETE CONES

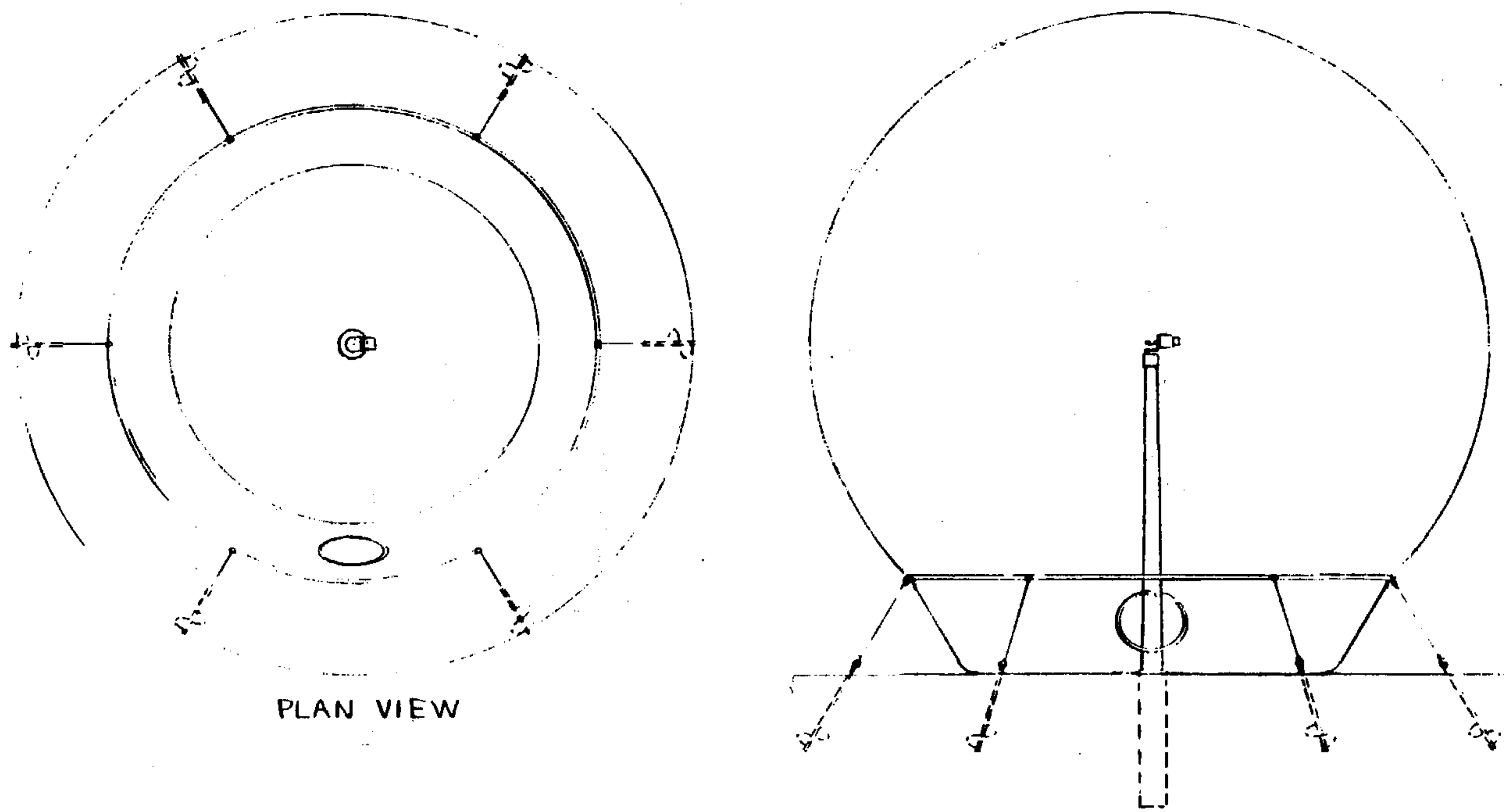


2-3-83 K HERNLEY

SHEET

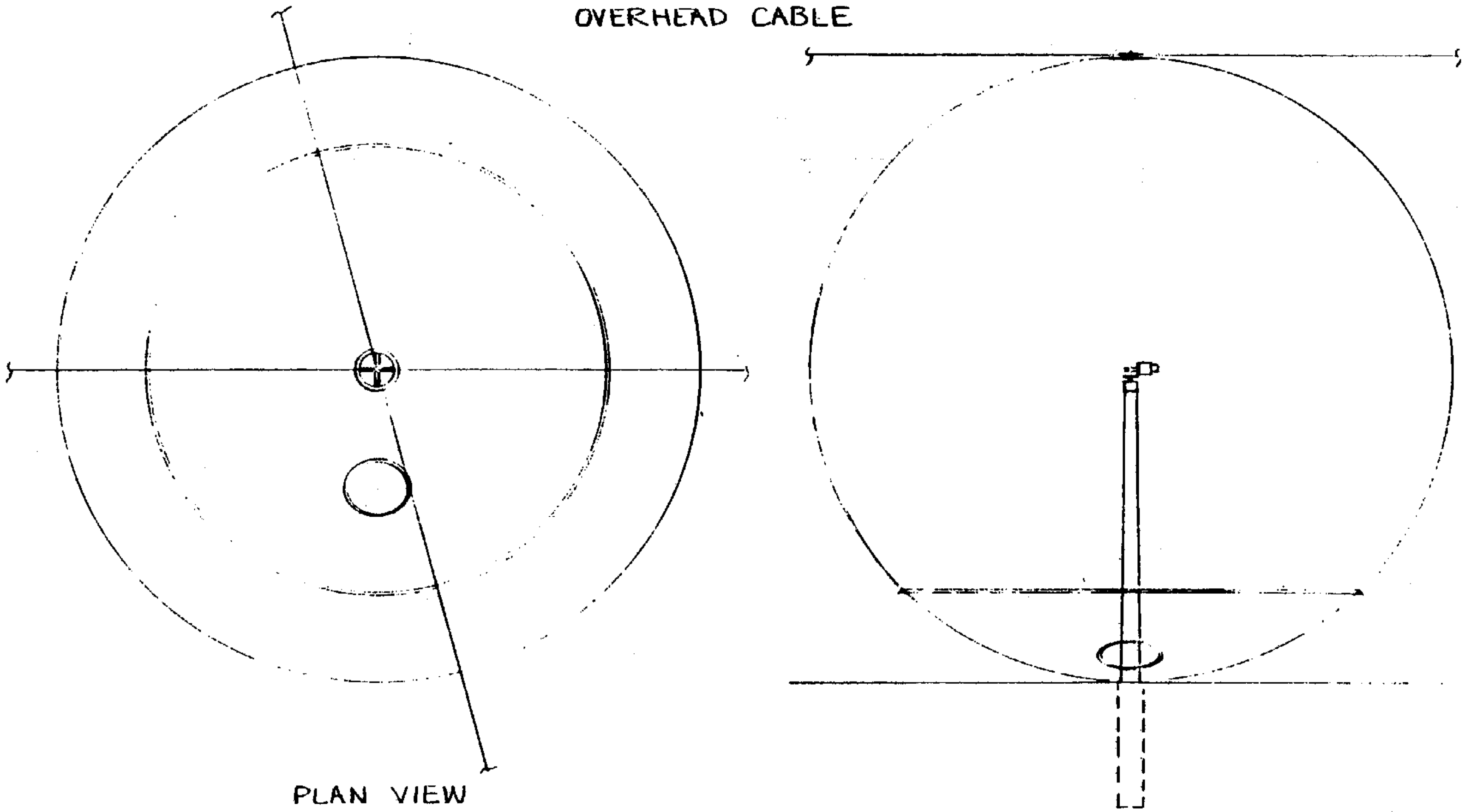
D1 4802 8100 REV 8/71

FIGURE 3-10 HELIOSTAT BASE / FOUNDATION CONCEPT
SCREW IN ANCHORS



2-3-83 K. HUNLEY

FIGURE 3-11 HELIOSTAT BASE FOUNDATION CONCEPT
OVERHEAD CABLE

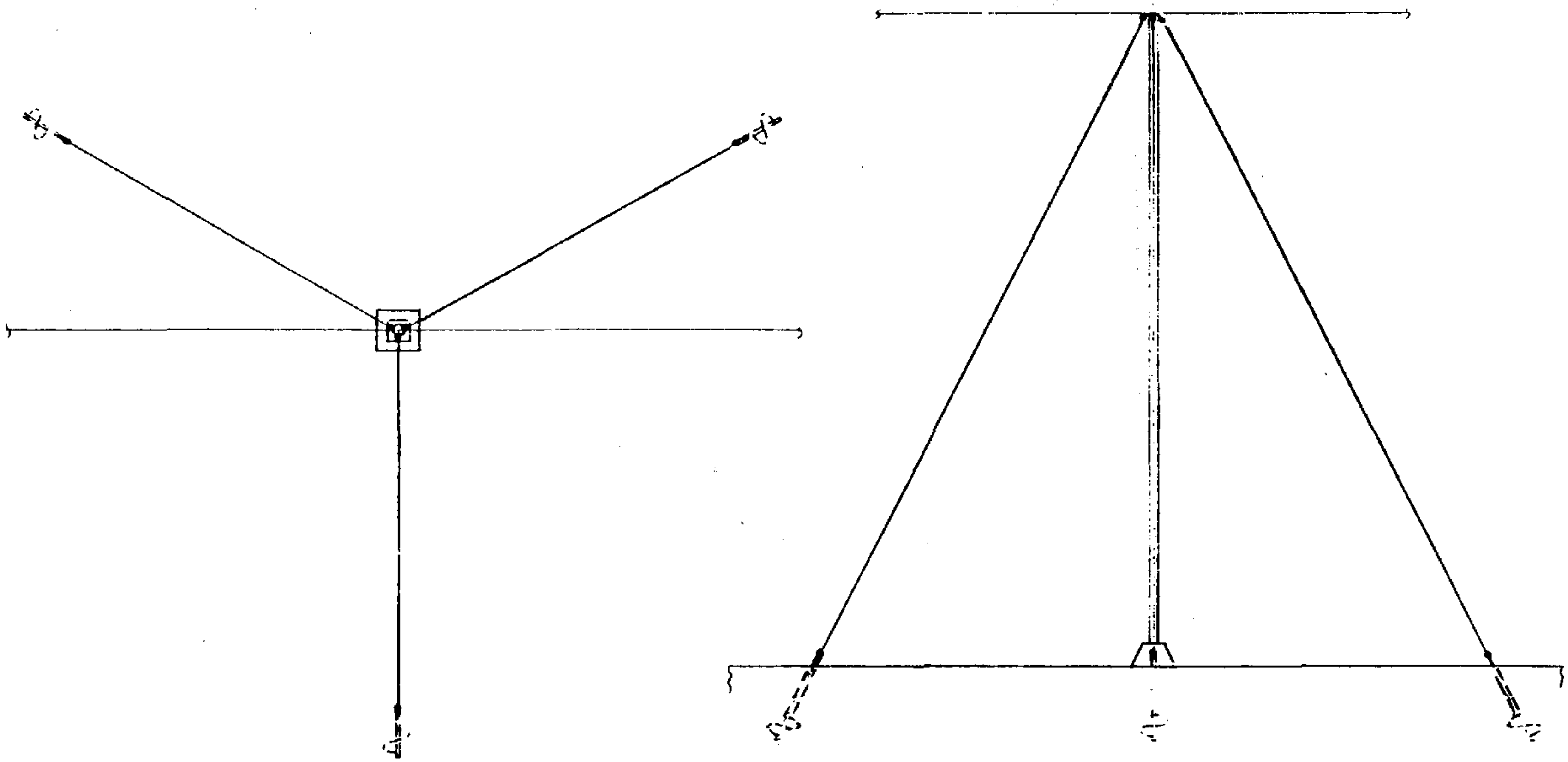


PLAN VIEW

ELEVATION VIEW

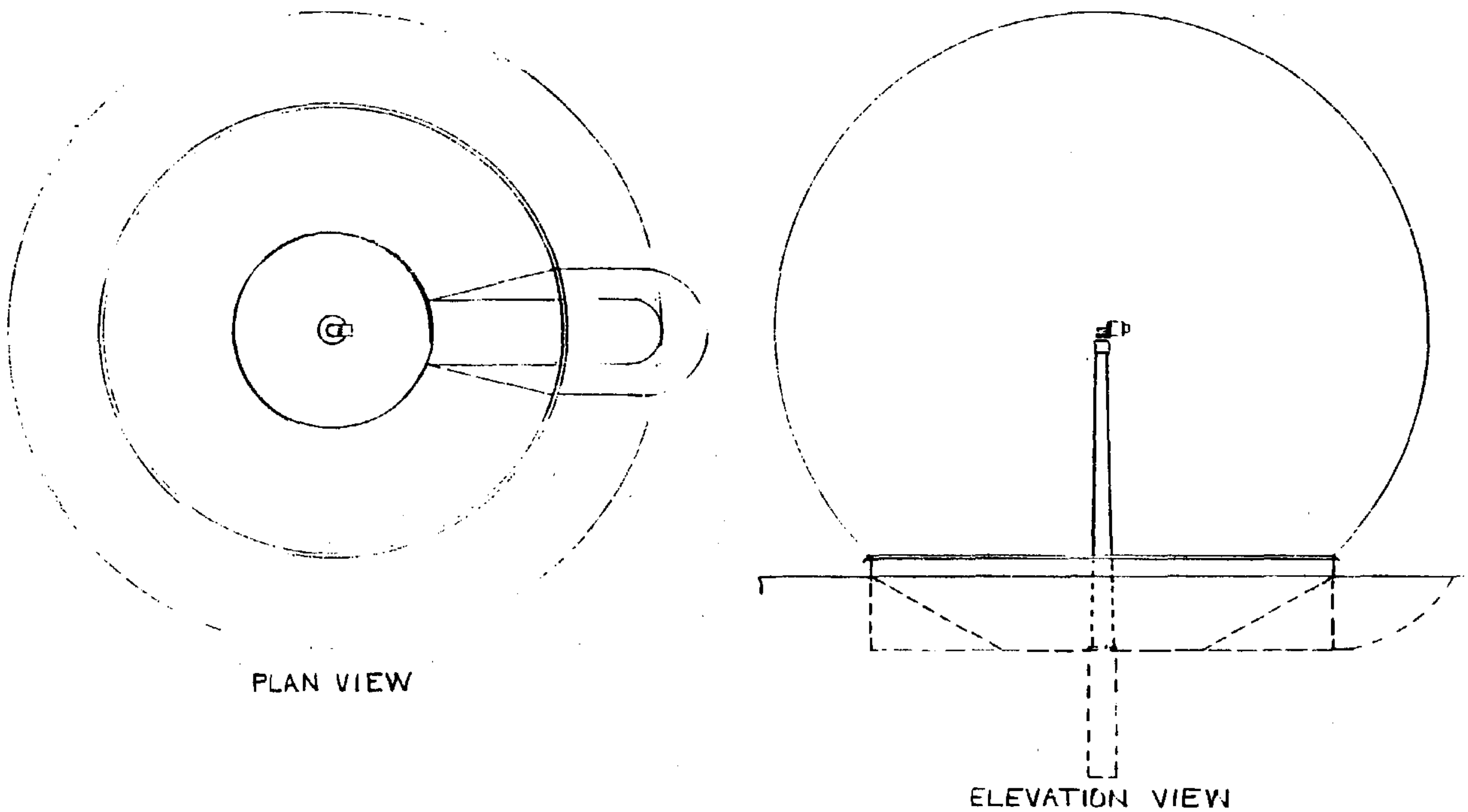
2-3-83 K. HENLEY

FIGURE 3-12 HELIOSTAT BASE / FOUNDATION CONCEPT
OVERHEAD CABLE SUPPORT POLES & ANCHORS



2-3-83 K HERNLEY

FIGURE 3-13 HELIOSTAT BASE / FOUNDATION CONCEPT
EARTH FILLED PLASTIC



2-3-83 K. MCKNLEY

TABLE 3-1

ENCLOSURE & REFLECTOR BASES

TRADE STUDY CONCEPTS

30 FOOT DIA ENCLOSURE

CONCEPTS	MATERIAL COST [1]	LABOR & TOOLING COST [2]	TOTAL COST 1983$	COST RANK	ATTACHMENT CONFIDENCE	SUITABILITY TO ALL TERRAIN	FINAL RANK	
METAL DISH	804	287	1091	8	HI	LO	8	
CONCRETE RING	503	211	714	7	HI	MED	6	
CONCRETE RING-REBAR TRUSS	424	180	605	3	MED	MED	3	
CONCRETE RING-PIPE STRUT	425.	173	598	2	MED	HI	2	[3]
CONCRETE CONES	508	176	684	6	MED	MED	7	
SCREW IN ANCHORS	322	144	466	1	MED	MED	1	← SELECT
OVERHEAD CABLE	485	163	648	5	LO	LO	4	
EARTH FILLED PLASTIC	501	140	641	4	LO	LO	5	

INFORMATION SOURCES:

[1]
- SUPPLIER QUOTES
- PROTOTYPE HELIOSTAT CONTRACT
- VENDOR CATALOGS
- ENGR ESTIMATES

[2]
- MEANS COST DATA
- PROTOTYPE HELIOSTAT CONTRACT
- EQUIPMENT SUPPLIERS
- LABOR RATES: SANDIA HELCAT MANUAL + INFLATION

[3] ALTERNATE CONCEPT FOR DIFFICULT TO EXCAVATE TERRAIN

strut which was the only high rating. The second and third ranked concepts were essentially equal in cost. The concrete ring with pipe-strut is favored because of its terrain independence. This design was selected as the alternate base/foundation for difficult soils.

Figures 3-14 through 3-17 are conceptual drawings of the selected base/foundation.

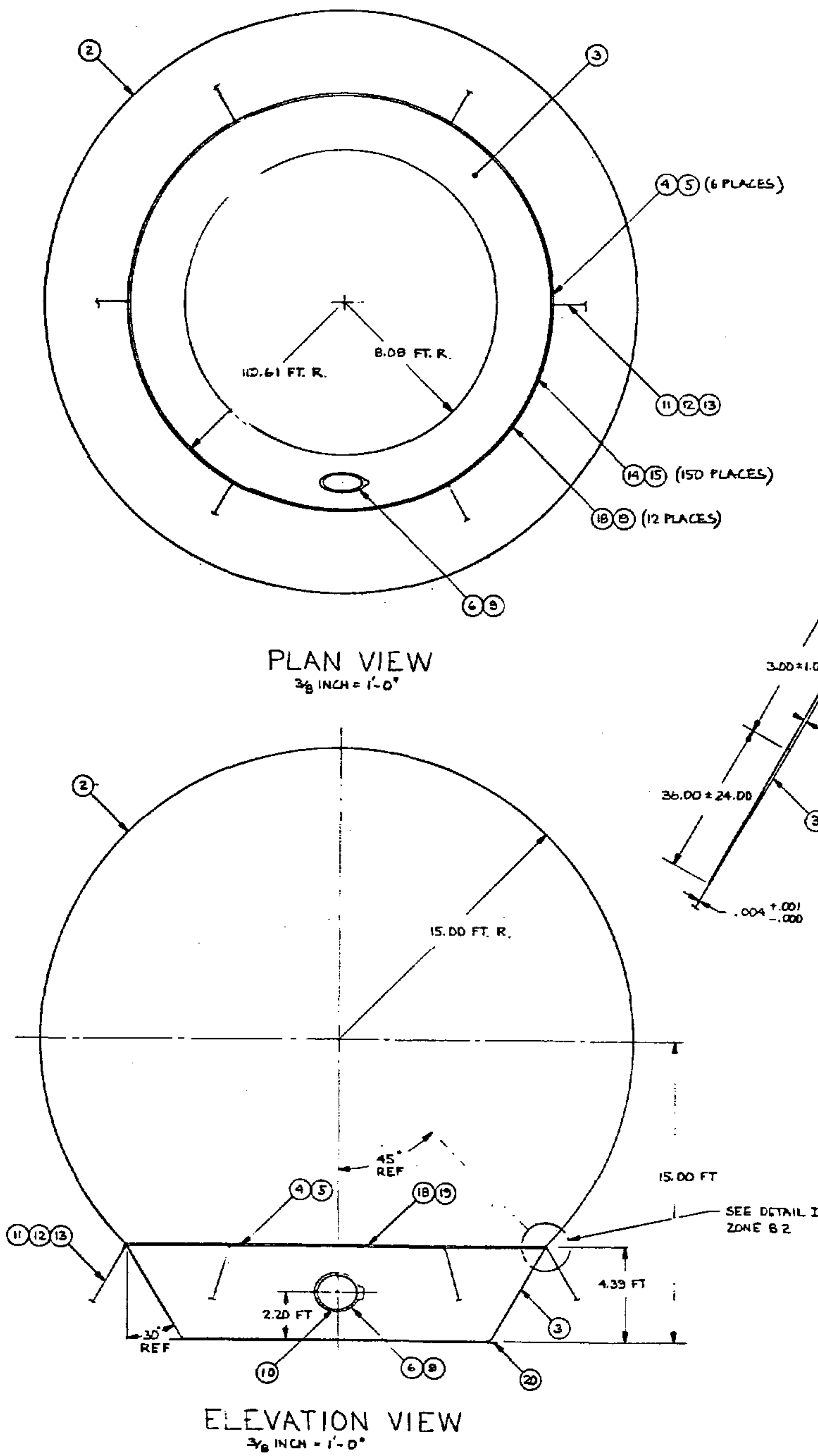
Base Shell

The .01 cm (.004 in.) base shell is made by thermoforming Kynar 1100 (Pennwalt Kynar/acrylic alloy) in a manner similar to the forming of the enclosure. Instead of free blowing the shell it will be blown against a flat surface to form the flat bottom shown in Figure 3-14. The pre-form blank diameter will be the same as for the enclosure so that mating flanges will result. Clamping angles are provided at the base shell/enclosure interface to assure leak tight closure and to provide connection points for the ground anchoring system. An air tight port with a removable cover is provided for access during installation and for unscheduled maintenance activities over the heliostat operational life. (See Figure 3-15.)

Ground Anchors

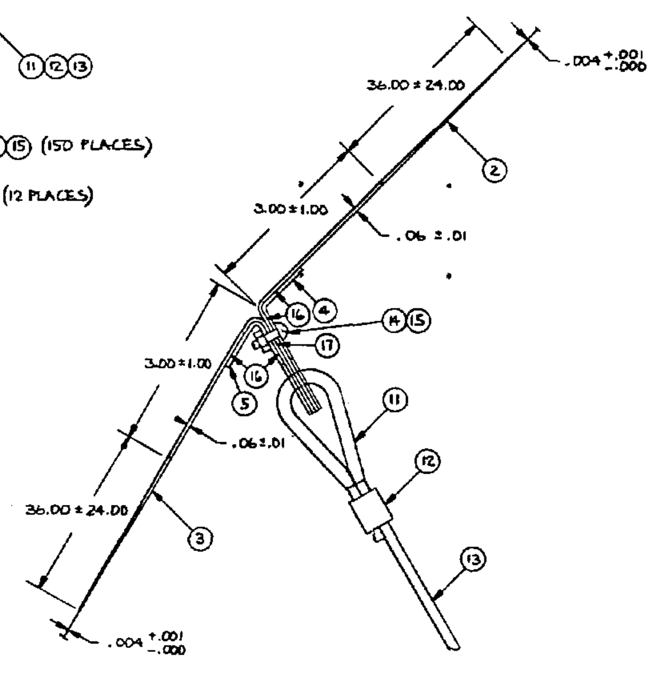
Six screw-in ground anchors provide the reaction to wind induced loads. An automatic installation machine installs the six anchors and augers the pedestal pile hole during a single set-up to assure concentricity. The upper end of the anchor includes an eye to which the tie cable is attached. The other end of the tie cable is connected to the base/enclosure interface clamp angle. Special tooling allows setting the tie cables to the desired pre-tension. An analysis of wind loads and heliostat reactions (see Section 3.6) estimated the load in a ground anchor to be 3360 lb. in a 90 MPH wind (see Figures 3-14, 3-15 and 3-16).

1. PENNWALT CORP., PENNWALT BUILDING, PHILADELPHIA, PENN, 19102 BLOW FORM PREMOLDED BLANK TO SHAPE SHOWN.
2. HOT ROLLED STEEL SHEET PER ASTM A635. AFTER PUNCHING AND FORMING SAND BLAST AND HOT DIP GALVANIZE PER ASTM A 386.
3. MAKE FROM ACCEPTABLE PORTIONS OF REJECTED -3 PARTS OR FROM .004 +.001 -.000 THICK FILM OF KYNAR/ACRYLIC ALLOY 1140 FROM SOURCE 1
4. INJECTION MOLD FROM TYPE II MEDIUM DENSITY POLYETHYLENE ANY SOURCE
5. Mc MASTER CARR SUPPLY CORP, PO BOX 54960, LOS ANGELES, CALIF 90054.
6. JOSEPH T. RYERSON & SON BOX 3525, SEATTLE, WA 98124
7. R.D. ABBOTT CO. INC. P.O. BOX 4275, LONG BEACH, CALIF. 90804.
8. HOLE PATTERNS IN MATING PARTS MUST MATCH FOR FASTENER INSTALLATION.



PLAN VIEW
3/8 INCH = 1'-0"

ELEVATION VIEW
3/8 INCH = 1'-0"



DETAIL I
FULL SIZE

QTY REQD	QTY REQD	QTY REQD -6	QTY REQD -1	PART NUMBER	DESCRIPTION		REV LTR
			1	-20	GROUND COVER - 20 FT. DIA. × 4 MIL BLACK POLYETHYLENE SHEETING	5	
			12	-19	LWR ANGLE .063 × 2.0 × 55.0 6061-T6 ALUMINUM SHEET OR COIL	6	
			12	-18	UPR ANGLE .063 × 2.0 × 55.0 6061 T6 ALUMINUM SHEET OR COIL	6	
			AR	-17	SEALANT - BUTYL RUBBER - CAT NO 9407T14	5	
		AR	AR	-16	ADHESIVE VERSALOK 521	7	
			150	-15	8-32 ROUND HEAD PHILLIPS MACHINE SCREW 18-8 STAINLESS STL. CAT. NO. 91773D192	5	
			150	-14	8-32 HEX MACHINE SCREW NUT 18-8 STAINLESS STL. CAT. NO. 91841A009	5	
			6	-13	CABLE - 1×19 GALVANIZED 3/16" CAT NO 3450T17	5	
			6	-12	SLEEVE - COPPER 3/16" CAT. NO. 3572T30	5	
			6	-11	THIMBLE - GALV. STEEL 3/16" CAT. NO. 3434T12	5	
			30	-10	SCREW - 8-32 × 1/4 PAN HEAD PHILLIPS 18-8 CRES CAT. NO. 91772D190	5	
			1	-9	INNER RING - POLYETHYLENE	4	
		1		-8	OUTER RING - POLYETHYLENE	4	
		1		-7	WINDOW - KYNAR/ACRYLIC ALLOY 1140	3	
			1	-6	OUTER PORT ASSY		
			6	-5	LWR ANGLE 16GA × 3.0 × 24.0 STL SHT	2	
			6	-4	UPR ANGLE 16GA × 3.0 × 24.0 STL SHT	2	
			1	-3	BASE - KYNAR/ACRYLIC ALLOY 1140	1	
			1	-2	ENCLOSURE - KYNAR 460	1	
			—	-1	ENCLOSURE & BASE ASSY		

PARTS LIST

USED ON SK 61001	DRAWN K. Henley 2-5-83	BOEING CORPORATE OFFICES SEATTLE, WA 98124
	CHECKED M.J. Berry 3-12-83	PLASTIC HELIOSTAT ENCLOSURE & BASE ASSY
SECT NO.	ENGR K. Henley 3-14-83	
GROUP ORG K 6100	PROJ M.J. Berry	SIZE E FSCM NO 81205 DWG NO. SK 61002
		SCALE: NOTED SH 1 OF 2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGLES ± 1.0° DECIMALS ± .03

SK 61002

FIGURE 3-14

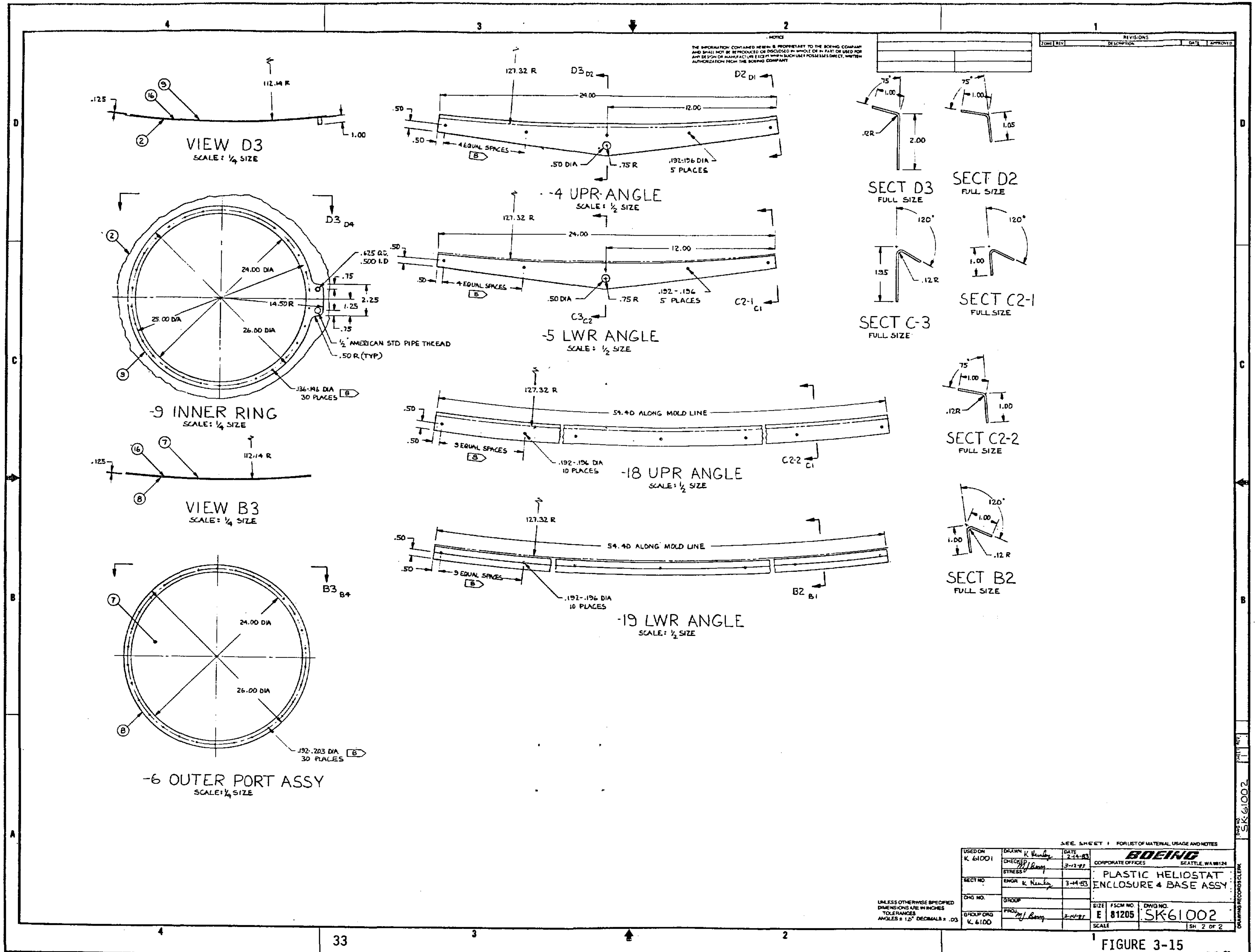

VIEW D3
SCALE: 1/4 SIZE
-4 UPR ANGLE
SCALE: 1/2 SIZE
SECT D3
FULL SIZE
SECT D2
FULL SIZE
-9 INNER RING
SCALE: 1/4 SIZE
-5 LWR ANGLE
SCALE: 1/2 SIZE
SECT C-3
FULL SIZE
SECT C2-1
FULL SIZE
1/2" AMERICAN STD PIPE THREAD
.50 R (TYP)
.136-.146 DIA 30 PLACES
-18 UPR ANGLE
SCALE: 1/2 SIZE
54.40 ALONG MOLD LINE
SECT C2-2
FULL SIZE
VIEW B3
SCALE: 1/4 SIZE
-19 LWR ANGLE
SCALE: 1/2 SIZE
SECT B2
FULL SIZE
-6 OUTER PORT ASSY
SCALE: 1/4 SIZE
.192-.203 DIA 30 PLACES
SEE SHEET 1 FOR LIST OF MATERIAL, USAGE AND NOTES
BOEING
PLASTIC HELIOSTAT ENCLOSURE & BASE ASSY
SIZE E
FSCM NO. 81205
DWG NO. SK61002
SH 2 OF 2
USED ON K 61001
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
D1 5007 3280 REV. 3/80

FIGURE 3-15

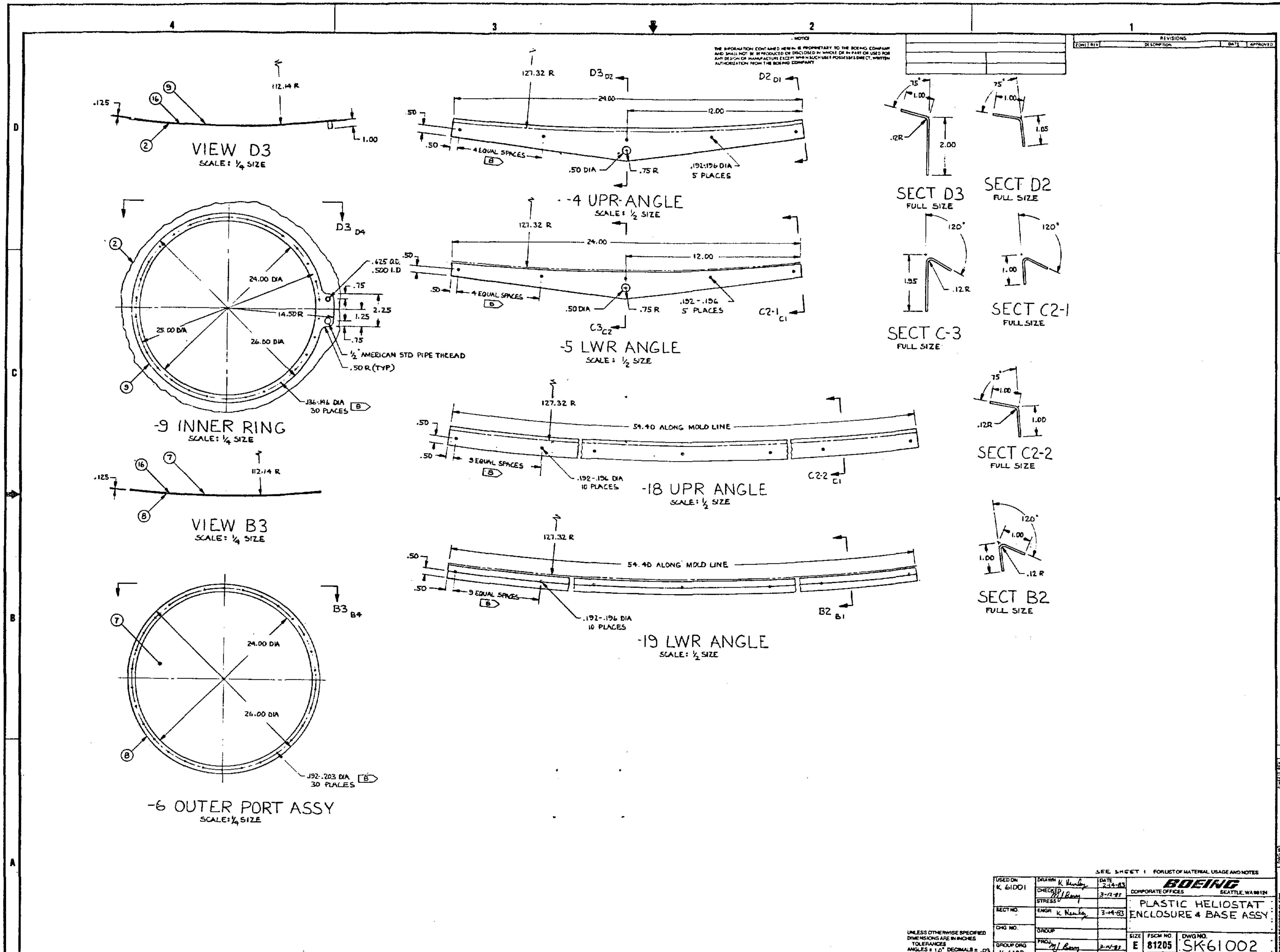

VIEW D3
SCALE: ¼ SIZE
-4 UPR ANGLE
SCALE: ½ SIZE
SECT D3
FULL SIZE
SECT D2
FULL SIZE
-9 INNER RING
SCALE: ¼ SIZE
-5 LWR ANGLE
SCALE: ½ SIZE
SECT C-3
FULL SIZE
SECT C2-1
FULL SIZE
-18 UPR ANGLE
SCALE: ½ SIZE
SECT C2-2
FULL SIZE
VIEW B3
SCALE: ¼ SIZE
-19 LWR ANGLE
SCALE: ½ SIZE
SECT B2
FULL SIZE
-6 OUTER PORT ASSY
SCALE: ¼ SIZE
24.00 DIA
25.00 DIA
26.00 DIA
14.50 R
127.32 R
112.14 R
54.40 ALONG MOLD LINE
½" AMERICAN STD PIPE THEAD
.50 R (TYP)
.136-.196 DIA 30 PLACES
.192-.196 DIA 10 PLACES
.192-.203 DIA 30 PLACES
SEE SHEET 1 FOR LIST OF MATERIAL USAGE AND NOTES
BOEING
CORPORATE OFFICES SEATTLE, WA 98124
PLASTIC HELIOSTAT ENCLOSURE & BASE ASSY
USED ON K 61001
GROUP ORG K 6100
SIZE E
FSCM NO 81205
DWG NO. SK61002
SH 2 OF 2
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ANGLES ± 1.0° DECIMALS ± .03

FIGURE 3-15

Pedestal

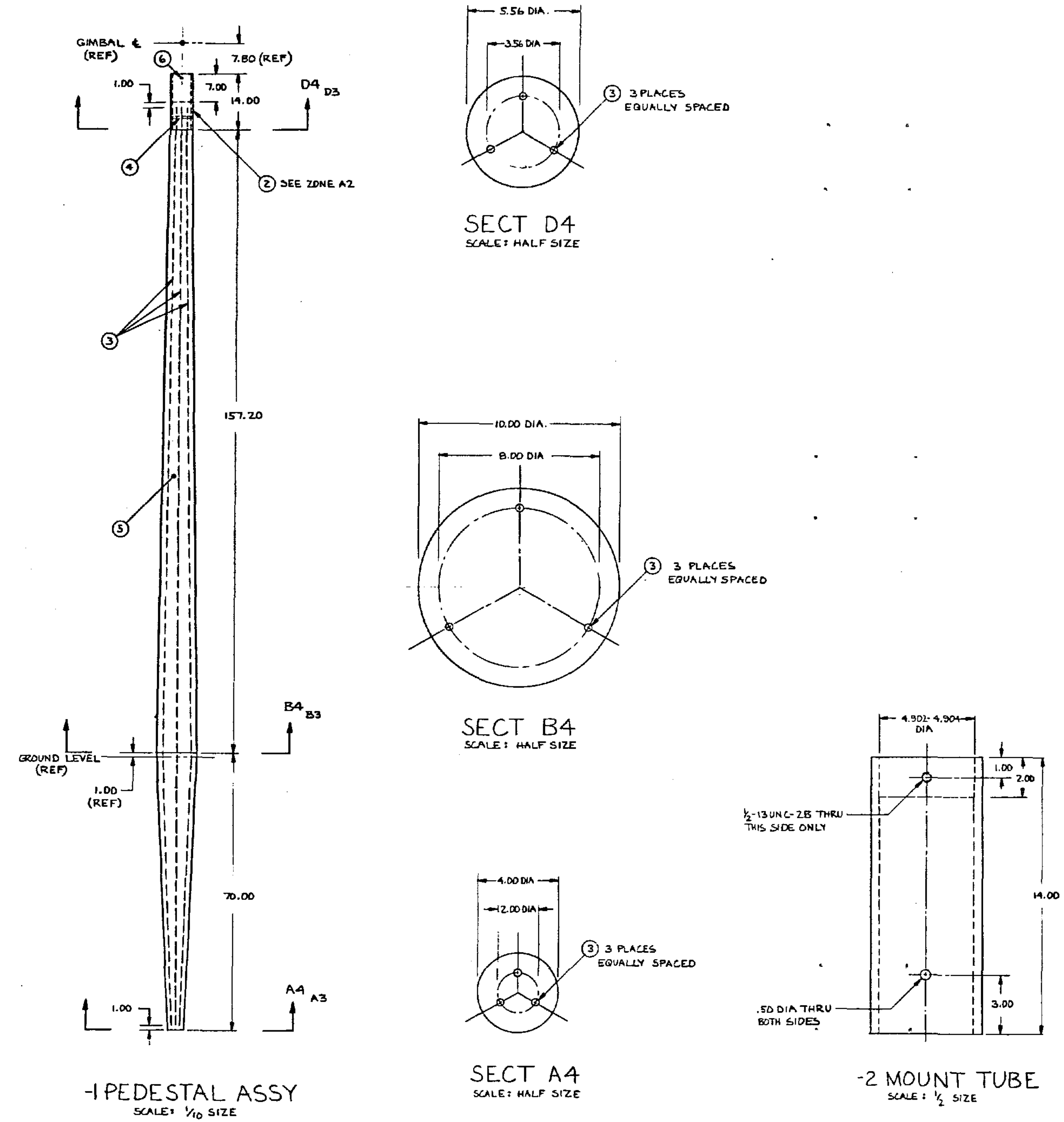
The pedestal is a steel reinforced concrete, double tapered, truncated cone. It tapers from the ground plane up to the drive connection, and from the ground plane downward into the hollow pile. It is pre-fabricated on site. Details are shown in Figure 3-16 and 3-17. During installation the pedestal is simply lowered into the cast hollow pile which has tapered internal walls that mate with the lower end of the pedestal. Concrete-to-concrete friction precludes rotary motion during reflector operation. The upper end of the pedestal includes a cast-in mounting for installation of the drive unit.

Air Supply

To limit deflection of the protective enclosure the air supply system maintains an enclosure pressure equal to or greater than the wind impact pressure generated by a 40 m/s (90 MPH) wind. The simplicity of the system results in a high reliability over its 30 year life. A layout of the air supply assembly is shown in Figure 3-18. Four components make up the system; a prefilter, blower, a primary filter and a pressure relief valve. These components are located external to the heliostat in a sheet metal cannister above the HC enclosure. The maximum power consumption of the air supply system is 15 watts.

A positive internal pressure 6.9 KN/m^2 (0.1 psig) above external ambient pressure is required to maintain clearance between the inflated enclosure and the reflector structure during specified 40 m/s (90 MPH) wind velocity. This differential pressure was calculated by integrating the wind impact pressure distribution over the frontal area of the protective enclosure.

Ambient temperature and pressure variations result in the requirement for variable air flow into and out of the enclosure. This variable flow rate plus steady state leakage are additive. The air supply system must be sized for the maximum demand, coinciding with the worst-case climatic conditions, to compensate for this flow rate variation. Analysis of climatic data for New



QTY REQD	PART NUMBER	DESCRIPTION
1	-6	SET SCREW HEX SOCKET ALLOY STEEL CUPPOINT 1/2-13 × 1/2 McMASTER CARR CAT NO 91375A 707
AR	-5	CONCRETE - 7 SACKS/YD MAX 6 GAL H_2O/SACK MAX AGGREGATE 1 IN. MIN COMP 3000 PSI 28 DAY
1	-4	BAR - 1/2" DIA × 5.60 HOT ROLLED STEEL PER ASTM A 575
3	-3	REBAR - NO 3 × 234" PER ASTM A 615 GRADE 40
1	-2	MOUNT TUBE - 5" × 14.0" EXTRA STRONG SCHED 80 PIPE PER ASTM A 53
—	-1	PEDESTAL ASSY

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANGLES ± 1/2° DECIMALS ± .03

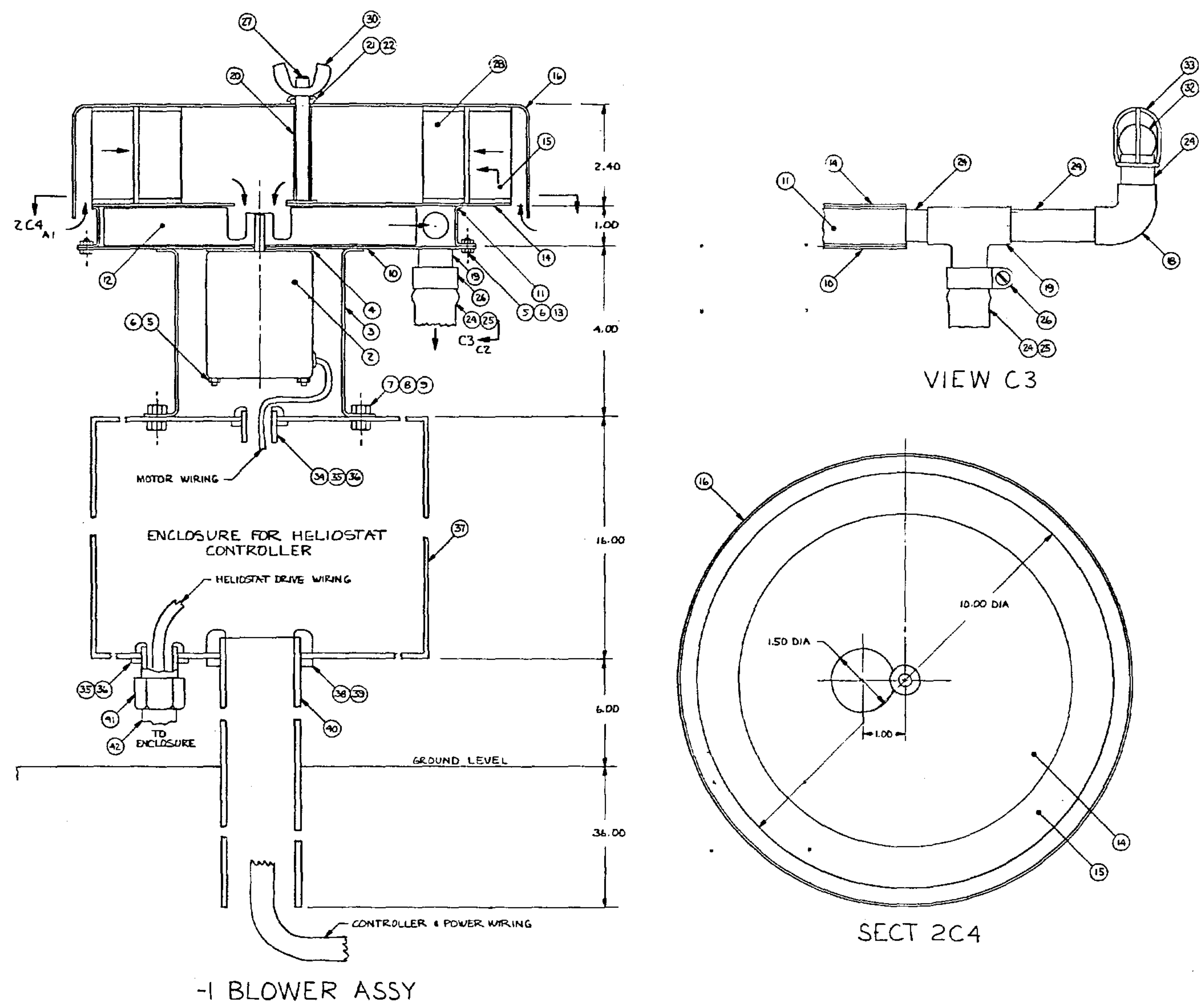
USED ON SK61001 | DRAWN K Hanley 3-8-83 | CHECKED 3-12-83 | ENGR K Hanley 3-19-83 | PROJ M J Berg 3-14-83 | GROUP ORG K6100

BOEING CORPORATE OFFICES SEATTLE, WA 98124

PLASTIC HELIOSTAT PEDESTAL ASSY

SIZE E | FSCM NO. 81205 | DWG NO. SK61007 | SCALE: NOTED | SH 1 OF 1

FIGURE 3-17



QTY REQD -1	PART NUMBER	DESCRIPTION
1	-42	LIQUID TIGHT FLEX CONDUIT 1/2 IN × 60 NORTH COAST ELECTRIC
1	-41	CONNECTOR - LIQUID TIGHT FLEX CONDUIT 1/2 IN NORTH COAST ELECTRIC CAT. NO STN-50
1	40	CONDUIT - HEAVY DUTY HOT-DIPPED GALVANIZED 1 1/2 DIA × 43 IN - NORTH COAST ELECTRIC
1	-39	DRIVE NUT 1 1/2" NORTH COAST ELECTRIC CAT. NO. BL150
1	-38	CONDUIT BUSHING - MOLDED NON METALLIC 1 1/2" NORTH COAST ELECTRIC CAT. NO. 24-112
1	-37	ENCLOSURE - NEMA TYPE 12 - 6×12×16 NORTH COAST ELECTRIC CAT. NO. 161206
2	-36	DRIVE NUT 1/2" NORTH COAST ELECTRIC CAT. NO. BL-50
2	-35	CONDUIT BUSHING - MOLDED NON METALLIC 1/2" NORTH COAST ELECTRIC CAT NO 24-12
1	-34	NIPPLE - RIGID CONDUIT 1/2" DIA CLOSE NORTH COAST ELECTRIC CO.
1	-33	PRESSURE RELIEF COVER INJECTION MOLDED POLYETHYLENE
1	-32	PRESSURE RELIEF BALL, .850 DIA ALUMINUM ALCOA 43 F OR EQUV.
1	-31	
1	-30	WING NUT 5/16 - 18 ZINC PLATED STEEL McMASTER CARR CAT. NO. 90866A030
1	-29	
1	-28	2ND STAGE FILTER - 7.75 OD. × 5.75 I.D × 2.30 PLEATED ACROPOR 0.45 µm GELMAN INST CO.
1	-27	STUD 5/16 - 18UNC-2A × 3.0 WITH 3/4 DIA RES WELD HEAD PER SAE J429
1	-26	HOSE CLAMP - 5/16 - 7/8 STAINLESS STEEL McMASTER CARR CAT. NO. 5321K16
1	-25	EXHAUST HOSE - 5/8 I.D. × 15/16 O.D. × 60.0 SBR McMASTER CARR CAT. NO. 5288K53
AR	-24	EXHAUST TUBE - MAKE FROM 3/4 O.D × 16 GA × 6.0 STEEL TUBE PER ASTM A 513 TYPE 5
1	-23	-
1	-22	O-RING 5/16 I.D. × 7/16 O.D. × 1/16 BUNA N McMASTER CARR CAT. NO. 9452K19
2	-21	CUP WASHER - 3/4 O.D × 5/16 I.D. × 18 GA HOT ROLLED STEEL SHEET PER ASTM A 569
1	-20	SPACER 7/16 O.D. × 18 GA × 2.20 STEEL TUBE PER ASTM A 513 TYPE 5
1	-19	TUBE FITTING - TEE FOR 3/4 OD TUBE SIMILAR TO McMASTER CARR CAT NO 5520K12
1	-18	TUBE FITTING - 90° ELBOW FOR 3/4 OD TUBE SIMILAR TO McMASTER CARR CAT NO 5520K62
1	-17	
1	-16	FILTER COVER - 18 GA × 17.0 DIA HOT ROLLED STEEL SHEET PER ASTM A 569
1	-15	1ST STAGE FILTER NO. CA352 FRAM CORP, PROVIDENCE, RHODE ISLAND
1	-14	UPR MOUNT PL - 18 GA × 10.0 DIA HOT ROLLED STEEL SHEET PER ASTM A 569
8	-13	HEX HEAD MACHINE SCREW 10-24UNC-2A × 1/4 ZINC CHROMATE STEEL McMASTER CARR CAT. NO. 90267D 238
1	-12	ROTOR - DIE CAST ALUMINUM 7.5 OD. PER IMC MAGNETICS CORP DWG SK-1862
1	-11	SCROLL - FORM FROM 18 GA × 10.0 DIA HOT ROLLED STEEL SHEET PER ASTM A 569
1	-10	LOWER MOUNT PLATE 18 GA × 9.50 DIA HOT ROLLED STEEL SHEET PER ASTM A 569
8	-9	LOCK WASHER ZINC PLATED STEEL HELICAL SPRING 1/4 IN. McMASTER CARR CAT. NO. 91102A029
8	-8	HEX MACHINE SCREW NUT 1/4-20UNC-2B ZINC PLATED STEEL McMASTER CARR CAT. NO. 90480A029
8	-7	HEX HEAD CAP SCREW 1/4-20UNC-2B × 1/2 ZINC CHROMATE STEEL McMASTER CARR CAT NO 91236A537
12	-6	LOCK WASHER ZINC PLATED STEEL HELICAL SPRING NO. 10 McMASTER CARR CAT. NO. 91102A011
12	-5	HEX MACHINE SCREW NUT 10-24UNC-2B ZINC PLATED STEEL McMASTER CARR CAT NO 90480A011
4	-4	MOTOR MOUNT STUD 10-24 UNC-2A × 3.25 WITH 7/8 DIA RES. WELD HD PER SAE J429
1	-3	MOTOR HOUSING - 4.0 OD × 16 GA × 5.0 LONG STEEL TUBING PER ASTM A 513 TYPE 5
1	-2	BLOWER MOTOR 115 V 60 HZ 15 WATTS NOM. IMC MAGNETICS CORP SK-1862
—	-1	BLOWER ASSY & ELECTRICAL ENCLOSURE

PARTS LIST

USED ON SK61001

DRAWN 3-2-83 · CHECKED 3-12-83 · ENGR 3-19-83

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ANGLES ± 1/2° DECIMALS ± .03

GROUP ORG K6100

BOEING CORPORATE OFFICES SEATTLE, WASH

PLASTIC HELIOSTAT
BLOWER ASSY & ELECTRICAL ENCLOSURE

SIZE E · FSCM NO. 81205 · DWG NO. SK61006

SCALE: FULL · SH 1 OF 1

FIGURE 3-18

Mexico indicates that to maintain constant pressure, flow rate will vary between +0.04 m^3/min (+1.48 cfm)to -0.05 m^3/min (-1.73 cfm), the minus sign indicating flow out of the enclosure.

Enclosure leak rate is considered a negative flow and is determined by summing the individual points of leakage. A total leak rate of 0.006 m^3/min (0.2 cfm) has been estimated.

Combining the above rates indicates that the air pump must supply a peak air flow of 0.05 m^3/min (1.68 cfm) at 6.9 KN/m^2 (0.1 psig) and that the enclosure must vent a total of 0.043 (1.53 cfm) at 6.9 KN/m^2 (0.1 psig).

In operation, ambient air is drawn through the system prefilter, then a primary filter through the blower and expelled into the enclosure. As shown in Figure 3-18 a pressure relief valve has been incorporated in the manifold to vent excess blower air and air from the enclosure which occasionally must be relased due to ambient temperature or pressure changes. The pressure relief valve incorporates a sharp-edged seat and ball poppet. Relief pressure is determined by the weight of the ball versus the net unseating force generated by the internal heliostat pressure. This scheme eliminates springs which are difficult to tune and prone to failure.

Incoming air first passes through a Gelman type-E glass-fiber depth-filter, then through a Gelman Acropor membrane filter with a pore size of 0.45 um. A layer of glass scrim separates the two filter medias. The first filter layer will entrain 99.7% of the total mass of airborne particulate. 99.99% of the remaining mass will be filtered out by the membrane layer.

The various components of the air-supply package are mounted external to the heliostat in a formed sheet metal cannister. The cannister is designed to prevent water from entering the system. Pressurized air is transferred from the cannister to the heliostat through a 1.6 cm (0.63 in.) diameter air hose which connects the cannister supply port to a penetration fitting on the base shell. Air flow within the cannister is directed by integral sheet metal manifolding. The bonnet of the cannister is retained by a single wing nut.

3.6 Enclosure

The protective enclosive (Figure 3-14) is a transparent fluorocarbon (polyvinylidene fluoride) material thermoformed to a spherical shape. The spherical enclosure is truncated at a 45° angle from the spherical center to interface with the base dish (also thermoformed fluorocarbon). Flanges exist on both the enclosure and the base shell that are of equal diameter and width to allow mating and fastening.

The diameter of 9.15m (30.0 ft.) provides a clearance of 18.3cm (7.2 in.) from the reflector support ring. This clearance accommodates assembly and installation tolerances plus enclosure deflection due to maximum design winds. The enclosure film thickness is 0.01 cm (.004 in.).

3.6.1 Material

Kynar resin produced by Pennwalt is the selected enclosure material. Previous experience by BEC with Kynar grade 460 resulted in small thermoformed domes with measured transmittance of 0.88. Higher values are probable with process variations such as surface polishing or anti-reflective coating. Pennwalt recently announced a new Kynar grade identified as Kynar 700. The purpose of the new grade is to improve formability through reduced viscosity. Most properties are the same as Kynar 460. BEC tested a laboratory sample of oriented 4 mil Kynar 700 and found the specular transmittance to be 0.87. The improved grade 700 may prove to be superior in the thermoforming and extrusion process.

3.6.2 Load Analysis

Details of the structural analysis which support the design are described in the following sub-sections.

Design Loads = The principle loads acting on the enclosure are those caused by the environment (wind, snow, ice, and earthquake), and the internal static air pressure used to support the membrane enclosure. Previous studies have shown that wind loading is the critical environmental load. Only wind loads will be treated here. Undisturbed wind above smooth terrain is known to assume logarithmic velocity profile, according to atmospheric boundary layer theory. Design wind profiles are commonly specified by power laws which give results similar to a logarithmic description. These take the form:

$$V_Z = V_{REF} \left(\frac{Z}{H_{REF}} \right)^a$$

where V_Z = Wind velocity at height Z above ground
V_{REF} = Wind velocity at reference height H_{REF}
a = Exponent affecting shape of profile

The specification requires that:

1) heliostats be designed for wind according to a power law with H_{REF} equal to ten meters, and a equal to 0.15, and

2) heliostats shall survive a maximum wind velocity, including gusts, of 40 meters per second (90 mph) at ten meters above the ground without damage.

Reference 3-3 gives the following equations for lift and drag respectively.

$L = K_L\, q\, R^2$ where K_L = Lift coefficient

$D = K_D\, q\, R^2$ K_D = Drag coefficient
q = Wind dynamic pressure
R = Dome radius

The lift, drag and pressure lift forces acting on the heliostat due to the peak survival wind of 40 meters per second (90 mph) were estimated to be:

LIFT LOAD L = 27,500 Newtons (6184 lb.)

DRAG LOAD D = 9,160 Newtons (2061 lb.)

PRESSURE LIFT = 12,800 Newtons (2881 lb.)

Transparent enclosure film thickness is controlled by the internal pressure and the allowable stress of the film. The internal pressure of 6.9 KN/m^2 (0.1 psig) is exerted to balance the external wind pressure resulting from a 90 mph wind (at 32.5 ft. elevation). The yield strength of the oriented polyvinylidene fluoride has been measured to be 69.0 MN/m^2 (10,000 psi). For a 9.15m (30 ft.) enclosure the film thickness was calculated to be 0.01cm (.004 in.) using the approach outlined in Reference 3-3.

Reaction to the enclosure/base shell sphere to wind loads is through the 6 ground anchors. Figure 3-19 shows the worst case loading configuration where maximum drag occurs in a plane containing 2 anchors; one at maximum tension, one nearly relaxed. The reactions of the 6 anchors are shown, with the maximum reaction = 3362 lb. The anchor system was designed accordingly (see Section 3.5 and Figures 3-14, 3-15 and 3-16).

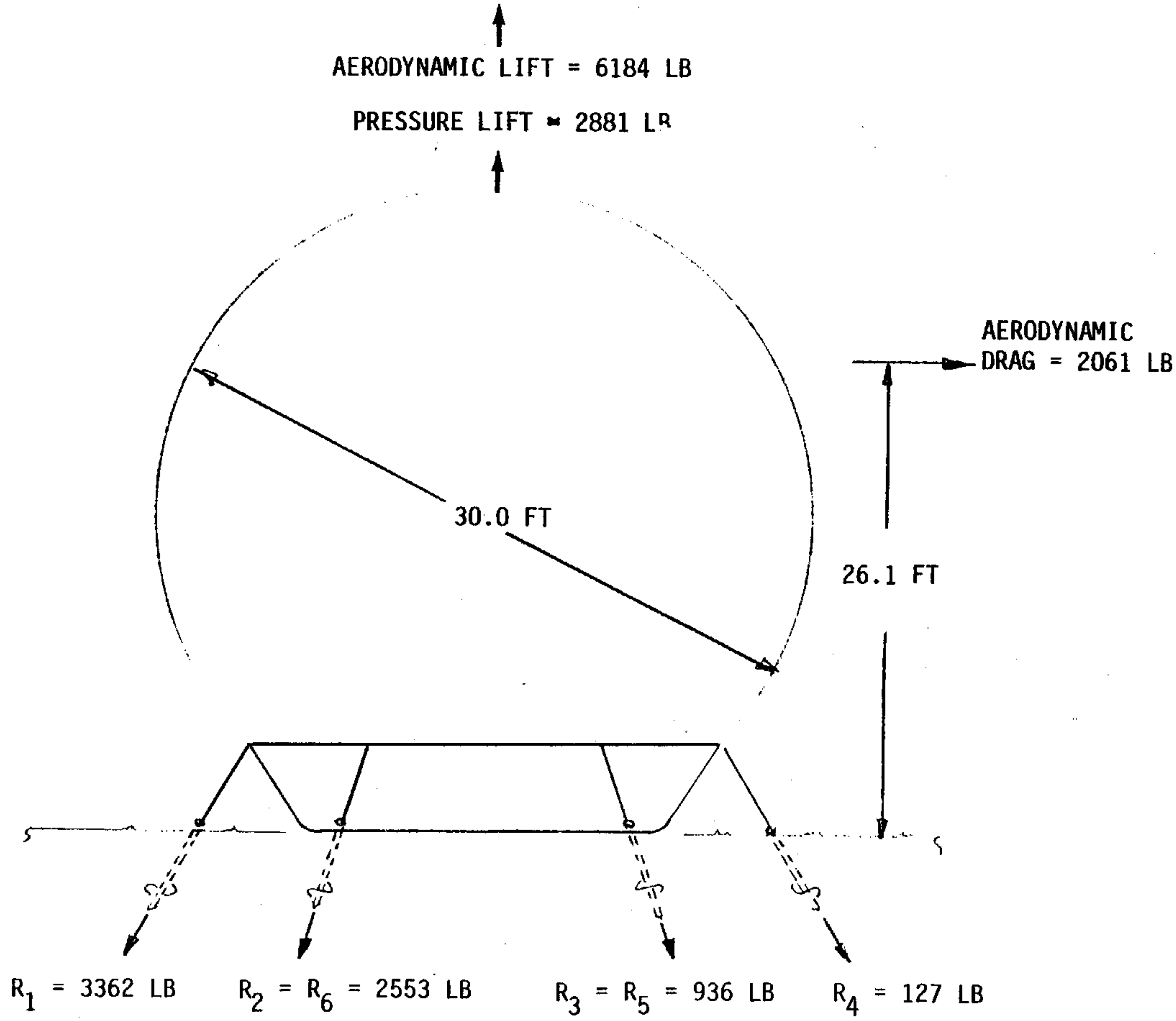


FIGURE 3-19 ENCLOSURE WIND LOADS AND REACTIONS
(90 MPH AT 32.8 FT)

3.7 Size Trade Study

A study was performed to assist in the selection of the most cost effective size for the heliostat. Previous studies (References 3-1, 3-4) generally selected diameters in the region of 25 to 35 feet. It was believed that a better size optimization could be performed using the DELSOL and HELCAT codes than was previously possible. (Brief discussions of the HELCAT and DELSOL codes are given in sections 5.0 and 6.0.). Heliostats in the size range of 8 feet through 37 feet were considered.

3.7.1 Plant BusBar Energy Cost vs. Heliostat Size

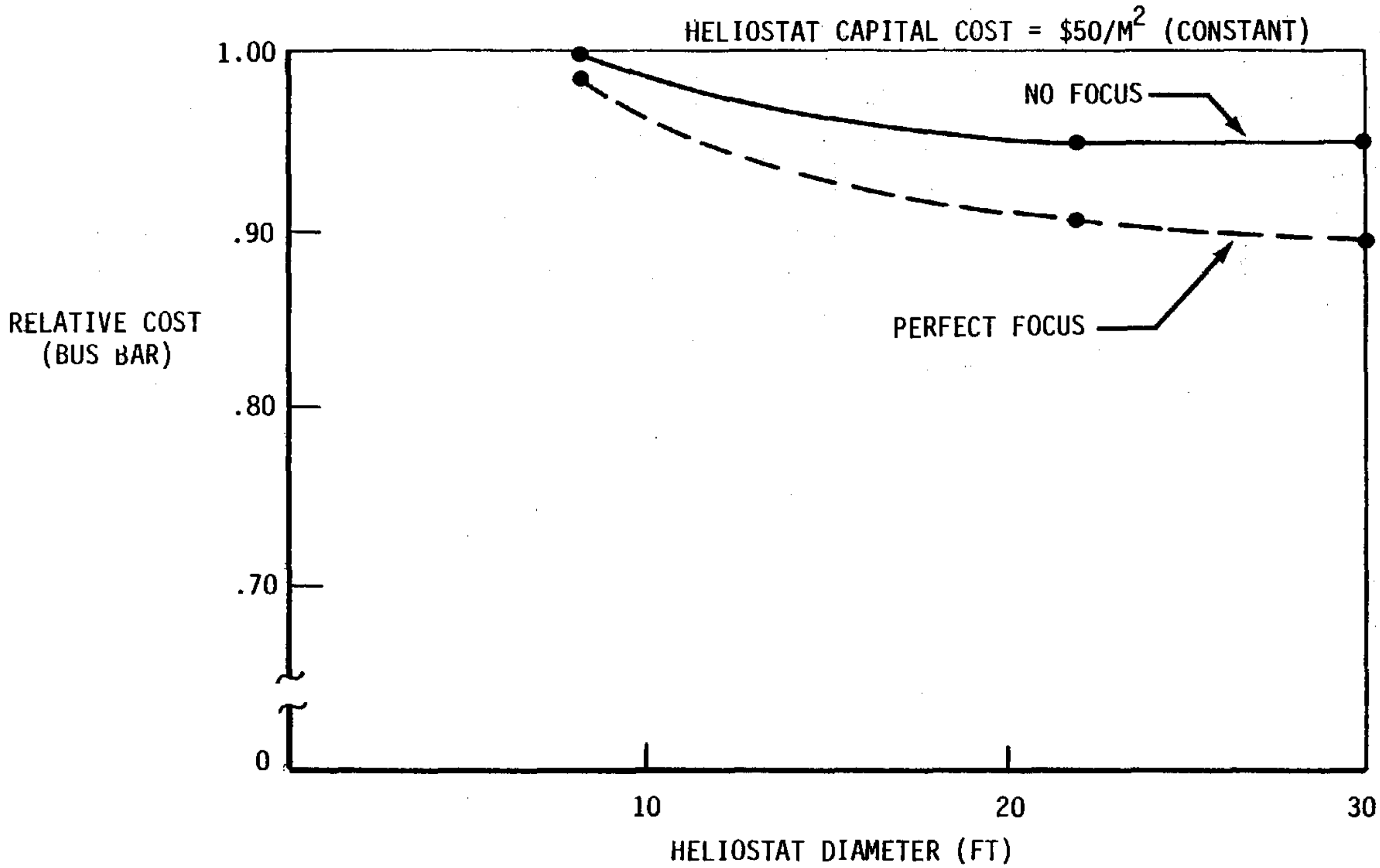
The first analysis was performed with the DELSOL code. It was assumed that heliostats of all sizes could be fabricated and installed for $\$50/m^2$. The intent of the analysis was to determine what effect heliostat size had on other plant costs such as land, tower, receiver, etc. The DELSOL code has provision for perfectly focused or perfectly flat reflectors. Both cases were run. Figure 3.7-1 shows the results of this analysis.

Larger sizes are favored in terms of busbar energy costs. For non-focusing (flat) heliostats greater than approximately 20 feet in diameter size increase offers no advantages. For focusing heliostats the large size advantage continues up through 30 feet, but appears to be disappearing. Unless small heliostats (<20 feet) can be shown to cost less in terms of $\$/m^2$ than large heliostats, the conclusion is that the best choice would be for a heliostat about 30 feet in diameter. Heliostat installed costs for 3 sizes were estimated and are discussed in the following paragraphs.

3.7.2 Heliostat Installed Cost vs. Size

Installed costs for three sizes, 8 ft., 30 ft., and 37 ft. were estimated. These costs were obtained with the use of HELCAT code. The costs include materials, labor, purchased components, factory, land, transportation, and economic parameters such as cost of money, inflation, return to investors, etc.

FIGURE 3.7-1 BBEC VS. HELIOSTAT SIZE (DELSOL)



While determining costs for the three sizes it became apparent that costs for wiring and controls would be constant without regard to size. No strategy was developed that allowed for reduced wiring and controls costs with reduced size. Other heliostat components did not exhibit this problem. Therefore, cost estimates were prepared for the three sizes with and without wiring and controls costs included. The HELCAT results are shown in Figure 3.7-2.

Figure 3.7-2 shows that below 30 ft. the installed cost increases dramatically if wiring and controls are included. However, even if wiring and controls are excluded the cost in $\$/m^2$ of the 8 ft. heliostat is 35% higher than the 30 ft. heliostat. The graph shows that even if the costs of wiring and controls could be made constant in $\$/m^2$ the relative cost of small heliostats is significantly greater than the large ones for the designs and sizes of this study.

3.7.3 Size Selection

Both overall plant cost and installed heliostat cost considerations indicated that a diameter of 30 ft. is substantially more cost effective than smaller diameters. Also, diameters larger than 30 ft. appear to offer little or no cost advantage. The size selected for this study was therefore 30 ft.

3.8 Focusing Study

The BEC plastic heliostat design utilizes gravity focusing rather than active focusing. No provision exists for gravity sag focusing in DELSOL. The DELSOL code model has provision for perfect focusing (focal length - slant range) and no-focusing (perfectly flat). Neither of these cases would be quite attainable for practical reasons. (A perfectly flat reflector would require near infinite tensile stress).

Gravity focusing was approximated by dividing the heliostat field into annular zones, determining average elevation angles and establishing the required film stress to obtain the desired gravity sag for each zone. During the day the elevation angle would deviate about the average. The standard deviation was calculated. DELSOL analyses were performed for the gravity focus approximation and non-focused and perfect focused cases. These analyses

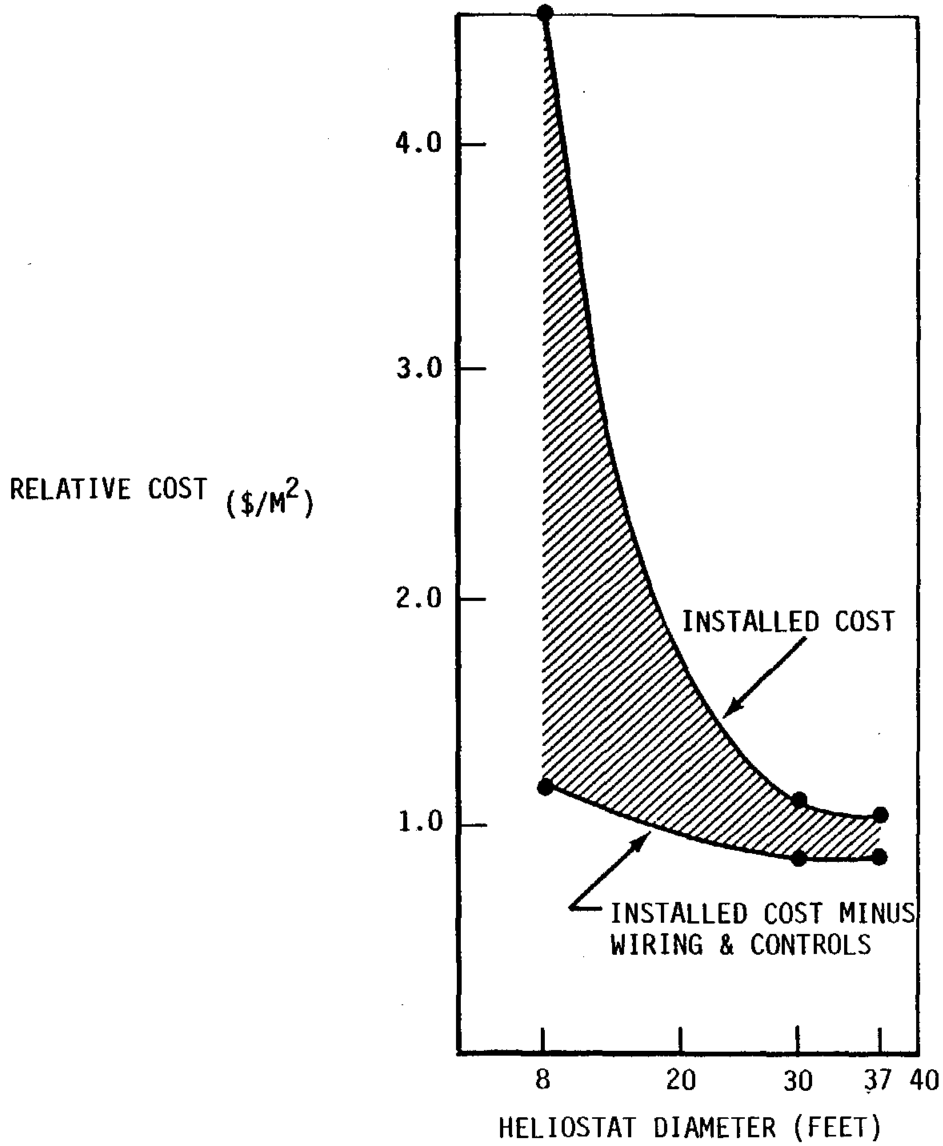


FIGURE 3.7-2 INSTALLED COST VS SIZE (HELICAT)

provided intercept efficiency versus time of day. Figure 3.8-1 is a plot of the 3 cases and the gravity plus 1σ case (this latter case gives the intercept efficiency obtained when the heliostat elevation angles are one standard deviation off the average).

Figure 3.8-1 shows that the simulated gravity focus + 1σ is quite close to the perfect focus case except for 4 and 5 hours before and after solar noon. Even then the departure is only about .5% loss in intercept efficiency.

Since losses in intercept efficiency are made up by adding heliostats to outer field rows the .5% loss will be amplified by a factor of perhaps 2 or 3. This can be demonstrated by referring back to Figure 3.7-1, a plot of relative busbar cost versus heliostat diameter for perfect focus and flat mirrors. The difference between perfect focus and non-focus for a 30 ft. diameter heliostat is about 5% in terms of busbar energy costs. Returning to Figure 3.8-1, it is seen that the intercept efficiency difference between perfect focus and non-focus is about 2%. Therefore, approximately 6% greater BBEC would be incurred because of 2% decrease in intercept efficiency. Similarly, a 1.5% increase in BBEC would result from a .5% decrease in intercept efficiency. The 1.5%, or approximately 1.65 mils/kW hr, is the additional energy cost due to gravity focusing.

The additional energy costs due to gravity focusing can be avoided if active focusing can be provided to the reflector assembly. The active focusing, obviously, will add back some costs because of required systems and hardware. An estimate of the heliostat hardware additional costs for active focusing that would equal the energy cost avoidance (elimination of gravity costs) can be made. Assume 40% of BBEC are attributed to heliostat and BBEC = 110 mils/kW hr. The heliostat portion of the BBEC is then about 44 mils/kW hr. From above the energy costs avoidance of active focusing is 1.6 mils/kW hr or 3.6%. If the heliostat installed cost is $2700, the active focusing hardware could cost (.036) 2700 = $97.00. If the entire $97.00 is spent on active focusing hardware no cost benefit has been realized, since the avoidance equals the expenditure.

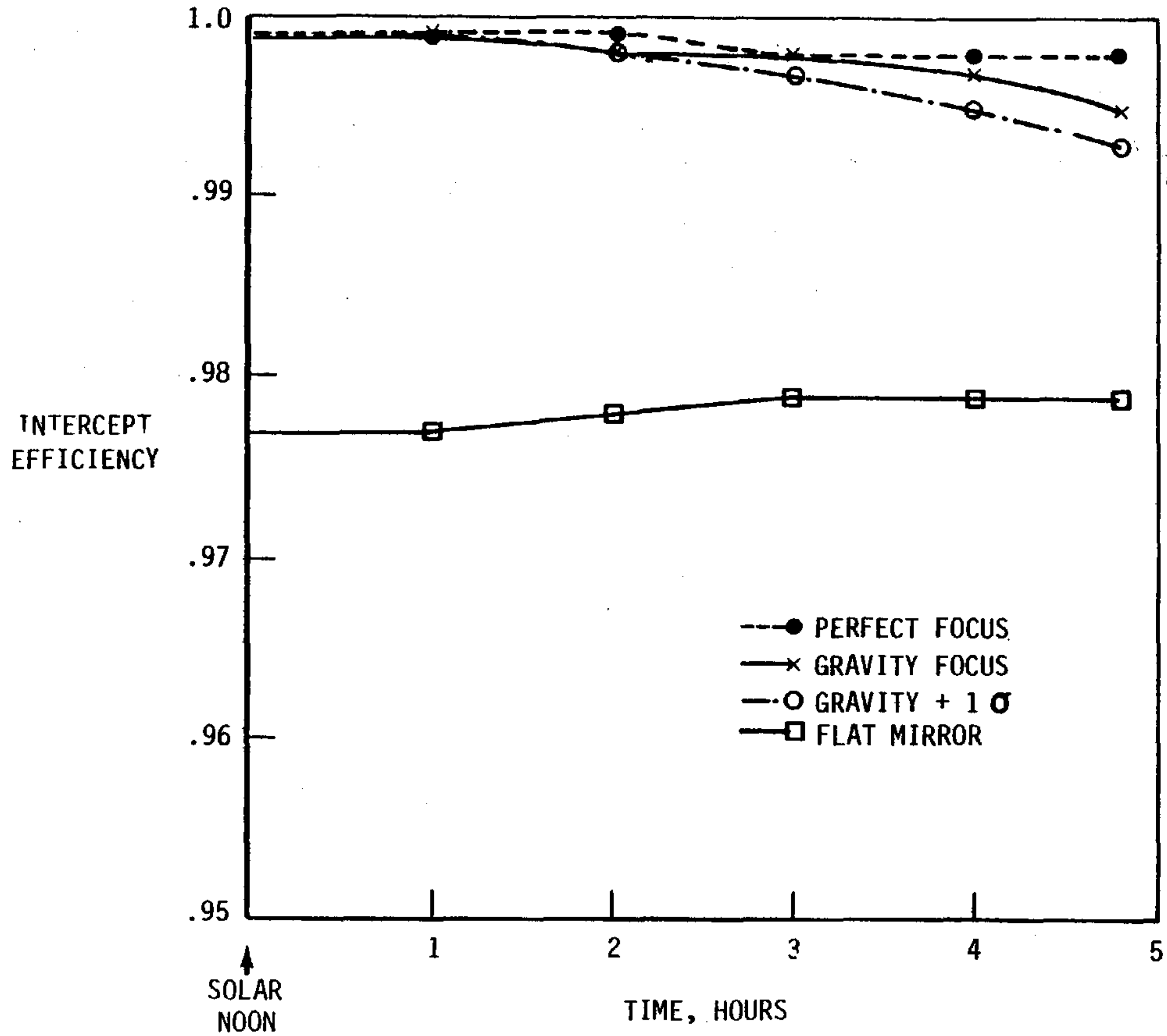


FIGURE 3.8-1
INTERCEPT EFFICIENCY VS. TIME OF DAY

Based upon the above analyses active focusing was not included, since it was considered unlikely that active focusing hardware could be provided for much less than the break-even allowance of $97.00. The analysis was an approximation, however, and further experimental and analytical work in this area is warranted.

Variations in temperature will cause changes in membrane stress. Previous work described in Reference 3-1 predicted a change of ± 30% in membrane stress across the temperature range of 60°C to -30°C. The gravity focus analysis presented in 6.1.2 showed that the intercepted energy was not very sensitive to variations in focal length (from Figure 3.8-1 .999 for perfect focus to .977 for flat mirror).

4.0 HELIOSTAT MANUFACTURING AND INSTALLATION PLAN

The smaller components and detail parts which are readily shipped by truck or rail will be procured from off-site sources. Large components such as the reflector, base dish and enclosure will be manufactured at the Central Manufacturing Facility (CMF). Table 4-1 is the make/buy list for heliostat components. Manufactured components are packaged and shipped to the Site Assembly Building (SAB) directly. Assembly of the reflector and final assembly of the heliostat prior to field installation will be performed in a SAB (see Figure 4-1).

Final assembly at the SAB includes fabrication of the reflector, assembly of the heliostat, and pressurization of the enclosure. The completed heliostat is transported to the prepared heliostat site where the pedestal is inserted in the pile and anchor cable connections are made. The transporter serves as the final assembly base as well as the site installation fixture.

4.1 Manufacturing (CMF)

The CMF consists of several buildings with a total floor area of approximately 280,000 ft^2 located on 17 acres of land. Production of enclosures, base shells and reflector membrane material from polymer resins occurs at the CMF. Concepts for the CMF buildings are shown in Figure 4-2.

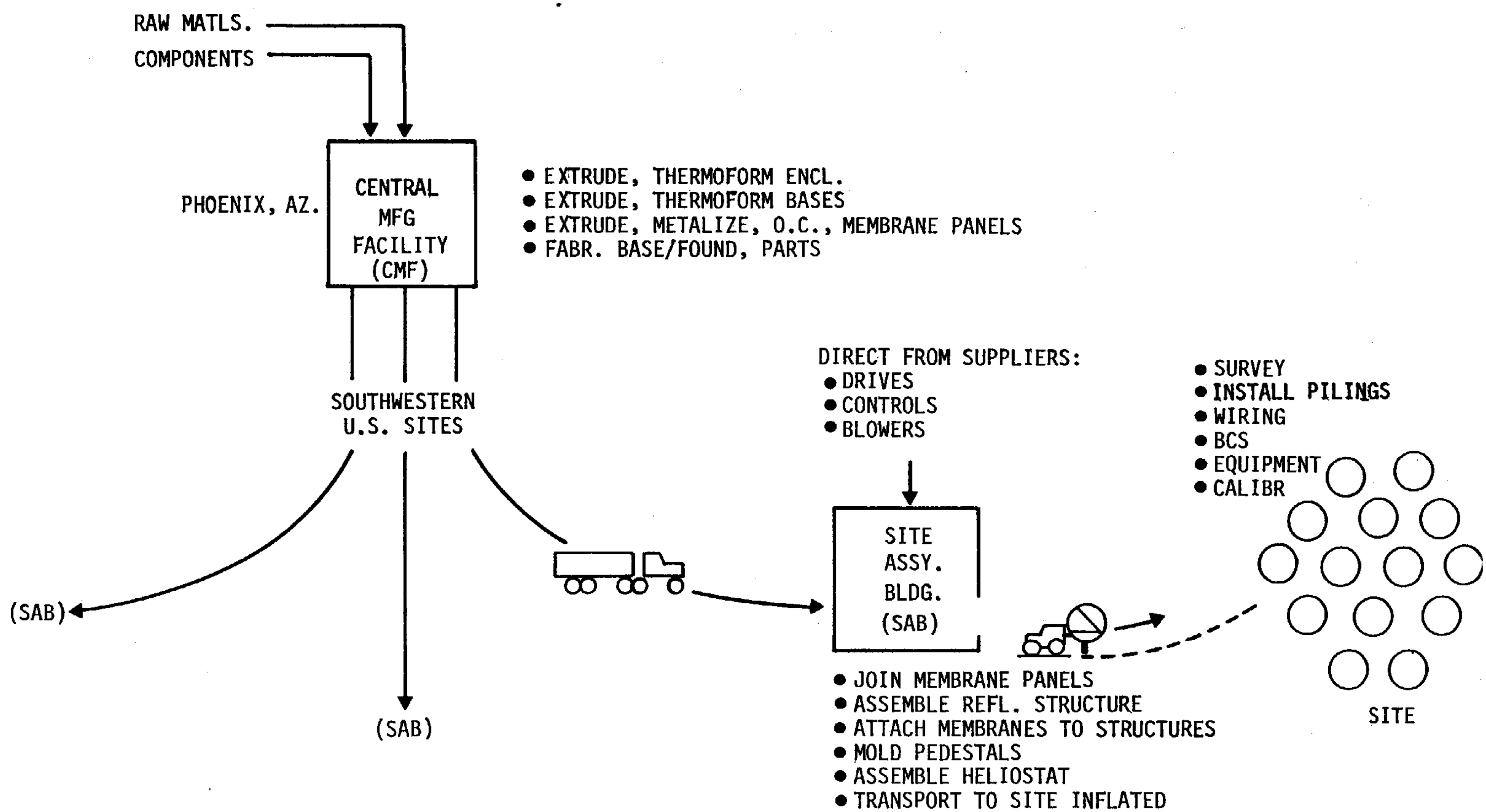
4.1.1 Enclosure Fabrication

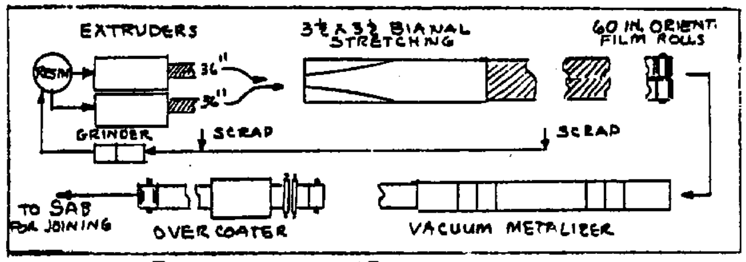
Two manufacturing lines are required to meet the annual production requirements of 50,000 enclosures per year. The lines, as shown in Figure 4-2, consist of three extruders that take Kynar resin and recycled Kynar scrap and form 8 foot wide strips which are subsequently welded and cut and result in preforms which are then mounted in the fixture and thermoformed (thermoforming is described in detail in Reference 4-1). The completed enclosures are packaged for shipment to the SAB. Approximately 120,000 ft^2 of factory floor space are required.

Table 4-1. Make/Buy List

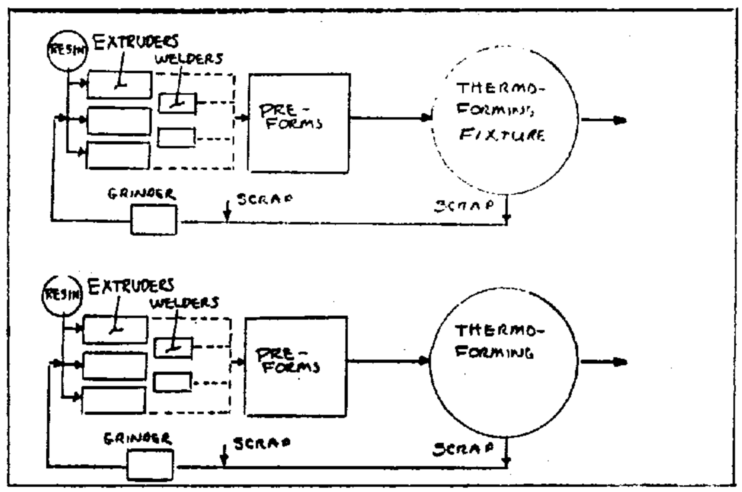
Item	Make (M) Buy (B)	Drawing Number
Reflector structure	M	SK61003
Relfector membrane	M	SK61003
Azimuth/elevation drive	B	SK61005
Controls/wiring	B	--
Enclosure	M	SK61002-1
Air supply	B	SK61006
Base shell	M	SK61002-1
Ground anchor	B	SK61004
Pile	M	SK61004
Pedestal	M	SK61007

FIGURE 4-1
MANUFACTURING, ASSY, INSTALLATION SCENARIO

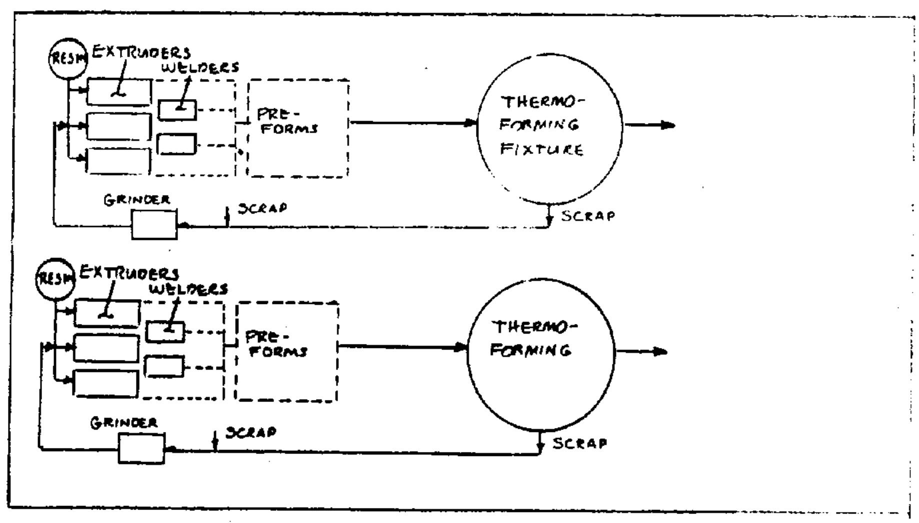




REFLECTOR MEMBRANE FACILITY



BASE SHELL FACILITY



ENCLOSURE FACILITY

FIGURE 4-2

CENTRAL MANUFACTURING FACILITIES (CMF)

4.1.2 Base Shell Fabrication

The two manufacturing lines for base shell production are very similar to those used in enclosure production. Less factory area (100,000 ft^2) is necessary because of smaller size of the base and the simpler handling requirements.

4.1.3 Reflector Membrane Fabrication

Two PMMA extruders provide 36 inch unoriented material to be fed into the 3-1/2 axial by 3-1/2 logitudinal biaxial orientation frame. Sixty inch wide rolls of oriented film are produced. The PMMA film is then aluminized in a vacuum metalizer. Finally an aluminum overcoat is applied. The finished film rolls are shipped to the SAB where reflector fabrication is performed.

4.2 Site Assembly (SAB)

4.2.1 Reflector Fabrication

The reflector structure parts are assembled and bonded in the SAB. This operation is followed by the application of the flat foamed surface shown in Figure 3-2. The reflector membrane is also formed at the SAB by bonding together 6 strips of metalized PMMA film manufactured at the CMF. The membrane is stretched to the desired tension and bonded to the flat surface of the reflector structure.

4.2.2 Heliostat Assembly

The following is the sequence of heliostat assembly:

(1) A base shell and pedestal are mounted on the assembly/transporter fixture.

(2) The drive unit is installed on the pedestal. Power and signal wires are routed and connected to base penetrations.

(3) The reflector is installed on the drive unit.

(4) The enclosure is lowered over the reflector and connected to the base shell. Anchor cables are connected to base/enclosure interface flange.

(5) The heliostat is inflated and pressurized.

(6) The drive system is operated to verify function and clearances.

(7) The transporter tractor is connected to the fixture in preparation for transit to the site. The temporary air supply (on tractor) is connected to maintain pressure during transit. (See Figure 4-3).

4.3 Heliostat Installation

Heliostat pedestal piles are installed at the surveyed locations in the field. They consist of reinforced tapered, hollow, concrete piles. The installation equipment consists of a drill platform and an anchor driving apparatus mounted on a motorized tractor vehicle. One set of this equipment drilling pile holes, setting molds and installing ground anchors is capable of preparing 40 heliostat sites in an eight hour shift. A follow-up vehicle will fill the pile mold with concrete. The pile is allowed to cure and is covered to avoid collection of debris.

The factory assembled, functionally checked, and internally clean heliostat arrives at the site from the SAB over plant dedicated roads. This vehicle and transport fixture is shown in Figure 4-3. The fixture is that utilized in the plant assembly process. It provides a clamping support to the pedestal for

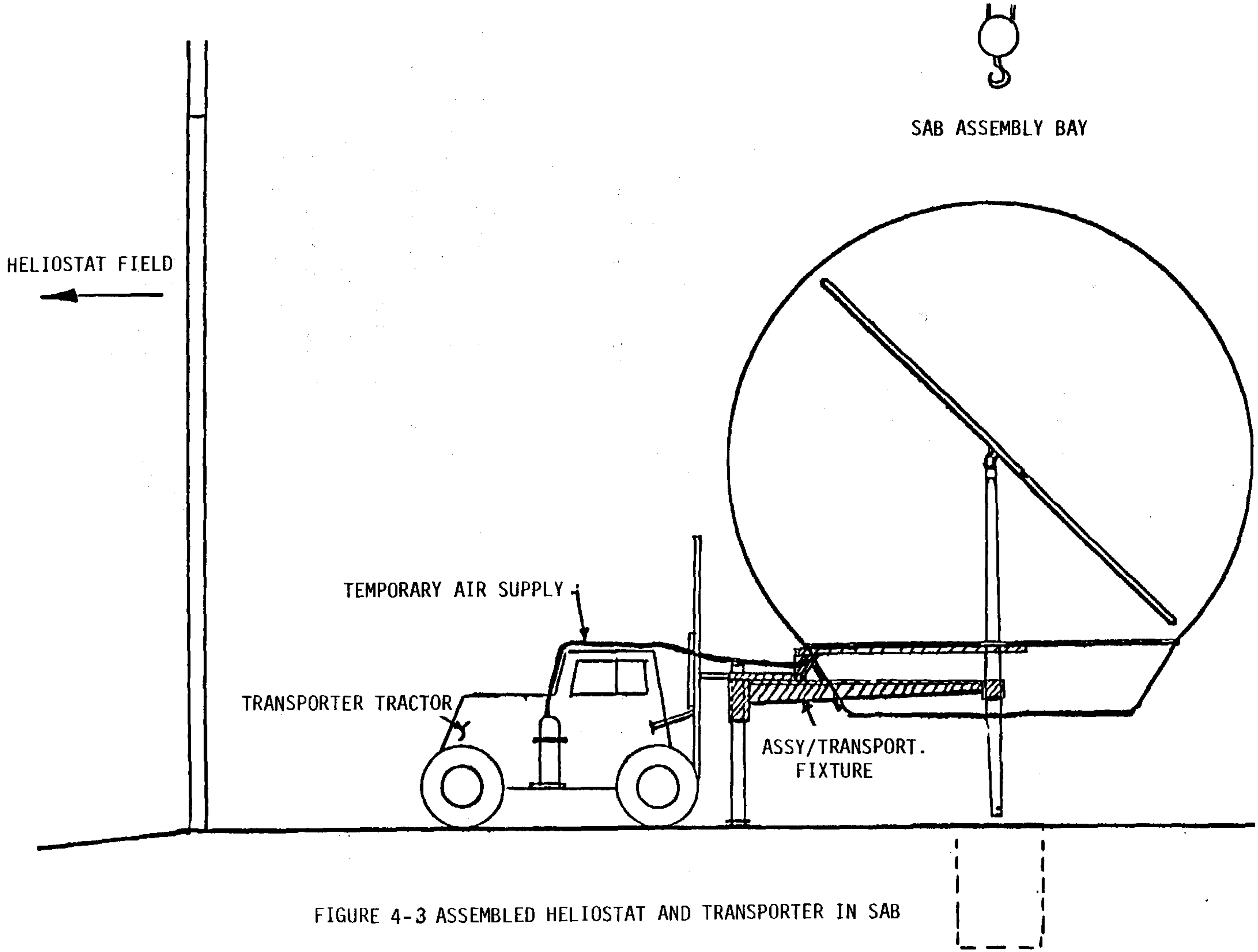


FIGURE 4-3 ASSEMBLED HELIOSTAT AND TRANSPORTER IN SAB

(1) A base shell and pedestal are mounted on the assembly/transporter fixture.

(2) The drive unit is installed on the pedestal. Power and signal wires are routed and connected to base penetrations.

(3) The reflector is installed on the drive unit.

(4) The enclosure is lowered over the reflector and connected to the base shell. Anchor cables are connected to base/enclosure interface flange.

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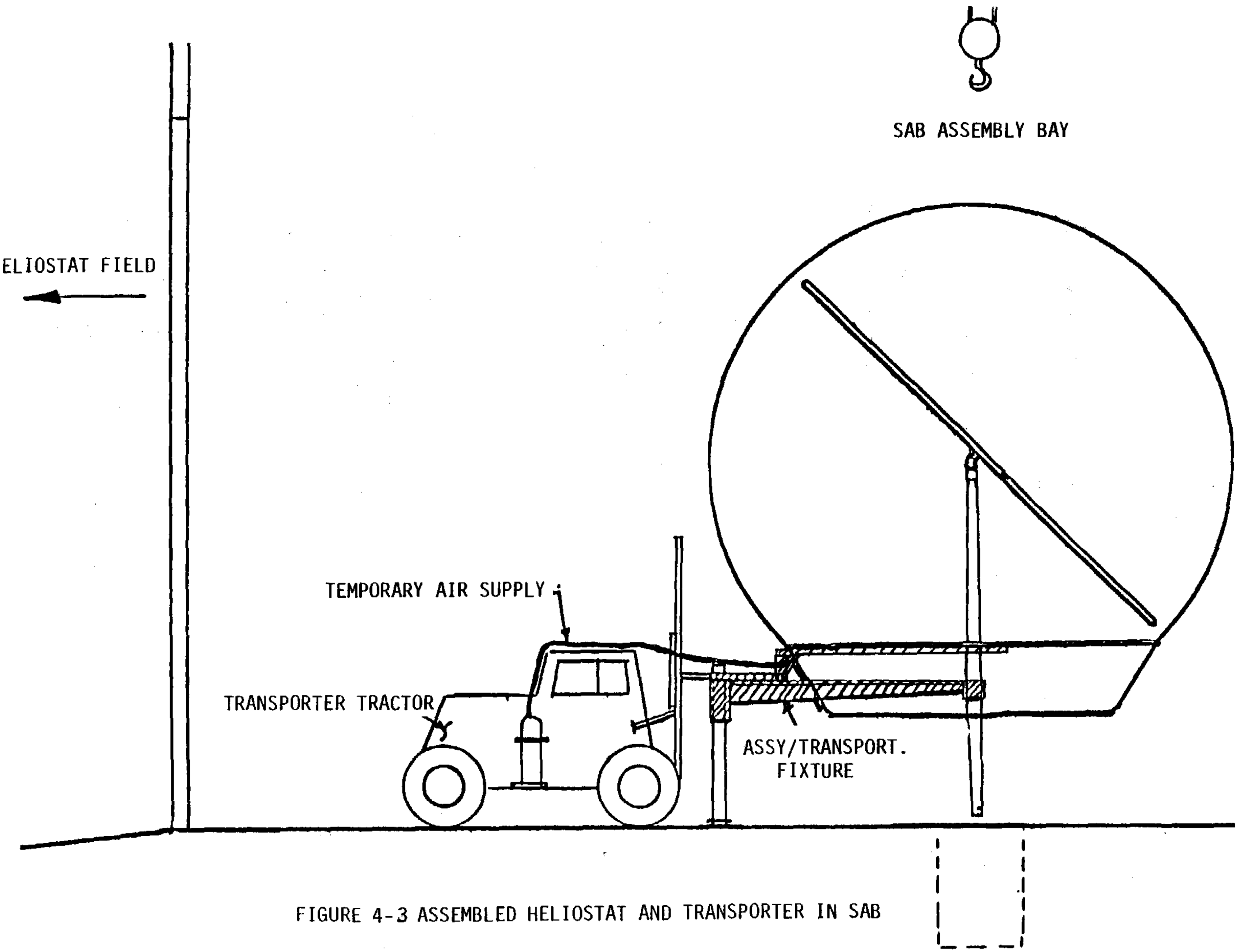


FIGURE 4-3 ASSEMBLED HELIOSTAT AND TRANSPORTER IN SAB

support during transit and installation. The heliostat and fixture is lowered until the pedestal seats in the pile. The cables connecting the enclosure/base flange are connected to the ground anchors and cable tension is set to the desired values.

The power connection to the blower is transferred from tractor power to field. The assembly fixture is now removed from the heliostat, returned with the transporter vehicle to the SAB, and recycled into the assembly line.

The power and signal wiring connection is now made to the heliostat controller, the ground connection made, and the heliostat is ready for functional checkout and alignment processes.

5.0 HELIOSTAT INSTALLED COSTS

Cost estimates were prepared for the component procurement, fabrication, assembly and installation of the BEC enclosed plastic heliostat. Prices for materials, tooling, transportation and equipment and quantities of required labor, facilities and land were obtained from manufacturers, previous studies or engineering estimates. The HELCAT code was used to compute the "Total Required Revenue" in capital dollars per heliostat. This section covers the model parameters, estimate inputs and the computed cost by cost breakdown structure, profit center and total required revenue.

5.1 Analysis and Model Inputs

Pricing was based upon a production rate of 50,000 heliostats per year at a central manufacturing facility located in Phoenix, Arizona. Manufactured components were shipped by truck to the various southwestern sites and assembled in site assembly buildings. All costs are in 1983 dollars. When cost data was used from previous studies the data was inflated at 6%/yr to the 1983 value. Labor rates used were:

Factory - $10.58/hr
Site Craft - $17.23/hr
Outside - $33.50/hr

Table 5.1-1 shows the input parameters used in the HELCAT calculations.

The reflector membrane material is manufactured at the CMF and shipped in 60 inch wide rolls to the SAB where it is used to make the membranes. Pricing for all factory equipment and labor for reflector material is included in CBS 4410. Also included under CBS 4410 are some equipment and facilities costs for the SAB reflector final assembly requirements.[1] The reflector structure parts are assembled at the SAB prior to installation of the membranes. Transportation costs from the CMF to the SAB are included.

[1]Subsequent to completion of the cost analysis it was discovered that the SAB facility costs had been included as a factory cost, being improperly charged against 50,000 heliostats per year rather than the 8,000 heliostats at a site. Assuming a reusable temporary Butler-type building for heliostat assembly and existing site warehousing for other site support activities, the impact on site costs would be an approximate 1 1/2 to 2% increase.

TABLE 5.1-1

H E L C A T OPTIONS AND MODEL PARAMETERS

PARAMETER MATRIX

		FACTORY	SITE	TRANSPORTATION
1	DURATION OF COST PROJECTION - YEARS	10.000	10.000	10.000
2	BASE RATE DIRECT LABOR COST - $/HOUR	10.580	17.230	15.000
3	BASE RATE PROD FACILITY COST - $/SQFT	50.000	0.000	0.000
4	LAND COST FOR PROD FACILITY - $/ACRE	20000.000	0.000	0.000
5	INFLATION RATE	.060	.060	.060
6	RETURN TO BOND HOLDERS	.102	.102	.102
7	RETURN TO EQUITY HOLDERS	.166	.166	.166
8	COMBINED INCOME TAX RATE	.500	.500	.500
9	INVESTMENT TAX CREDIT	.100	.100	.100
10	EQUITY FRACTION	.800	.800	.800
11	PROPERTY TAX AND INSURANCE FRACTION	.040	.040	.040
12	PURCHASED MATERIAL SCRAP FRACTION	.010	.010	.010
13	MAINTENANCE FRACTION	.020	.040	.040
14	GENERAL AND ADMINISTRATIVE FRACTION	.090	0.000	0.000
15	WORKING CAPITAL FRACTION	.170	0.000	0.000
16	RAW MATERIAL SCRAP FRACTION	.030	.030	.030
17	TOOLING LIFETIME (ACCOUNTING) - YEARS	5.000	5.000	5.000
18	EQUIPMENT LIFETIME (ACCOUNTING) - YEARS	10.000	10.000	10.000
19	FACILITY LIFETIME (ACCOUNTING) - YEARS	30.000	30.000	30.000
20	FACILITY CONSTRUCTION PERIOD - YEARS	3.000	0.000	0.000
21	FACILITY PLANT ENGINEERING FRACTION	.100	0.000	0.000
22	FACILITY STARTUP QUANTITY	20000.000	0.000	0.000
23	COST REDUCTION COEFFICIENT - START UP	.920	0.000	0.000
24	TOOLING LIFETIME (TAX) - YEARS	3.000	3.000	3.000
25	EQUIPMENT LIFETIME (TAX) - YEARS	8.000	8.000	8.000
26	FACILITY LIFETIME (TAX) - YEARS	25.000	25.000	25.000
27	BASE RATE TRANS COST - $/LB	.035	.035	.035
28	INDIRECT FRACTION - LABOR	.270	.300	.300
29	INDIRECT FRACTION - MATERIAL	.004	0.000	0.000
30	INDIRECT FRACTION - TOOL'G,EQUIP'T,FAC'Y	.006	0.000	0.000

SPECIAL COST MATRICES

CATEGORY NUMBER	FACILITY $/SQ FT	LABOR $/HR	TRANSPORT (UNITS VARY)
1	40.	9.00	650.000 $/TRKLOAD
2	60.	12.00	130.000 $/TRKLOAD
3	80.	18.00	0.000
4	100.	21.00	0.000
5	120.	25.00	0.000
6	140.	30.00	0.000
7	0.	0.00	0.000
8	0.	0.00	0.000
9	0.	0.00	0.000

The drive actuator was designed by BEC and Winsmith and the production was priced by Winsmith. The CBS 4420 factory costs show this item as a flow through cost.

Transportation directly to the site was priced by BEC.

BEC prepared no design or cost estimate for wiring and controls for the Second Generation Heliostat program. It was beyond the scope of the present program to perform such a design effort, so the cost estimate was made based upon the Second Generation contractor's average. Controls were considered a purchased item under CBS 4430, while field wiring was included as a purchased item under CBS 4460 (site construction).

The base shells are thermoformed at the CMF, packaged and shipped to the SAB. Pricing for all factory equipment and labor to manufacture preforms and thermoform base shells was included in CBS 4440. Also included were costs for purchase of air supplies, materials, tooling and labor for miscellaneous parts and necessary factory facilities and land.

Factory costs for the enclosure manufacture included purchase of the Kynar resin, preform extrusion tooling, thermoforming equipment, labor, facilities and land and appear in CBS 4450. Packaging and transportation costs were also estimated.

CBS 4460, site cost, includes estimated costs for final assembly, field wiring, site survey, installation and checkout, initial calibration, and site equipment to support these operations. Equipment for cleaning of enclosures was also priced.

Appendix A lists the cost estimates that were input to the analysis.

5.2 Analysis Results

A summary of the results of the analysis are shown in Table 5.2-1. (see Appendix A for detailed results). A cost matrix of six cost breakdown structure headings by three location (factory, transportation, site) categories is provided. The total installed cost is seen to be \$2636.20 per heliostat. For a $59 m^2$ heliostat this converts to $\$44.68/m^2$.

TABLE 5.2-1 HELIOSTAT COST ANALYSIS RESULTS

COST SUMMARY BY PROFIT CENTER

TOTAL REQUIRED REVENUE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	REFLECTIVE ASSEMBLY 4410	DRIVES 4420	CONTROLS 4430	FOUNDATION/ PEDESTAL 4440	ENCLOSURE 4450	ASSY/INSTALLATION (INCL FIELD WIRING) 4460	TOTALS BY LOCATION
FACTORY	327.21	251.00	417.75	388.61	527.15	9.09	1920.81
TRANSPORTATION	40.95	.26	0.00	26.00	52.00		119.21
SITE			0.00	0.00		596.18	596.18
TOTALS	368.16	251.26	417.75	414.61	579.15	605.27	

TOTAL FOR TOTAL REQUIRED REVENUE 2636.20

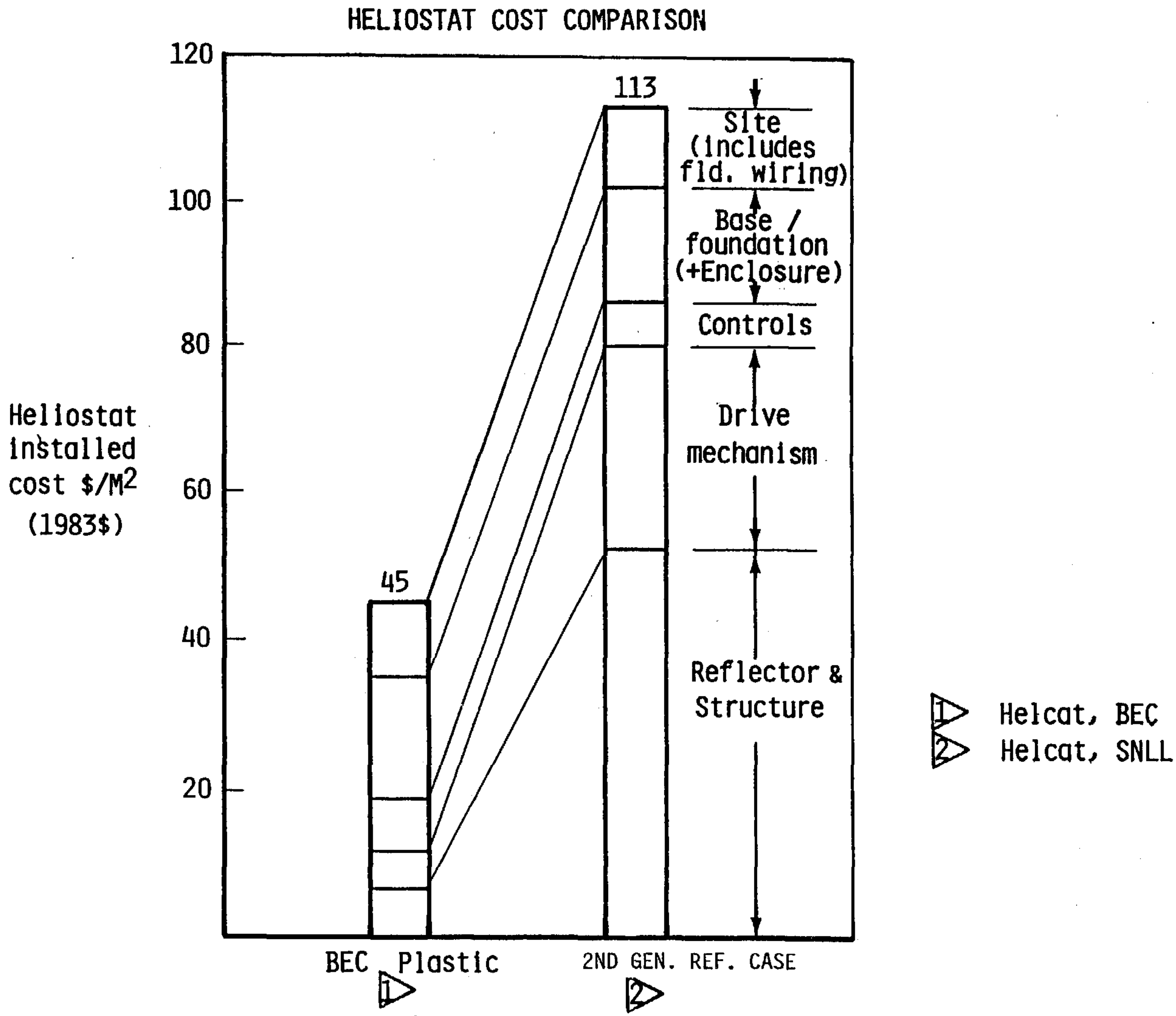


FIGURE 5.2-1 HELIOSTAT COST COMPARISON

Figure 5.2-1 compares BEC plastic enclosed heliostat costs with the reference case. The most impressive savings occur in the reflective assembly and drive mechanism costs. No savings was attempted in the controls category. The cost of the plastic heliostat base/foundation plus the protective enclosure was about equal to the reference case base/foundation. Site costs (including field wiring) were approximately equivalent.

6.0 POWER PLANT ENERGY COSTS

Analyses were performed to determine the power plant delivered energy costs, or BBEC (bus-bar energy costs). In addition, energy cost sensitivities to variations in heliostat capital cost, heliostat O&M costs (operation and maintenance) and heliostat optical properties ($\rho\tau^2$) were evaluated. The DELSOL computer code, with modifications for plastic enclosed heliostats, was employed for the analyses. The following paragraphs discuss the analysis approach, tools and results.

6.1 Plant Performance and Cost Analysis

The objectives of the plant analysis subtask have been to determine the performance and cost of candidate enclosed plastic heliostat designs and to compare the results with similar data from a glass heliostat design. The plant analysis approach is illustrated in Figure 6.1-1. Plastic and glass heliostat cost and performance were evaluated while the non-heliostat subsystems were held constant. The study performance requirements and analysis assumptions presented earlier in Table 2.0-1 were used to maintain a consistent comparison between the two heliostat types. The following subsections discuss the analytical tool used to perform these evaluations. The reference glass heliostat case will also be presented.

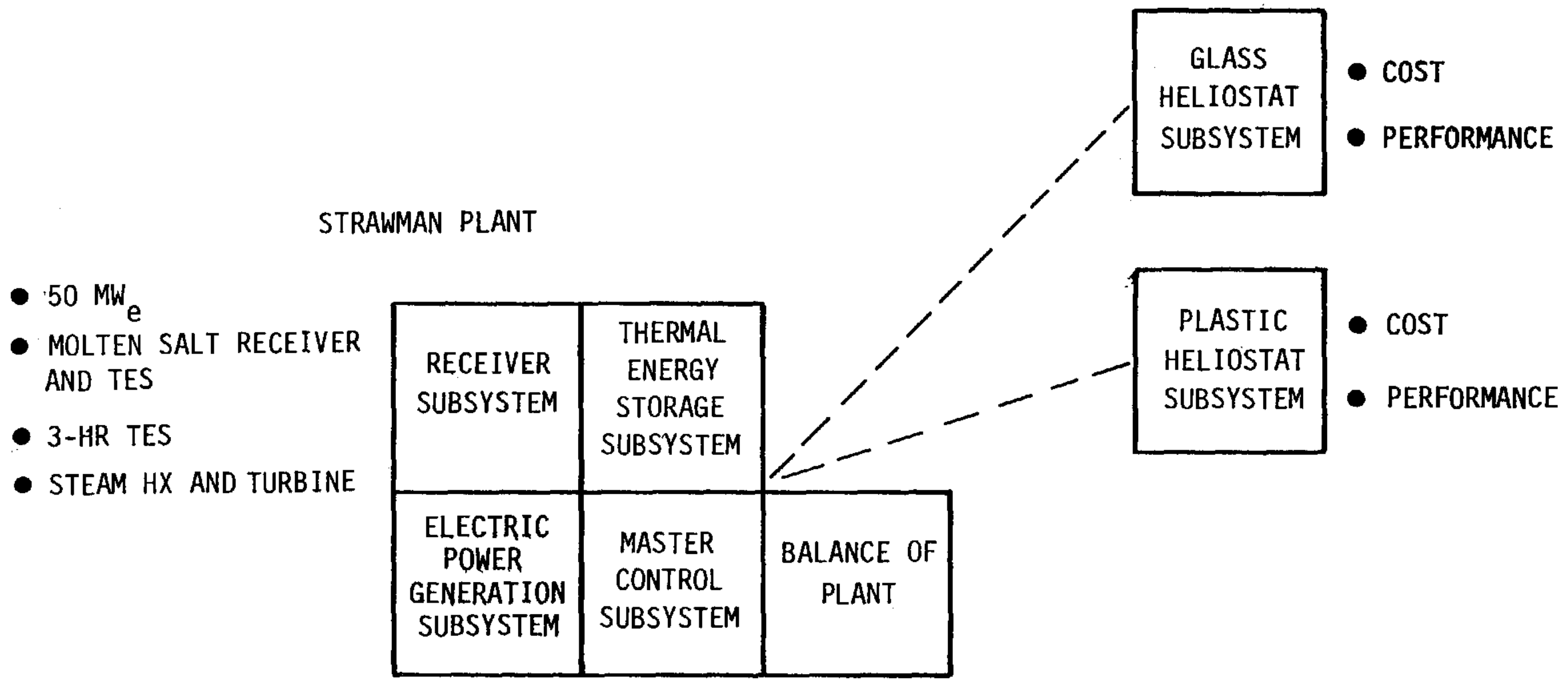
6.1.1 Plant Analysis Computer Code

The analytical tool used to perform the plant performance and cost calculations was a modified DELSOL 2 code developed by SERI (ref. 6.1-1) to evaluate enclosed plastic heliostat designs. The modified code was compared to the standard DELSOL 2 code (ref. 6.1-2) and was found to reasonably account for the additional optical losses experienced with enclosed heliostats.

The modifications made by SERI to DELSOL 2 were in two areas: (1) effective mirror reflectance, and (2) dome shadowing and blocking. These topics are briefly discussed in the following paragraphs.

FIGURE 6.1-1

PLANT ANALYSIS APPROACH



Effective Mirror Reflectance

An enclosed plastic optical analysis must account for two passes of the solar energy through the dome material plus one reflection from the plastic reflector. The transmission of the dome material is known to vary with incidence angle. Also, the incidence angle between the sun's rays and the dome vary over the dome. This variation also depends upon the heliostat position in the field, time of day and day of year. An analysis was performed to evaluate these effects on the dome transmittance value.

The transmittance of the dome material is illustrated in Figure 6.1-2. BEC has measured the transmittance of dome materials as a function of incidence angle using the test setup illustrated in Figure 6.1-3. Typical transmission data normalized to the zero incidence value are presented in Figure 6.1-4. These data represent the expected incidence angle variation for a well-developed, polished plastic film. Also presented in Figure 6.1-4 is similar data assuming transmission through a film with an index of refraction of n = 1.418. The agreement between the two curves is consistent with similar findings at SERI (Reference 6.1-3).

The optical model considered in integrating the transmittance over the dome is illustrated in Figure 6.1-5. The integration analysis follows that of Reference 6.1-4. In that reference, the integrated, 2-pass transmittance, τ^2, is given by,

$$\bar{\tau}^2 = \sum_{K=0}^{5} A_K \omega^{2K} \frac{1}{\pi} \int du\,dv \left(u^2 + v^2 \cos\phi\right)^K$$

where

$u^2 + v^2 \leq 1$, integration variables

$\omega = R_H / R_O < 1$, ratio of heliostat radius to dome radius

ϕ = incidence angle between solar rays and heliostat normal

A_K = curve fit coefficients obtained from $\tau(\phi)$ data,

$$\tau^2(\xi) = \sum_{K=0}^{5} A_K \sin^{2K} \xi$$

ξ = incidence angle between incoming solar rays and normal to dome surface

Least squares curve fitting made to the data of Figure 6.1-4 produced the A_K coefficients shown in Table 6.1-1. These data were used to solve for the

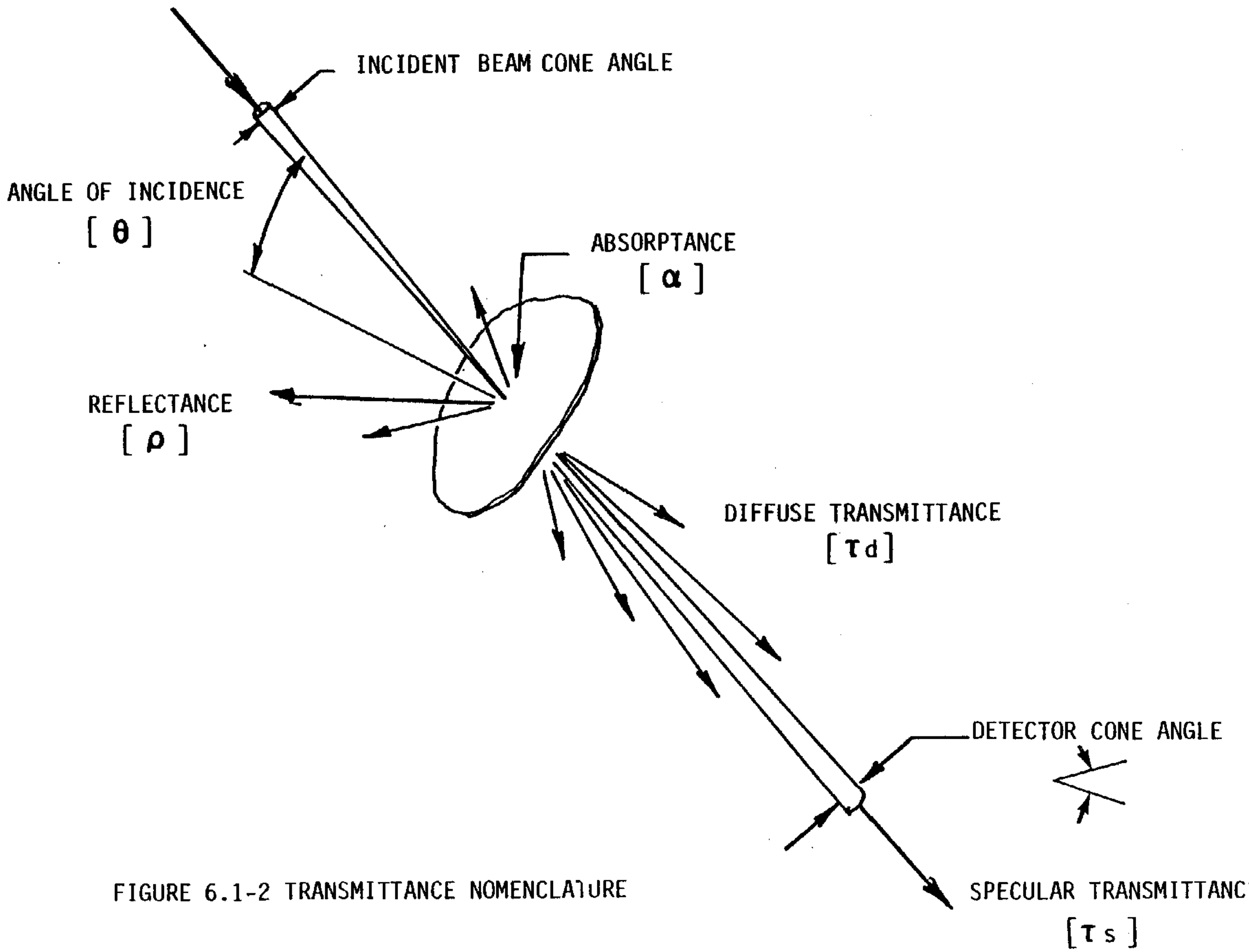
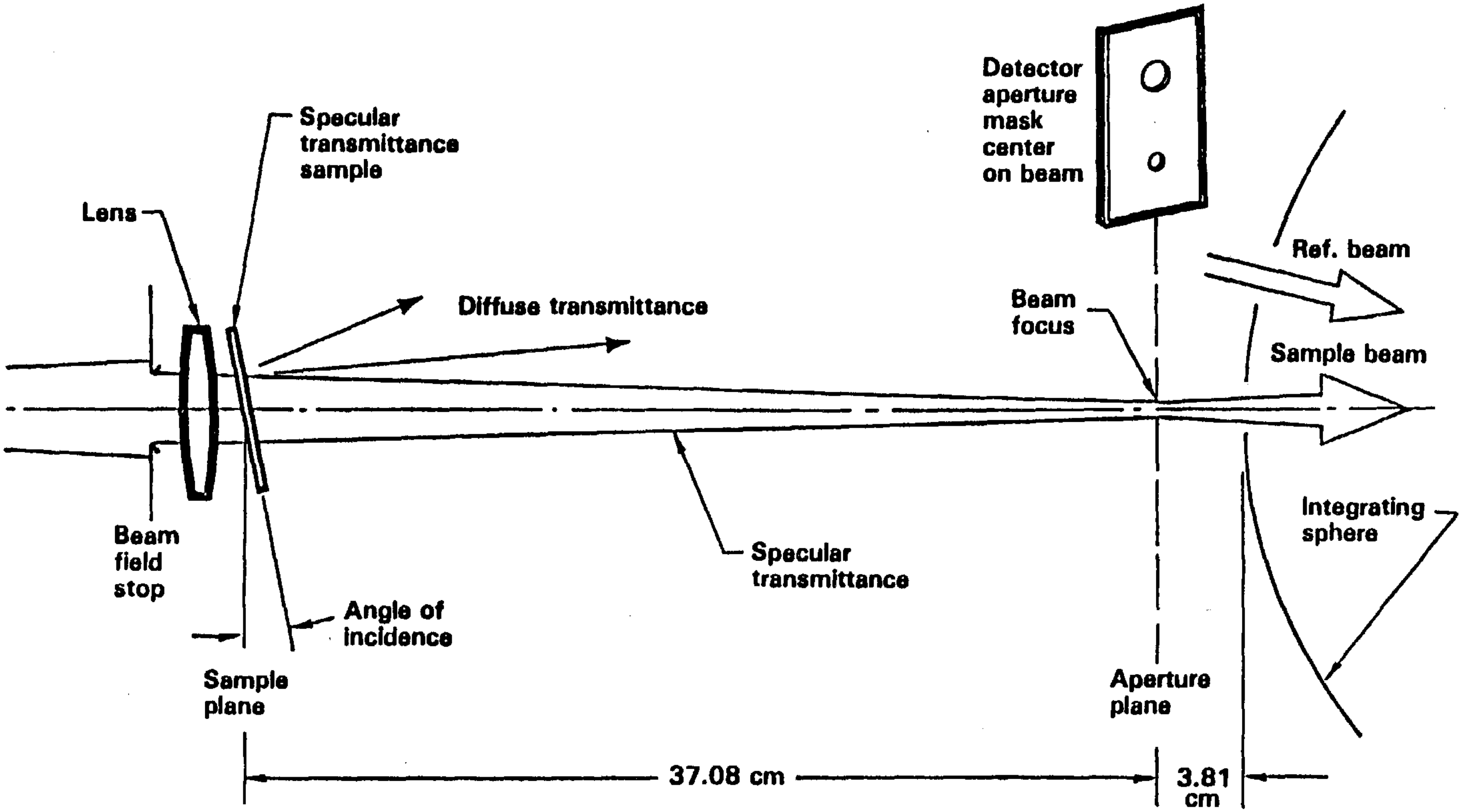


FIGURE 6.1-2 TRANSMITTANCE NOMENCLATURE



Resolution of system

0.32 cm dia. aperture passes 98 percent of beam (without sample), 0.5° cone

FIGURE 6.1-3 SPECTROPHOTOMETER

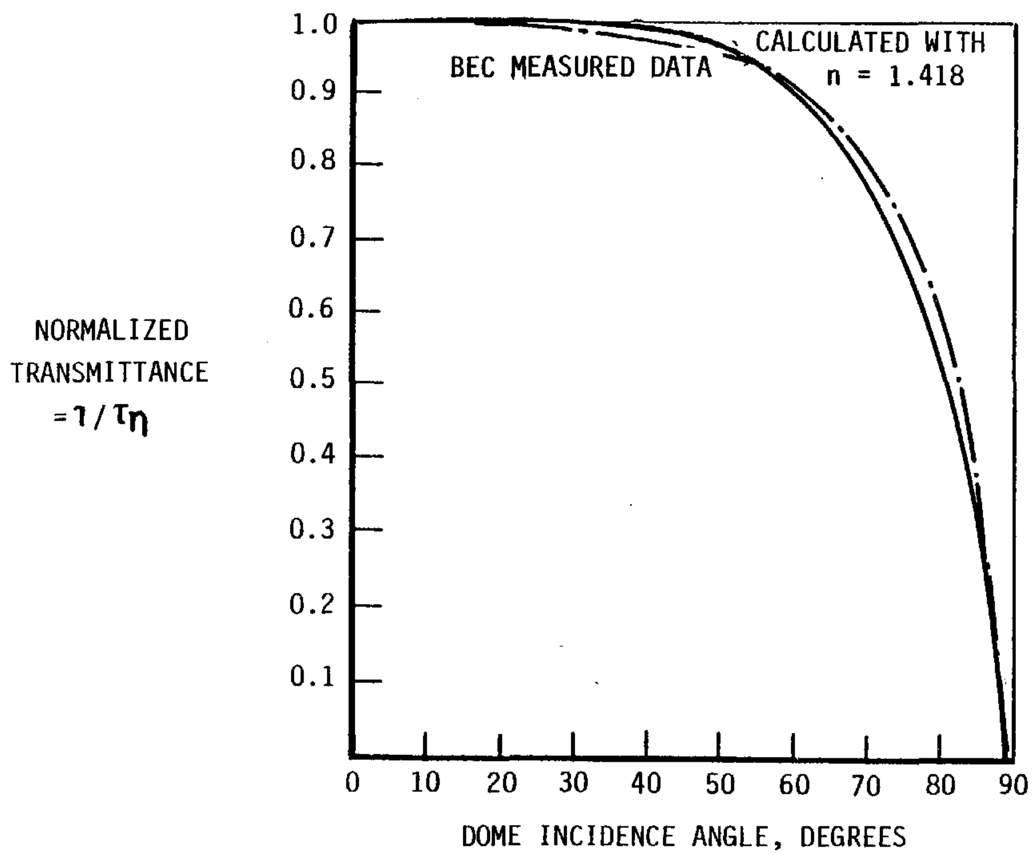


FIGURE 6.1-4
NORMALIZED DOME TRANSMISSION DATA

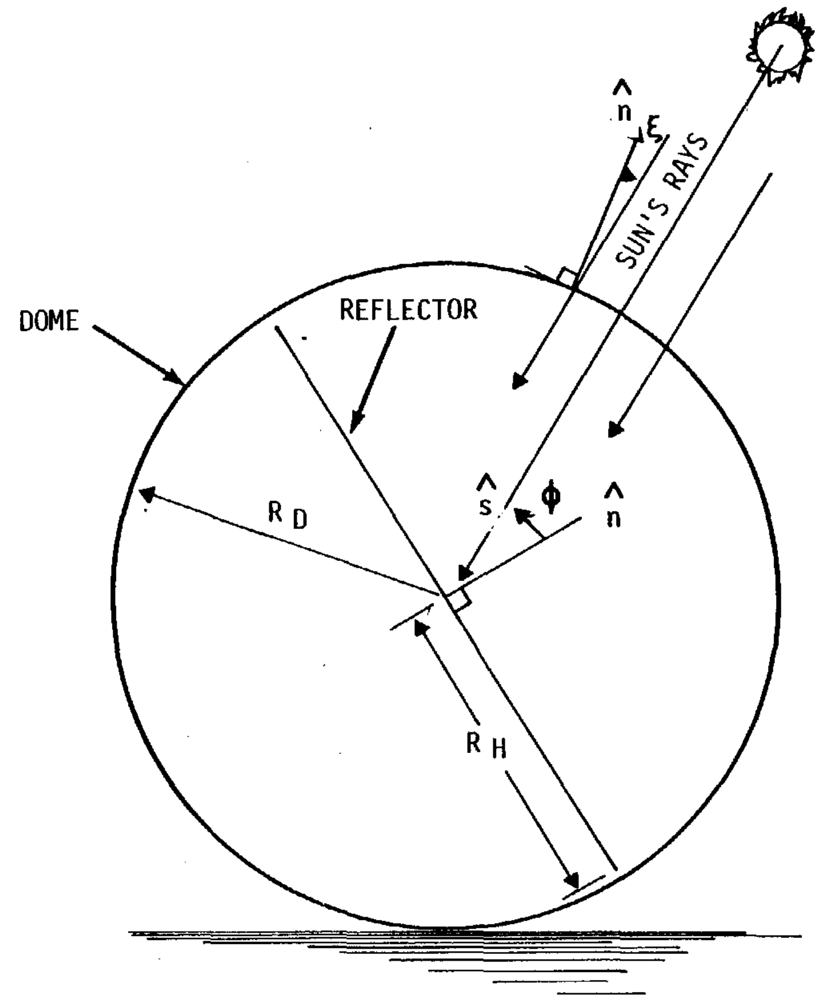


FIGURE 6.1-5 DOME TRANSMITTANCE OPTICAL MODEL

integrated transmittance values shown in Figure 6.1-6. These data are nondimensionalized by the square of the normal incidence transmittance. Several values of the heliostat to dome radius ratio are shown. The w = 0.96 line would be most typical of BEC enclosed plastic heliostat designs. The data in Table 6.1-1 and Figure 6.1-6 are also consistent with similar data calculated by SERI (ref. 6.1-5).

A further analysis was performed to account for the variation in the incidence angle over a typical heliostat field as a function of time of day and day of the year. The DELSOL 2 program was used to produce a field layout typical of what would be expected for a plastic enclosed heliostat (data from the BEC Prototype Heliostat program, Ref. 6.1-6 was used). With that field layout (10864 heliostats, radial stagger pattern), the incidence angle, ϕ, between the heliostat normal and the incoming solar rays was calculated for each sector of the field. Using the integration methods used to produce Figure 6.1-6 yielded the $\bar{\tau}^2$ for each sector of the field. Weighting the sector values by the number of heliostats per sector, a field-averaged $\bar{\tau}^2$ value was calculated. The weighted, field averaged $\bar{\tau}^2$ is 0.93 times the square of the normal transmittance.

Similar calculations can be made as a function of time of day and day of year. Those data are presented in Table 6.1-2. These data show that the field averaged $\bar{\tau}^2$ remains nearly constant at 0.93 of the normal transmittance squared. It was concluded that a single, appropriately chosen transmittance value could represent the dome transmission over the entire year. For example if the normal transmittance was $\tau_n = 0.88$, then

$$\bar{\tau}^2 = 0.93\ (0.88)^2 = 0.72$$

with the mirror reflectance value, ρ, an effective mirror reflectance value can be defined

$$\rho_{eff} = \rho \times \bar{\tau}^2$$

assuming the above $\bar{\tau}^2$ value and $\rho = 0.86$, then in this case

$$\rho_{eff} = 0.86 \times 0.72 = 0.62$$

This value can be input into the DELSOL 2 program as the heliostat reflectance (DELSOL 2 parameter RMIRL).

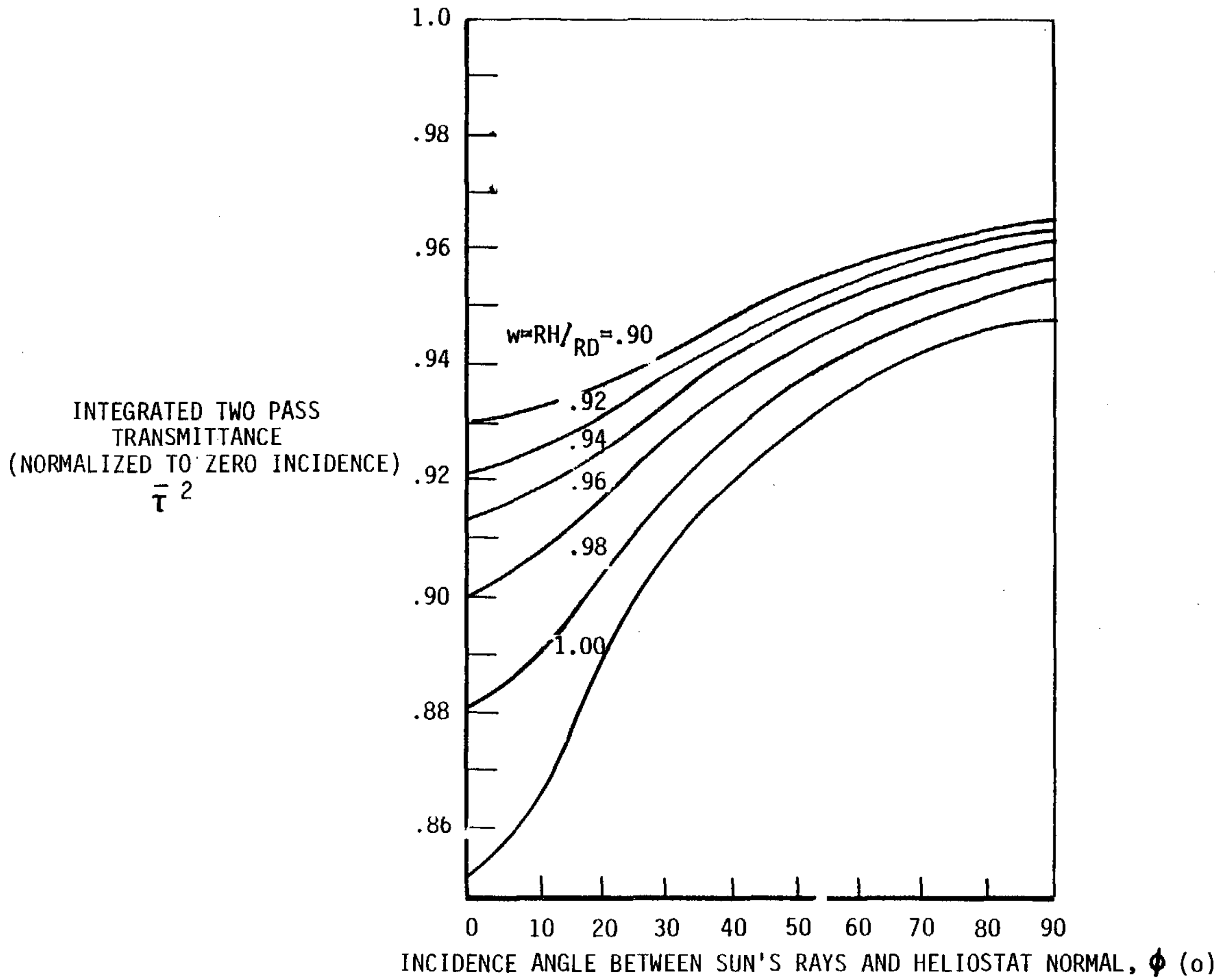


FIGURE 6.1-6 INTEGRATED TWO PASS TRANSMITTANCE DATA

Table 6.1-1. Two Pass Dome Transmittance Curve Fit Coefficients

$$\tau^2(\theta) = \sum_{i=0}^{5} A_i \sin^{2i}\theta$$

i	Ai
0	+ 0.779685
1	- 1.101869
2	+ 10.60400
3	- 35.91640
4	+ 48.03514
5	- 22.31322

TABLE 6.1-2

Field Averaged, Two-Pass Dome Transmittance
Data Normalized to Zero Incidence

	DAY OF YEAR				
Hour of Day	354.75	35.38	81.0	126.63	172.25
0	.9314	.9314	.9319	.9326	.9330
1	.9314	.9314	.9318	.9326	.9228
2	.9316	.9315	.9318	.9324	.9327
3	.9323	.9320	.9319	.9323	.9326
4		.9327	.9326	.9326	.9324
5			.9332	.9331	.9327
6				.9335	.9331
Daily Average	.9316	.9316	.9320	.9326	.9327
Hours Operation	6.61	7.73	9.61	11.08	11.69
Plant Stop Time (Zenith-75°)	3.31	3.86	4.80	5.54	5.84

Dome Shadowing and Blocking

The major modification made by SERI to the DELSOL 2 code was to add a calculation of shadowing and blocking due to the dome enclosure material. The additional shadowing and blocking is illustrated in Figure 6.1-8. Heliostat number 1 shadows a part of heliostat number 2. The shadowing of mirror 2 by mirror 1 represented by area A_1 would be calculated by the normal DELSOL 2 routines. However, the dome shadowing represented by region A_2 would not. Also, since the enclosure material is not opaque, the dome "halo" region must account for the dome transmission. The SERI modifications used to calculate the dome shadowing are A_2 weighted by the radial intensity function of the partially transmitting dome material. This dome shadowing and blocking factor is then added to the mirror shading and blocking factor.

A first order estimate of the dome shading and blocking can be made by considering the halo region of the dome as being opaque. Using the same geometry as in Figure 6.1-8, the total shadowing by mirror plus dome would be given by

$$S_{D+M} = \frac{A_1 + A_2}{A_H} = \frac{A_1}{A_H} \left(1 + \frac{A_2}{A_1} \right)$$

without the dome, the blocking is given by

$$S_m = A_1/A_H$$

These ratios can be calculated and plotted against the heliostat centerline to centerline spacing as shown in Figure 6.1-9. These data show that the dome shadowing is only important when the heliostats overlap slightly, i.e., when the centerline-to-centerline distance is $\geq$ 1.7 dome radii. Figure 6.1-9 shows the dome adding about 28% more at 1.7 dome radii or 58% more at 1.8 dome radii.

These data show that dome shadowing and blocking losses should add at most 0.01 to the total plant shadowing and blocking loss factors. This result is consistent with previous BEC dome shadowing and blocking evaluations (ref. 6.1-6).

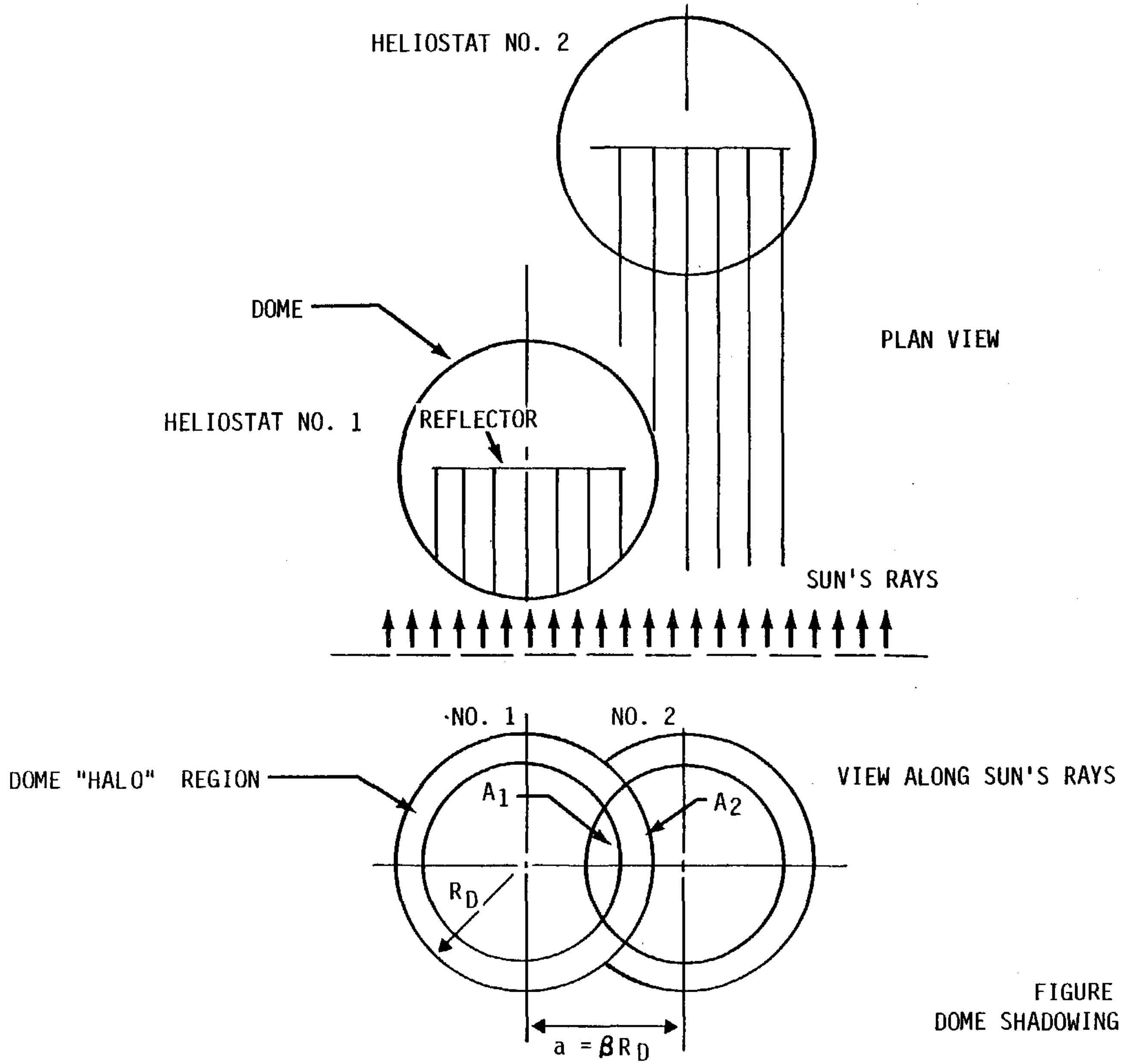


FIGURE 6.1-8
DOME SHADOWING AND BLOCKING

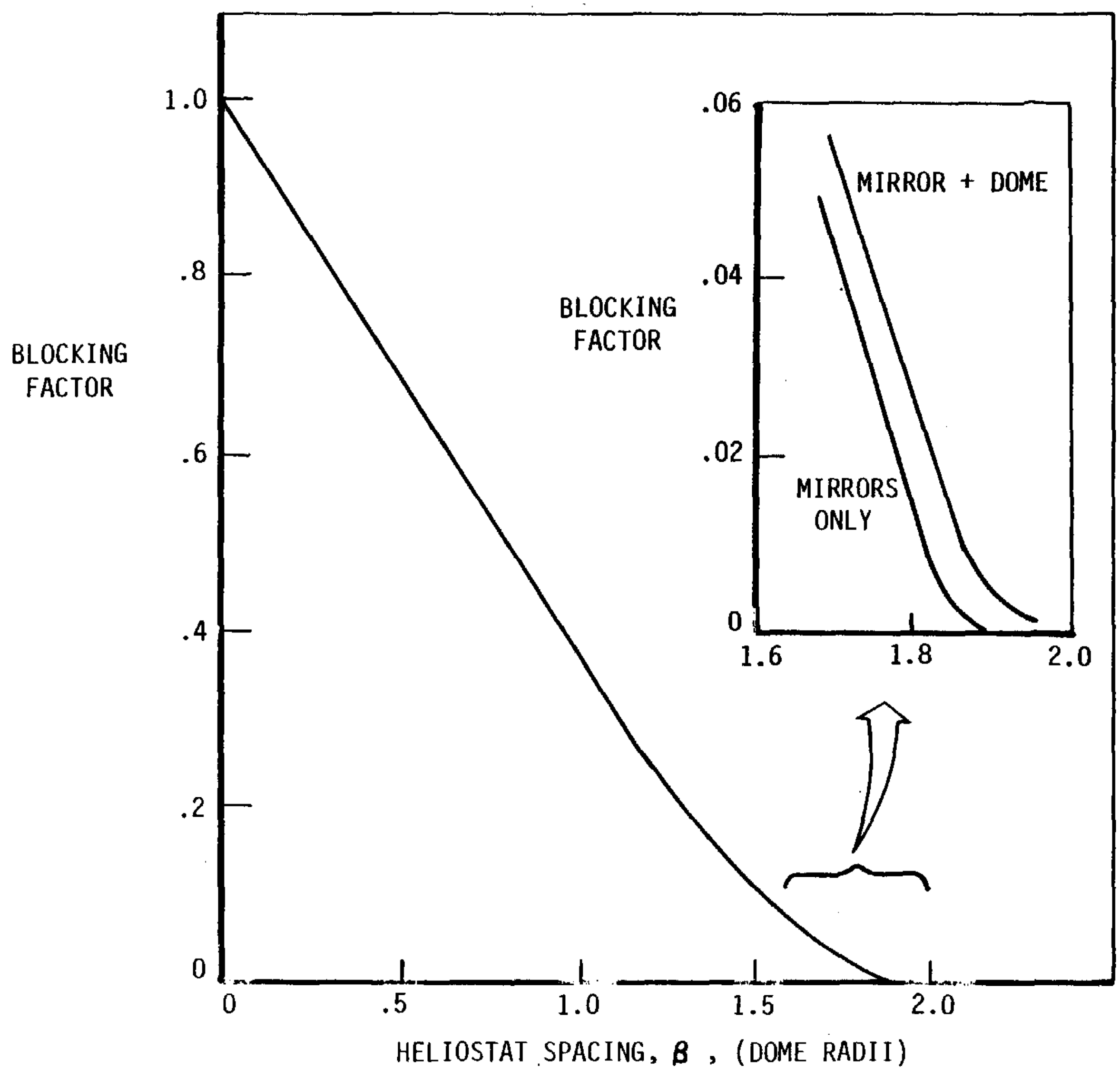


FIGURE 6.1-9 DOME SHADOWING AND BLOCKING RESULTS

6.1.2 Gravity Focus Analysis

A plastic membrane reflector stretched over a support ring will deflect causing a catenary-type surface. For the small membrane deflections experienced in the BEC reflector, the surface is very nearly a paraboloid. With the assumption of a parabolic surface, the focal length, f, of the gravity focused membrane can be calculated as a function of the membrane stress, σ, the membrane density, ρ_m, and the elevation angle, α, by the following

$$f = \frac{\sigma / \rho_m}{\sin \alpha}$$

This relationship is illustrated in Figure 6.1-10. The mirror elevation angle can be calculated as a function of position in the field, time of day and day of the year. Assuming a constant membrane stress of σ = 1000 psi and a membrane density of ρ_m = 0.043 lbm/in^3, the focal length can also be calculated over the field. As can be seen the focal length varies both radially and azimuthally around the field. As the sun moves, the elevation angle and hence the focal length change.

The DELSOL 2 heliostat focusing options are: no-focus (flat mirrors), focal length equal to slant range (perfect focus) and user defined focal lengths. The last option is intended to allow a selection of focal length in each heliostat row radially from the tower. However, to calculate annual performance and optimize the field size, tower height, and receiver dimensions, the focal lengths per row are maintained constant. There does not exist a heliostat computer code which will allow the continuously changing reflector focal length.

In order to produce an approximation to the gravity focus case, a DELSOL 2 run was made for a perfectly focused heliostat, i.e., all focal lengths were set equal to the slant range. With this field layout, the gravity focused focal lengths that would be experienced were calculated for each field sector for the afternoon of day 81, March 21. The average focal length in each radial row was calculated. Also calculated was the standard deviation for each focal length average. An hour-by-hour performance calculation was made using DELSOL 2 and the gravity focused focal lengths. The resulting performance data were

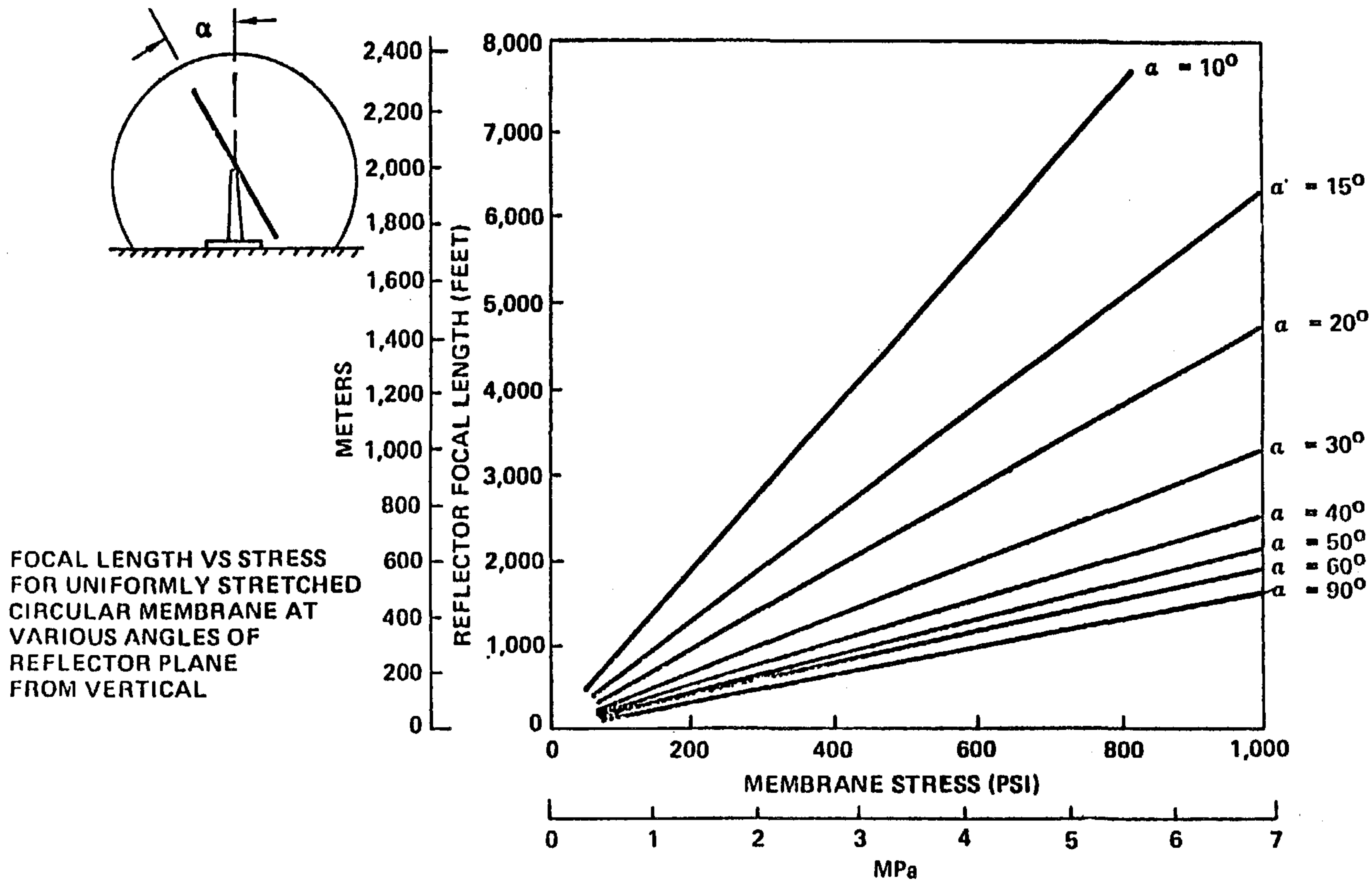


FIGURE 6.1-10 MEMBRANE DEFLECTION DUE TO GRAVITY

compared to the perfect focus and no focus data for the same heliostat field. These data have been previously presented in Figure 3.8-1.

6.1.3 Enclosed Heliostat Performance

Figure 6.1-11 presents the design point and annual average plant performance for the selected enclosed plastic heliostat design.

6.2 Glass Heliostat Reference Case Performance

The heliostat design and performance data listed in Table 6.1-3 were provided by Sandia based on their evaluations in the second generation heliostat program. The cost data supplied by Sandia were in 1980$. The cost basis for this study is 1983$. An inflation rate of 6%/year was assumed to bring component costs to 1983 levels. The assumed unit cost data are presented in Table 6.1-4.

Based on the performance requirements of Table 2.0-1, the heliostat performance of Table 6.1-3, and the unit cost data of Table 6.1-4, the modified DELSOL 2 code was employed to produce an optimized system design. The field layout is illustrated in Figure 6.1-12. The design point and annual average plant performance is given in Figure 6.1-13. Table 6.1-5 presents a summary of the plant design and cost data. The estimate of busbar energy cost from this system is 127 mils/kWhr.

6.3 Heliostat Operation and Maintenance

Operation and maintenance cost expressed as a percent of installed cost is the required input to DELSOL. Operations costs consisted primarily of a plant operator, labor and electrical power required by the blowers, drives and controls. Maintenance is divided between materials (and equipment) and labor. Needed materials include washing materials, filters and pre-filters, replacement parts, and the scheduled replacement enclosures. Labor requirements are scheduled (enclosure replacement, heliostat washing, filter changes, alignment checks) and unscheduled (replacement of failed components). The cost of the enclosure replacement machines is included as a maintenance item. Heliostat washing equipment and maintenance trucks were included in heliostat capital costs under CBS 4460, Site Costs.

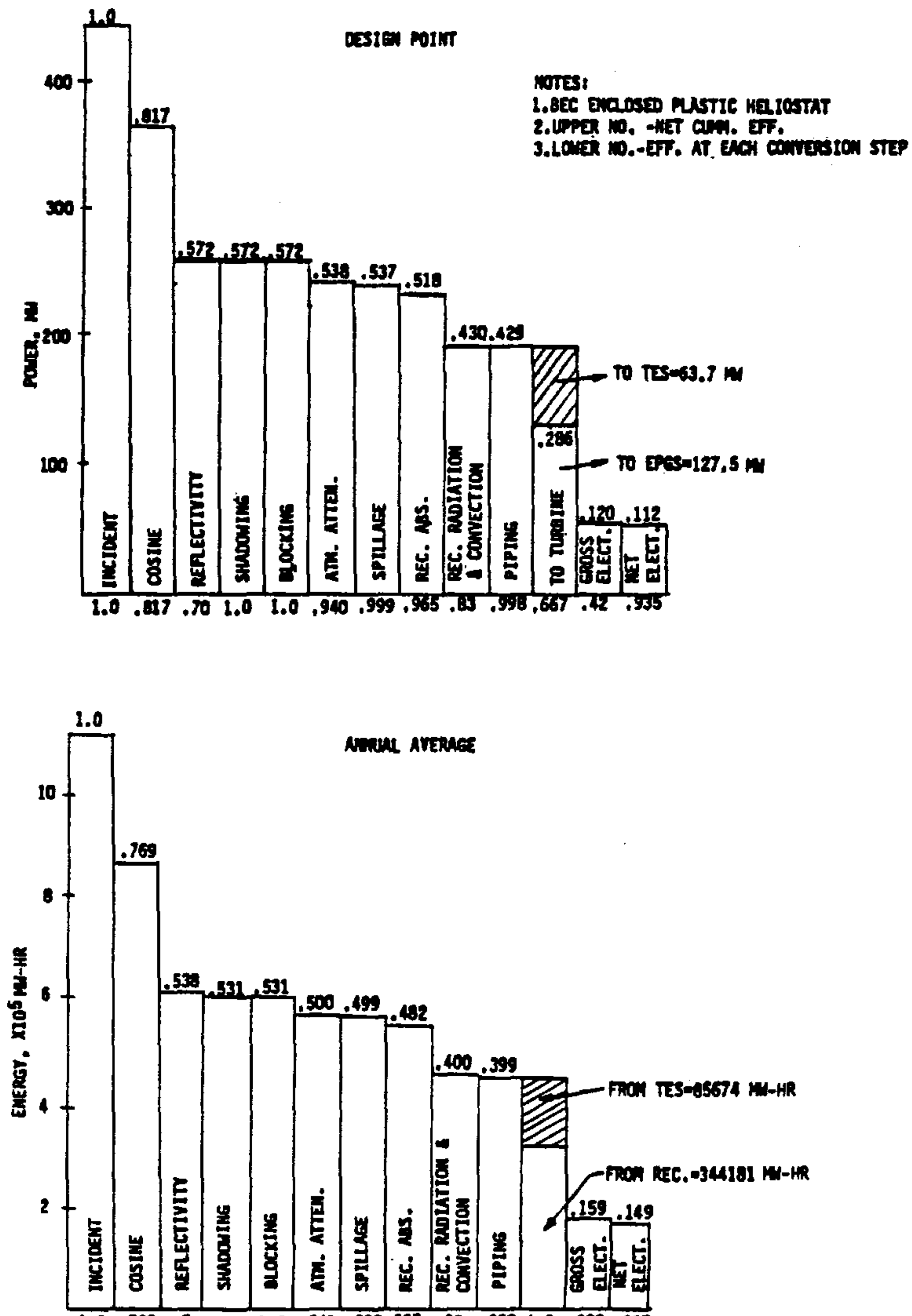


FIGURE 6.1-11 BEC ENCLOSED PLASTIC HELIOSTAT DESIGN POINT AND ANNUAL AVERAGE PLANT PERFORMANCE

Table 6.1-3. Reference Heliostat Performance Data

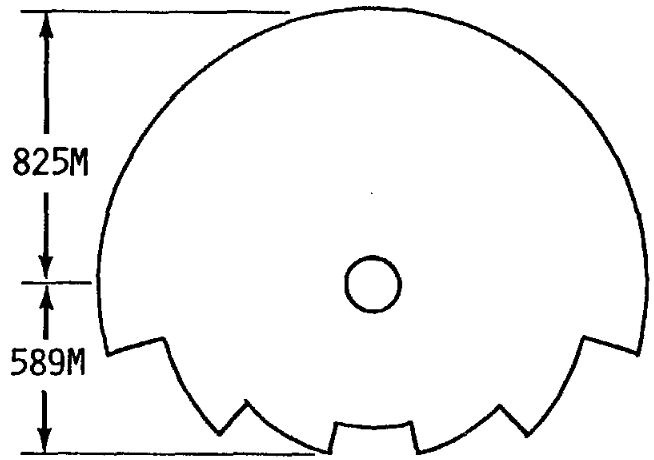
Heliostat width	8.66m
Heliostat height	6.86m
Reflectivity	0.92
Ratio of mirror area to total area	0.957
Canting	on axis
Cant focal length	slant range
Panel focal length	2.0 tower heights vertical 6.0 tower heights horizontal
No. of cant panels	14
Std. deviation elevation	0.0002
Std. deviation azimuth	0.0002
Std. deviation surface normal	0.0012 (horiz. and vert.)
Std. deviation reflected vector	0.0000 (horiz. and vert.)

Table 6.1-4. Unit Cost Data
1983$

Component	DELSOL 2 Variable	Unit Cost
Heliostat (incl. wiring)	CH	113.15$/$M^2$*
Land	CL	2.50 $/$M^2$
Tower cost parameters	CTOW1	3.403 X $10^6$$
	CTOW2	-2.622 X $10^4$$/m^2
	CTOW3	1.6534 X 10^2 $/$M^2$
Ref. receiver cost	CREC1	2.92 X 10^6
Ref. receiver area	ARECRF	1084m^2
Ref. rec. pump cost	CRPREF	7.539 x $10^5$$
Ref. storage pump cost	CSPREF	1.6966 x $10^5$$
Ref. piping cost - hot	CHPREF	1.483 x 10^4 $/m
Ref. piping cost - cold	CCPREF	0. $/m
Ref. TES containment cost	CSTREF	5.161 x $10^6$$
Ref. TES medium cost	CSTRMD	3.618 x $10^6$$
Ref. heat exchanger cost	CHEREF	1.7135 x $10^6$$
Ref. EPGS cost	CEGREF	30.67 x $10^6$$
Fixed cost	CFIXED	7.865 x $10^6$$

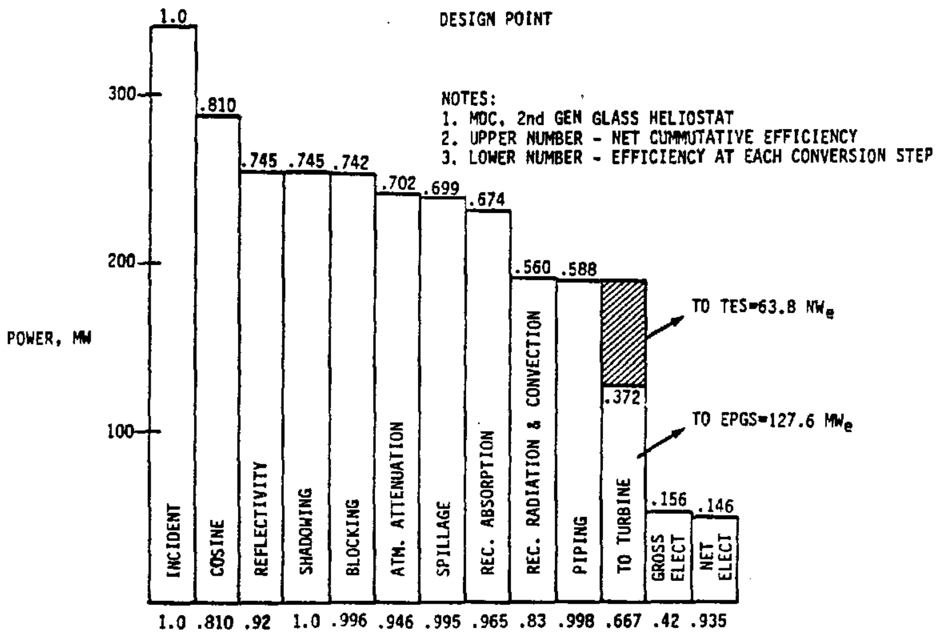
* 113.15 (1983$) = 95 (1980$) x $(1.06)^3$

2ND GEN. REF CASE 50 MW_e FIELD



No. of Heliostats	6609
Land area	1.96 KM^2
Tower Height	110M
Receiver Height	16.8M
Diameter	12.0M
Levelized BBEC	127 MILS/KW-HR
% Heliostat Cost	49.0%

FIGURE 6.1-12 GLASS HELIOSTAT REFERENCE CASE FIELD LAYOUT



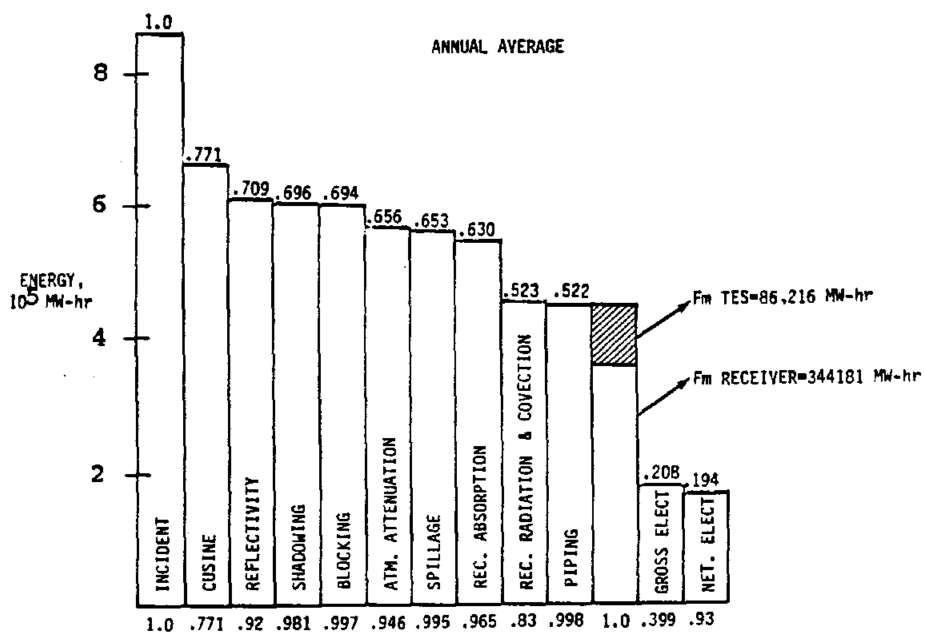


FIGURE 6.1.13 GLASS HELIOSTAT REFERENCE CASE DESIGN POINT AND ANNUAL AVERAGE PLANT PERFORMANCE

Table 6.1-5. Glass Heliostat Reference Case Plant Design Summary

Number of heliostats	6609	
Land area, km^2	1.94	
Mirror area, km^2	0.37	
Tower height, m	110m	
Receiver height, m	16.8m	
width, m	12.0m	
		%
Direct capital cost, $10^6$$	85.59	100
Land	4.85	5.67
Heliostat	41.95	49.01
Tower	2.58	3.01
Receiver	2.04	2.38
Piping	3.17	3.70
Pumps	0.37	0.43
Storage	5.83	6.81
EPGS	16.09	18.80
Heat Exchangers	0.86	1.01
Fixed	7.87	9.19

A component reliability analysis was performed by the Boeing Aerospace Company on the plastic heliostat design to determine failure rates for blowers, filters, drive actuators, drive motors and ground anchor assemblies. Control system failure rate data was determined for the BEC Prototype Heliostat study (Reference 3-1) and was used again here.

Heliostat washing costs were based on the BEC Second Generation estimate of 8 washes per year, using 3 machines with 2 operators per machine. Approximately \$8.00 per year per heliostat for washing materials was allotted.

Table 6.3-1 summarizes first year maintenance and operation costs in terms of \$/heliostat and $\$/m^2$. The total cost is $\$1.94/m^2$ which equates to 4.34% of the heliostat capital cost of $\$44.68/m^2$.

Table 6.3-1. Operation and Maintenance Cost Summary

Element	\$/Hel.-Yr.	\$/m^2
Maintenance		
Materials:		
Enclosure replacement	39.17	.66
Encl. repl. machines	1.39	.024
Washing mat'l.	8.00	.13
Filters/prefilters	.40	.006
26 gearboxes		
124 motors		
98 blowers		
3 domes	4.84	.082
3 refl.		
3 bases		
67 HC		
Labor - Unscheduled		
HC repairs	3.66	.062
Drive (G-box + motor)	.25	.004
Blower	.11	.002
Enclosure	.00	.000
Reflector	.01	.000
Base	.01	.000
-Scheduled		
Enc. replace	4.39	.074
Enc. Wash	24.97	.423
Filters	.56	.009
Align. check	1.72	.029
Field Operations	15.90	.269
Field Power		
Blower, drives, controls	9.56	.162
TOTALS	114.94	1.94

$$\% \text{ O/M} = \frac{1.94}{44.68} \times 100 = 4.34$$

6.4 Bus-Bar Energy Cost

Results from the DELSOL analyses are given in Table 6.4-1. The levelized BBEC was determined to be 110 mils/kW-hr for the BEC plastic heliostat. This compares to 127 mils/kW-hr for the reference case heliostat. Figure 6.4-1 shows side-by-side comparisons of the two power plant cases.

At first glance one might conclude that the reference case heliostat costs only 16% more than the plastic heliostat. However, the heliostat only accounts for 31.7% and 49.0% of the plant costs for plastic and reference case, respectively. When balance of plant costs are subtracted a more realistic picture of cost advantage is seen. Figure 6.4-2 makes this comparison, which is shown to be approximately 38%.

Table 6.4-1. BEC Plastic Heliostat Power Plant Description

Heliostat

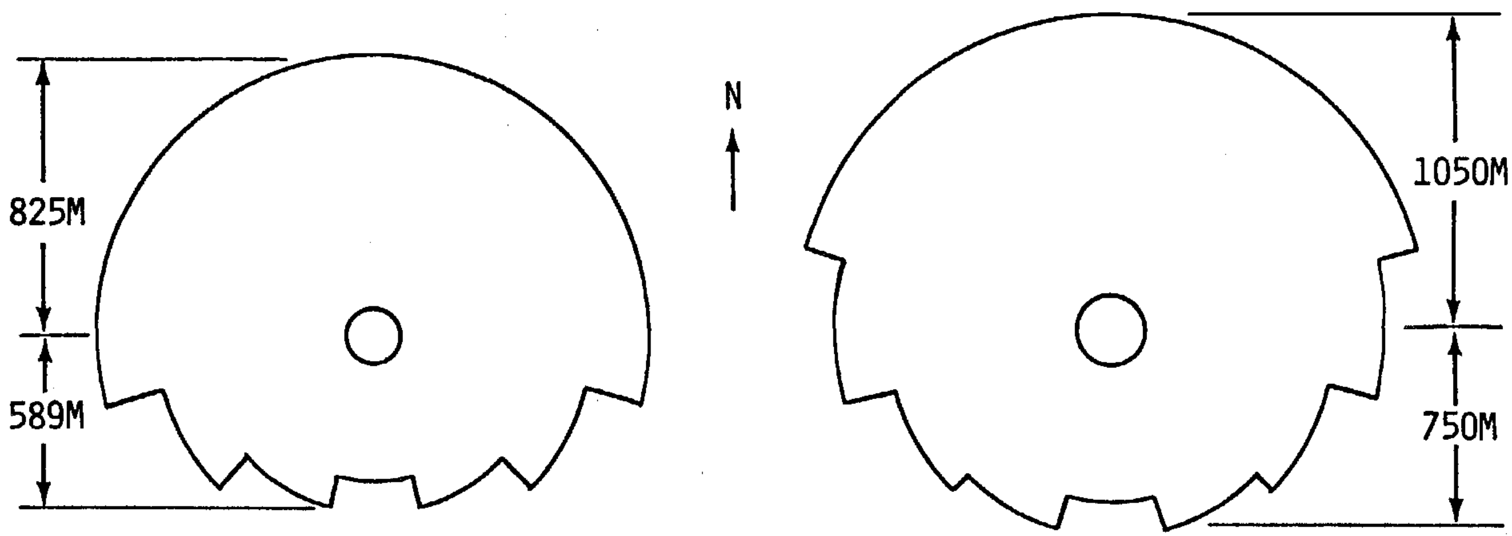
Heliostat refl. area: 59.03m^2
Heliostat optical performance: $\rho\tau^2$ = .75
Heliostat installed cost: \$44.68/m^2
Levelized first year heliostat O/M cost: 4.34%

Plant

Elec. power:	50MWe
Tower height:	140 meters
Receiver dimensions:	Diameter - 12.0 meters
	Height - 17.25 meters
Number of heliostats:	8018
Land area:	2.424km^2
Plant cost:	\$66.63 x 10^6
Heliostat costs:	\$21.15 x 10^6
Balance of plant cost:	\$45.48 x 10^6
Annual elec. production:	167,243 MW_e-hr
Levelized BBEC:	110.49 mils/kW-hr

2ND GEN. REF CASE 50 MW_e FIELD

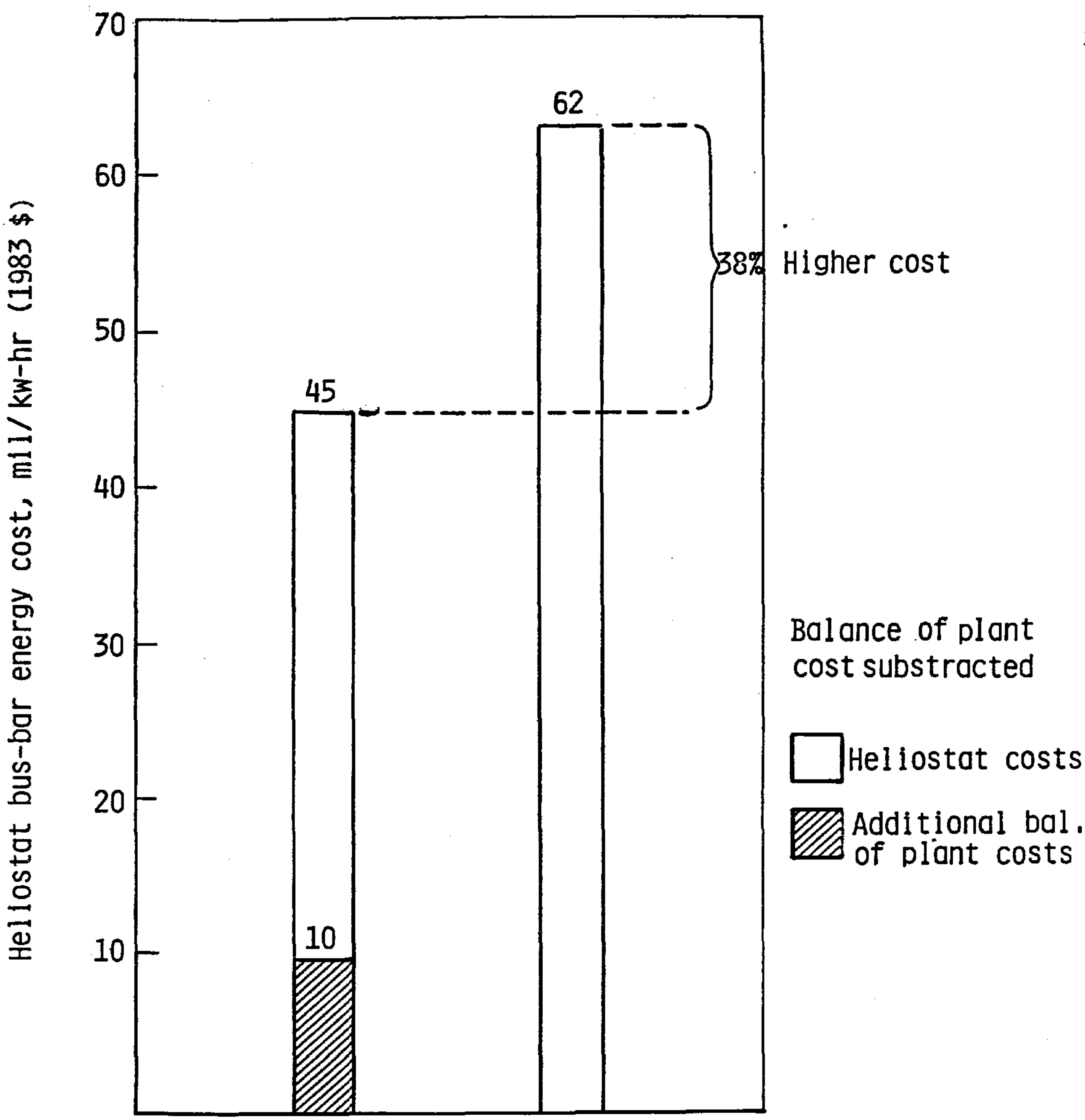
BEC PLASTIC 50 MW_e FIELD



No. of Heliostats	6609
Land area	1.96 KM^2
Tower Height	110M
Receiver Height	16.8M
Diameter	12.0M
Levelized BBEC	127 MILS/KW-HR
% Heliostat Cost	49.0%

No. of Heliostats	8018
Land Area	2.42 KM^2
Tower Height	140M
Receiver Height	17.3M
Diameter	12.0M
Levelized BBEC	110 MILS/KW-HR
% Heliostat Cost	31.7%

FIGURE 6.4-1 POWER PLANT COMPARISON



	BEC Plastic	2ND GEN. REF. CASE
Capital	45 $/M2	113 $/M2
O/M	4.34%	1.70

FIGURE 6.4-2 BBEC COMPARISON

6.5 Sensitivity Analyses

6.5.1 BBEC Sensitivity to Heliostat Capital Cost

Energy costs were determined for the BEC plastic and reference heliostats with the values for installed costs increased by 30% and decreased by 30%. These data, along with baseline values are plotted in Figure 6.5-1. The sensitivities are identified by the slopes of the plots. For one dollar of savings per square meter the BEC plastic heliostat would save 0.95 mils/kW-hr, while the reference Second Generation heliostat would save 0.57 mils/ kW-hr.

Figure 6.5-2 is a non-dimensionalized plot of sensitivities. In this form the differences in absolute costs are ignored and the relative sensitivities are compared. From this point of view the reference heliostat is more sensitive to capital cost variations.

6.5.2 BBEC Sensitivity to O/M Cost

Energy costs were determined for the BEC plastic and Second Generation reference case heliostats with the values for O/M costs increased by 30% and decreased by 30%. These data, along with baseline values are plotted in Figure 6.5-3. The sensitivities are identified by the slopes. For one percent of savings the BEC plastic heliostat would save 3.92 mils/kW-hr, while the reference Second Generation heliostat would save 7.76 mils/kW-hr.

Figure 6.5-4 is a non-dimensionalized plot of O/M sensitivities. In this form the differences in absolute costs are ignored and the relative sensitivities are compared. From this point of view the BEC heliostat is more sensitive to O/M cost variations.

6.5.3 BBEC Sensitivity to Optical Properties

Energy costs were determined for the BEC plastic heliostat with values for $\rho\tau^2$ for enclosure and reflector materials now available, for the baseline materials and for theoretically optimum materials. $\rho\tau^2$ values are:

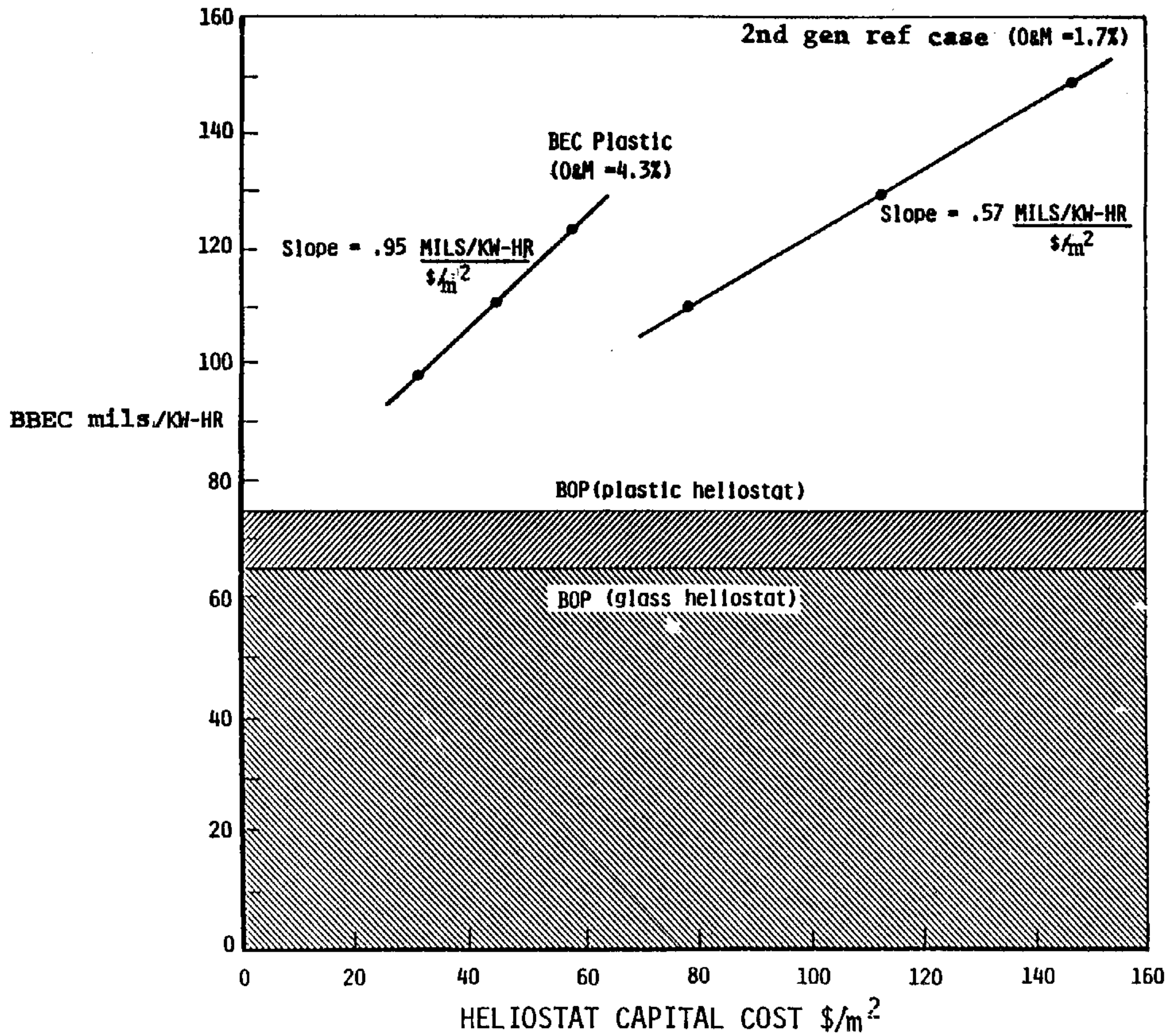


FIGURE 6.5-1 SENSITIVITY COMPARISON BBEC/CAPITAL COST

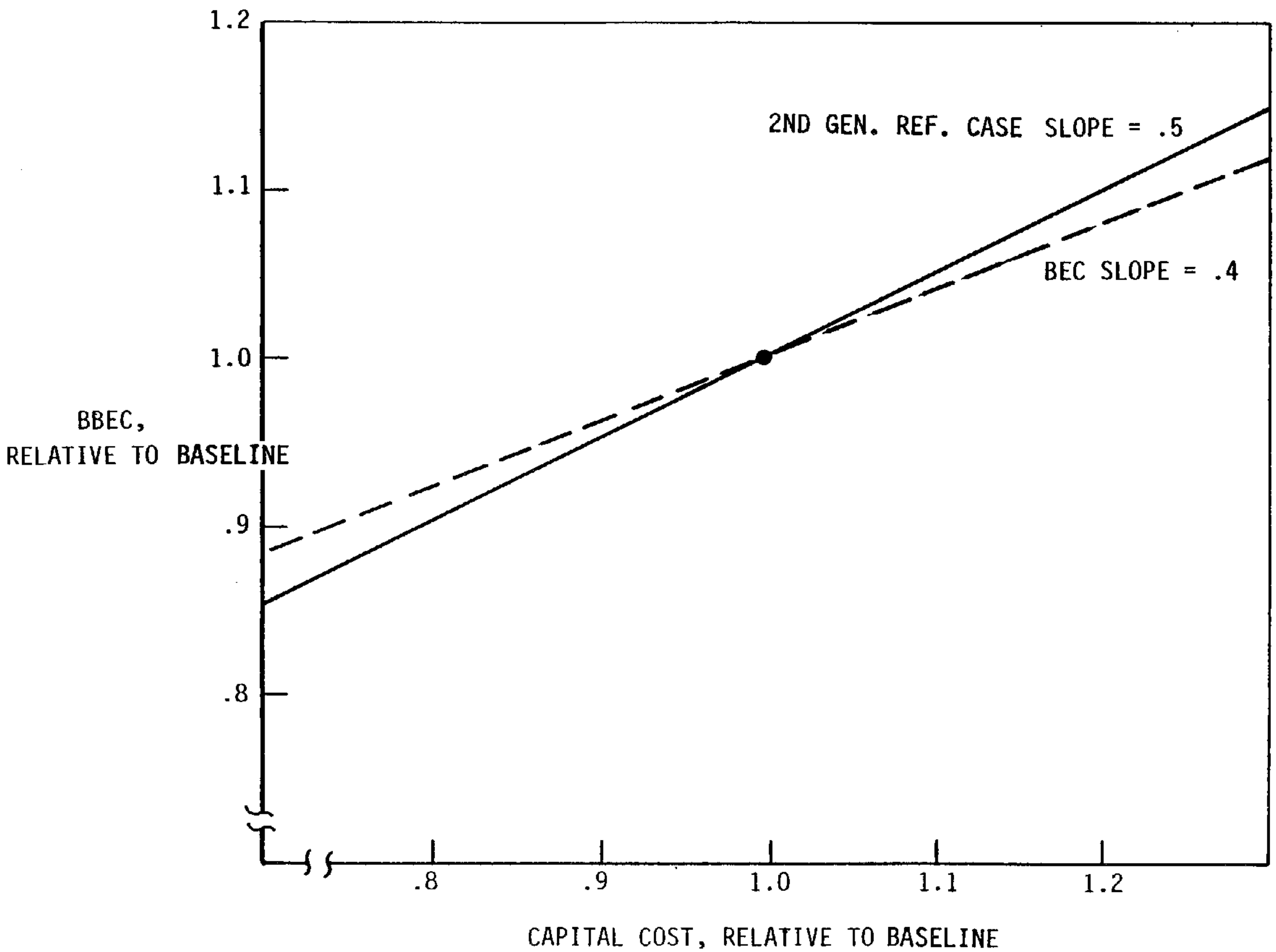


FIGURE 6.5-2 NON-DIMENSIONALIZED SENSITIVITY BBEC/CAPITAL COST

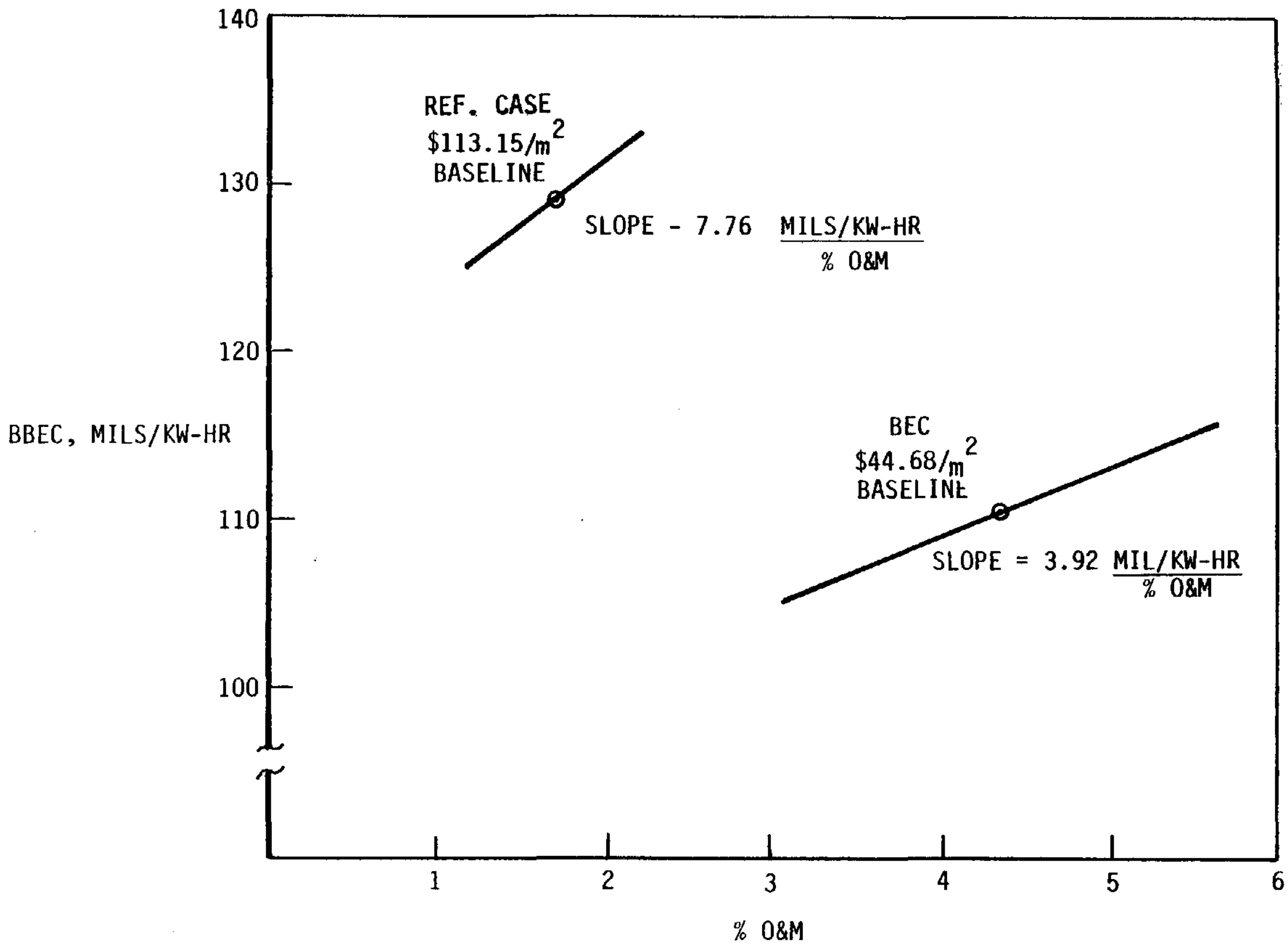


FIGURE 6.5-3 SENSITIVITY COMPARISON BBEC/O&M

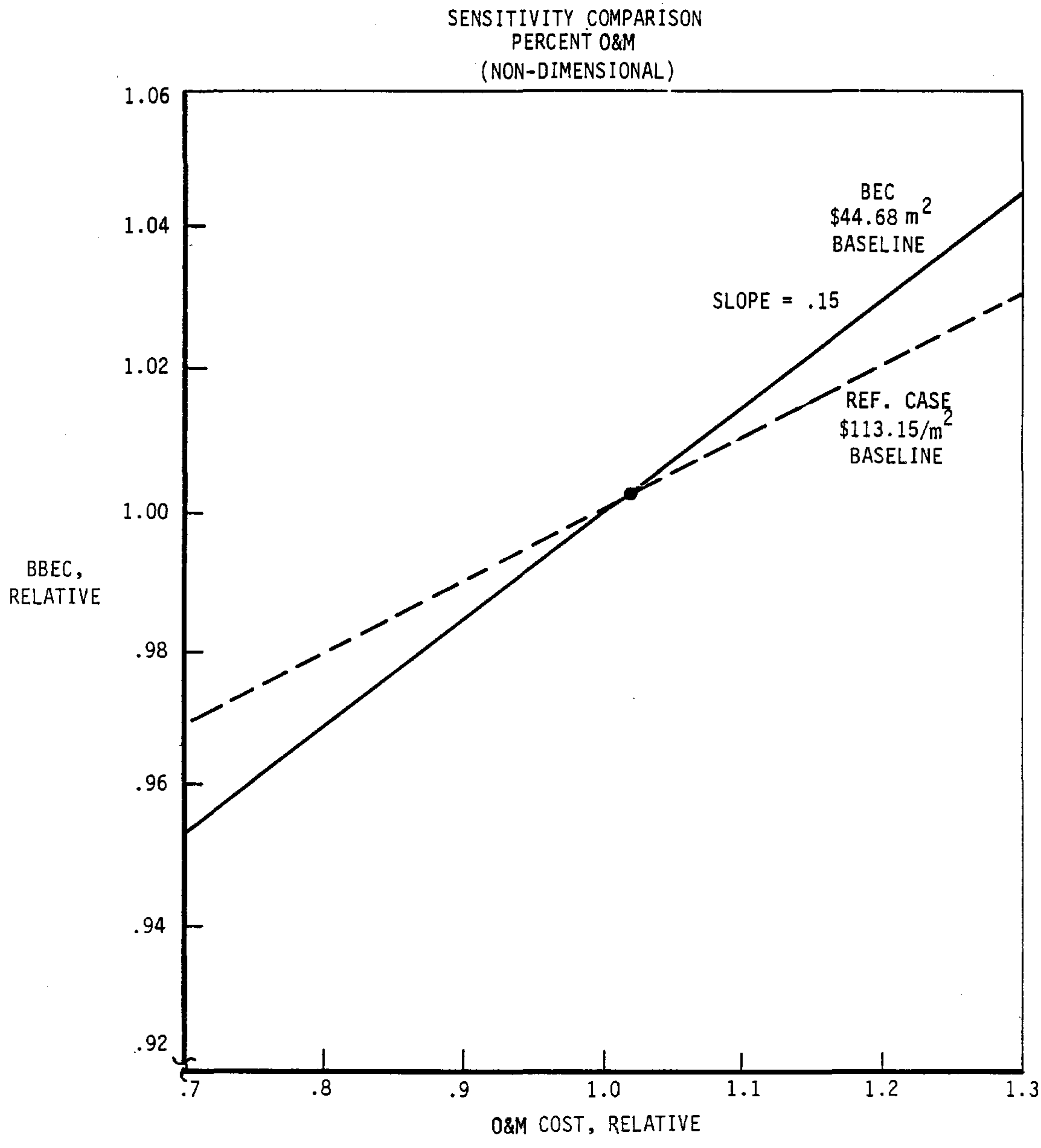


FIGURE 6.5-4 NON-DIMENSIONALIZED SENSITIVITY BBEC/O&M

$\rho\tau^2$	Materials
.67	Aluminized PMMA; Kynar
.75	Aluminized PMMA; Specular Kynar
.85	Silvered film; AR coated Kynar

BBEC data is plotted in Figure 6.5-5. The plot is approximately linear, with the slope indicating the sensitivity. For one unit of $\rho\tau^2$ improvement, .8 mil/kW-hr savings would be realized. For instance, if the baseline value of .75 is improved to .85 (ten units), an improvement of 8 mils/kW-hr would result. Obviously, improvements in τ are the most effective.

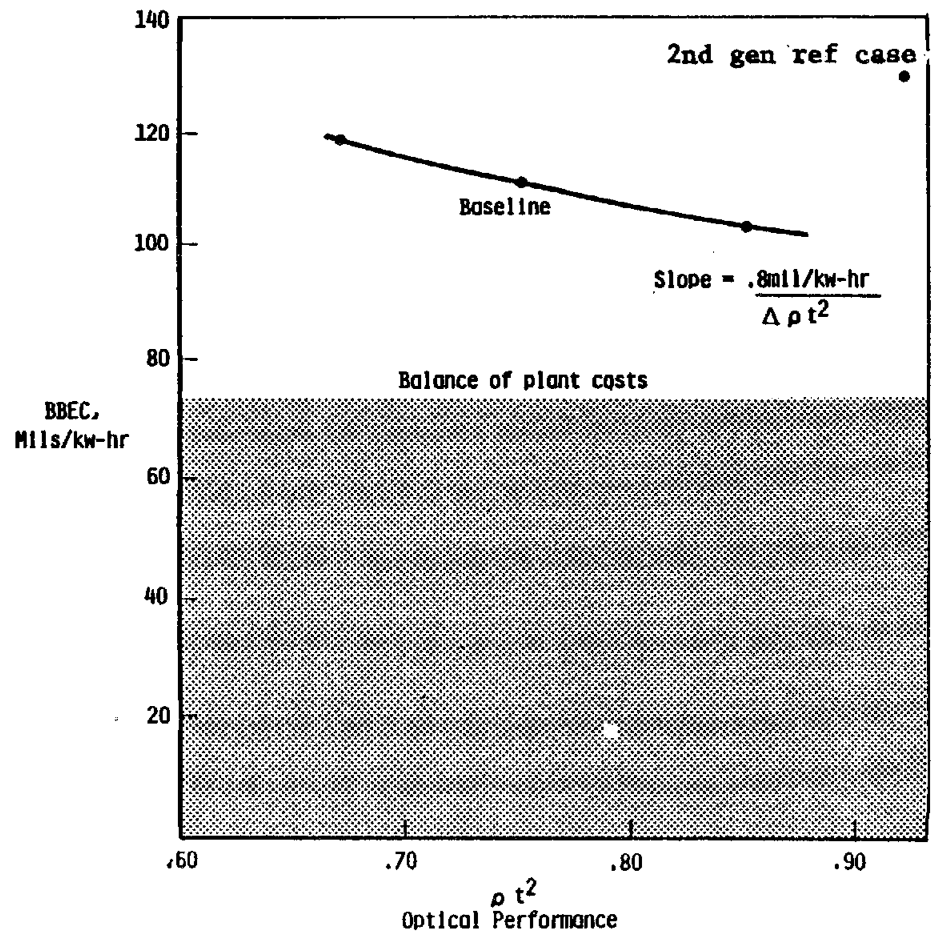


FIGURE 6.5-5 OPTICAL PROPERTY SENSITIVITY BBEC/ρt^2

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Plastic enclosed heliostats offer a significant opportunity for collector subsystem cost reduction. In this study the reference case glass heliostat was estimated to have a 150% higher capital cost and nearly 40% higher busbar energy cost cost for a 50-MW_e power plant. Further analysis and development is needed to arrive at the optimum design and to evaluate the payoff more precisely.

7.2 Recommendations for Future Research and Development

Areas identified as requiring further research and development are discussed here. The work is catagorized into "near term" and "longer term" depending upon whether the period of accomplishment would be in the next year or before 1990.

7.2.1 Near Term (1983-1984)

Design and cost analyses should continue to determine capital and busbar energy costs at high production rates of about 250,000 heliostats per year. This production rate is approximately what would be required to provide 1000 to 2000 MW_e additional power per year. It is also the rate at which the minimum achievable capital cost is expected to occur. Commercial fabricator(s) would be employed to assist with the production analysis and pricing.

Design and fabrication of scale model prototypes is recommended. Complete heliostats in the diameter range of 7 to 10 feet should be fabricated and installed in the field at a southwestern U.S. site for long term exposure testing. Thermoformed KYNAR enclosures would be preferred, but gore-formed enclosures could be provided at some cost savings. Experience from these prototypes would be applied to a next generation of larger prototypes.

While gravity-sag focus was favored over active focus using the analytical tools available at this time, it is recommended that a more thorough analysis be performed. This would require some code writing or possible modification of the existing DELSOL code.

7.2.2 Longer Term (Before 1990)

Thermoforming of large diameter enclosures in at least 2 or 3 steps is recommended. This will allow step-wise process development before committing to the large expense of a final, large thermoforming facility. Diameters of less than 10 feet, 20 feet and finally 30 feet are envisioned. Optical and mechanical properties evaluations would be performed at each size level to verify process controls before moving on to the next size.

A continuing materials development program is essential to obtain optimum performing polymeric films. Reflectivity improvements may be realized through surface improvements of the metallized PMMA or posible silverization of PMMA or KYNAR. Improvements in the transmissivity of KYNAR may be achieved by surface coatings or treatments. In addition alternate materials should be investigated on a continuing basis.

New ideas in the area of wiring and controls should be pursued. At this time these costs account for about 30% of the capital cost of a plastic heliostat and are assumed fixed without respect to heliostat size.

8.0 REFERENCES

3-1 Solar Central Receiver Prototype Heliostat SAN/1604-3, prepared by Boeing Engineering and Construction Company, June, 1978

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APPENDIX A

HELIOSTAT COST ANALYSIS

COST BREAKDOWN STRUCTURE

CBS	DEFINITION
4410	Reflective Assembly
4420	Drives
4430	Controls
4440	Foundation Pedestal
4450	Enclosure
4460	Assembly/Installation (including field wiring)

```
/*
/*        MAILING INSTRUCTIONS
/*
/*        NAME          MARK BERRY
/*        PHONE         575-5606
/*        MAILSTOP      83-PS
/*
```

H E L C A T

A HELIOSTAT COST ANALYSIS TOOL

VERSION 1.0

EDITION DATE AUGUST 13, 1981

REVISION SEPTEMBER 22, 1981
MINOR REVISIONS MADE BY BEC FOR DOMED HELIOSTATS FEB , 1983

H E L C A T OPTIONS AND MODEL PARAMETERS

MODEL OPTIONS

STRAIGHT LINE DEPRECIATION
WITH NO LEARNING CURVE COST REDUCTION

PARAMETER MATRIX

		FACTORY	SITE	TRANSPORTATION
1	DURATION OF COST PROJECTION - YEARS	10.000	10.000	10.000
2	BASE RATE DIRECT LABOR COST - $/HOUR	10.580	17.230	15.000
3	BASE RATE PROD FACILITY COST - $/SQFT	50.000	0.000	0.000
4	LAND COST FOR PROD FACILITY - $/ACRE	20000.000	0.000	0.000
5	INFLATION RATE	.060	.060	.060
6	RETURN TO BOND HOLDERS	.102	.102	.102
7	RETURN TO EQUITY HOLDERS	.166	.166	.166
8	COMBINED INCOME TAX RATE	.500	.500	.500
9	INVESTMENT TAX CREDIT	.100	.100	.100
10	EQUITY FRACTION	.800	.800	.800
11	PROPERTY TAX AND INSURANCE FRACTION	.040	.040	.040
12	PURCHASED MATERIAL SCRAP FRACTION	.010	.010	.010
13	MAINTENANCE FRACTION	.020	.040	.040
14	GENERAL AND ADMINISTRATIVE FRACTION	.090	0.000	0.000
15	WORKING CAPITAL FRACTION	.170	0.000	0.000
16	RAW MATERIAL SCRAP FRACTION	.030	.030	.030
17	TOOLING LIFETIME (ACCOUNTING) - YEARS	5.000	5.000	5.000
18	EQUIPMENT LIFETIME (ACCOUNTING) - YEARS	10.000	10.000	10.000
19	FACILITY LIFETIME (ACCOUNTING) - YEARS	30.000	30.000	30.000
20	FACILITY CONSTRUCTION PERIOD - YEARS	3.000	0.000	0.000
21	FACILITY PLANT ENGINEERING FRACTION	.100	0.000	0.000
22	FACILITY STARTUP QUANTITY	20000.000	0.000	0.000
23	COST REDUCTION COEFFICIENT - START UP	.920	0.000	0.000
24	TOOLING LIFETIME (TAX) - YEARS	3.000	3.000	3.000
25	EQUIPMENT LIFETIME (TAX) - YEARS	8.000	8.000	8.000
26	FACILITY LIFETIME (TAX) - YEARS	25.000	25.000	25.000
27	BASE RATE TRANS COST - $/LB	.035	.035	.035
28	INDIRECT FRACTION - LABOR	.270	.300	.300
29	INDIRECT FRACTION - MATERIAL	.004	0.000	0.000
30	INDIRECT FRACTION - TOOL'G,EQUIP'T,FAC'Y	.006	0.000	0.000

SPECIAL COST MATRICES

CATEGORY NUMBER	FACILITY $/SQ FT	LABOR $/HR	TRANSPORT (UNITS VARY)
1	40.	9.00	650.000 $/TRKLOAD
2	60.	12.00	130.000 $/TRKLOAD
3	80.	18.00	0.000
4	100.	21.00	0.000
5	120.	25.00	0.000
6	140.	30.00	0.000
7	0.	0.00	0.000
8	0.	0.00	0.000
9	0.	0.00	0.000

REFERENCE QUANTITY, COST REDUCTION COEFFICIENT

FACTORY SITE/TRANSPORT

MATERIALS	100000., .960	50000., .980
LABOR	50000., .940	50000., .980

BEC PLASTIC SELECTED DESIGN B

4410 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM		QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=M 4410 SOURCE:RYERSON	REFLECTOR STRUCTURE				162.00 / HELIOSTAT
ENTRY TYPE=M 4410 SOURCE: ROHM&HAAS	REFLECTOR MEMBRANE PMMA RESIN				20.14 / HELIOSTAT
ENTRY TYPE=M 4410 SOURCE:BEC PROTOTYPE	REFLECTOR MEMBRANE ADHESIVES				10.71 / HELIOSTAT
ENTRY TYPE=E 4410 SOURCE:PENNWALT EST.	PROCESS EQUIP. PMMA EXTRUDER				500000.
ENTRY TYPE=E 4410 SOURCE:PENNWALT EST.	PROCESS EQUIP. BIAXIAL ORIENT.				2000000.
ENTRY TYPE=E 4410 SOURCE:AIRCO TEMESCAL	PROCESS EQUIP. METALIZER				6000000.
ENTRY TYPE=E 4410 SOURCE:BEC EST.	PROCESS EQUIP. COATER				1000000.
ENTRY TYPE=E 4410 SOURCE:PENNWALT	PROCESS EQUIP. SCRAP GRINDER				50000.
ENTRY TYPE=E 4410 SOURCE:BEC EST.	PROCESS EQUIP. MEMBRANE PANELS				150000.
ENTRY TYPE=E 4410 SOURCE:BEC PROTOTYPE	PROCESS EQUIP. MEMBR TO STRUCTURE				1660000.
ENTRY TYPE=L 4410 SOURCE:BEC EST.	FACTORY LABOR REFL. MEMBRANE CMF	.1440E+01	HRS / HELIOSTAT		
ENTRY TYPE=B 4410 SOURCE:BEC	REFLECTOR FACILITIES CMF	.6000E+05	SQFT		
ENTRY TYPE=A 4410 SOURCE:BEC	REFLECTOR LAND CMF	.4000E+01	ACRE		
ENTRY TYPE=Q 4410	REFLECTOR QTY/YR	.5000E+05	/YR		

```
TOTAL PURCHASED MATERIALS=      0.00 $/HELIOSTAT
TOTAL RAW MATERIALS=    192.85 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR=    1.4400    HRS/HELIOSTAT
TOTAL CONSUMABLES=      0.00    $/HELIOSTAT
LAND REQUIRED=    4.0000    ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE=    60000.    SQ FT
TOTAL EQUIPMENT COST= 11360000.    $
TOTAL TOOLING COST=         0.    $
QUANTITY=    50000.    / YEAR

TOTAL DIRECT LABOR COST=     15.24 $/HELIOSTAT
TOTAL PRODUCTION FACILITY COST    3000000.  $
```

BEC PLASTIC SELECTED DESIGN B

4420 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

	ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=Z 4420 SOURCE:WINSMITH	GIMBAL ACTUATOR				251.00 / HELIOSTAT
ENTRY TYPE=Q 4420	GIMBAL QTY/YR	.5000E+05	/YR		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
LAND REQUIRED= 0.0000 ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE= 0. SQ FT
TOTAL EQUIPMENT COST= 0. $
TOTAL TOOLING COST= 0. $
QUANTITY= 50000. / YEAR
TOTAL SUBCONTRACTS AND FLOW-THROUGH EXPENSES= 251.00 $/HELIOSTAT

BEC PLASTIC SELECTED DESIGN B

4430 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS	P=PURCHASED MATERIALS	L=DIRECT LABOR HOURS
S=SUPPLIES AND CONSUMABLES	T=TOOLING	E=EQUIPMENT
B=BUILDING OR FACILITY SIZE	A=LAND FOR PRODUCTION FACILITY	Q=QUANTITY
X=TRANSPORTATION REQUIREMENTS	Y=SITE-RETAINED CAPITAL	Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=Z 4430 CONTROLS SOURCE:2ND GEN CONTRACTOR AVG				399.00 / HELIOSTAT
ENTRY TYPE=Z 4430 CONTROLS BCS SOURCE:SANDIA 2ND GEN				18.75 / HELIOSTAT
ENTRY TYPE=Q 4430 CONTROLS QTY	.5000E+05	/YR		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
LAND REQUIRED= 0.0000 ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE= 0. SQ FT
TOTAL EQUIPMENT COST= 0. $
TOTAL TOOLING COST= 0. $
QUANTITY= 50000. / YEAR
TOTAL SUBCONTRACTS AND FLOW-THROUGH EXPENSES= 417.75 $/HELIOSTAT

BEC PLASTIC SELECTED DESIGN B

4440 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS	P=PURCHASED MATERIALS	L=DIRECT LABOR HOURS
S=SUPPLIES AND CONSUMABLES	T=TOOLING	E=EQUIPMENT
B=BUILDING OR FACILITY SIZE	A=LAND FOR PRODUCTION FACILITY	Q=QUANTITY
X=TRANSPORTATION REQUIREMENTS	Y=SITE-RETAINED CAPITAL	Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

		ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=M SOURCE:PENNWALT	4440	BASE DISH KYNAR				108.00 / HELIOSTAT
ENTRY TYPE=M SOURCE:BEC	4440	SUPPORT/FOUNDATION/BLOWER				163.00 / HELIOSTAT
ENTRY TYPE=S SOURCE:BEC	4440	BASE PACKAGING				4.00 / HELIOSTAT
ENTRY TYPE=T SOURCE:PENNWALT/BEC	4440	TOOLING KYNAR EXTRUSION CMF				1200000.
ENTRY TYPE=T SOURCE:PENNWALT/BEC	4440	TOOLING KYNAR THERMOFORMING CMF				600000.
ENTRY TYPE=T SOURCE:BEC	4440	TOOLING SUPPORT PARTS CMF				200000.
ENTRY TYPE=L SOURCE:BEC	4440	LABOR KYNAR THERMOFORMING CMF	.1000E+01	HRS / HELIOSTAT		
ENTRY TYPE=L SOURCE:BEC	4440	LABOR SUPPORT PARTS CMF	.5500E+00	HRS / HELIOSTAT		
ENTRY TYPE=B SOURCE:BEC	4440	BASE FACILITY CMF	.1000E+06	SQFT		
ENTRY TYPE=A SOURCE:BEC	4440	BASE LAND	.6000E+01	ACRE		
ENTRY TYPE=Q	4440	BASE QTY	.5000E+05	/YR		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 271.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 1.5500 HRS/HELIOSTAT
TOTAL CONSUMABLES= 4.00 $/HELIOSTAT
LAND REQUIRED= 6.0000 ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE= 100000. SQ FT
TOTAL EQUIPMENT COST= 0. $
TOTAL TOOLING COST= 2000000. $

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QUANTITY=     50000.     / YEAR

TOTAL DIRECT LABOR COST=      16.40 $/HELIOSTAT
TOTAL PRODUCTION FACILITY COST     5000000.  $
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BEC PLASTIC SELECTED DESIGN B

4450 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS	P=PURCHASED MATERIALS	L=DIRECT LABOR HOURS
S=SUPPLIES AND CONSUMABLES	T=TOOLING	E=EQUIPMENT
B=BUILDING OR FACILITY SIZE	A=LAND FOR PRODUCTION FACILITY	Q=QUANTITY
X=TRANSPORTATION REQUIREMENTS	Y=SITE-RETAINED CAPITAL	Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ENTRY	ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST	
ENTRY TYPE=M 4450 SOURCE:PENNWALT	ENCLOSURE KYNAR				364.00	/ HELIOSTAT
ENTRY TYPE=S 4450 SOURCE:BEC	ENCLOSURE PACKAGING				8.00	/ HELIOSTAT
ENTRY TYPE=T 4450 SOURCE:PENNWALT/BEC	ENCOSURE TOOLING EXTRUDER CMF				1800000.	
ENTRY TYPE=T 4450 SOURCE:PENNWALT/BEC	ENCLOSURE TOOLING THERMOFORM CMF				750000.	
ENTRY TYPE=L 4450 SOURCE:BEC	FACTORY LABOR CMF	.2500E+01	HRS / HELIOSTAT			
ENTRY TYPE=B 4450 SOURCE:BEC	ENCLOSURE FACILITY CMF	.1200E+06	SQFT			
ENTRY TYPE=A 4450 SOURCE:BEC	ENCLOSURE LAND	.7000E+01	ACRE			
ENTRY TYPE=Q 4450	ENCLOSURE QTY	.5000E+05	/YR			

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 364.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 2.5000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 8.00 $/HELIOSTAT
LAND REQUIRED= 7.0000 ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE= 120000. SQ FT
TOTAL EQUIPMENT COST= 0. $
TOTAL TOOLING COST= 2550000. $
QUANTITY= 50000. / YEAR

TOTAL DIRECT LABOR COST= 26.45 $/HELIOSTAT
TOTAL PRODUCTION FACILITY COST 6000000. $

BEC PLASTIC SELECTED DESIGN B

4460 FACTORY COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS	P=PURCHASED MATERIALS	L=DIRECT LABOR HOURS
S=SUPPLIES AND CONSUMABLES	T=TOOLING	E=EQUIPMENT
B=BUILDING OR FACILITY SIZE	A=LAND FOR PRODUCTION FACILITY	Q=QUANTITY
X=TRANSPORTATION REQUIREMENTS	Y=SITE-RETAINED CAPITAL	Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

	ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=B 4460 SOURCE:BEC	REFLECTOR FACILITIES SAB	.4000E+05	SQFT		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
LAND REQUIRED= 0.0000 ACRES
PRODUCTION FACILITY (BASE RATE COST CATEGORY) SIZE= 40000. SQ FT
TOTAL EQUIPMENT COST= 0. $
TOTAL TOOLING COST= 0. $
QUANTITY= 0. / YEAR
TOTAL PRODUCTION FACILITY COST 2000000. $

DEFAULT QUANTITY USED IN PROFIT CENTER CALCULATION
DEFAULT QUANTITIES = 50000.(FACTORY), 5400.(TRANSPORT/SITE)

BEC PLASTIC SELECTED DESIGN B

4460 SITE COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

	ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=L 4460 SOURCE:BEC	SITE LABOR	.5400E+01	HRS / HELIOSTAT		
ENTRY TYPE=M 4460 SOURCE:2ND GEN CONTRACTOR AVG	FIELD WIRING				326.00 / HELIOSTAT
ENTRY TYPE=L 4460 SOURCE:BEC	INST. C/O LABOR	.3300E+01	HRS / HELIOSTAT		
ENTRY TYPE=T 4460 SOURCE:BEC	SITE TOOLING	.3000E+01	YR		50000.
ENTRY TYPE=L 4460 SOURCE:BEC	SITE SURVEY	.2500E+00	HRS / HELIOSTAT		
ENTRY TYPE=Z 4460 SOURCE:BEC	INITIAL CALIBR.				7.18 / HELIOSTAT
ENTRY TYPE=Y 4460 SOURCE:BEC	SITE EQUIPMENT				120000.
ENTRY TYPE=Y 4460 SOURCE:STAR EQUIP. CO.	WASHING EQUIP.				225000.
ENTRY TYPE=Y 4460 SOURCE:BEC	MAINT VANS				30000.
ENTRY TYPE=Q 4460	INST C/O QTY	.8000E+04	/STE		

A-14

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 326.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 8.9500 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
WEIGHTED EQUIPMENT COST= 0. $ TIMES YEARS USED / SITE
QUANTITY= 8000. / SITE
TOTAL SUBCONTRACTS AND FLOW-THROUGH EXPENSES= 7.18 $/HELIOSTAT
TOTAL SITE-RETAINED CAPITAL= 375000.00 $

TOTAL DIRECT LABOR COST= 154.21 $/HELIOSTAT

BEC PLASTIC SELECTED DESIGN B

4410 TRANSPORTATION COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=X 4410 REFL TRANS TO SITE SPECIAL TRANSPORTATION COST CATEGORY 1 SOURCE:BEC	.6300E-01	TRUCKLOADS		
ENTRY TYPE=Q 4410 REFLECTOR QTY/SITE	.8000E+04	/STE		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
WEIGHTED EQUIPMENT COST= 0. $ TIMES YEARS USED / SITE
QUANTITY= 8000. / SITE
SPECIAL TRANSPORTATION COST CATEGORY 1 = .063 TRUCKLOADS
INPUT (NOT COMPUTED) TRANSPORTATION COST 40.95 $

BEC PLASTIC SELECTED DESIGN B

4420 TRANSPORTATION COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=X 4420 DRIVE TRANS TO SITE SPECIAL TRANSPORTATION COST CATEGORY 1 SOURCE:BEC	.4000E-03	TRUCKLOADS		
ENTRY TYPE=Q 4420 DRIVE QTY TO SITE	.8000E+04	/STE		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
WEIGHTED EQUIPMENT COST= 0. $ TIMES YEARS USED / SITE
QUANTITY= 8000. / SITE
SPECIAL TRANSPORTATION COST CATEGORY 1 = .000 TRUCKLOADS
INPUT (NOT COMPUTED) TRANSPORTATION COST .26 $

BEC PLASTIC SELECTED DESIGN B

4440 TRANSPORTATION COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS
P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL
L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=X 4440 BASE TRANS TO SITE SPECIAL TRANSPORTATION COST CATEGORY 1 SOURCE:BEC	.4000E-01	TRUCKLOADS		
ENTRY TYPE=Q 4440 BASE QTY TO SITE	.8000E+04	/STE		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
WEIGHTED EQUIPMENT COST= 0. $ TIMES YEARS USED / SITE
QUANTITY= 8000. / SITE
SPECIAL TRANSPORTATION COST CATEGORY 1 = .040 TRUCKLOADS
INPUT (NOT COMPUTED) TRANSPORTATION COST 26.00 $

BEC PLASTIC SELECTED DESIGN B

4450 TRANSPORTATION COSTS

KEY TO ENTRY TYPES

M=RAW MATERIALS
S=SUPPLIES AND CONSUMABLES
B=BUILDING OR FACILITY SIZE
X=TRANSPORTATION REQUIREMENTS

P=PURCHASED MATERIALS
T=TOOLING
A=LAND FOR PRODUCTION FACILITY
Y=SITE-RETAINED CAPITAL

L=DIRECT LABOR HOURS
E=EQUIPMENT
Q=QUANTITY
Z=SUBCONTRACTS AND FLOW-THROUGH EXPENSES

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
ENTRY TYPE=X 4450 ENCLOSURE TO SITE SPECIAL TRANSPORTATION COST CATEGORY 1 SOURCE:BEC	.8000E-01	TRUCKLOADS		
ENTRY TYPE=Q 4450 ENCLOSURE QTY TO SITE	.8000E+04	/STE		

TOTAL PURCHASED MATERIALS= 0.00 $/HELIOSTAT
TOTAL RAW MATERIALS= 0.00 $/HELIOSTAT
TOTAL (BASE RATE COST CATEGORY) DIRECT LABOR= 0.0000 HRS/HELIOSTAT
TOTAL CONSUMABLES= 0.00 $/HELIOSTAT
WEIGHTED EQUIPMENT COST= 0. $ TIMES YEARS USED / SITE
QUANTITY= 8000. / SITE
SPECIAL TRANSPORTATION COST CATEGORY 1 = .080 TRUCKLOADS
INPUT (NOT COMPUTED) TRANSPORTATION COST 52.00 $

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4410 - REFLECTIVE ASSEMBLY

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			327.21
DIRECT MATERIALS		198.64	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	192.85		
SCRAP	5.79		
DIRECT LABOR		15.24	
CONSUMABLES		0.00	
INDIRECT COSTS		12.28	
MAINTENANCE, PLANT ENGINEERING	5.74		
OTHER INDIRECTS	6.53		
CAPITAL REPLACEMENT ALLOWANCE		20.38	
PROPERTY TAX AND INSURANCE		7.01	
GENERAL & ADMINISTRATIVE		23.14	
INTEREST EXPENSE		3.58	
INCOME TAXES		20.89	
RETURN TO EQUITY HOLDERS		23.29	
OTHER EXPENSES		2.79	
ANNUALIZED ONE-TIME COSTS	2.79		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4420 - DRIVES

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			251.00
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		0.00	
MAINTENANCE, PLANT ENGINEERING	0.00		
OTHER INDIRECTS	0.00		
CAPITAL REPLACEMENT ALLOWANCE		0.00	
PROPERTY TAX AND INSURANCE		0.00	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		0.00	
INCOME TAXES		0.00	
RETURN TO EQUITY HOLDERS		0.00	
OTHER EXPENSES		251.00	
SUBCONTRACTS & FLOW-THROUGH	251.00		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4430 - CONTROLS

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE		417.75

DIRECT MATERIALS		0.00
PURCHASED MATERIALS	0.00	
RAW MATERIALS	0.00	
SCRAP	0.00	
DIRECT LABOR		0.00
CONSUMABLES		0.00
INDIRECT COSTS		0.00
MAINTENANCE, PLANT ENGINEERING	0.00	
OTHER INDIRECTS	0.00	
CAPITAL REPLACEMENT ALLOWANCE		0.00
PROPERTY TAX AND INSURANCE		0.00
GENERAL & ADMINISTRATIVE		0.00
INTEREST EXPENSE		0.00
INCOME TAXES		0.00
RETURN TO EQUITY HOLDERS		0.00
OTHER EXPENSES		417.75
SUBCONTRACTS & FLOW-THROUGH	417.75	

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4440 - FOUNDATION/PEDESTAL

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			388.61
DIRECT MATERIALS		279.13	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	271.00		
SCRAP	8.13		
DIRECT LABOR		16.40	
CONSUMABLES		4.00	
INDIRECT COSTS		9.04	
MAINTENANCE, PLANT ENGINEERING	2.80		
OTHER INDIRECTS	6.24		
CAPITAL REPLACEMENT ALLOWANCE		9.68	
PROPERTY TAX AND INSURANCE		4.82	
GENERAL & ADMINISTRATIVE		29.30	
INTEREST EXPENSE		2.46	
INCOME TAXES		14.64	
RETURN TO EQUITY HOLDERS		16.00	
OTHER EXPENSES		3.14	
ANNUALIZED ONE-TIME COSTS	3.14		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4450 - ENCLOSURE

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			527.15
DIRECT MATERIALS		374.92	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	364.00		
SCRAP	10.92		
DIRECT LABOR		26.45	
CONSUMABLES		8.00	
INDIRECT COSTS		12.90	
MAINTENANCE, PLANT ENGINEERING	3.42		
OTHER INDIRECTS	9.48		
CAPITAL REPLACEMENT ALLOWANCE		12.18	
PROPERTY TAX AND INSURANCE		6.19	
GENERAL & ADMINISTRATIVE		39.94	
INTEREST EXPENSE		3.15	
INCOME TAXES		18.83	
RETURN TO EQUITY HOLDERS		20.54	
OTHER EXPENSES		4.06	
ANNUALIZED ONE-TIME COSTS	4.06		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4460 - ASSEMBLY/INSTALLATION

FACTORY COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			9.09
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		1.04	
MAINTENANCE, PLANT ENGINEERING	.80		
OTHER INDIRECTS	.24		
CAPITAL REPLACEMENT ALLOWANCE		.88	
PROPERTY TAX AND INSURANCE		.80	
GENERAL & ADMINISTRATIVE		.28	
INTEREST EXPENSE		.41	
INCOME TAXES		2.50	
RETURN TO EQUITY HOLDERS		2.66	
OTHER EXPENSES		.51	
ANNUALIZED ONE-TIME COSTS	.51		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4460 - ASSEMBLY/INSTALLATION

SITE COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			596.18
DIRECT MATERIALS		335.78	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	326.00		
SCRAP	9.78		
DIRECT LABOR		154.21	
CONSUMABLES		0.00	
INDIRECT COSTS		47.01	
MAINTENANCE, PLANT ENGINEERING	.75		
OTHER INDIRECTS	46.26		
CAPITAL REPLACEMENT ALLOWANCE		3.19	
PROPERTY TAX AND INSURANCE		.29	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		.15	
INCOME TAXES		.55	
RETURN TO EQUITY HOLDERS		.96	
OTHER EXPENSES		54.06	
SUBCONTRACTS & FLOW-THROUGH	7.18		
SITE-RETAINED CAPITAL	46.88		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4410 - REFLECTIVE ASSEMBLY

TRANSPORTATION COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			40.95
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		0.00	
MAINTENANCE, PLANT ENGINEERING	0.00		
OTHER INDIRECTS	0.00		
CAPITAL REPLACEMENT ALLOWANCE		0.00	
PROPERTY TAX AND INSURANCE		0.00	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		0.00	
INCOME TAXES		0.00	
RETURN TO EQUITY HOLDERS		0.00	
OTHER EXPENSES		40.95	
TRANSPORTATION CHARGES	40.95		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4420 - DRIVES

TRANSPORTATION COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			.26
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		0.00	
MAINTENANCE, PLANT ENGINEERING	0.00		
OTHER INDIRECTS	0.00		
CAPITAL REPLACEMENT ALLOWANCE		0.00	
PROPERTY TAX AND INSURANCE		0.00	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		0.00	
INCOME TAXES		0.00	
RETURN TO EQUITY HOLDERS		0.00	
OTHER EXPENSES		.26	
TRANSPORTATION CHARGES	.26		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4440 - FOUNDATION/PEDESTAL

TRANSPORTATION COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			26.00
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		0.00	
MAINTENANCE, PLANT ENGINEERING	0.00		
OTHER INDIRECTS	0.00		
CAPITAL REPLACEMENT ALLOWANCE		0.00	
PROPERTY TAX AND INSURANCE		0.00	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		0.00	
INCOME TAXES		0.00	
RETURN TO EQUITY HOLDERS		0.00	
OTHER EXPENSES		26.00	
TRANSPORTATION CHARGES	26.00		

HELIOSTAT COST MODEL

DETAILED BREAKDOWN

BEC PLASTIC SELECTED DESIGN B

4450 - ENCLOSURE

TRANSPORTATION COSTS

PRODUCTION YEAR 1

TOTAL REQUIRED REVENUE			52.00
DIRECT MATERIALS		0.00	
PURCHASED MATERIALS	0.00		
RAW MATERIALS	0.00		
SCRAP	0.00		
DIRECT LABOR		0.00	
CONSUMABLES		0.00	
INDIRECT COSTS		0.00	
MAINTENANCE, PLANT ENGINEERING	0.00		
OTHER INDIRECTS	0.00		
CAPITAL REPLACEMENT ALLOWANCE		0.00	
PROPERTY TAX AND INSURANCE		0.00	
GENERAL & ADMINISTRATIVE		0.00	
INTEREST EXPENSE		0.00	
INCOME TAXES		0.00	
RETURN TO EQUITY HOLDERS		0.00	
OTHER EXPENSES		52.00	
TRANSPORTATION CHARGES	52.00		

COST SUMMARY BY PROFIT CENTER

TOTAL REQUIRED REVENUE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	327.21	251.00	417.75	388.61	527.15	9.09	1920.81
TRANSPORTATION	40.95	.26	0.00	26.00	52.00		119.21
SITE			0.00	0.00		596.18	596.18
TOTALS BY COMPONENT	368.16	251.26	417.75	414.61	579.15	605.27	

TOTAL FOR TOTAL REQUIRED REVENUE 2636.20

COST SUMMARY BY PROFIT CENTER

DIRECT MATERIALS

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	198.64	0.00	0.00	279.13	374.92	0.00	852.69
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		335.78	335.78
TOTALS BY COMPONENT	198.64	0.00	0.00	279.13	374.92	335.78	

TOTAL FOR DIRECT MATERIALS 1188.47

COST SUMMARY BY PROFIT CENTER

DIRECT LABOR

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	15.24	0.00	0.00	16.40	26.45	0.00	58.09
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		154.21	154.21
TOTALS BY COMPONENT	15.24	0.00	0.00	16.40	26.45	154.21	

TOTAL FOR DIRECT LABOR 212.30

COST SUMMARY BY PROFIT CENTER

CAPITAL REPLACEMENT ALLOWANCE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	20.38	0.00	0.00	9.68	12.18	.88	43.12
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		3.19	3.19
TOTALS BY COMPONENT	20.38	0.00	0.00	9.68	12.18	4.07	

TOTAL FOR CAPITAL REPLACEMENT ALLOWANCE 46.31

COST SUMMARY BY PROFIT CENTER

PROPERTY TAX AND INSURANCE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	7.01	0.00	0.00	4.82	6.19	.80	18.82
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		.29	.29
TOTALS BY COMPONENT	7.01	0.00	0.00	4.82	6.19	1.09	

TOTAL FOR PROPERTY TAX AND INSURANCE 19.11

COST SUMMARY BY PROFIT CENTER

GENERAL & ADMINISTRATIVE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	23.14	0.00	0.00	29.30	39.94	.28	92.66
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		0.00	0.00
TOTALS BY COMPONENT	23.14	0.00	0.00	29.30	39.94	.28	

TOTAL FOR GENERAL & ADMINISTRATIVE 92.66

COST SUMMARY BY PROFIT CENTER

INTEREST EXPENSE

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	3.58	0.00	0.00	2.46	3.15	.41	9.60
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		.15	.15
TOTALS BY COMPONENT	3.58	0.00	0.00	2.46	3.15	.56	

TOTAL FOR INTEREST EXPENSE 9.75

COST SUMMARY BY PROFIT CENTER

INCOME TAXES

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	20.89	0.00	0.00	14.64	18.83	2.50	56.86
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		.55	.55
TOTALS BY COMPONENT	20.89	0.00	0.00	14.64	18.83	3.05	

TOTAL FOR INCOME TAXES 57.41

COST SUMMARY BY PROFIT CENTER

RETURN TO EQUITY HOLDERS

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	23.29	0.00	0.00	16.00	20.54	2.66	62.49
TRANSPORTATION	0.00	0.00	0.00	0.00	0.00		0.00
SITE			0.00	0.00		.96	.96
TOTALS BY COMPONENT	23.29	0.00	0.00	16.00	20.54	3.62	

TOTAL FOR RETURN TO EQUITY HOLDERS 63.45

COST SUMMARY BY PROFIT CENTER

OTHER EXPENSES

BEC PLASTIC SELECTED DESIGN B

PRODUCTION YEAR 1

	4410	4420	4430	4440	4450	4460	TOTALS BY LOCATION
FACTORY	2.79	251.00	417.75	3.14	4.06	.51	679.25
TRANSPORTATION	40.95	.26	0.00	26.00	52.00		119.21
SITE			0.00	0.00		54.06	54.06
TOTALS BY COMPONENT	43.74	251.26	417.75	29.14	56.06	54.57	

TOTAL FOR OTHER EXPENSES 852.52

1.0 PERFORMANCE REQUIREMENTS

1.0.1 Performance Requirements

Primary performance characteristics for collector subsystem and certain elements were established; these are listed in Table 1-1. In addition, secondary performance characteristics were also prescribed for the subsystem and certain elements; they are listed in Table 1-2.

1.1 DESIGN AND CONSTRUCTION REQUIREMENTS

1.1.1 General Design Requirements

The collector subsystem is intended for use by public and private electric utilities, and by commercial firms which use high-quality heat for industrial processes. Thus, prime considerations in designing the collector are performance, durability, reliability, safety, and acceptale life-cycle costs. General design and construction requirements were established which are compatible with these considerations; they are summarized in Table 1-3.

1.1.2 Environmental Design Criteria

The collector subsystem is intended to be used with electric power and industrial process heat (IPH) plants located in the southwestern United States. Thus, the environmental design criteria are based, in part, on conditions expected in that region of the country; they are summarized in Table 1-4.

TABLE 1-1 *Collector Subsystem Primary Performance Requirements*

COMPONENT	REQUIREMENT ①
SYSTEM	o REFLECT 95% OF REDIRECTED ENERGY ON RECEIVER AT < 60° o FUNCTION DURING ALL PLANT STEADY-STATE MODES o POWER INCREMENTS IN TRACKING MODE OF ≤ 10% o EMERGENCY DEFOCUS TO < 3 % POWER IN 120 SECONDS
COLLECTOR FIELD	o AVERAGE STRUCTURAL SUPPORT STATIC DEFLECTIONS ≤ ± 1.7 MRAD FOR MIRROR NORMAL, EACH AXIS (12 M/S WIND; 0° - 50°C; ANY LOCATION; ALL ORIENTATIONS; NO GRAVITY; NO TEMPERATURE EFFECTS) o HEAT FLUX ON UNIRRADIATED PORTIONS OF RECEIVER ≤ 2500 W/M²
HELIOSTAT	o 90% OF REFLECTED ENERGY WITHIN THEORECTICAL BEAM SHAPE + 1.4 MRAD FRINGE FOR 60 DAYS WITHOUT ALIGNMENT (0 M/S WIND; 0° - 50°C; GRAVITY; ALL ORIENTATIONS; ANY LOCATION; HELIOSTAT TRACKING) o BEAM POINTING ERROR ≤ ± 1.5 MRAD EACH AXIS (SAME CONDITIONS AS BEAM QUALITY) o STRUCTURAL DEFLECTION (EXCLUDING FOUNDATION) ≤ ± 1.2 MRAD (12 M/S WIND; 0° - 50°C; ALL ORIENTATIONS; ANY LOCATION; NO GRAVITY; NO WAVINESS; NO FACET MISALIGNMENT) o 2-POINT AIMING
FOUNDATION (2" ABOVE GROUND)	o TILT OR TORSIONAL ROTATION ≤ ± 0.5 MRAD (12 M/S WIND; PLASTIC DEFLECTION FROM 22 M/S WIND) o PLASTIC DEFLECTION ≤ ± 0.15 MRAD (SINGLE 22 M/S WIND)

① Tolerances are 1 sigma values.

TABLE 1-2 *Collector Subsystem Secondary Performance Requirements*

COMPONENT	REQUIREMENT
SYSTEM	o MEET PERFORMANCE @ 12 M/S WIND, 0° - 50°C, GRAVITY o TRACK WITH DEGRADED PERFORMANCE WHEN WIND IS 16 M/S o INITIATE STOW FROM EXTERNAL SIGNAL o INCORPORATE LIGHTNING PROTECTION o OPERATE FROM -9° - 50°C (PLUS INSOLATION ON UNPROTECTED COMPONENTS) o REQUIRE MINIMUM MAINTENACE o ANNOUNCE ANY COMPONENT FAILURE TO HAC o PROVIDE FAULT ISOLATION INFORMATION ON CRITICAL COMPONENTS o MINIMIZE HAZARDS TO OPERATIONS/ MAINTENANCE PERSONNEL AND THE PUBLIC
HELIOSTAT	o CAPABLE OF BEING POSITIONED FOR STOW, CLEANING OR MAINTENANCE ≤ 15 MINUTES (FROM ANY OPERATIONAL ORIENTATION)
CONTROLS	o CONTROL HELIOSTATS BY COMPUTER o SAFE BEAM CONTROL STRATEGY

TABLE 1-3 *Collector Subsystem Design and Construction Requirements*

COMPONENT	REQUIREMENT
SYSTEM	o 30 YEAR LIFE o COMMERCIAL DESIGN AND CONSTRUCTION STANDARDS (UBC/ 1976; AISCM/8TH EDITION; NATIONAL ELECTRIC CODE; NEMA AND MS-454 o OFF-THE-SHELF COMPONENTS o TOLERATE POWER TRANSIENTS o MINIMIZE SUSCEPTIBILITY TO AND GENERATION OF EMR o CORROSION PROTECTION ON ALL PARTS o COMPONENTS OR ASSEMBLIES TRANSPORTABLE BY TRUCK o WORKMANSHIP CONSISTENT WITH GOOD COMMERCIAL PRACTICE o ALL MAJOR ELEMENTS AND ASSEMBLIES TO HAVE NAMEPLATES o LIKE PARTS TO BE INTER- CHANGEABLE o DESIGN TO FACILITATE OPERATON AND MAINTENACE; USE MS-1472 AS GUIDE
COLLECTOR FIELD	o NOT BE VULNERABLE TO EXTENSIVE FIRE DAMAGE o HELIOSTATS NOT DIRECTLY ADJACENT TO A FIRE SHOULD NOT SPREAD TO OTHER PARTS OF THE FIELD
HELIOSTAT	o MAINTAIN STRUCTURAL INTEGRITY IN ANY POSITION IN A 22 M/S WIND o NO ELEVATION OR AZIMUTH DRIFT IN DRIVES o SURVIVE 19 mm HAIL @ 20 M/S IN ANY ORIENTATION o WITHSTAND AND/OR OPERATE WHEN SUBJECTED TO WIND-INDUCED VIBRATIONS o ENVIRONMENTALLY SEALED DRIVES o COST-EFFECTIVE STOWAGE o COST-EFFECTIVE REFLECTIVITY AND AREA

TABLE 1-4 *Environmental Design Criteria for Production Collector Subsystem*

Environmental Condition	Functional Capability Required When Subjected To Environmental Conditions of Values Shown While					
	Operating ①				Not Operating ①	
	Startup and Shutdown	Steering	Defocusing	Stowing	Structural Integrity (Any Position)	Survival
Gravity	Local	Local	Local	Local	Local	Local
Earthquake	-	-	-	-	UBC Seismic Zone 3	UBC Seismic Zone 3
Wind						
Speed (Includes Gusts)	≤ 16 m/s	0 to 12 m/s	0 to 16 m/s	0 to 22 m/s	0 thru 22 m/s	0 thru 40 m/s
Rise Rate	0.01 m/s^2	0.01 m/s^2	0.01 m/s^2	0.01 m/s^2	0.01 m/s^2	0.01 m/s^2
Dust Devils (Cyclonic Winds)	0 to 16 m/s	0 to 12 m/s	0 to 17 m/s	0 to 17 m/s	0 to 17 m/s	0 to 17 m/s
Direction	Any	Any	Any	Any	Any	Any
Angle from Horizontal	±10°	±10°	±10°	±10°	±10°	±10°
Temperature ①	-9 to 50°C	0 to 50°C	0 to 50°C	0 to 50°C	-10 to 50°C	-30 to 50°C
Precipitation						
Rain						
Annual Average	750 mm	-	-	750 mm	750 mm	750 mm
24-Hour Rate	≤ 75 mm	-	-	≤ 75 mm	≤ 75 mm	≤ 75 mm
Ice/Freezing Rain Thickness	≤ 50 mm	-	-	≤ 50 mm	≤ 50 mm	≤ 50 mm
Hail						
Diameter	-	-	-	≤ 20 mm	≤ 20 mm	≤ 25 mm
Speed	-	-	-	≤ 20 m/s	≤ 20 m/s	≤ 23 m/s
Special Gravity	-	-	-	0.9	0.9	0.9
Temperature	-	-	-	0 thru 6.7°C	0 thru 6.7°C	0 thru 6.7°C
Snow						
24-Hour Rate	0.3 m	-	-	0.3 m	0.3 m	0.3 m
Max. Loading	250 Pa	-	-	250 Pa	250 Pa	250 Pa
Insolation						
Max Flux	1100 w/m^2	1100 w/m^2	1100 w/m^2	1100 w/m^2	1100 $2/m^2$	1100 w/m^2
Rate of Change	④	④	④	④	④	④
Lightning						
Maximum Stroke	200,000 AMPS	200,000 AMPS	200,000 AMPS	200,000 AMPS	200,000 AMPS	200,000 AMPS
Direct Hit	Loss of 1 Helio ok	Loss of 1 Helio ok	Loss of 1 Helio ok	Loss of 1 Helio ok	Loss of 1 Helio ok	Loss of 1 Helio ok
Adjacent Hit ③	Minimize Damage	Minimize Damage	Minimize Damage	Minimize Damage	Minimize Damage	Minimize Damage

Notes: ① Paragraph references are to Sandia specification A10772, Rev. 6, 10-10-79

③ Damage to be minimized subject to appropriate cost/risk limits (TBD).

④ Collector shall be capable of performance indicated when subjected to flux changes associated with passage of opaque cloud; flux shall be assumed to drop from 1100 w/m^2 to 0 w/m^2 and return to 1100 w/m^2.

① For components installed in an uncontrolled environment.

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