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CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM
PHASE 1. CDRL ITEM 2

Pilot Plant Preliminary Design Report
Volume 3, Book 2. Collector Subsystem

By
Raymon W. Hallet, Jr.
Robert L. Gervais

Date Published—November 1977

Work Performed Under Contract No. EY-76-C-03-1108

McDonnell Douglas Astronautics Company
Huntington Beach, California

MASTER

U.S. Department of Energy

Solar Energy

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PREFACE

This report is submitted by the McDonnell Douglas Astronautics Company to the Department of Energy under Contract EY-76-C-03-1108 as the final documentation of CDRL Item 2. This Preliminary Design Report summarizes the analyses, design, test, production, planning, and cost efforts performed between 1 July 1975 and 1 May 1977. The report is submitted in seven volumes, as follows:

- Volume I, Executive Overview
- Volume II, System Description and System Analysis
- Volume III, Book 1, Collector Subsystem
Book 2, Collector Subsystem
- Volume IV, Receiver Subsystem
- Volume V, Thermal Storage Subsystem
- Volume VI, Electrical Power Generation/Master Control Subsystems and Balance of Plant
- Volume VII, Book 1, Pilot Plant Cost and Commercial Plant Cost and Performance
Book 2, Pilot Plant Cost and Commercial Plant Cost and Performance

Specific efforts performed by the members of the MDAC team were as follows:

- McDonnell Douglas Astronautics Company
Commercial System Summary
System Integration
Collector Subsystem Analysis and Design
Thermal Storage Subsystem Integration
- Rocketdyne Division of Rockwell International
Receiver Assembly Analysis and Design
Thermal Storage Unit Analysis and Design
- Stearns-Roger, Inc.
Tower and Riser/Downcomer Analysis and Design
Electrical Power Generation Subsystem Analysis and Design
- University of Houston
Collector Field Optimization
- Sheldahl, Inc.
HelioStat Reflective Surface Development
- West Associates
Utility Consultation on Pilot Plant and Commercial System Concepts

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Section 5

PILOT PLANT PLANS AND SCHEDULES

5.1 PRODUCTION PLANS

This section deals with the methods and plans for the manufacture of the 10-MW collector heliostats and associated controls. The baseline described is shown in Figure 5-1 and covers the closed-loop system; however, an open-loop system is being considered so additions and deletions of hardware which may result from a change to the open-loop system are noted in the text and art by the legend "delete for open loop."

The manufacturing plans described reflect the most efficient and lowest-cost production methods and were developed in close coordination with engineering during the SRE program. Processes and methods in general are similar to and in some cases identical to what is intended for commercial.

Production plans cover activities associated with the procurement, fabrication, assembly, and transportation of reflector panel assemblies, reflector support structures, drive units, pedestals, and controllers, and are described in more detail in succeeding paragraphs. In summary these plans provide for:

- Low-cost steel fabrication methods,
- Low-cost steel materials,
- Efficient and low-cost drive assembly,
- Long-life hardware finishes,
- Efficient final assembly at site,
- Low-cost and efficient transportation plans,
- Progressive proving and verification of design and tooling to minimize risk,
- Low-cost and producible electronics,
- Low-risk production schedules.

Figure 5-1. Heliostat and Sensor Pole Assembly

5.1.1 Make-or-Buy

The MDAC heliostat make-or-buy policy is based on the premise, "effective hardware at the least cost." The rationale for MDAC make selections is the need to control critical interfaces. Except for purchased parts all items which do not directly affect a critical interface will be subcontracted within the Los Angeles/Orange County areas for fabrication and/or subassembly.

The MDAC heliostat make-or-buy list is shown in Figure 5-2.

5.1.1.1 Reflective Surface

The reflective surface panels will be produced at MDAC-Huntington Beach. The plane of the mirror surface is critical, and rigid controls will be required during bonding operations. Panel materials and components parts will be purchased.

5.1.1.2 Reflector Support Structure

The main and cross beams of the reflector support structures are subcontract items. The intention is to obtain subcontractors in Los Angeles or Orange counties to minimize shipment requirements between fabricator and galvanizer, and site. Both the main and cross beams will be shipped directly from the galvanizer to the MDAC Coolwater Facility for final assembly.

5.1.1.3 Tracking Mirror

The tracking mirror assembly (mirror and studs) will be produced at MDAC for the same reason the reflective surface is. The mirror frame assembly is a subcontract item. The mirror and frame assembly will be shipped directly to the Coolwater Facility for heliostat installation.

5.1.1.4 Pedestal

The pedestal is a subcontract item. It will be subcontracted in the Los Angeles/Orange counties area to take advantage of a competitive vendor situation. The pedestal will be shipped directly from the fabricator to the Barstow site.

<p>REFLECTIVE SURFACE MIRROR STYROFOAM STEEL BACK PLATE ATTACH CUPS BONDED ASSEMBLY</p>	<p>BUY BUY BUY BUY MAKE</p>
<p>REFLECTIVE SUPPORT STRUCTURE MAIN BEAM ASSEMBLY CROSS BEAM ASSEMBLY SUPPORT STRUCTURE ASSEMBLY</p>	<p>SUBCONTRACT SUBCONTRACT MAKE MDAC BARSTOW AREA SITE</p>
<p>TRACKING MIRROR FRAME SUBASSEMBLY MIRROR BONDED ASSEMBLY FINAL ASSEMBLY</p>	<p>SUBCONTRACT MAKE MAKE MDAC BARSTOW AREA SITE</p>
<p>PEDESTAL</p>	<p>SUBCONTRACT</p>
<p>DRIVE SUBSYSTEM AZIMUTH AND ELEVATION DRIVE KITS MACHINE CAST HOUSINGS AND ATTACH FITTINGS DRIVE MOTORS POSITION INDICATORS CABLE SUPPORT AND SHIELD DRIVE SUBSYSTEM ASSEMBLY</p>	<p>SUBCONTRACT MAKE MDAC-HUNTINGTON BEACH SUBCONTRACT SUBCONTRACT SUBCONTRACT MAKE MDAC-HUNTINGTON BEACH</p>
<p>SENSOR POLE AND SENSOR SENSOR POLE SENSOR</p>	<p>SUBCONTRACT MAKE MDAC-HUNTINGTON BEACH</p>
<p>ELECTRICAL AND CONTROL HELIOSTAT PROCESSOR FIELD PROCESSOR PEDESTAL CABLES SENSOR CABLES</p>	<p>MAKE MDAC-HUNTINGTON BEACH MAKE MDAC-HUNTINGTON BEACH MAKE MDAC-HUNTINGTON BEACH MAKE MDAC-HUNTINGTON BEACH</p>
<p>HELIOSTAT FINAL ASSEMBLY</p>	<p>MAKE MDAC BARSTOW AREA SITE</p>

Figure 5-2. Make-or-Buy List

5.1.1.5 Drive Subsystem

The criticality of heliostat drive assembly of MDAC and vendor parts dictates that the drive subsystem be assembled by MDAC-Huntington Beach.

The azimuth and elevation drive kits will be subcontracted. The kits will be inspected at the subcontractor's plant and delivered to MDAC-Huntington Beach ready for installation in the drive assemblies.

Castings for the drive units will be procured locally. These castings will be machined in the MDAC-Huntington Beach machine shop.

The drive motors will be procured from electric motor manufacturers. The drive system position indicators, cable support, and drive shield will be procured in Los Angeles and Orange counties.

Drive unit subassembly will be done at MDAC-Huntington Beach. To ensure proper interface, MDAC will control the assembly and testing of the drive subsystem.

Text which does not apply
to the open-loop design is
shaded, as in the following
two paragraphs.

5.1.1.6 The Sensor Pole and Sensor

The sensor pole is an assembly made of standard low-carbon steel pipe and fittings. This assembly will be subcontracted.

The sensor is an MDAC design and will be fabricated and assembled and tested at MDAC Huntington Beach.

5.1.1.7 Heliostat Controls

MDAC will make the pedestal electrical box assembly at Huntington Beach. Component placement in the basic package has been designed for automatic mechanical insertion; however, for Pilot Plant quantities, package assembly will be done by hand to avoid initial nonrecurring costs of automatic mechanical equipment costs.

The field controller will also be produced at MDAC-Huntington Beach for the same reason as the pedestal electrical box assemblies are.

The pedestal cables will require specific routing on the heliostat assembly at installation. For the Pilot Plant, the cables will be made at Huntington Beach.

5.1.1.8 Heliostat Final Assembly

The critical heliostat interfaces are the upper surfaces of the substructure cross beams, the relationship of the drive unit attach surfaces, and the panel attachments of the reflective surfaces. In order to adequately control these interfaces, the cross beams will be welded to the torque tube by MDAC at the Barstow facility.

MDAC will perform the final assembly of all heliostat components at the Coolwater site.

5.1.2 Manufacturing Plan and Schedules

The manufacturing plan for the 10-MW Pilot Plant is based on the following criteria:

- ATP, 15 January 1978.
- Preproduction design release, 1 June 1978.
- Preproduction unit, 1 September 1978 (final assembly complete).
- Production design release, 1 October 1978.
- Total number of units, 1,760 plus spares (1,795 plus spares for the open-loop concept).
- Basic tooling rate, 10 per day.

The production rate of 10 heliostats per day can be supported most economically by using conventional tooling methods, leaving automated types of tooling to future higher production rates and quantity.

A summary flow of the heliostat manufacturing process in Figure 5-3 gives an overview of the locations of all major component production.

A key element of the manufacturing plan is to assemble the heliostat at the Coolwater factory site, then transport the assembly to the prepared Pilot Plant foundation nearby for installation. Another key point is the plan to procure subcontracted items in Los Angeles or Orange Counties to minimize shipping costs.

The "total heliostat" assembly and transport concept has already been checked out at MDAC-Huntington Beach. A complete heliostat was assembled in the engineering test labs for SRE tests, then picked up as a unit and transported to the factory yard and installed on a foundation bolt circle. The unit demonstrated good balance en route and was set down easily on the bolt pattern on the foundation.

The MDAC heliostat manufacturing plan has the following advantages:

- Noncritical parts and assemblies are fabricated in Los Angeles and Orange Counties where manufacturing capabilities are readily available.
- Transportation costs for raw materials, parts, and assemblies are minimal because of the close proximity of manufacturing operations.
- Shipments will be made by truck to the Coolwater facility. No special wide-load permits will be required.
- Final assembly of the heliostat at the Pilot Plant site reduces transportation costs.
- A final functional checkout will be performed in the site factory before field installation.

Commercial specifications will govern materials and processing, and sound quality assurance procedures will be followed to assure that the manufacture of hardware meets the functional specifications. Section 5.1.4 provides more detail on the Quality Assurance Plan.

Manufacturing operations will be ordered and controlled using detailed MDAC operation sheets. Key part and assembly inspections are listed, and inspection results recorded.

A detailed schedule for the timely accomplishment of all planned manufacturing activities is presented in Figure 5-4. Schedule analysis indicates there are no significant production schedule problems.

A series of operations are planned to systematically develop and prove the production design, tooling, and hardware. First, the production design will be verified upon release with the fabrication and assembly of one "preproduction" heliostat built to the drawings but without production tooling. Second, and upon completion of design verification, a second heliostat will be produced to the production design and using the production tooling. Upon completion of the tooling proof and complete production heliostat, the production program will be committed. To assure an efficient and orderly integration of material and hardware flow, buildup to the production rate of 10 heliostats per day will take place over a period of 10 wk. These progressive steps are shown in detail in Figure 5-4. Figure 5-5 summarizes total factory output of the Pilot Plant production.

5.1.2.1 MDAC-Huntington Beach Manufacturing Facility

Reflective surface and drive unit assembly activities will be conducted in a single production complex at MDAC-Huntington Beach. This decision was based on several factors: (1) importance of contractor control of critical fabrication and assembly activities, (2) advantages of operating in an established manufacturing plant with its support facilities and services already in place, and (3) proximity of many subcontractors in the Los Angeles/Orange Counties industrial base.

MDAC plans to place its collector subsystem production operation in approximately 32,600 ft² of existing buildings (Figure 5-6). The facility will be temperature-controlled. Operations will include reflector panel assembly, tracking mirror production, drive unit assembly, and production of the electrical and control systems. These operations are discussed in detail here.

Figure 5-4. Manufacturing Schedule (Page 1 of 2)

Figure 5-4. Manufacturing Schedule (Page 2 of 2)

TASK PHASING PLAN SERIAL NO.			TASK PHASING PLAN ☐ SCHEDULE ☒																											
DATE			DESCRIPTION FACTORY OUTPUT BY WEEK / MONTH																											
PRODUCTION SCHEDULE SERIAL NUMBER			ISSUING AUTHORITY: _____ PREPARED BY: _____ NAME _____ PHONE _____																											
MODEL	ELEMENT/WBS	TYPE	PRODUCTION SCHEDULES AND STATISTICS																											
REVISED	PAGE NUMBER																													
SUPERSEDES	OF																													
WBS No.	ITEM	<div style="display: flex; justify-content: space-between;"> 1979 1980 </div> <div style="display: flex; justify-content: space-between;"> JUNJULAUGSEPOCTNOVDECJANFEBMARAPRMAYJUN </div>																												
4190.121	DRIVE ASSY	WK	5	2	9	6	3	0	7	4	1	7	2	5	2	9	6	3	0	7	4	1	7	2	5	2	9	6	3	0
.122		CUM	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
		MO	30	126	219	190	220	200	160	220	210	200	20

Figure 5-6. MDAC Huntington Beach Manufacturing Facility Floor Plan (32,600 Sq Ft)

Reflector Panel

The reflector panel assembly (Figure 5-7) is a composite structure consisting of:

- A. The reflecting surface is a 0.125-in. thick by 85-in. wide by 114-in. long second surface mirror.
- B. The styrofoam core assembly is a 2-in. thick by 85-in. wide by 114-in. long bonded subassembly.
- C. The galvanized sheet metal backup plate made up of two pieces — 38 and 48-in. widths each 0.020 in. and 114 in. long — will be positioned to provide a 1-in. longitudinal overlap. The two-piece construction is necessary due to the unavailability of commercial thin-gage galvanized sheet metal in the 85-in. width.
- D. The four galvanized attach cups are die-formed and assembled with a weld nut.

Specific controlling factors which influence the panel manufacturing concepts are:

- A. The total output is anticipated to be based on approximately 1,760 or more collectors, which requires the production of 10,560 reflector panel assemblies 10 mo.
- B. The bonding cure time of 10 hr for the panel adhesive influences curing space requirements.

Fabrication of the reflector panel assembly influences the physical characteristics of the Huntington Beach facilities in several ways. Materials and purchased items will be delivered by truck. The storage area will be sufficient to accommodate approximately a 10-wk supply of materials. The area will also serve as the "soaking" chamber.

Shipping from the facility will be done daily in special transporting racks. One day of production amounts of 60 panels which are carried in 5 racks. The shipping area must be able to accommodate 5 racks.

5-15

Figure 5-7. Reflector Panel Assembly

Raw materials and subcontracted parts are received through a vertibule (which assists in maintaining temperature) and moved to the storage and soaking area. Handling within the plant is by wheeled vehicles, self-propelled or manual, and a light gantry-type crane (over the drive assembly area).

The critical reflector assembly interface is the precise positioning of the attach points with respect to the flat mirror surface. Fabrication capability has been specifically designed to meet this important requirement.

The quantity of tools and the facility size can provide 60 assemblies in a two-shift operation.

The adhesive application is accomplished under a vacuum hood using a traveling nozzle-mix applicator. The applicator preforms the catalyst resin mix at the nozzles, thereby minimizing work life and cleanup problems. Accurate control of deposition (pattern and quantity) can be maintained with this mechanism.

The sequence of reflector panel assembly operations is arranged to ensure that materials will flow in a progressive manner with a minimum amount of handling (Figure 5-8).

The galvanized steel backing plates which are purchased cut to size and lightly sanded on one surface are moved directly to the storage area. Selective sanding of the opposite side for attach fittings will be done before assembly. Two of each lot of 6 of the 48-in. -wide panels are corner-notched as received. These prepared sheets are proportioned to the adhesive application area in the proper combination to accommodate assembly requirements.

The core assembly activity necessary to obtain an assembly of proper width is begun by removing material from the warehouse area. The styrofoam is passed through a special wood working-type planer which removes material

Figure 5-8. Reflector Panel Assembly Flow

from both top and bottom surfaces simultaneously to achieve superior parallelism. A quantity of sheets are slit lengthwise in the table saw to provide the proper combination to achieve the 85-in. -wide panels.

Three styrofoam pieces 24 in. wide are held in a fixture where adhesive is applied in measured amounts from a nozzle-mixing applicator. The three edge-treated pieces plus the saw cut piece (13 in. wide) are transferred to and assembled in a bonding fixture. This assembly is allowed to cure at ambient temperature. The completed panel is moved to the adhesive application area before bonding.

The mirrors are moved in their shipping crate by fork truck from storage to the adhesive application area where they are unloaded for inclusion in the assembly process one at a time.

The attach cups, supplied as a completed item, are stored in the warehouse until required at the bonding operation.

The assembly of the reflector panel involves the following sequence of operations as shown in Figure 5-8:

- Prepare the applicator table by covering it with a disposable vinyl sheet.
- Remove a mirror from the packing case, verify its condition, and place it on the table.
- Apply adhesive.
- Slide the mirror on a vinyl sheet onto a transfer cart.
- Position the styrofoam core assembly on the covered table and apply adhesive.
- Hand-carry the core onto transfer cart.
- Position a 38-in. wide galvanized sheet and hand-roll approximately 1-in. -wide adhesive strip on one edge.
- Move to transfer cart with the 48-in. -wide sheet.

The transfer cart is manually moved adjacent to the fixtures in the bond cure area for immediate loading. Use of these bonding fixtures is scheduled systematically to meet production requirements.

The bond cure sequence follows:

- Slide the mirror from the cart to the fixture.
- Remove the vinyl sheet and check the mirror's location.
- Place the core assembly in the fixture on top of the mirror.
- Position the 38-in. steel strip against the locators in a manner similar to the previous step.
- Position the 48-in. -wide steel strip against locators in a similar manner.
- Close the bonding fixture and release the loading plate.
- Position the cup-locating attachments to the fixture.
- Position prepared attach cups and secure.
- Provide undisturbed ambient cure.

The bonding fixture is designed to establish the critical relationships of the reflecting surface and the mounting points. Precision-machined spacers provide the locating mechanism.

After the cure cycle is completed, the reflector assembly is removed from the fixture, placed on a transfer cart, and moved to an edge-sealing table. The edges are sealed with a material extruded from a hand-held air-operated applicator. The table is constructed so that permits it to be moved or rotated to present all four edges to the operator with minimum movement of the applicator.

The sealed assemblies are removed and stacked on a flat table for a 2-hr cure of the edge sealant. Stacking is accomplished by interleaving with 2-in. foam rubber.

After panel assembly verification (see Section 5.1.4, Quality Assurance Plan), the completed reflector assembly is loaded into a special stacking, shipping unit that will accommodate 6 pairs (12 panels), sufficient for two collectors.

Tracking Mirror. The tracking mirror is an assembly (Figure 5-9) consisting of a galvanized steel frame structure supporting the sensing mirror and is affixed to the collector assembly.

The structural portion is essentially a triangle-shaped weldment 18 in. across and 33 in. long, fabricated from 1 x 2 in. rolled channel sections. The steel is hot-dip galvanized for weather protection. The reflecting mirror is a 27-1/2 by 40-1/2-in. laminated mirror to which three 1/4 by 20-in. special studs have been bonded for fastening the mirror to the frame.

Drive Unit Assembly. The drive unit assembly configuration is shown in Figure 5-10. This assembly is made up of two separate drives bolted together, the azimuth drive unit and the elevation drive unit. The drive assembly housings will be machined at MDAC-Huntington Beach. The remainder of the components will be received at Huntington Beach from the suppliers for assembly. The orbidrive units will be received as pre-assembled kits from Compudrive Corporation, Massachusetts.

The drive unit machining sequence is shown in Figure 5-11. Most of the machining will be done using numerically controlled equipment. The numerical control (NC) method of machining was selected because it offered the most cost-effective approach to satisfying the Pilot Plant requirement of 1,700 to 1,800 units. The tolerance control for interchangeability between the hardware items requires a high level of repeatability, which can be maintained by the NC method. The MDAC-Huntington Beach facility was selected for its extensive experience and high level of capability in NC machining.

The first equipment grouping shown in the manufacturing flow diagram is a numerically controlled vertical turret lathe. This machine will perform all of the boring and turning required on the three drive housings.

The next major series of machining operations is performed on an M-200 Milwaukeeematic machining center. This machine is expressly designed for

Figure 5-9. Tracking Mirror

Figure 5-10. Drive Unit Assembly

Figure 5-11. Drive Unit Manufacturing Flow

the kind of work required in the remaining machining of the parts. The machine has rapid part indexing, automatic tool changing, and the latest technologies in cutter compensation and internal diagnostics for minimizing cutter costs and machine downtime.

The azimuth base will have all required holes machined on a vertical boring mill. This will allow use of the same tooling as on the vertical turret lathe.

The approach to minimizing the types and quantities of machines, as demonstrated by the flow diagram, has several key advantages:

- The same programmer can program the parts, using the same approach to each.
- Cost of startup during tooling proveout is minimized.
- Setup changeover time and effort are minimized.
- Machining feeds and speeds can readily be optimized.

The assembly flow for the azimuth and elevation drive units is shown in Figure 5-12.

The assembly of the azimuth drive begins with the installation of tapered roller bearings between the orbidrive shaft outside diameters and the azimuth drive inside diameters. The orbidrive kits will be put on pallets in the inverted position so the shaft can be lifted directly up from the kit and positioned to the press for the bearing installation.

The bearing cup will be heated to assist installation onto the shaft. The following sequence of operations will complete the bearing installation:

- Hoist the azimuth drive housing to the press.
- Position a prechilled bearing cone into the housing inside diameter and seat. Invert the unit and repeat.
- Position the shaft onto a collar on the press table. Hoist the drive housing over the shaft until the bearing cone and cup seat.
- Position a preheated bearing cone over the shaft seat with press pressure of approximately 6,000 lb. This will lock the shaft into the drive housing.

Figure 5-12. Drive Unit Assembly Flow

The next operation will position the spacer against the bearing cup to ensure constant preload to the bearing. The steps of this operation are illustrated in Figure 5-13.

The next operation will hand-assemble the orbidrive kit back into the output shaft in the following sequence:

- Position shaft assembly holding an eccentric, bearings, bearing retainers, and keys into the shaft.
- Position the cam over the bearing.
- Position the roller pins between the cam and the output shaft, position the spacer, and then position the roller pins between the cam and the output disk.
- Position the O-ring seal into the output shaft.
- Position the disk over the bearing, lining up the roller pins to slide into the involute lobes of the disk.
- Align the disk hole pattern to the housing hole pattern and secure with six bolts.

The final azimuth drive assembly operation will install the motor and small input (45:1 reduction ratio) orbidrive unit, which will be subassembled as a bench operation; the 45:1 unit can be slid over the 960:1 orbidrive unit shaft key and secured to the base with two bolts in one operation. The operation will be performed on an assembly cart with a lifting tool to assist final seating of the motor and 45:1 subassembly.

Elevation drive assembly will proceed according to the same general order as for the azimuth drive. The major exceptions will be that the motor and 45:1 orbidrive kit will be assembled in the horizontal position after the support and support bearing are installed on the opposite end of the elevation drive unit. The elevation unit will then be hoisted from the assembly cart or bench directly onto the azimuth drive assembly. It will be bolted in place, and the entire drive assembly will then be hoisted onto a pallet. The drive assembly will be positioned so that the elevation drive motor is straight up and will then be strapped to the pallet. The pallet will be moved by forklifted to a flatbed truck for transport to the Coolwater storage area.

Figure 5-13. Bearing Installation Sequence

The drive assembly rate will be directly paced by the final assembly area rate of 50 units per week. A two-week line supply of drives will be maintained at the storage area. Thus, the risk of final assembly line stoppage at no increase in storage cost will be minimized because the storage area will be in the field.

The assembly of the azimuth and elevation drives will be located in the same building as the mirror panel assembly facility. This will provide for maximum use of manpower and minimize the amount of supportive personnel and facilities that would otherwise be required if independent areas were used. As shown on the layout (Figure 5-6) the drive assembly area will be located adjacent to the receiving shipping area. This will minimize total forklift transport time and distance in the building because the drive assembly has a higher density of parts and entails greater frequency of transport than does the mirror area. The floor arrangements is U-type flow from drive component parts storage through assembly and back out to the shipping area. The projected area is 2,100 ft² for storage and 1,500 ft² for assembly, a total of 3,600 ft². The figures are based on a 10-wk line supply on all items except MDAC-machined parts; these will have a 2-wk line supply in the drive assembly storage area and a 6 to 8-wk line buffer supply stored at the MDAC-Huntington Beach machining facility, where adequate storage area exists.

The sequence of assembly requires lifting and positioning of all major assembly items and the assembled unit. The weights of the parts dictate the use of overhead hoisting throughout the assembly area. A gantry crane of 1-ton capacity will meet the requirements. In order to install the bearings, an oven for expanding and a dry-ice container for shrinking the bearing parts will be required to assist the press operation. A 10-ton hydraulic press with pressure shutoff valves will meet all bearing installation load requirements. All transport from storage and to shipping will be by fork truck.

All bolting will be done by air-powered torque guns at the assembly points. The motor test station will have conduit trenched on the floor to prevent restriction of forklift or crane travel.

As noted in the tooling requirements, the assembly tooling will be needed to handle the drive hardware between the press and the drive joining station. Fixtures will not be required for accurate positioning of the hardware during assembly. All final positioning will be done by hand with handling-fixture assistance. Eyebolts will be used to pick up each of the major hardware items. A sling with snap hooks will remain with the crane for lifting.

Four assembly carts will assist in installation of the motor and 45:1 orbital drive unit into the drive, and facilitate transport between the press and joining station.

Electrical and Control Systems

The electrical and control system (Figure 5-14) consists of a heliostat controller, field controller, heliostat sensor, and interconnecting cables between controllers, sensor, and drive motors and encoders.

Heliostat Controller. The assembly flow for the heliostat controller is shown in Figure 5-15. The controller has three printed circuit boards that are made from epoxy glass material. Copper circuitry on both sides is interconnected by through-plated holes. These boards will be purchased and received ready for component insertion. Component placement on the boards has been designed for automatic mechanical insertion of both dual in-line packages and components with axial leads.

After component insertion, the boards are flow-soldered and cleaned. Component insertion, flow-soldering, and cleaning operations will be enclosed in an existing area of 500 ft² at MDAC-Huntington Beach. The equipment is in-line so that product movement is minimized.

Both the board assembly and flow-solder equipment have the capacity to meet the schedule rate. Other than the tape to drive the assembly machine, no special tools or fixtures will be required, and there will be no critical operations.

The three assembled boards will go into two separate assemblies. The microprocessor board will be installed in a small box that will shield the

Figure 5-14. Electrical and Control System

Figure 5-15. Heliostat Processor Flow

board from electrical "noise" generated by the switch board and power supply board. The other two boards will be assembled into a stack with the switch board on top.

The housing for the heliostat processor will be a catalog item modified by the vendor. When received, the box (approximately 12 by 12 in.) will have holes for entrance and exit of power and data cables, mounting straps welded on two sides with holes drilled, and the removable tray punched for parts mounting.

The microprocessor assembly and the switchboard-power supply assembly will be mounted on the prepunched tray, along with a terminal strip and circuit breaker. Connections between the terminal strip and breaker will be hardwired. Interboard connections will be made by flat cable. This will eliminate costly processing of individual wires and will improve product reliability.

Subassembly will be done at workbenches and will occupy approximately 200 ft² of the existing electronic clean room assembly area at MDAC-Huntington Beach. There will be no critical operations or requirements for special tools.

A functional test will follow the burn-in. Failed units will be sent to a separate work station where defective components will be identified and replaced. The tray assembly will be functionally tested again but will not go through a second component burn-in. The probability of failure will thus be greatly reduced at minimum cost. Tray assemblies that pass the functional test will be routed to the assembly area, where the trays will be installed into the housing boxes and packed for shipment.

The test area will occupy approximately 325 ft² of the existing electrical-electronic test area at MDAC-Huntington Beach. Two ovens will be required for component burn-in.

Field Controller. One field controller will be required for every 24 heliostat controllers. The field controller will consist of a large printed circuit board and a power supply. Both items will be purchased. The board design, components, and assembly process will be similar to those described for the heliostat controller boards (Figure 5-15). The purchased housing for this controller will be similar to the heliostat housing but larger (approximately 18 by 18 in.) since both the field controller and the heliostat controller will be packaged in this one box and mounted on one of the 24 pedestals.

Motor and Encoder Cables. Cables connecting the controller assembly to the heliostat drive motors are of conventional design and construction (see Figure 5-16). Cable material will be purchased with the proper wire size and covering. Two cables will be required, one for the azimuth drive and encoders, and one for the elevation drive and encoders.

Cables will be cut to length, and the outer covering will be removed at each end. Purchased connectors will be installed on both ends. After automatic continuity check, the cables will be kitted for shipment. Cable fabrication and test will be done in the existing cable shop at MDAC-Huntington Beach and will occupy approximately 300 ft².

Heliostat Sensor. The heliostat sensor assembly is shown in Figure 5-17. The housing will be made of nonmetallic material and will provide support and alignment for a dust shade, red glass lens, light baffle, connector, and a hybrid thick-film assembly. All components will be purchased. The hybrid thick-film assembly will be received in an aged condition.

Final assembly of this unit (Figure 5-18) will be done in an inert atmosphere so that optical distortion from fogging will not affect the pointing accuracy of the heliostat control electronics. A mask will be silk-screened onto both sides of the lens, and the hybrid thick-film assembly will be soldered directly to the connector pins. After the connector assembly is tested, it will be mounted into the housing body, and O-rings will seal the connector-housing interface. This assembly, along with the other parts, will then be

Figure 5-16. Cable Assembly

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DELETE FOR OPEN LOOP

Figure 5-17. Sensor Assembly

Figure 5-18. Sensor Assembly Flow

DELETE FOR OPEN LOOP

placed in a glove box filled with dry nitrogen, where the housing will be positioned in a bonding jig. The light baffle will be positioned into index slots in the housing and the lens will be positioned on top of the baffle.

Solvent epoxy will secure the dust cover to the housing. The assembly will be clamped into the bonding jig, and the jig will be removed from the glove box. After ambient cure of the epoxy, a functional test will be performed with a high-intensity penlight to determine diode response in each quadrant. The unit will then be packaged.

Sensor Cable. A cable will interconnect the sensor and the controller assembly (Figure 5-14). The cable material will be purchased with the proper wire size and outer covering. The cables will be cut to length and the outer covering will be removed from both ends. Purchased connectors will be placed on both ends, an automatic continuity check will be made, and the cable will be packed and kitted with the sensor for shipment. Cable fabrication and test will be done in the existing cable shop at MDAC-Huntington Beach and will occupy approximately 300 ft².

5.1.2.2 Final Assembly Facility at Pilot Plant Site

Support structure subassembly and heliostat subassembly and final assembly will be done in a new building on the Pilot Plant site, near the Pilot Plant field to minimize transportation and assembly costs. Also, final assembly of all components including electrical is more efficient in a controlled factory environment than in the field.

The heliostat will be put together in three operations — support structure assembly and heliostat primary and final assembly. The location of these operations as they are performed in the field site building is shown in Figure 5-19.

The reflector support structure will be assembled and spot-welded in two stations in this building. Items to be assembled will be stored outside the building.

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Figure 5-19. MDAC Factory at Site

In the event of inclement weather which prohibits field site installation, temporary storage of completed units has been provided. During these periods, the special fork truck used to supply the field would be used to move the finished heliostats from the assembly stations to the temporary holding area outside the building. The assemblies are bolted to a concrete footing as a safety precaution.

The final assembly building at the site is described in detail in Section 5.1.3, Facilities Plan. A description of the operations within the building follows:

Spot Weld Subassembly. The main beam assembly and cross beams stored outside are brought in by fork truck to the two assembly spot-welding stations. In this critical operation, the main beam assembly is positioned by reference to its drive attach holes and clamped. The four cross beams are positioned on the fixture and clamped.

The exact positioning of each cross beam is determined by using its reflector mounting holes. Precision-machined brackets locate these holes, using the known base plate, to provide the correct relationship to the main beam assembly attach holes. (The main beam was assembled earlier using these reference holes.)

The commercial material tolerances are considered and irregularities compensated for because the mirror mounting points and the rotating attach points are held in the proper relationship without force fitting or the use of shims.

The completed reflector support structure is verified and accepted by Quality Assurance as a product of a certified tool (see the Quality Assurance Plan, Section 5.1.4).

Primary Subassembly. The drive unit, support structure, and panels are joined in the primary subassembly operation (Figure 5-20). The drive assembly is moved from outside storage into one of the three primary assembly stations by fork truck and mounted on a floor fixture. The fixture

Figure 5-20. Drive and Reflector Assembly

provides the proper working height and conditions for the assembly done at this station. A fork truck with a special handling attachment positions and holds the reflector structure to the drive unit during assembly. The subassembly is now properly positioned to permit assembly of the reflector units.

The reflector panel assemblies are positioned at the assembly station by fork truck from outside storage in the special shipping container. Four operators are used to manually remove the panels from the container and position it on the structure. Subsequently, each man installs one of the four panel bolts. The assembly is made by inserting color-coded variable-thickness spacers (to provide a predetermined angularity) between the faces of the attach cups on the back of the panel and over the holes in the flanges of the support structure where the attach bolting is done. This then mates the critical locating points to provide the necessary assembly accuracy.

Final Assembly. Upon completion of primary subassembly, the unit is moved by a specially designed fork truck to one of five final assembly (Figure 5-21) positions where the base unit (pedestal), provided from outside storage, has been bolted to a floor retainer. A work platform then is positioned and the reflector and drive subassembly are bolted to the base after the electrical cable is positioned for final connections.

The electrical assembly involves connecting cables to the position indicator and motor drive for both azimuth and elevation. It also involves arranging the takeup mechanism in the pedestal and connecting the wiring through the junction box.

The final mechanical connection is made by bolting the drive base unit to the pedestal. Pedestal and reflector unit are oriented with respect to one another to provide maximum shade from the sun for the electrical control box, which is bolted to the base of the pedestal in this station.

The final checkout in the station will include a production acceptance test to check the elevation and azimuth drives and the electronics. From this position, the completed assembly is removed by fork truck to the field for installation.

Figure 5-21. Final Assembly

5.1.3 Facilities Plan

The major plan elements which comprise the production facilities baseline are described in this section. They are summarized as follows:

- A. Site Selection. Indicates rationale for selecting production locations.
- B. Layout. Provides tooling and equipment arrangements and total square footage of dedicated production functions.
- C. Design and Construction. Indicates MDAC approach to providing new construction, building installations, and equipment emplacements.
- D. Equipment Provisioning. Enumerates anticipated factory equipment requirements for the collector subsystem production program.
- E. Schedule. Establishes milestones for activating a production capability in consonance with the manufacturing plan.

5.1.3.1 Site Selection Plan

Two primary locations have been designated for collector subsystem operations; (1) a mirror-bonding and drive unit assembly factory at MDAC-Huntington Beach, and (2) a final assembly plant at the 10-MW Pilot Plant site near Barstow (Figure 5-22). Placement of reflector surface and drive unit assembly work at Huntington Beach is considered advantageous because of the dependence of these activities on the kinds of support offered by an established manufacturing plant, e.g., material receiving, fabrication shops, inspection, warehousing, and packaging and transportation services. Completed units will be transported by truck over the interstate highways. Collector subsystem final assembly operations will take place in a new building on Southern California Edison property at the Coolwater generating plant at Barstow. The assembly facility will be adjacent to the 10-MW Pilot Plant site (Figure 5-23). This decision was dictated by the need to minimize distance between the assembly facility and the field deployment area.

5.1.3.2 Factory Layouts

Two separate layouts have been developed to provide facility planning criteria for activating a 10-MW collector subsystem production capability.

- A. Reflector and Drive Unit Assembly Operations. As shown earlier in Figure 5-6, a Huntington Beach factory layout has been defined

Figure 5-22. Pilot Plant Heliostat Production Locations

Figure 5-23. Proposed Site for Final Assembly Operations

which integrates the reflector and drive unit subassembly operations into a single production complex. The plant has the necessary tools and equipment to support the desired full-production output of 10 collector subsystems per day.

- B. Heliostat Final Assembly Operations. A new low-cost building, shown in Figure 5-19, is planned for construction which would accommodate reflective structure frame welding, in-process storage, and heliostat final assembly and staging operations. Office space requirements for field personnel and documentation storage will be fulfilled either within the new building or a permanent structure designated by Stearns-Roger for possible emplacement at the 10-MW Pilot Plant field.

5.1.3.3 Facility Design and Construction Plan

The MDAC Huntington Beach factory concept for reflector and drive unit subassembly is centered about a modest physical plant for dedicated production work. The entire factory inclusive of drive unit assembly can be comfortably accommodated with an overhead clearance of less than 12 ft, and standard exterior accesses. A 2,000-lb gantry crane will support assembly handling operations. All remaining operations will be moved with ground-supported handling systems.

The final assembly building proposed is at the Pilot Plant site.

5.1.3.4 Equipment Provisioning

In addition to building construction/installation requirements noted in the previous section, two general-purpose equipment items have been identified to support heliostat final assembly and checkout stations. They are (1) a spot-welder, power supply, and jib crane, and (2) three standard forklifts of 5,000-lb capacity.

Site installation equipment times are identified later in Table 5-5 of Section 5.2.1.5.

5.1.3.5 Schedules Plan

A facilities activation schedule has been prepared (Figure 5-24) which establishes major planning/implementation milestones for both the reflector/drive unit factory and the final assembly facility. Upon acceptance of the plan by the Department of Energy, design and equipment acquisition efforts will be initiated to support the timely completion of tasks outlined in the preceding subsections.

5.1.4 Quality Assurance Plan

MDAC's quality program will provide an independent audit of functional-department compliance with established plans and procedures that have been developed to ensure that the installed collector subsystem meets performance requirements with high reliability. Our QA plans will include specific measures to verify that hardware and software conform as the subsystem is constructed, and to validate fulfillment of requirements when the subsystem is complete.

In determining what controls are needed, the following aspects of the collector subsystem program were considered:

- Relative importance of hardware characteristics in determining production performance.
- Quantity and type of tooling.
- Capability of production processes.
- Division of tasks between suppliers and our own plant.
- Decisions to ship directly from suppliers' plants to the field sites.
- Provision of an on-site assembly facility.
- Availability (or lack) of interfacing subsystems at the time of installation.
- Quantities and lot sizes to be produced.

The structural elements of the heliostat are such that primary reliance for tolerance control can be placed on tooling rather on inspection. First-article inspection will prove the tooling capability, and periodic sampling inspection or tooling inspection will verify the ability of the tooling to continue to maintain the tolerances. See Sections 5.2.2 and 5.3.3 for descriptions of significant inspection controls.

Figure 5-24. Facilities Activation Schedule

5.1.4.1 Quality Control Policies

Key MDAC quality control policies for the collector subsystem program are as follows:

Supplier Control. Adequacy of a supplier's quality control systems is a prime consideration in selection of suppliers and is significant in determining the inspection and testing to be done by MDAC. We will determine when it is appropriate to order and accept off-the-shelf items of vendors' design and when it may be necessary to specify additional screening or testing as a condition of purchase. MDAC inspection may be imposed at the source when newly designed hardware is to be accepted at the supplier's plant and shipped directly to the field site. The aim is to gain assurance with minimum inspection and with testing performed at the optimum time and place to avoid redundancy. Suppliers' performance will be evaluated systematically to make certain that control is effective.

Receiving Inspection. In keeping with supplier control policy, MDAC will make maximum use of vendors' test reports and other objective evidence of control at the source. The evidence will be examined on receipt, and shipments will be checked for damage in transit. Results of receiving inspections will be retained, tabulated, and used to measure suppliers' performance.

Tooling Control. Proof of tooling is the key to controlling hardware with a minimum of inspection and rework. Designed tools are inspected for conformance to the tool designs and then are proved by complete inspections of first production articles. Tools thus certified are reverified at intervals, thus permitting product acceptance with only sampling inspection during the intervening run.

Process Control. Following initial proof of the capability of a process such as adhesive bonding or spot welding, critical elements of the process (e. g., time, temperature, viscosity, pressure) are continuously monitored and recorded. Periodic reverification that the result is acceptable permits acceptance of articles produced in the interval.

Inspection Planning. The inspection plan is described in Section 5.3.3. The plan will take maximum advantage of the assurance obtained through the tooling and process controls just described. Information fed back from inspection operations, installation experience, and test results will be analyzed to permit adjustment of inspection control points, sampling frequency, and test procedures.

Test Planning. Test procedures will be analyzed to ensure that they properly evaluate the characteristics that control end-item performance. This analysis will be formally recorded. A change control discipline will provide for more analysis when hardware design or test procedure must be changed, thus preserving the integrity of accept and reject criteria. Test tree analysis will confirm that all necessary characteristics have been tested at the appropriate assembly levels and will expose and eliminate unnecessary redundancies. Optimization will be achieved by considering all planned testing by suppliers, in-plant, in the assembly building, and in the field. Relative depths of checkout at the unit level, heliostat cell level, and subsystem level will be considered.

Correction of Defects. Nonconforming items will be identified, withheld, and isolated for disposition. Where rework cannot bring the item into exact conformance, an engineering review will be required if an alternative approach or repair is to be applied. The basic groundrule for such reviews will be that no alternative will be acceptable if it adversely affects functional performance, interchangeability, durability, reliability, effective use or operation, or safety. It will be required that a quality assurance representative concur in the dispositions, which will be documented and authenticated. When warranted, a formal commitment for corrective action to prevent recurrence of the nonconformance will be established and monitored.

Feedback and Program Audit. Results of inspections and tests will be documented, collected, and filed at a central location to permit quick retrieval, selective tabulation, and analysis. From this procedure, we will gain the capability to detect recurring trouble and to evaluate the stability of the product and the performance of processes, suppliers, and

MDAC operations. During the operational phase, any malfunction or requirement failure will be formally recorded and evaluated to establish corrective action.

Certification of Quality. Based on the objective evidence of vendor certifications, acceptance inspection records, documented test results, and checkout reports, MDAC will formally certify completion and readiness at required points. This procedure will culminate in certification of each completed subsystem and of the entire system as required by contract. Legally required inspections, reports, and certifications by and for Governmental agencies will be similarly formalized.

5.1.4.2 Company Support

The QA policies and activities described above will be supported by standardized disciplines and technical facilities at MDAC. These resources include the capabilities of our engineering and quality control laboratories. Measurement equipment and process control equipment are subject to scheduled calibrations that are traceable to the National Bureau of Standards. Employee training and certification programs guarantee the required skills. Hardware moves and operation sequences are controlled by work orders that provide for inspection entries at preplanned points as a condition of continuing with the work.

Specifics on verification methods to be used are given in the following sections of this volume:

- 4.3.6 Field Controller (for software verification).
- 5.2.2 Checkout.
- 5.3.2 Qualification Tests.
- 5.3.3 Acceptance Inspection and Test.

5.1.5 Packaging and Transportation

The basic heliostat components that are to be shipped to the subassembly plant are the pedestals, torque tubes, cross beams, drive units, main mirror segment assemblies, tracking mirrors, controllers, junction boxes, sensor poles, and sensor components. All are readily transportable by commercial carriers. Highway carriers will be the primary transport mode.

Handling for assembly and maximum use of trailer cargo space have been major considerations in all package design. Procedures and schedules to control movement of material will be developed to avoid unnecessary multiple handling and ensure conformance to schedule demands. Purchased items will be shipped directly to the assembly location.

Packaging, truck loading, and tiedown concepts provide necessary protection and handling capability to ensure safe delivery. Maximum use will be made of cost-effective, reusable designs. Packs exceeding 75 lb will be suitable for forklift handling. Detailed concepts for most of the items to be transported are described in the following sections and in Figure 5-25. Both manufactured and purchased items are included because their handling and storage at the site are of major importance. MDAC will provide packaging instructions for all purchased items.

5.1.5.1 Packaging

- A. Pedestals and Sensor Poles. Both items will be shipped on open flatbed trucks with lumber spacers between layers. Units will be alternated to permit flange nesting for a tight load. Pairs of pedestals will be steel-strapped to reduce handling and prevent rolling during transport and storage. Sensor poles will be strapped in groups of four.
- B. Torque Tubes. Torque tubes will have the drive-unit mounting supports and inboard beam-mounting flanges attached, thus creating an irregular item to handle and stack. Three assemblies will be handled together by placing them across and strapping them to spacers of 4 x 4 lumber. Alternate units can be offset to achieve a tight pack for handling and storage. Precision mounting surfaces will be protected.
- C. Cross Beams. These flanged beams will be reverse-nested and bundled in fours with filament tape. Bundles will then be steel-strapped together in threes for shipping and storage. Lumber dunnage between layers of bundles will provide spacing for fork entry during loading and unloading.

REUSABLE

MIRRORS — 12 PER FIXTURE

REUSABLE

DRIVE UNITS — 1 PER PALLET

CROSS BEAMS — 12 PER BUNDLE

TORQUE TUBES — 3 PER BUNDLE

PEDESTALS — 2 PER BUNDLE

SENSOR POLES — 4 PER BUNDLE

Figure 5-25. Major Item Handling and Shipping Units

- D. Drive Units. Drive units will be steel-strapped to skidded bases. The reflector assembly mounting support opposite the elevation drive will provide a flat surface upon which to lay the unit for a stable load configuration. The drive is dense (900 lb), so single-tier truck shipment will achieve near-capacity shipping weights. No overbox is planned. Before final assembly, film wrap will be applied to protect areas susceptible of water incursion. If stacking in storage is needed before final assembly, tier racks can be used to provide a greater measure of protection than wood covers.
- E. Reflective Surface Assemblies. The edge strength of glass will be capitalized upon by shipping and storing the mirrors vertically. Tracking mirrors will be packed in fours in the standard glass crates in which they were received. Mounting studs will be fitted with 2-in. styrofoam pads for mirror protection. Pairs will be placed with stud sides facing and one mirror rotated 180 deg to nest the studs. Glass surfaces will be separated with interleaving paper. Mirror boxes will be palletized on edge in groups of 12 and strapped for handling and storage.

The mirror assemblies will be handled on a shipping and storage fixture designed for maximum truck loading. Pairs of assemblies will be used face-to-face with filament tape. The glass will be kept from direct contact by adhesive-backed cushioning patches. Because of the cushion characteristics of the foam sandwich construction, the mounting disks will be allowed to contact one another directly. The slightly sloped fixture back will provide stability during loading and removal of the panels. Strapping will be used to maintain a snug pack for handling, shipment, and storage.

- F. Shock-Sensitive Equipment. Sensors, calibration equipment, controllers, junction boxes, and other electrical equipment will be cushion-packed in fiberboard or wooden containers (depending on weight) for protection against shock and vibration.

5.1.5.2 Transportation

Transportability analyses and cost studies indicate that highway transportation is the most cost-effective mode over the relatively short distance to the

Pilot Plant. The use of flatbed trailers with removable sideracks is planned for most loads to facilitate loading and unloading. Initial deliveries will contain two weeks' work supply (generally less than full-truckload quantities). For economy, subsequent shipments will be made in truck-load quantities when practical. Mirror panels loaded face to face will have tarpaulin covers to protect against casual road hazards and blowing sand, and to ensure that no hazardous reflections are produced by exposed mirror edges. Critical items will be loaded and unloaded by specially trained personnel. A summary of hardware sizes, weights, unitizing, and truck-loading patterns is given in Table 5-1. National Motor Freight Shipping Classification data is presented in Table 5-2.

5.1.5.3 Traffic Control

A traffic-control system is planned to schedule and control movement of materials to and from the assembly site. Advanced planning will ensure availability of ample highway-carrier equipment to maintain delivery schedules. Deliveries will be coordinated with assembly site personnel so as to have proper unloading and handling equipment and manpower available, and to minimize double handling. Single-day round trips from the Los Angeles area should be achievable by unloading all but mirror trailers immediately upon arrival. Reflective surface assembly trailers can be dropped, and the return load of empty fixtures can be picked up for quick turnaround. Average usage will be two trucks per week for panel assemblies and only two or three trucks per month for the other major items.

5.1.5.4 Storage and Handling

Components will be handled and stored in their shipping configurations until ready for further assembly. To minimize handling, items will be trucked directly to storage at the Coolwater factory site. Experienced personnel will ensure safe movement for all items that are critical or difficult to handle.

5.1.5.5 Disposal of Packaging Waste

Waste management will be implemented for disposal of packaging materials that are no longer needed. Biodegradable and recyclable materials (e.g.,

Table 5-1

SUMMARY OF TRANSPORTATION DATA FOR MAJOR ITEMS

Item	Total Quantity	Item Weight (lb)	Number Unitized	Unitized Weight (lb)	Unitized Lifts per Truckload	Loading Pattern Unit Loads (w x l x h)	Total Items per Truckload	Shipping Weight per Truckload (lb)	Total Truckloads	Shipping Interval (days)
Mirror panels ¹	9,864	187	12	2,600	8	2 x 4 x 1	96	21,000	103	1-3
Drive units ²	1,644	900	1	935	48	4 x 12 x 1	48	45,000	34	4-6
Cross beams ³	6,576	165	12	2,000	24	6 x 2 x 2	288	48,000	23	7-9
Torque tubes ³	1,644	603	3	1,825	24	2 x 2 x 6	72	44,000	23	7-9
Pedestals ³	1,644	365	2	750	30	4 x 3 x 5	60	22,500	28	6-8
Sensor poles ³	1,644	100	4	430	64	4 x 2 x 8	256	27,500	7	30
Tracking mirrors ⁴	1,644	29	12 boxes of 4 each	1,550	12	2 x 6 x 1	576	18,600	3	120

¹ Requires 40 reusable fixtures.

² Requires 300 reusable pallets.

³ 4 x 4 lumber can be reused.

⁴ Mirror packs can be reused.

Table 5-2

NATIONAL MOTOR FREIGHT CLASSIFICATION DATA FOR MAJOR ITEMS

Item	NMFC Item	NMFC Article Name	Class Rates		Minimum Weight (1,000 lb)
			LTL	TL	
Mirror panels 85 x 114 x 2 1/2 in., 187 lb	137440 Sub 2	Mirrors, NOI, not bent, exceeding 120 united in. but not exceeding 15-ft length or 7 1/2-ft width	125	70	16.2
Drive units 38 x 23 x 29 in., 900 lb	133300 Sub 1	Machinery Group, Machinery NOI	100	45	24.2
Cross beams 216 x 12 x 2 in., 165 lb	104420	Iron or Steel, Beams, NOI	50	35	40.2
Torque tubes 193 x 12 x 12 in., 603 lb	133390	Machinery Group, Machine Parts NOI	85	45	24.2
Pedestals 20-in. dia x 108 in. with 27-in. flange one end, 365 lb	133390 Sub 4	Machinery Group, Machine Parts NOI	85	45	24.2
Sensor poles 5-in. dia x 188 in. with 12-in. flange one end, 100 lb	96740	Hardware Group, Standards NOI, Iron	70	40	36.2
Tracking mirrors 28 x 41 x 2 in., 29 lb	137440 Sub 1	Mirrors, NOI, not bent, 120 united in. or under	100	70	16.2

wood, fiberboard) have been selected as primary packaging materials. Containers, skids, fixtures, and other packagings that are not salvaged or reused will be removed to a community refuse disposal area. No packaging will be left at the assembly area or installation site.

5.1.6 Procurement Plan

The material and subcontracting plan described in this section will use MDAC's established material system. The system is under the surveillance of the Air Force Plant Representative - Air Force Contract Management Division (AFSC), in accordance with Government directives. It currently is unconditionally approved (as of 25 October 1974). Therefore, the section does not dwell on the specifics of the system, but addresses the elements that we feel are particularly supportive of the Pilot Plant program.

5.1.6.1 Material Support

Material support covers procurement activity for all hardware items. MDAC's procurement and material systems integrate the functions of material planning, handling, control and inventory management, receiving GFE administration, and source development and selection. Also provided are the administration of procurement from small businesses and minority-owned enterprises, purchasing, cost and price analysis, supplier followup, and traffic management.

Source Surveys

Long-lead and other critical procurement items are being identified to assess cost, availability, and degree of development of all items composing the program hardware. These data are developed through preparation of requests for information (RFI's) which contain short, concise technical and program requirements for the selected components. The RFI's are issued to representative, competent industry sources for the specific items. (This step has already been taken for many items of program hardware.)

The use of the RFI data acquisition system has proven particularly useful for obtaining a clearer understanding of hardware cost and the availability of lead-time items. This information is used to substantiate design tradeoff conclusions.

Source Selection

Source selection for all key hardware and service items will be conducted in accordance with existing MDAC policies.

Several key subsystem elements will be withheld from competitive procurement to preserve continuity from the Subsystem Research Experiment (SRE) program to the Pilot Plant program. In the collector subsystem, single-source procurement will be used for the essential components of the azimuth and elevation drive units. The Caloria HT-43 used in the thermal storage subsystem will also be obtained from a single source.

All other procured hardware will be obtained through competitive procedures. Following the RFI cycle, competitive bid packages will be prepared, and quotation requests will be issued to qualified suppliers. After receipt of competitive bids, MDAC will conduct fact-finding visits to suppliers who are considered to be within the "zone of contention." During these visits, we will evaluate each bidder's manufacturing methodology, costs, and capabilities to determine the "should" costs and the suppliers' abilities to support the program schedule demands. All of these factors will be assessed before suppliers are selected and procurement action is initiated.

Material Control

Material requirements will be released for buying action through the use of the direct-procurement-action work release order system. This system affords minimum-time response and maximizes combining like items for efficient procurement. When material has been received and inspected in accordance with quality requirements, it will be routed into controlled inventory. Issue will be made from inventory in accordance with the requirements of the using organization.

Purchasing

MDAC's Purchasing Department is divided into commodity buying groups. This approach affords the most efficient method of securing hardware items and service, in that the buyers most familiar with specific commodities are assigned the acquisition tasks. Further, this method provides for the greatest number of supplier quotations and capabilities, and provides the assurance that the products and services are obtained from the most qualified source at a reasonable price.

Incorporated into the purchase order requirements for selected key items will be the right to conduct vendor meetings with Department of Energy representatives in attendance. Contract requirements will also include a milestone chart depicting significant events to allow tracking of vendor

progress. The Equal Opportunity clause appropriate for the contract will be included as part of the standard purchase order terms and conditions

Status and Followup

All critical items will be tracked by procurement personnel. This tracking will take the form of weekly telephone conversations to assess progress against previously determined milestones. Periodic on-site reviews will also be conducted.

If, during the course of a subcontract, it becomes apparent that a supplier cannot meet his commitments for delivery and technical performance, Material Management will immediately notify the Program Office to develop a solution. In addition, MDAC's general policy is to place personnel in residence at the supplier facility during the period of fact-finding and to have them remain on-site until MDAC has assurance of the supplier's ability to satisfy program needs.

5.1.6.2 Spare Policy

The selection and procurement of spares will be based on ensuring timely support of test operations while minimizing the cost of spare components. Since most components subject to failure will be repairable, spares of the complete units will not be required. In procurement of such items, MDAC will determine supplier repair capabilities and necessary turnaround times in advance.

A limited number of spares will be procured for items that are not repairable and may be subject to failure or damage. These items will be selected on the basis of engineering design considerations and failure-rate expectations. A preliminary analysis has already been performed, and a list of such items is included in the technical volumes and in the cost volume. As the detailed design is released for fabrication and procurement, specific spares will be authorized.

Spare components will be shipped to the test site with other hardware and will be subject to controlled use as authorized by the MDAC field-site manager. Repairable items removed because of malfunction or damage will be given expedited handling for return to the factory or supplier.

5.1.6.3 Subcontract Management

MDAC has tentatively selected a number of subcontractors whose product-

related skills and technology backgrounds form an integral part of our program approach. These subcontractors are identified in Table 5-3, along with the tasks for which they will be responsible and the rationale for their choice. The work listed covers all areas of subcontracted work anticipated for the Pilot Plant phase.

Management of subcontractor activities will be a team effort, with close contact and coordination planned at program management, contractual, and technical levels. The Material Program Manager, working with the Program Manager, will control and coordinate all subcontract effort. Subcontract negotiator/administrators will be responsible for subcontract preparation, negotiation, and administration. A technical manager will be assigned as a single point of contact for each subcontractor to ensure continuous technical coordination and communication. The subcontract negotiator and administrators will maintain close liaison with managers to ensure consistency with contract requirements.

The subcontract negotiator/administrators will use several management tools to maintain subcontract control:

- Technical requirements will be controlled by the use of engineering requirement specifications that describe the items or services being supplied. Changes to these specifications will be controlled through formal release procedures that will prevent unauthorized deviations from the technical baseline.
- The scope of work to be accomplished by subcontractors will be controlled through statements of work approved and issued by the Program Manager and incorporated into the subcontracts.
- Monthly financial and progress reports will be required from subcontractors will be monitored against previously determined milestone schedules and budgets.
- Any significant deviation from the plan will be immediately reported to the Program Manager so that he may initiate action to establish a workaround plan.

To ensure good technical and contractual communications, periodic review meetings will be held. To fulfill Department of Energy requirements for

Table 5-3
RATIONALE FOR SUBCONTRACTOR SELECTION

Subcontractor	Task	Rationale
Rocketdyne, Canoga Park	Receiver subsystem	MDAC selected Rocketdyne to support the Phase I SRE program. Experience acquired through SRE background establishes rationale to retain key team member for Pilot Plant.
	Thermal storage subsystem	Same as described above. In addition, MDAC and Rocketdyne have filed a joint patent application on the innovative design approach for this subsystem.
Stearns-Roger, Denver	Collector subsystem field installation support and system integration	Stearns-Roger has supported MDAC in the development of site installation plans for both the SRE and Pilot Plant planning. Additionally, their assistance in system engineering and integration has been vital in Pilot Plant requirement definition. Their expertise in tower design and balance-of-plant definition is considered essential.
University of Houston	Collector subsystem field layout	The University of Houston has developed a computer model whose use is considered mandatory to establish the field layout for the Pilot Plant program. The model will also be used to optimize collector locations as a result of changes to interacting subsystems.
Compudrive Corporation, North Billerica, Massachusetts	Collector subsystem drive-unit component manufacturer	MDAC's drive unit for the Pilot Plant incorporates proprietary elements produced by Compudrive.

participation in subcontractor reviews, the review activity will be included as part of the subcontract work statements.

5.1.6.4 Make-or-Buy

Standard MDAC practices have been used to develop the make-or-buy plans for system design and for production and test of the hardware.

Our make-or-buy analysis for any program is performed in accordance with established business practices and government regulations, with the following objectives:

- To produce products and services of high-quality and technical excellence at the lowest possible overall costs, consistent with performance, reliability, and delivery commitments.
- To give full consideration to the technical capability of MDAC and other MDC components for work related to their fields of specialization and requiring close integration with other products.
- To assign to outside suppliers work that requires specialized capability or work that they can carry out to meet performance, quality, and delivery requirements at a lower total cost than MDAC can achieve.
- To give fair opportunity to small-business firms and minority-owned enterprises, and to place work, where possible, in areas of concentrated unemployment or underemployment.

The detailed analysis and preparation of the recommended make-or-buy plan is performed by a subcommittee headed by the Program Manager and composed of representatives by each MDAC functional organization (engineering, manufacturing, quality assurance, material, etc). The plan covers both design and fabrication decisions for each significant hardware element. The overall plan and all major decisions are then reviewed by a formal committee appointed by the MDAC President. This committee is chaired by the Vice President - Fiscal Management and is composed of directors of the MDAC functional organizations. All make-or-buy decisions are therefore assured of management review that reflects MDAC's total design, fabrication, production, and procurement experience.

5.2 INSTALLATION, CHECKOUT, AND MAINTENANCE PLANS

5.2.1 Installation and Checkout Plan

The plan provides that the collector subsystem will be installed and checked out on schedule and at the lowest cost (see the following tabulation):

<u>Concepts</u>	<u>Benefits</u>
<ul style="list-style-type: none">● Heliostats designed for ease of installation.● Heliostat components are pre-assembled at the factory.● Installation tools and procedures are validated prior to deployment.● Installation equipment designed to support maintenance.● Checkout verification at Huntington Beach on production heliostat.	<ul style="list-style-type: none">● Reduces requirements for specialized installation.● All critical tasks accomplished in factory environment.● Installation techniques optimized prior to starting installation.● Reduces support equipment cost.● Ensures early availability of final checkout procedure.

In accordance with the concepts, the requirements for equipment, procedures, facilities, and personnel during the installation and checkout phase have been established to make effective use of MDAC capabilities.

Two alternate heliostat systems, closed-loop and open-loop, are under consideration. Basic differences between the two systems are as follows:

- A. The closed-loop system uses a sensor, sensor pole, and associated cabling to accurately control movement of the heliostat and reflectance to the receiver.
- B. The open-loop system does not employ a sensor, sensor pole, and associated cabling.

For purposes of clarity, installation and checkout of the closed-loop system is described in detail with differences for the open-loop system noted.

Heliostat subassemblies and components of the subsystem will be fabricated at MDAC-Huntington Beach, where all critical manufacturing tasks are performed under controlled conditions. Subassemblies and components are then shipped to the Pilot Plant site in standard-size trucks.

Each heliostat will be completely assembled in an assembly building. The assembled heliostat, consisting of reflectors, drive units, pedestal, and controller, is then transported by a specially equipped forklift to the foundation site where it is secured in place.

Installation and checkout procedures will be prepared during the preproduction phase of the program, validated at Huntington Beach by usage with the preproduction heliostat, and then used throughout the installation phase.

At the site, crew chiefs will record satisfactory completion of all tasks directly in the installation procedures. A QA representative will audit progress.

5.2.1.1 Installation and Checkout Phases

MDAC has developed a four-phase installation and checkout plan to implement the basic concepts:

- A. Preparation Phase. Includes all detailed planning and preparation activities necessary to support the heliostat field installation and checkout. This consists of the preparation of procedures and the design and manufacture of special tools and equipment required during installation and checkout.
- B. Validation Phase. Crucial to the successful accomplishment of installation and checkout. MDAC will assemble, install, align, and check out one complete preproduction heliostat, sensor, and field controller in a special test area at Huntington Beach. Components will be installed and checked out in strict accordance with the installation procedures, using the tools and equipment which are intended for use at the field site. Any deviations from the procedures and equipment will be identified and corrected during this validation phase.

Upon completion of the validation phase, there will be positive assurance that the collector subsystem can be installed and checked out in strict compliance with the written procedures.

- C. Site Activities Phase. Consists of establishing MDAC office and shop facilities and setting up the collector subsystem installation and checkout equipment at the site. Installation and checkout of the heliostats, sensors*, and controllers are started and continue in a methodical uninterrupted sequence until all of the required collector subsystem equipment is installed and checked out.
- D. Final Installation Activities Phase. Consists of MDAC activities necessary to deliver installation and checkout equipment, maintenance procedures, equipment and spares to the customer, and remove any excess equipment and materials.

5.2.1.2 Installation Sequence

The sequence in which tasks are performed for a single heliostat is shown in Figure 5-26 (closed-loop system) and Figure 5-27 (open-loop system). During field installation, the tasks are actually performed in parallel. The sequence starts with the foundations completely installed.

Three leveling nuts on each foundation are adjusted to a plane in two axes using a pedestal leveling fixture and an inclinometer (Figure 5-28). Once a level plane is established, the three leveling nuts are secured with locking nuts.

The heliostat, consisting of reflector panels, drive units, pedestal, and controller will be assembled and wired in the assembly building on site. A heliostat handling fixture, specially adapted to a forklift, is mated to the completely assembled heliostat (Figure 5-29). The heliostat is lifted clear of its assembly fixture and is then transported to the assigned foundation (Figure 5-30).

The heliostat is positioned over the foundation and the pedestal restraining strap is released. This leaves the heliostat suspended from the forklift

*Not applicable to open-loop system.

Figure 5-26. HelioStat Installation Sequence (Closed-Loop System)

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Figure 5-27. HelioStat Installation Sequence (Open-Loop System)

Figure 5-28. Leveling Nut Adjustment on Foundations

NOTE:
FORKLIFT OMITTED
FOR CLARITY

Figure 5-29. Handling Fixture Mated to Heliostat

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Figure 5-30. Heliostat Installation on Foundation

adapter lifting eye, and free to be guided onto the foundation anchor bolts. As soon as the lower pedestal flange comes to rest on the three level nuts, retaining nuts are installed on the same three anchor bolts. The handling fixture is disengaged from the heliostat. Next, the other five nuts under the pedestal flange are positioned against the under surface of the flange. After installing the five retaining nuts, all eight retaining nuts are torqued.

The sensor mirror, which was removed from the heliostat to provide access for the forklift adapter hoist, is reinstalled.

Power and control cables are connected to the field or heliostat controller, depending upon the designated location of the heliostat. A cell field controller installed on a specific heliostat will control that heliostat and provide control signals to 23 other heliostat controllers in the cell. There is a total of 24 heliostats comprising one cell. Cable laying is done earlier in the program by the general contractor.

Open-Loop Control Alignment

Functional and electrical checks of the heliostat using the field controller test set include continuity, phasing, motor rotation directions, polarity, and signal strength. Azimuth reference of the heliostat is aligned (Figure 5-31) by mounting a theodolite on the reflector surface and sighting a known reference point on a flagpole 25 to 30 ft high. The azimuth encoder data output is recorded on tape for later input to the Master Control software. Elevation reference is aligned by driving the heliostat reflector horizontal to the ground and mounting an inclinometer on the reflective surface to verify that the surface is in a horizontal position. The output data from the encoder is then recorded on tape.

Following the recording of the heliostat reference data, the field location of each heliostat, in X and Y axis coordinates, must be established and recorded for input to the Master Control. For the proper open-loop control of the heliostat field these data must include longitude and latitude coordinates and the precise local time.

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Figure 5-31. Heliostat Referencing

The next operation involves obtaining and recording data to establish a curve of the eccentric movement of the reflective surface as it rotates in azimuth-while in a nominal horizontal position. These data points will be picked off and recorded using an electronic leveling device attached to the reflective surface of the heliostat.

Final verification of the alignment of each heliostat will be accomplished by directing the heliostat beam onto a reflective target mounted on the tower below the receiver panels. This target is presently envisioned as being passive. Verification data will be obtained and recorded through the use of a digital eye located in the field. Further development and testing of the open-loop system may lead to the use of an active target with readout and recording instrumentation.

Closed-Loop Control Alignment

*Functional and electrical checks of the heliostat using the mobile field test station include continuity, phasing, motor rotation directions, polarity, and signal strength. The mobile field test station is connected directly to the controller of the heliostat under test.

*During the electrical and functional checks, azimuth reference of the heliostat is aligned (Figure 5-31) by mounting a theodolite on the reflector surface and sighting a known reference point on a previously installed flagpole 25 to 30 ft high. The azimuth encoder is adjusted at this time. Elevation reference is aligned by driving the heliostat reflector horizontal to the ground, mounting an inclinometer, and adjusting the elevation encoder to a level condition. A programmed series of commands fed into the controller causes the heliostat to be driven to preset limits of travel in elevation and azimuth.

*The sensor pole is installed, leveled and secured. Sensor mount and sensor are installed, and the sensor is roughly aligned on the receiver. Necessary conduit is installed and the sensor cable is installed between the sensor and the controller. Electrical checks are made of continuity, AGC, and polarity.

*After electrical checkout tasks are completed and verified, the sensor is aligned on the receiver panel. Since this is a closed-loop tracking system,

*Not applicable to open-loop system.

tracking accuracy is dependent on the accuracy with which the sensor is aligned. One technician, riding in a cherry picker (Figure 5-32) directs another technician at the mobile field test station in driving the heliostat in elevation and azimuth until the reflected spot is on the receiver panel. Directions are transmitted by walkie-talkie radio sets. When the reflected spot is on the receiver panel, the controller is commanded to track. While tracking is in progress, the technician in the cherry picker adjusts the sensor to align the reflected spot with the designated aim point on the receiver. The sensor is then locked.

Operational Checkout

After installing heliostats, verification tests and checkouts are performed to ensure compatibility of a field controller and a cell of heliostats. The mobile field test station is connected to the field controller, and the cell of heliostats is commanded to individually acquire sun, normal track, synthetic track, slew-off receiver, wash position, inverted position, and stow position. This test verifies that each heliostat in a cell is properly interfaced with the field controller.

The final collector subsystem test of the installation phase takes place prior to Pilot Plant system testing. During this activity, it will be necessary to have water flowing through the receiver panel. Cell-by-cell tests of tracking, slew-off, and stowage actions are performed (Figure 5-33). Stringent safety precautions must be enforced to preclude personnel injuries from reflected beams.

5.2.1.3 Schedules

Installation and checkout operation schedules have been coordinated with storage and assembly rates to effect a smooth transition of activities in consonance with the four phases of the installation and checkout plan mentioned in Section 5.2.1. Figure 5-34 identifies time-phasing projections for major closed-loop system installation and checkout activities.

Figure 5-35 identifies time-phasing projections for major open-loop system installation and checkout activities.

Figure 5-32. Heliostat Sensor Alignment

Figure 5-33. Heliostat Cell Checkout

Figure 5-34. Collector Subsystem – Field Site Installation and Checkout Schedule (Closed Loop)

Figure 5-35. Collector Subsystem — Field Site Installation and Checkout Schedule (Open Loop)

Figure 5-36 provides unit rate projections for scheduled closed-loop installation and checkout tasks.

5.2.1.4 Procedures

Procedural support requirements will be satisfied by providing low-cost instructions for installation and checkout of the collector subsystem. Simple, commercially acceptable methods will allow quick-reaction preparation and reproduction of drawings.

Initial drafts of collector subsystem installation procedures will be prepared during the preparation phase at MDAC-Huntington Beach. Procedures will be validated to maximum possible extent during the validation phase when one complete preproduction heliostat, sensor, and field controller are assembled and checked out in a special test area at Huntington Beach. Operations will be performed in strict accordance with the written instructions. Any deficiencies noted during validation will be corrected by redlining the procedures. Changes will be incorporated in the final production of the drawing, and delivered at the onset of the site activities phase.

Procedures will be updated throughout the program, as required to reflect equipment modifications and procedural improvements.

Collector Subsystem Installation Procedures (CSIP's)

Installation and checkout instructions are a variation of the site activation kit work order, which MDAC used successfully during installation and checkout of the US Army Safeguard Spartan Missile site.

Each CSIP (Figure 5-37) will be a discrete integrated planning document which will identify:

- Special tools, materials, and test equipment.
- Supplementary drawings.

It will provide:

- Step-by-step instructions.
- Safety requirements.
- Incremental buyoff provisions.
- Installation and checkout historical data package.

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	1979												1980																								
	JUL			AUG			SEP			OCT			NOV			DEC			JAN			FEB			MAR			APR			MAY			JUN			
	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	3	10	17	24	31		
LEVEL FOUNDATIONS	WK	4	5	0	0	3	0	3	0	3	4	5	0	0	3	0	3	0	3	4	5	0	0	3	0	3	4	5	0	0	3	0	3	0	3		
	CUM	4	9	0	3	3	0	6	3	3	10	5	3	10	13	3	13	10	3	17	12	3	17	20	3	23	20	3	27	22	3	25	22	3	28		
	MO	372				603				515			270																							1760 TOTAL PEAK RATE = 27/DAY	
INSTALL HELIOSTATS	WK	5	5	0	0	2	0	2	0	5	5	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0		
	CUM	5	10	0	2	2	0	4	2	5	9	4	5	9	14	5	14	19	5	19	24	5	24	29	5	29	34	5	34	39	5	39	44	5	44		
	MO	38				147				180			220			200			160			220			210			260			185					1760 TOTAL PEAK RATE = 18/DAY	
CONNECT & CHECKOUT FIELD CABLEING	WK													2	3	5	4	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0		
	CUM													2	5	0	4	9	0	4	9	0	4	9	0	4	9	0	4	9	0	4	9	0	4		
	MO													146			205			225			176			243			231			220			243	77	1760 TOTAL PEAK RATE = 11/DAY
SET HELIOSTAT REFERENCE	WK													2	3	5	4	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0		
	CUM													2	5	0	4	9	0	4	9	0	4	9	0	4	9	0	4	9	0	4	9	0	4		
	MO													95			200			220			176			243			231			220			243	132	1760 TOTAL PEAK RATE = 11/DAY
INSTALL SENSOR POLES	WK																																				
	CUM																																				
	MO																																				1760 TOTAL PEAK RATE = 27/DAY
INSTALL SENSORS	WK																																				
	CUM																																				
	MO																																				1760 TOTAL PEAK RATE= 18/MAY
ALIGN SENSORS	WK																																				
	CUM																																				
	MO																																				1760 TOTAL PEAK RATE = 18/DAY
CELL OPERATIONAL CHECKOUT	WK																																				
	CUM																																				
	MO																																				7% TOTAL PEAK RATE = 3.4/DAY

Figure 5-36. Collector Subsystem – Field Site Installation and Checkout Rates (Closed Loop)

10-MW SOLAR THERMAL PILOT PLANT
COLLECTOR SUBSYSTEM INSTALLATION PROCEDURE

TITLE: HELIOSTAT INSTALLATION

DATE: _____

TABLE OF CONTENTS

OK TO ISSUE: _____

SHEET

(DIRECTOR - SITE INSTALLATION)

TITLE SHEET
PAGE LIST AND CHANGE STATUS
INSTALL HANDLING FIXTURE ON HELIOSTAT
RELEASE PEDESTAL BASE
HOIST HELIOSTAT AND INSTALL PEDESTAL
SAFETY STRAP
POSITION TRANSPORTER AT FOUNDATION
LOWER HELIOSTAT ON FOUNDATION
AND SECURE WITH ANCHOR NUTS
REMOVE TRANSPORTER FROM HELIOSTAT
TORQUE ANCHOR NUTS
INSTALL SENSOR MIRROR
ADJUST SENSOR MIRROR

1
2
3
3
4
5
5
6
6
7
8

COORDINATION

DEPT _____ NAME _____ DATE _____

(OPERATIONS)

(SITE INSTALLATION)

(QUALITY ASSURANCE)

(CHIEF PROGRAM ENGINEER)

REMARKS

(ECP _____ INCORPORATED)

EFFECTIVITY: _____

MCDONNELL DOUGLAS ASTRONAUTICS CO.
HUNTINGTON BEACH, CALIF.

MCDONNELL DOUGLAS

SIZE

A

CODE IDENT NO.

18355

DRAWING NO.

MDAC-CSIP-02

SCALE

REV New

SHEET

1

Figure 5-37. Collector Subsystem Installation Procedure - Sample (1 of 3)

[illegible]

MCDONNELL DOUGLAS

A

18355

MDAC-CSIP-02

2

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1. TOOLS, MATERIALS, AND EQUIPMENT REQUIRED:

PART NO.	NOMENCLATURE/DESCRIPTION	QTY
JD380	FORKLIFT, 2-TON CAPACITY (MIN)	1
1DXXXXX	FIXTURE, HELIOSTAT HANDLING	1

2. PRELIMINARY REQUIREMENTS

2.1 LEVELING NUTS ADJUSTED ON FOUNDATION DESIGNATED FOR HELIOSTAT, SERIAL NO.

2.2 HELIOSTAT IS COMPLETELY ASSEMBLED ON PEDESTAL, WITH REFLECTOR HORIZONTAL TO FLOOR OF ASSEMBLY BUILDING

2.3 SENSOR MIRROR NOT INSTALLED ON HELIOSTAT

2.4 VERIFY LOAD/TEST RECERTIFICATION REQUIREMENTS OF HELIOSTAT HANDLING FIXTURE AND FORKLIFT ARE CURRENT

3. INSTALL HANDLING FIXTURE ON FORKLIFT

3.1 VERIFY/REMOVE FORKS FROM FORKLIFT

3.2 DRIVE FORKLIFT INTO POSITION FOR INSTALLING HANDLING FIXTURE

WARNING

HANDLING FIXTURE WEIGHS APPROXIMATELY 250 POUNDS. DO NOT LIFT FIXTURE MANUALLY

3.3 MOUNT HANDLING FIXTURE BY ENGAGING ADAPTER HOOKS ONTO SURFACE OF FORKLIFT WHERE FORKS WERE NORMALLY INSTALLED

4. DRIVE FORKLIFT TO HELIOSTAT WITH FIXTURE IN LOWERED POSITION

5. INSTALL HANDLING FIXTURE ON HELIOSTAT

5.1 POSITION HANDLING FIXTURE BELOW 28-INCH SLOT IN REFLECTOR SURFACE WITH SADDLE APPROXIMATELY ONE FOOT FROM PEDESTAL

5.2 RAISE HANDLING FIXTURE TO HEIGHT REQUIRED TO INSTALL SLING, AND MOVE FORWARD UNTIL SADDLE CONTACTS PEDESTAL

UNIT EFFECTIVITY:

VAL →

MCDONNELL DOUGLAS ASTRONAUTICS CO.
HUNTINGTON BEACH, CALIF.

MCDONNELL DOUGLAS

SIZE	CODE IDENT NO.	DRAWING NO.
A	18355	MDAC-CSIP-02
SCALE	REV New	SHEET 3

DD FORM 1, AUG 68

Figure 5-37. Collector Subsystem Installation Procedure – Sample (3 of 3)

Since development, preparation, and validation of CSIP's represents a nonrecurring cost to the program, the quantity of heliostats will not affect production costs. The number of CSIP's needed to accomplish installation and checkout activities has been optimized for task efficiency and quality control.

For any selected quantity of heliostats, MDAC proposed to develop, produce, and validate the CSIP's identified in Table 5-4.

Necessary buyoff points are incorporated in each CSIP. Quality Assurance personnel will certify the validity of each critical operation by stamping or signing at the designated buyoff points. Thus, the completed CSIP serves as the historical record for installation and checkout operations.

5.2.1.5 Tools, Heavy Equipment, and Test Equipment (Table 5-5)

Types and quantities of equipment for installation and checkout operations have been selected with economical and expeditious objectives in view. All equipment is portable. Upon completion of collector subsystem installation and checkout operations, the major portion of equipment can be used for maintenance operations (see Support Plan, Section 5.2.3). MDAC will deliver necessary items of equipment to the customer for maintenance purposes during Pilot Plant system testing as dictated by the customer's operational plans.

5.2.1.6 Facilities

The installation and checkout operations office will be located in the same building at the site that is used for final assembly of the heliostat. The building is described in Section 5.1.2.2.

5.2.1.7 Site Organization (Figure 5-38)

The site organization will be staffed with personnel to facilitate collector subsystem installation and checkout tasks.

The MDAC installation supervisor will be thoroughly knowledgeable in all aspects of collector subsystem design and operation. He will function as a structural/mechanical advisor during the preparation and validation phases

Table 5-4
COLLECTOR SUBSYSTEM INSTALLATION PROCEDURES

Number	Title/Description
MDAC-CSIP-01	<p>Foundation Leveling</p> <p>Provide procedure for adjusting pedestal leveling nuts using special leveling tool.</p>
MDAC-CSIP-02	<p>Heliostat Installation</p> <p>Provide procedures for installing heliostat handling fixture, transporting heliostat, and installing heliostat on foundation.</p>
MDAC-CSIP-03	<p>Power and Control Cables Connection</p> <p>Provide procedures for connecting power cable to field and heliostat controllers, control cables to field and heliostat controllers.</p>
MDAC-CSIP-04	<p>Heliostat Referencing and Checkout</p> <p>Provide procedures for aligning heliostat to known reference point. Provide procedures for operational checkout of a heliostat using mobile field test station and azimuth encoders.</p>
MDAC-CSIP-05	<p>Sensor Pole Installation*</p> <p>Provide procedures for installing and leveling pole on foundation.</p>
MDAC-CSIP-06	<p>Sensor Installation*</p> <p>Provide procedures for installing sensor mount and sensor on pole, and connecting electrical cable.</p>
MDAC-CSIP-07	<p>Sensor Alignment*</p> <p>Provide procedures for aligning and locking sensor.</p>
MDAC-CSIP-08	<p>Test and Checkout</p> <p>Provide procedures for test and checkout of a cell of heliostats using the mobile field test station. Refer to available engineering drawings for cabling, wiring, logic, and functional diagrams.</p>
MDAC-CSIP-09	<p>Heliostat Coordinates Verification and Vertical Deviation Checks**</p>

*Closed-loop system only
**Open-loop system only

Table 5-5
INSTALLATION AND CHECKOUT EQUIPMENT

Nomenclature	Quantity
Heliostat Handling Fixture	2
Handling Sling, Heliostat Mirrors	2
Mobile Workstand (Cherry Picker)*	2
Pedestal Leveling Fixture	2
Power Torque Wrench	2
Forklift	1
Multimeter-Volt Ohmmeter	6
Digital Voltmeter	6
Pickup Truck, Modified to Incorporate Workstand in Truck Bed	2
Mobile Crane	1
Walkie-Talkie Communication Sets	4
Inclinometer	2
Theodelite	2
Mobile Field Test Station	2
Reflector Washing Equipment	TBD
*Not applicable to open-loop system	

at MDAC-Huntington Beach, and then he will move to the field site for the site activities phase. He will personally monitor validation activities to ensure that procedures have been satisfactorily developed. He will be cognizant of all installation and checkout activities at site.

The QA site representative will monitor assembly, installation, and checkout activities to ensure that collector subsystem components are installed in accordance with MDAC's strict quality and personnel safety controls. He will audit procedures and activities where discrepancies and failures occur.

The field service representative will be knowledgeable in all aspects of collector subsystem operation. He will work with crews performing mechanical, electrical, alignment, and checkout functions. He will also serve as deputy installation supervisor.

Figure 5-38. Site Organization

Field installation and checkout crews will be composed of qualified mechanical and electrical technicians to perform mechanical, electrical, alignment, and checkout tasks. MDAC plans to hire technicians in Barstow and provide a line supervisor from Huntington Beach. Local hiring provides advantages of flexible staff size, local area participation, and decreases personnel relocation expenses.

Support personnel, such as forklift drivers, crane operators, technicians helpers, and clerks, will be hired locally.

5.2.1.8 Personnel Safety

MDAC maintains a consistent management policy of ensuring that all operations comply with current safety standards, regulations, and requirements. The policy will be implemented and enforced by the operating supervisors. The field manager will be responsible for ensuring that installation and checkout activities are performed in accordance with appropriate safety regulations. He will receive guidance and assistance from the MDAC Employee Safety Department, and with respect to equipment design, from the Safety Branch of the Effectiveness Engineering Department.

Installation and checkout operations will be performed in accordance with detailed written instructions. Instructions will include caution and warning notices to ensure that all personnel are aware of potential safety hazards.

5.2.2 Electronic Support Equipment Mobile Station

Installation, checkout, and maintenance of the electrical components in the collector field, e.g., wire, cable, field controllers, motors, sensors, etc., requires general-purpose and specialized electrical test equipment. Use of a micro processor-controlled mobile test station is planned for collector field use. The station will simulate electrical stimuli, measure responses, and evaluate the operation of heliostat electronics prior to site activation. It will also troubleshoot heliostat electronics during maintenance operations.

The proposed support hardware and software are based on MDAC's Universal Digital Test Set (UDTS), an existing microprocessor-controlled test set, and associated software.

The electronic support equipment station (ESES) is a microprocessor-controlled test center containing all the hardware and software elements necessary to test and check out a field controller and heliostat controller and to test and verify the operation of the heliostat hardware and application software. It provides a self-contained test and verification process, supports acceptance and validation test, and minimizes the time and effort devoted to card and end-item testing. The proposed electrical support equipment is shown in Figure 5-39. Three essentially identical systems are planned; one for factory use and two for collector field usage. The factory unit will be packaged for bench and/or floor operation. The two field units will each be packaged in an air-conditioned standup maxivan to provide the most flexibility and mobility. The van will have an auxiliary power generator sized to provide van power and heliostat power (24 heliostats and one field controller) in the absence of primary heliostat power.

5.2.2.1 Basic Operation

The ESES will perform both subsystem-level and card-level testing, fault isolation, and operations control in the factory and in the field. As an example of its capability consider a field controller location somewhere in the collector field. The ESES will be capable of simulating Master Control if Master Control is not available for test purposes or if it is down; it can simulate the field controller and talk to Master Control; it can simulate the field controller and operate the cell (typically 24 heliostats); and it can provide power for operation of the cell including field controller and 24 heliostats if power is not available. In addition to field controller operations the ESES will monitor heliostat sensor and encoder outputs and also provide simulation of these outputs when required. A hand-held portable manual motor controller is planned for direct motor control. This unit can bypass both the field and heliostat controllers. Figure 5-40 illustrates these capabilities.

5.2.2.2 Hardware Design Description

As previously mentioned, the electronic support equipment station is based upon the UDTS design. The UDTS contains a microprocessor controller, CRT or keyboard console, high-speed paper tape reader, line printer, dual-drive floppy disk, and adapter unit for connecting to the circuit card

Figure 5-39. Electronic Support Equipment Station

Figure 5-40. Electronic Support Equipment Station (ESES) Subsystem Operating Capabilities

assemblies. The ESES also contains general-purpose test equipment and special interfaces for testing collector field hardware. The heart of the DSP support hardware is the microprocessor controller, an Intel microcomputer development system (MDS-800) with 32K bytes of read/write (RAM) memory, 2K bytes of ROM, and 256 bytes of programmable read-only memory (PROM).

The dual-drive floppy disk provides for storage of the various card and unit test programs, the MDS-800 support software, and data or programs necessary to support software development. The line printer provides for permanent copy of test results, and program dumps.

The CRT and associated keyboard console provides a convenient man-machine interface for controlling tests and displaying data and test results, viewing the contents of selected registers and portions of memory and interacting with a field controller or heliostat controller during hardware and software testing or software development.

The paper tape reader is used to read the new or modified test programs and data into the support equipment or to accept programs for subsequent loading into field controllers.

The printed circuit card interface box is simply a receptacle for the various cards in the field and heliostat controllers. Actual logic, circuitry, and components required to interface the cards with ESES test equipment, either the microprocessor or general purpose equipment, will be located in the microprocessor drawer.

The manual motor controller may be used with the station or as a detached unit for motor operation. As a detached unit, a portable power cord to the test station or a utility receptacle is required. The controller can interface directly with the azimuth and elevation motors circumventing all normal operating circuitry such as field controllers and heliostat controllers.

The motor load panel provides simulated loads for a heliostat controller when it is in a test mode and no actual heliostat movement is desired. Two motors identical to the actual heliostat motors are expected to provide the required load.

The sensor/encoder panel will provide simulated sensor and encoder outputs for heliostat controller tests. It will also provide a means of monitoring actual sensor and encoder outputs during adjustment and troubleshooting exercises. Outputs will be displayed on general-purpose test equipment.

The test equipment will be provided in the test station to facilitate troubleshooting. It will avoid the use of loose test equipment and the uncontrolled test operations that normally are involved. A digital multimeter will monitor sensor and encoder outputs, motor voltages, power supply voltages, wire and circuit resistance, etc. An oscilloscope will monitor and observe noise, switching transients, pulse shapes, etc during troubleshooting and circuit-evaluation operations. A digital counter will check out and evaluate pulse trains. A chart recorder will provide hard-copy records for later evaluation or documentation. A portable multimeter, megger, and AC current probe will also be provided. The ESES will contain all necessary cables to interface with field controllers, heliostat controllers, motors, encoders, sensors, printed circuit card, etc. The number of cables and the test setup complexity will be minimized to facilitate test operations.

A digital eye system as developed during SRE will be available in the field versions of the station. The system will include the camera, controller, monitor, and minicomputer; see Section 6 for details.

The ESES for field use will be packaged in an air-conditioned stand-up maxivan vehicle. This will maximize the utility, self-sufficiency, and organization of the test station. The outdoor environment (heat, sunlight, etc), a rapid response time, and the desire to have controlled and organized test operations were the key considerations in this decision to use a test van concept. An auxiliary AC generator will power the van although provisions will be provided to use utility power if available. The generator will be sized to handle the operations of a collector field cell which includes one field controller and 24 heliostats under slewing conditions.

5.2.3 Subsystem Support Plan

The baseline support concepts defined in Section 4.2.13 are expanded in this section to provide subsystem support planning data for establishing an efficient

maintenance capability. Maintenance concepts are applied to subsystem hardware elements to identify the maintenance resources required to maintain equipment performance and operational availability. Maintenance resources identified include manpower/skills, spares and repair parts, support equipment, maintenance procedures training, and facility requirements.

The level of detail and confidence in the requirement estimates at this time are constrained by the current hardware design definition. Also, collector subsystem requirements must be integrated with the overall pilot plant support requirements to assure a cost-effective support operation. When refined to reflect the firm hardware design and reshaped as necessary to interface with other subsystem requirements, the support plan will provide the necessary information for acquisition and implementation of an efficient maintenance program.

5.2.3.1 Equipment Maintenance

The basic corrective and scheduled maintenance tasks for the collector subsystem have been determined by a hardware analysis to identify maintenance significant components. Maintenance significant components are defined as hardware items for which a discrete maintenance action is required based on the maintenance concept. Maintenance actions result from equipment failures or may be scheduled actions such as cleaning or lubrication to prevent equipment deterioration or sustain performance characteristics. Table 5-6 lists the maintenance significant components and provides a brief description of the required maintenance actions.

Corrective Maintenance

The corrective maintenance actions described in Table 5-6 have been further analyzed to identify task times, manhours per task, labor classifications, and manhours per year. Off-site repair of failed components will be accomplished at MDAC-Huntington Beach or vendor locations. The off-site repair cycle is discussed in Section 5.2.3.2. Table 5-7 provides an estimate of the elapsed time to repair (EMT-R) and elapsed time to remove and replace (EMT-R/R) for each maintenance-significant item. An estimate is also provided for the percentage of time the component will be removed

Table 5-6
MAINTENANCE SIGNIFICANT ITEM LIST

Component	Corrective Maintenance	Scheduled Maintenance
Field Controller	Remove and replace on failure. Minor repair on-site. Major repair and overhaul at MDAC.	None
Heliostat Controller	Remove and replace on failure. Minor repair on-site. Major repair and overhaul at MDAC.	None
Elevation and Azimuth Drive Assemblies	Remove and replace on failure. Repair and overhaul at MDAC.	Lubrication
Elevation and Azimuth Drive Motor and Reducer	Remove and replace on failure. Repair at manufacturer.	None
Elevation and Azimuth Shaft Encoder	Remove and replace on failure. Repair at manufacturer.	None
Elevation and Azimuth Shaft Turn Pickoff	Remove and replace on failure. Repair at MDAC.	None
Pedestal J-Box	Remove and replace detail parts on failure. Remove and replace box for major damage.	None
Pedestal	Structural repair. Remove and replace for major damage.	None
Reflector Panel	Remove and replace. Discard. Clean (in addition to scheduled requirements due to severe weather conditions).	Clean
Reflection Structure	Structural repair. Remove and replace for major damage.	None
Beam Sensor	Remove and replace on failure. Repair at MDAC.	None
Sensor Pole	Structural repair. Remove and replace for major damage.	None
Field Cables	Electrical Repair. Remove and replace for major damage.	None
Power Distribution Panel	Remove and replace detail parts. Replace panel for major damage.	None
Power Transmission	Remove and replace on failure.	None
Test Support Station	Remove and repair components on failure. Repair components at MDAC.	Calibrate Test Equipment, inspect, clean, adjust and lubricate CRT/ keyboard, tape reader, and recorder

Table 5-7 (Page 1 of 2)

CORRECTIVE MAINTENANCE
MAINTENANCE TASK TIME REQUIREMENTS (HOURS)

Item	Component	T _{P/S}	T _{FI}	T _R	T _{R/R}	T _{T/CO}	EMT-R	EMT-R/R	% R/R
1	Field Controller (F/C)	0.2	0.13	0.08	0.78	0.25	0.66	1.36	90
2	Heliostat Controller (H/C)	0.2	0.08	0.08	0.65	0.17	0.53	1.10	90
3	Azimuth Drive Assembly	0.3	0.50	-	1.63	0.25	-	2.68	100
4	Elevation Drive Assembly	0.2	0.50	-	1.48	0.25	-	2.43	100
5	Elevation Drive Motor and 1st-Stage Drive	0.2	0.50	-	0.59	0.25	-	1.54	100
6	Azimuth Drive Motor and 1st-Stage Drive	0.3	0.50	-	1.10	0.25	-	2.15	100
7	Elevation Shaft Encoder	0.2	0.50	-	0.25	0.15	-	1.10	100
8	Azimuth Shaft Encoder	0.2	0.50	-	0.53	0.39	-	1.62	100
9	Elevation Shaft Turn Pickoff	0.2	0.50	-	0.25	0.10	-	1.05	100
10	Azimuth Shaft Turn Pickoff	0.2	0.50	-	0.53	0.10	-	1.33	100
11	Pedestal J-Box (with F/C)	0.2	0.50	0.50	2.90	0.40	1.60	4.00	10
12	Pedestal J-Box (with H/C)	0.2	0.50	0.50	2.55	0.25	1.45	3.50	10
13	Pedestal	0.3	-	0.5	1.17	0.10	0.80	1.57	90
14	Reflector Panel	0.3	-	0.10	0.82	-	-	1.12	100
15	Reflector Structure	0.3	-	0.33	4.49	0.25	0.88	5.04	100
16	Beam Sensor	0.2	0.50	-	0.29	0.13	-	1.12	100
17	Sensor Pole	0.3	-	-	0.46	0.25	-	1.01	100
18	Pedestal Cables	0.2	0.50	0.50	0.71	0.25	1.45	1.66	25
19	Field Cables	0.3	0.50	1.08	5.00	0.25	2.13	6.05	25

Table 5-7 (Page 2 of 2)

CORRECTIVE MAINTENANCE
MAINTENANCE TASK TIME REQUIREMENTS (HOURS)

Item	Component	T _{P/S}	T _{FI}	T _R	T _{R/R}	T _{T/CO}	EMT-R	EMT-R/R	% R/R
20	Distribution Panel	0.2	0.33	0.20	3.00	0.50	1.23	4.03	10
21	Transformer	0.3	0.25	0.13	6.00	2.00	2.68	8.55	90

Legend:T_{P/S} = Preparation and secure timeT_{FI} = Fault isolation timeT_R = Repair in place timeT_{R/R} = Remove and replace timeT_{T/CO} = Test and checkout time

EMT-R = Elapsed maintenance time to repair in-place

EMT-R/R = Elapsed maintenance time to remove and replace

% R/R = Percent failures corrected by remove and replace action

and replaced (% R/R) versus repaired in place in the event of failure. Repair in-place is defined as replacement of detail parts, mechanical or electrical adjustments, structural or electrical repair, and similar actions not requiring removal of the component. The EMT-R and EMT-R/R is the summation of time to accomplish the task elements. Task elements include fault isolation, repair in-place or remove and replace (as appropriate), and test or checkout time subsequent to correcting the fault. An allowance for preparation and secure time is also included to account for obtaining required support equipment, travel time to and from the repair location, and any cleanup or storage of equipment subsequent to completing the maintenance action.

Table 5-8 presents the estimate of maintenance manhours to accomplish the remove/replace and repair in-place actions for each maintenance-significant component. An estimate of the time each labor classification is actively involved in the maintenance action is identified. Broad functional description of labor classifications have been used to identify requirements.

Table 5-9 presents the estimate of maintenance manhours per year for each functional labor classification. The predicted number of maintenance actions per year (MA/YR) is based on reliability estimates discussed in Section 4.2.12. Maintenance manhours per year are derived by multiplying the manhours per maintenance task shown in Table 5-8 by the MA/YR. The summation of the manhours per year for each labor classification provides the basis for estimating the overall manpower requirement, which is impacted by such factors as personnel use rates, crew standby requirements, maintenance queueing interface with other subsystems, and operational and maintenance policies.

Scheduled Maintenance

The scheduled maintenance actions for subsystem operating equipment consists of periodic cleaning of mirror surfaces to maintain required reflectivity, lubrication of elevation and azimuth drive units, and an annual inspection for damage and corrosion. Scheduled maintenance for maintenance support equipment includes test equipment calibration and servicing and load test recertification for handling and hoisting equipment. Tasks, frequency, time, and manpower requirements are identified in Table 5-10.

Table 5-8 (Page 1 of 3)

CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER MAINTENANCE TASK

Item	Component/Task	*EMT	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
1	Field Controller (F/C) Remove/Replace	1.36	1.36	1.36	1.36					
	Repair	0.66	0.66	0.66	0.66					
2	Heliostat Controller (H/C) Remove/Replace	1.10	1.10	1.10	1.10					
	Repair	0.53	0.53	0.53	0.53					
3	Azimuth Drive Assembly Remove/Replace	2.68	2.68	5.36		1.93	1.93	3.86		
4	Elevation Drive Assembly Remove/Replace	2.43	2.43	4.86		1.68	1.68	3.36		
5	Elevation Drive Motor and 1st- Stage Drive Remove/Replace	1.54	1.54	3.08						
6	Azimuth Drive Motor and 1st- Stage Drive Remove/Replace	2.15	2.15	4.30						
7	Elevation Shaft Encoder Remove/Replace	1.10	1.10	1.10						
8	Azimuth Shaft Encoder Remove/Replace	1.62	1.62	1.62						

*EMT = Elapsed Maintenance Time

Table 5-8 (Page 2 of 3)

CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER MAINTENANCE TASK

Item	Component/Task	*EMT	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
9	Elevation Shaft Turn Pickoff Remove/Replace	1.05	1.05	1.05						
10	Azimuth Shaft Turn Pickoff Remove/Replace	1.33	1.33	1.33						
11	Pedestal J-Box (with F/C) Remove/Replace	4.00	4.00	4.00						
	Repair	1.60	3.20							
12	Pedestal J-Box (with H/C) Remove/Replace	3.50	3.50	3.50						
	Repair	1.45	2.90							
13	Pedestal Remove/Replace	1.57	1.57	3.14	0.30	1.47	1.47	2.94		
	Repair	0.80		1.60						
14	Reflector Panel Remove/Replace	1.12	1.12	2.24		1.12		2.24		
15	Reflector Structure Remove/Replace	5.04	5.04	10.08		4.00		8.00		
	Repair	0.88		1.76						
16	Beam Sensor Remove/Replace	1.12	1.12	1.12	1.12					1.12

*EMT = Elapsed Maintenance Time

Table 5-8 (Page 3 of 3)

CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER MAINTENANCE TASK

Item	Component/Task	*EMT	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
17	Sensor Pole Remove/Replace	1.01	1.01	2.02	0.25		0.76			0.60
18	Pedestal Cables Remove/Replace	1.66	3.32							
	Repair	1.45	2.90							
19	Field Cables Remove/Replace	6.05	12.10	6.05					3.00	
	Repair	2.13	4.26							
20	Distribution Panel Remove/Replace	4.03	4.03	4.03			0.50			
	Repair	1.23	1.23	1.23						
21	Transformer Remove/Replace	8.55	8.55	12.60			2.00			
	Repair	2.68	2.68	2.68						

*EMT = Elapsed Maintenance Time

Table 5-9 (Page 1 of 3)
CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER YEAR

Item	Component/Task	*MA/YR	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
1	Field Controller (F/C)									
	Remove/Replace	1.89	2.6	2.6	2.6					
	Repair	0.21	0.1	0.1	0.1					
2	Heliostat Controller (H/C)									
	Remove/Replace	24.75	27.2	27.2	27.2					
	Repair	2.75	1.5	1.5	1.5					
3	Azimuth Drive Assembly									
	Remove/Replace	44	117.9	235.8		84.9	84.9	169.8		
4	Elevation Drive Assembly									
	Remove/Replace	44	106.9	213.8		73.9	73.9	147.8		
5	Elevation Drive Motor/1st-Stage Drive									
	Remove/Replace	71.6	110.3	220.6						
6	Azimuth Drive Motor/1st-Stage Drive									
	Remove/Replace	71.6	153.9	307.8						
7	Elevation Shaft Encoder									
	Remove/Replace	7	7.7	7.7						
8	Azimuth Shaft Encoder									
	Remove/Replace	7	11.3	11.3						

*MA/YR = Maintenance Actions per Year

Table 5-9 (Page 2 of 3)
CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER YEAR

Item	Component/Task	*MA/YR	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
9	Elevation Shaft Turn Pickoff Remove/Replace	7.8	8.2	8.2						
10	Azimuth Shaft Turn Pickoff Remove/Replace	7.8	10.4	10.4						
11	Pedestal J-Bcx (with F/C) Remove/Replace Repair	0.04 0.37	0.2 1.2	0.2						
12	Pedestal J-Bcx (with H/C) Remove/Replace Repair	1.00 9.00	3.5 26.1	3.5						
13	Pedestal Remove/Replace Repair	0.52 0.06	0.8	1.6 0.1	0.2	0.9	0.9	1.8		
14	Reflector Panel Remove/Replace	35.00	39.2	78.4		39.2		78.4		
15	Reflector Structure Remove/Replace Repair	1.45 1.45	7.3	14.6 2.6		5.8		11.6		
16	Beam Sensor Remove/Replace	3.00	3.4	3.4	3.4					3.4

Table 5-9. (Page 3 of 3)

CORRECTIVE MAINTENANCE
MAINTENANCE MANHOURS PER YEAR

Item	Component/Task	*MA/YR	Elect Tech	Mech Tech	Opt Tech	Crane Oper	Forklift Oper	Rigger	Trencher Oper	C-Picker Oper
17	Sensor Pole Remove/Replace	0.58	0.6	1.2	0.2		0.4			0.3
18	Pedestal Cables Remove/Replace	0.31	1.0							
	Repair	0.91	2.6							
19	Field Cables Remove/Replace	0.008	0.1	0.1					0.1	
	Repair	0.025	0.1							
20	Distribution Panel Remove/Replace	0.01	0.1	0.1			0.1			
	Repair	0.08	0.1	0.1						
21	Transformer Remove/Replace	0.018	0.2	0.2			0.1			
	Repair	0.002	0.1	0.1						
Totals		344	645	1,153	35	205	160	409	0.1	4

*MA/YR = Maintenance Actions per Year.

Table 5-10

SCHEDULED MAINTENANCE REQUIREMENTS

Component	System Quantity	Task	Frequency	Elapsed Time (Hr)	Manhours Per Task	Manhours Per Year
Subsystem Equipment						
Heliostat Reflectors	1,760	Clean	30 Days	*80	320	3,840
Heliostat Drive Units	3,520	Lubricate	Annual	117	117	117
Heliostat Assembly/Field	1,760	Inspect	Annual	88	88	88
Support Equipment						
Handling Sling, Mirror	2	Load certification	Annual	0.2	0.2	0.2
Test Support Station	2					
Printers, CRT/Keyboard Tape Reader, Recorder, Digital Eye System		Inspect and Service	30 Days	2	2	24
Multimeter, Oscilloscope, Digital Counter		Calibrate	6 Mo	6	6	12
						4,081

*All mirror surfaces in the entire heliostat field are chemically washed and rinsed with deionized water each month. Two crews of the 2 men each (using the support equipment described in Section 5.2.3.3) working 4 hr in the predawn and early morning hours, clean approximately 88 mirrors each day. This rate requires 20 working days or one calendar month to complete the total field.

Maintenance procedures are provided to accomplish these tasks as discussed in Section 3.2.3.5.

5.2.3.2 Spares Requirements

Spares and repair parts to support collector subsystem will be determined by analysis concurrent with hardware design release. The selection and quantity of items to be procured is based on the maintenance concept, predicted component failure rates, operational availability requirements, and repair cycle turnaround time. Spares and repair parts lists including quantities, unit cost, and procurement leadtime will be submitted for review and approval in sufficient time for procurement and on-site beginning 30 days prior to need dates. Ordering of system-peculiar spares (noncommercial items) will be made prior to completion of production runs to reduce acquisition costs.

Inventory control, warehousing, receipt and issuing of on-site spares and repair parts will be the responsibility of the site operator. MDAC-Huntington Beach will be responsible for these functions for off-site repair parts. Accountability and consumption reporting will meet customer requirements. In addition, MDAC will be responsible for accountability, tracking, control, and status reporting for all repairable items for which it is responsible.

A preliminary spares analysis has been conducted based on the current hardware design definition. Results of this analysis are presented in Table 5-11. Repairable items, upon failure, are removed from the system, placed in the repair cycle, and subsequently returned to spare stock inventory upon completion of repair. Component spare quantities are derived by determining the maximum number of items in the repair pipeline at any given time based on the failure rate and repair cycle time. A 30-day contingency supply, based on the failure rate, is added to the number of items in the repair pipeline to arrive at the total spares quantity required. The contingency supply accounts for a nonlinear failure rate and any unpredictable delays in the planned repair cycle process. The spares quantity of nonrepairable items (discard upon failure) is equal to the predicted number of failures during the time period.

Table 5-11
SPARES REQUIREMENTS

Component	Sys Qty	Failures Per Year	Repair Location	Repair Cycle (Days)	Pipeline Qty	30-Day Cont	Spares Qty
Field Controller (F/C)	74	2.1	MDAC	30	1	1	2
Heliostat Controller (H/C)	1,686	27.5	MDAC	30	3	3	6
Drive Motor, Azimuth and Elevation	3,520	23.2	MFG.	90	6	2	8
Input Reducer	3,520	120	MDAC	30	10	10	20
Drive Unit, Azimuth	1,760	44	MDAC	30	4	4	8
Drive Unit, Elevation	1,760	44	MDAC	30	4	4	8
Shaft Encoder	3,520	14	MFG.	90	4	1	5
Shaft Turn Pickoff	3,520	15.6	MDAC	30	2	2	4
Pedestal J-Box (F/C)	74	0.41	SITE	1	-	-	1
Pedestal J-Box (H/C)	1,686	10	SITE	1	-	-	1
Beam Sensor Unit	1,760	3	MDAC	30	1	1	2
Power Transformer	8	0.02	-	-	-	-	1
Power Distribution Panel	8	0.09	SITE	1	-	-	1
Reflector Panel	10,560	35	-	-	-	-	*70
Tracking Mirror	1,760	6	-	-	-	-	*12
Reflector Structure	1,760	2.9	SITE	1	-	-	1
Pedestal	1,760	0.58	SITE	1	-	-	1
Sensor Tower	1,760	0.58	SITE	1	-	-	1
Electrical Cable Set, Pedestal	1,760	1.22	SITE	1	-	-	1
Electrical Cable Set, Field	1	0.033	SITE	1	-	-	0
Collector Field Test Station	2	TBD	SITE	1	-	-	0
*2-yr Quantity							

Identification of line-item repair parts cannot be made at this time with any acceptable degree of confidence due to design definition. However, for planning purposes, repair parts costs can be approximated by multiplying the number of failures per year by 40% of the unit cost of the repairable item.

5.2.3.3 Maintenance Support Equipment

The following support equipment is required for corrective and scheduled maintenance tasks:

1. Mobile Workstand (Cherry Picker)	Beam Sensor Alignment
2. Mobile Crane	Heliostat Hoisting
3. Forklift	Miscellaneous Heavy Equipment Handling
4. Hoisting Slings - General Purpose	Heliostats and Miscellaneous Equipment Hoisting
5. Pickup Truck	General Purpose
6. Inclinator	Pedestal Leveling
7. Mobile Communications Set	Field Communications
8. Theodelite	Heliostat Alignment
9. Hoisting Sling, Heliostat Mirror	Mirror Panel Replacement
10. Pedestal Leveling Fixture	Pedestal Leveling
11. Reflector Washing Equipment	Heliostat Reflector Cleaning
12. Collector Field Test Station	Subsystem and Component Level Fault Isolation and Test

5.2.3.4 Facility Requirements

No facilities dedicated to collector subsystem maintenance are required. Indoor storage space is limited to that required for spare parts and minor maintenance support equipment items. Temperature or environmental conditioning is not a significant factor. Packaging and crating area requirements are minimal since no large items are sent off site for repair. Outside parking is adequate for all vehicles including the van that houses the collector field test station. Office space requirements for maintenance records and documentation can be integrated with similar requirements for other subsystems.

5.2.3.5 Maintenance Documentation

Documentation requirements for maintenance of collector subsystem components and support equipment will be satisfied by providing low-cost procedural instructions (see Figure 5-41).

Procedures will be prepared in consonance with the development of maintenance data analyses for subsystem logistics requirements. Maintenance data analyses will define collector subsystem requirements for scheduled and corrective maintenance, fault detection, inspection, alignment, adjustment, lubrication, repair, and spare parts. Simple, commercially acceptable methods will allow quick-reaction preparation and reproduction of drawings.

Procedures will be validated to the maximum possible extent during the installation and checkout phase at site. Technical data in maintenance procedures, such as diagrams, certain repair and fault isolation instructions, and preventive maintenance schedules, which cannot be validated, will be verified at meetings of MDAC and customer personnel. Final maintenance procedures will be updated, as required, to reflect equipment modifications and procedural improvements. To facilitate efficient and economical maintenance, MDAC will prepare and validate the collector subsystem maintenance procedures given in Table 5-12.

Safety requirements will be highlighted by appropriate "Cautions" and "Warnings" displayed in the procedures.

CSMP validation will be accomplished during installation and checkout on a noninterference basis and will be verified at meetings of MDAC and customer personnel.

5.2.3.6 Training Requirements

The subsystem support planning data developed for establishing an efficient maintenance program capability shall be the basis for the development of the training program. The planning data includes manpower, crew size, task, maintenance procedures, and personnel skills required to maintain the Pilot Plant system.

10-MW SOLAR THERMAL PILOT PLANT COLLECTOR SUBSYSTEM MAINTENANCE PROCEDURE				
TITLE: HELIOSTAT MAINTENANCE			DATE:	
TABLE OF CONTENTS		OK TO ISSUE:		
SHEET		(MANAGER – LOGISTICS SUP)		
		COORDINATION:		
		DEPT	NAME	
TITLE SHEET	1	(LOGISTICS SUPPORT)		
SHEET REVISION RECORD	2			
WASHING REFLECTIVE SURFACE	4	(ENGINEERING)		
LUBRICATION	5			
INSPECTION	8	(FIELD ENGINEERING)		
ALIGNMENT	10			
ADJUSTMENT	13			
CHECKOUT	15			
TROUBLESHOOTING	19			
DRIVE UNIT REMOVAL AND REPLACEMENT	21			
ELEVATION MOTOR AND FIRST STAGE DRIVE REMOVAL AND REPLACEMENT	23			
AZIMUTH MOTOR AND FIRST STAGE DRIVE REMOVAL AND REPLACEMENT	25			
SENSOR MIRROR REMOVAL AND REPLACEMENT	26			
REFLECTOR PANELS REMOVAL AND REPLACEMENT	26			
REFLECTOR/DRIVE UNIT REMOVAL AND REPLACEMENT	27			
PEDESTAL REMOVAL AND REPLACEMENT	27			
HELIOSTAT REMOVAL AND REPLACEMENT	28			
REMARKS: (NOTE PERTINENT INFORMATION SUCH AS EQUIPMENT DESIGN CHANGES, MAINTENANCE ADDITIONS OR DELETIONS, ETC)				
MCDONNELL DOUGLAS AERONAUTICS CO. <small>HUNTINGTON BEACH, CALIF.</small> MCDONNELL DOUGLAS		SIZE <div style="font-size: 2em; font-weight: bold;">A</div>	CODE IDENT NO. <div style="font-size: 2em; font-weight: bold;">18355</div>	DRAWING NO. MDAC-CSMP-02
		SCALE	REV New	SHEET 1

60-0213-1A02 (08 AUG 71)

Figure 5-41. Sample Maintenance Procedure (Sheet 1 of 3)

SHEET REVISION RECORD																	
SHEET NO.	REVISION																
1	NEW																
2	NEW																
3	NEW																
4	NEW																
5	NEW																
6	NEW																
7	NEW																
8	NEW																
9	NEW																
10	NEW																
11	NEW																
12	NEW																
13	NEW																
14	NEW																
15	NEW																
16	NEW																
17	NEW																
18	NEW																
19	NEW																
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MCDONNELL DOUGLAS ASTRONAUTICS CO.
HUNTINGTON BEACH, CALIF.

MCDONNELL DOUGLAS

SIZE
A

CODE IDENT NO.
18355

DRAWING NO.
MDAC-CSMP-02

SCALE

REV New

SHEET 2

60 0213-1A19 (01 DEC 71)

Figure 5-41. Sample Maintenance Procedure (Sheet 2 of 3)

HELIOSTAT REMOVAL

1. TOOLS, MATERIALS, AND EQUIPMENT REQUIRED:

PART NO.	NOMENCLATURE/DESCRIPTION	QTY
JD380	FORKLIFT, 2-TON CAPACITY (MIN)	1
1DXXXXX	FIXTURE, HELIOSTAT HANDLING	1

2. PRELIMINARY REQUIREMENTS

2. VERIFY LOAD/TEST RECERTIFICATION REQUIREMENTS OF HELIOSTAT HANDLING FIXTURE AND FORKLIFT ARE CURRENT

3. INSTALL HANDLING FIXTURE ON FORKLIFT

3.1 VERIFY/REMOVE FORKS FROM FORKLIFT

3.2 DRIVE FORKLIFT INTO POSITION FOR INSTALLING HANDLING FIXTURE

WARNING

HANDLING FIXTURE WEIGHS APPROXIMATELY 250 POUNDS. DO NOT LIFT FIXTURE MANUALLY

3.3 MOUNT HANDLING FIXTURE BY ENGAGING ADAPTER HOOKS ONTO SURFACE OF FORKLIFT WHERE FORKS WERE NORMALLY INSTALLED

4. DRIVE FORKLIFT TO HELIOSTAT LOCATION WITH FIXTURE IN LOWERED POSITION

5. INSTALL HANDLING FIXTURE ON HELIOSTAT

5.1 POSITION HANDLING FIXTURE BELOW 28-INCH SLOT IN REFLECTOR SURFACE WITH SADDLE APPROXIMATELY ONE FOOT FROM PEDESTAL

5.2 RAISE HANDLING FIXTURE TO HEIGHT REQUIRED TO INSTALL SLING, AND MOVE FORWARD UNTIL SADDLE CONTACTS PEDESTAL

5.3 INSTALL SLING AROUND MIRROR SUPPORT TUBE AND ONTO HOOK

5.4 RAISE FIXTURE UNTIL SLING IS TAUT

5.5 SECURE SADDLE TO PEDESTAL WITH STRAP

5.6 ADJUST FEET OF ROTATION RESTRAINTS UNTIL SECURE AGAINST MIRROR SUPPORT TUBE

6. REMOVE NUTS FROM ANCHOR BOLTS

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SIZE

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CODE IDENT NO.

18355

DRAWING NO.

MDAC-CSMP-02

SCALE

REV New

SHEET 3

60 0213 1A03 (06 AUG 71)

Figure 5-41. Sample Maintenance Procedure (Sheet 3 of 3)

Table 5-12 (Page 1 of 2)

COLLECTOR SUBSYSTEM MAINTENANCE PROCEDURES

Number	Title/Description
MDAC-CSMP-01	<p>Periodic Maintenance Requirements</p> <p>Provide tabular listings of periodic maintenance requirements for heliostat, sensor/sensor pole, special support equipment, special test equipment, and overall subsystem.</p>
MDAC-CSMP-02	<p>Heliostat Maintenance</p> <p>Provide instructions for the following:</p> <ol style="list-style-type: none"> 1. Wash reflective surface 2. Lube elevation and azimuth drives 3. Align 4. Adjust 5. Inspect 6. Checkout 7. Troubleshoot 8. Remove and replace drive unit assembly, elevation motor and first-stage drive, azimuth drive motor and first-stage drive, sensor mirror, reflector panels, reflector/drive unit, and pedestal, and complete heliostat.
MDAC-CSMP-03	<p>Sensor and Sensor Pole Maintenance</p> <p>Provide instructions for aligning beam sensor assembly, removing and replacing beam sensor assembly, and removing and replacing sensor pole including leveling.</p>
MDAC-CSMP-04	<p>Heliostat Adjustment and Sensor Alignment</p> <p>Provide procedures for positioning, adjusting, and setting components of heliostat, and initiating heliostat tracking, and locking sensor.</p>
MDAC-CSMP-05	<p>Field and Heliostat Controller Maintenance</p> <p>Provide instructions for troubleshooting controllers to removal and replacement of components (as spared); and instructions for removal and replacement of controllers.</p>
MDAC-CSMP-06	<p>Special Support Equipment Maintenance*</p> <p>Provide instructions for lubrication, adjustment, proof-load testing, and component removal and replacement as defined by maintenance analyses for pedestal lifting sling, mirror panel sling, and heliostat handling fixture.</p>

Table 5-12 (Page 2 of 2)

COLLECTOR SUBSYSTEM MAINTENANCE PROCEDURES

Number	Title/Description
MDAC-CSMP-07	<p>Special Test Equipment Maintenance*</p> <p>Provide instructions for test, adjustment, calibration, and component removal and replacement as defined by maintenance analyses for field controller test set.</p>
MDAC-CSMP-08	<p>Collector Subsystem Tests</p> <p>Provide instructions for periodic subsystem tests, single heliostat, and cell of heliostats (24). Refer to available engineering drawings for cabling, wiring, logic, and functional diagrams.</p>

*It is assumed that vendor data are available and adequate for common and commercial equipment. Procedural coverage is not planned.

This data when evaluated and compared with the existing capability of personnel assigned to the pilot plant system shall determine the type and depth of training provided.

The training program shall be time-phased to operational requirements to within 3 mo of actual personnel assignment to maintenance activities.

Although constrained by current hardware configuration definition, the following training courses for the collector subsystem have been tentatively identified:

- A. Reflector repair and handling.
- B. Heliostat removal and replacement.
- C. Heliostat alignment.
- D. Heliostat handling and transportation.
- E. Sensor removal and replacement.
- F. Field controller repair.

The primary method of presentation will be on-the-job or on-equipment training and will consist of approximately 25% classroom lecture or discussion and 75% on-equipment using the actual operational procedures for training. On-equipment will be directly supervised by a knowledgeable training engineer to prevent possible damage to operational equipment.

5.3 TEST PLANS

5.3.1 Development and Qualification Tests

5.3.1.1 Development Tests

MDAC does not envision any development testing in Phase 2. Extensive development testing has been accomplished in the SRE Program as follows (see Sections 4.2, 6.3, 6.4).

- Reflective Surface
 - Mirror-silvering, glass chemistry (iron content), reflectivity, salt spray, ultraviolet.
 - Panel-performance environmental exposure, backlighting, thermal cycling, deflection, compatibility, creep, strength.
- Reflector Cleaning. Washing and rinsing solution, application methods, fluid quantities, effect of stowage.
- Supporting Structure. Finishes, joints.
- Drive Unit. Compliance, efficiency, backlash, lifetime, bearing materials.
- Pedestal/Foundations. Strength, deflection.
- Beam Sensor. Signal linearity, stability, low-level insolation.
- Field Controller. Algorithms, stability limits, control gains.
- Collector System. Tracking accuracy, beam stability, beam dispersion, flux distribution, vibration modes, structural test.

5.3.1.2 Qualification Tests

MDAC has qualified all of the hardware in the Preliminary Design configuration except for:

- Qualification of the production packaged controllers.
- Qualification of the spot-welding of the structural cross beams to the torque tube fittings.

Successful qualification testing has been accomplished in the SRE program as follows (see Section 6.3, 6.4):

- Environmental.
 - Drive unit, beam sensor, control sensors: high and low temperatures (-30°C to 60°C), rain, icing, blowing dust.

- Reflectors (foam core and laminate): hail to 19 mm in operating position and 25 mm in stowed position. High and low temperatures, salt spray, ultraviolet, compatibility, rain, snow, frost.
- Structural. Collector deflection characteristics under operating conditions, strength and deflections under survival conditions. Vibration modes and frequencies exceed specifications.
- Life Tests
 - Drive units (orbidrive, harmonic, jacks), all subjected to accelerated 30-yr life tests.
- Performance
 - Tracks sun with an error of less than 1 mr at normal solar insolation.
 - Beam irradiance and distribution within 2% estimated values.

5.3.2 Acceptance Inspection and Test

Figure 5-42 portrays the flow of fabrication and assembly operations and related inspection and test points. The list of inspection operations precede the flow chart to which they relate so that the flow chart can be unfolded and the coded inspections and tests readily cross-referenced to the Significant Control Points (SCPs) identified in the hardware flow. SCP numbers precede each major inspection and test operation. These same SCP numbers are included in small circles located at appropriate points in the master flow chart. The inspection flow SCPs are numbered as follows:

- Q1 to 10 Panel Assembly
- Q11 to 20 Tracking Mirror
- Q21 to 30 Orbidrive Assembly
- Q31 to 40 Heliostat field control unit (Electronics)
- Q41 to 50 Sensor/Pole Assembly
- Q51 to 60 Support Structure Assembly
- Q71 to 80 Field Site Assembly Building Control

Quality control points are indicated in the chart (Figure 5-42) for inspection and test activities that have been planned. Following is a brief discussion of some of the more significant of the points and the principal controls to be applied. Only significant points are highlighted, but all collector subsystem hardware is subject to MDAC receiving and in-process inspection and control. The Quality Assurance Plan is discussed in Section 5.1.3.

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Figure 5-42. Collector Subsystem Significant Inspection Control Points

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5.3.2.1 Panel Assembly

Two quality control points are of principal concern. At Q1 in Figure 5-42 we control the mirror to be installed. Since the glass and mirror are sub-contracted, control is exercised by the suppliers. They are responsible to assure control in four primary characteristics: glass chemistry, reflectant efficiency, thickness, and flatness. A source survey will establish the supplier's ability to maintain this control. MDAC source inspection will be used initially and then reduced as warranted. Documented certification with each shipment will indicate continued conformance to requirements. Receiving inspection at MDAC's manufacturing facility will be for identification and shipping damage and to verify certification.

At Q6 and Q7 in the flow chart are control points in the assembly of the reflective panels. The essential requirements to be met and verified at this point are for bond integrity and flatness in the assembly, and attach cup positioning.

A. Bond integrity is controlled by:

1. Assuring adequate and constant application of adhesive over the surface.
2. Controlling time taken in applying adhesive.
3. Measuring shore hardness of coupons prepared as adhesive is applied.
4. Verifying that panel edges are sealed and that no adhesive is left on the mirror surface.

B. Flatness is controlled by:

1. Levelling the tables used to support the assembly. This will be verified on a scheduled basis to maintain tool control.
2. Proving the adequacy of the adhesive application and table flatness on a first article from each table and on a sampling basis thereafter to verify that the process remains in control.

C. Attach cup positioning is controlled by:

1. The attach cup's positioning are a critical and key element with respect to the flat mirror surface. A tooling fixture designed to specifically control the location of the attach cups for installation.

2. A first-article inspection will prove the tool with sample inspection scheduled to verify continued fixture control.

5.3.2.2 Tracking Mirror

At Q11 in the flow diagram we indicate control of the procured tracking mirror. This is essentially the same as the control indicated in Section 5.3.3.1 (Q1) for the main panel mirrors. Stud assemblies are bonded to the glass with bond integrity maintained as indicated in Section 5.3.3.1 (Q6).

At Q12, a final inspection verifies readiness of the tracking reflector assembly to ship to the field site.

The plane of the tracking mirror, when finally mounted and installed, must be parallel with the plane of the main panel mirrors. To achieve this, the planes are leveled in the assembly building at the field site.

5.3.2.3 Orbidrive Assembly (Elevation and Azimuth)

Failure mode and effect analysis (Section 4.2.12) indicate primary and secondary drive systems have the largest potential failure rate. Greater significance is assigned to the primary drive, because of its smaller size bearings and expected higher contact stress on the lobe interface rollers.

At Q21 in the flow chart (Figure 5-42), the supplier control approach is indicated. A source survey will establish the degree of MDAC source inspection, based on the supplier's quality system with particular attention to its control of critical characteristics. Controls required of the supplier will include: (1) material and process controls verifying conformance to specifications, (2) precision inspection of machined parts, made or procured, and (3) documented evidence with each shipment indicating conformance. Receiving inspection at MDAC's manufacturing facility will verify this certification, confirm identity, and check for shipping damage.

At Q22, in the flow chart we indicate controls for the housings and base castings to be procured from a supplier. A first article of each casting will be evaluated to assure:

- A. That the geometry of the casting is such that MDAC can achieve the required finished dimensions upon machining.
- B. That the chemical and metallurgical properties are as specified and that the casting is sound.

On this basis, pattern, core, and foundry practices are approved. With these established, each lot will be identified by heat number and accompanied with associated analytical reports (i. e. , penetrant and chemical) or by certificate of conformance.

At Q24 through Q27, standard quality control for numerically controlled machine applications will apply, including precision inspection to prove tape control and sampling inspection thereafter.

At Q28, critical assembly of azimuth housing to base interface is verified for measurement of assembly dimensions for spacer adjustment (shimming) requirements.

At Q29, the elevation and azimuth drive units are functionally tested before assembly into the orbdrive configuration.

5.3.2.4 Heliostat/Field Electronic Controller

Failure mode and effect analysis (Section 4.2.12) indicates that the heliostat electronics have the second most critical potential failure rate.

At Q31 through Q38 we will apply standard practices for electronic circuit board and panel assemblies.

At Q39 all electronic panel assemblies will be subjected to burn-in for a period established by design in order to screen out infant mortality of components. The units then go through 100% functional acceptance test. Failed units will be analyzed and any faulty components replaced before retest.

5.3.2.5 Sensor Assembly

At Q42 in the flow chart (Figure 5-42), we control the manufacture of the sensor assembly. The hybrid thick film circuit board and connector are purchased off-the-shelf, assembled, and given a preliminary test. Following the red glass silk-screened image process, all components are packaged, housed, hermetically sealed in a nitrogen atmosphere, and verified.

At Q43, after the ambient epoxy cure process is completed and verified, the sensor assembly is subjected to final functional acceptance test.

At Q44, the final assembly and checkout of the sensor pole assembly takes place at the field site "in position" location.

5.3.2.6 Reflector Support Structure

At Q51, the significant characteristics of the structure are the thickness of the torque tube wall and its straightness, flatness of cross beams, location of the fittings, and quality of the spot weld. These items are subcontracted and assembled in the assembly building at the field site. Their individual characteristics are controlled at source. Source survey and first-article inspection and receiving inspection will verify this control. Control of assembly operation is covered in Section 5.3.3.8.

5.3.2.7 Pedestal Assembly

The significant characteristics of the pedestal assembly will be controlled by the supplier who is to fabricate this end item. MDAC will perform a source survey and witness first-article inspection to establish control.

At Q61, in the flow chart (Figure 5-42), the significant characteristics to be verified by the supplier are: (1) tube wall thickness and straightness are as specified, (2) end plates are positioned such that they are perpendicular to tube centerline (parallel), and (3) the end plates are drilled and tapped holes aligned, so as to interface furnished tools simulating the base. These characteristics will be verified at the supplier by detail inspection on the first unit, followed by sample inspection. Control of assembly operation is discussed in Section 5.3.3.8.

5.3.2.8 Quality Control in the Assembly Building

Throughout this plan the emphasis has been on supplier control and MDAC fabrication control. The purpose was to assure that collector details and subassemblies arriving at Barstow would in all respects be ready for final assembly and checkout (see Section 5.2). With the exception of the first-article inspection identified below, Quality Control will perform a continuous audit of the final assembly operations and of the installation and checkout operations (Section 5.2). The quality engineer assigned the audit task will have the responsibility to assure that manufacturing procedures are followed in the manner and sequence that they were planned. It is considered that this is a significantly cost-effective approach to a quality collector system.

First-article verification to prove the tooling are:

- A. At Q52 in Figure 5-42, MDAC will control the assembly of the reflector support structure operation.

The weld fixture verifies the straightness of the torque tube. Cross beam flatness will have been verified at the vendor prior to shipment to the field. The weld fixture locates the torque tube, cross beams, and fittings for spot welding.

Spot-weld control is accomplished by automatic weld schedules which control amperage, pressure, and time, and by specified periodic destructive tests of spot-weld samples (coupons) which simulate the welds in material thickness and type.

A first-article inspection of the first completed structure assembly proves the capability of the weld fixture tool.

- B. All other assembly operations are accomplished procedurally and will be audited as described above.

5.3.2.9 Acceptance

See Section 5.2.1 for installation and checkout (acceptance) of the collector.

Section 6

SUBSYSTEMS RESEARCH EXPERIMENTS

The mission for the Collector Subsystem Research Experiment (SRE) was to provide the necessary subsystem research and test data to assure that the collector subsystem elements can eventually be produced, installed, and operated in a cost-effective manner. To fulfill the mission, subsystem hardware was produced, installed, and operated that is representative in design and performance of that planned for the Pilot Plant. All major Pilot Plant subsystem design and performance requirements were verified.

This section presents the MDAC approach to demonstrate that the Pilot Plant baseline design will meet Pilot Plant requirements. A summary of the requirements and the verification method is given in Section 6.1. The SRE hardware is described in Section 6.2. The assembly, subassembly, and component-level tests are described in Section 6.3. The subsystem level heliostat array tests are described in Section 6.4.

6.1 VERIFICATION ANALYSIS

Resolution of the technical, schedule, and cost issues associated with the collector subsystem involves several approaches, including SRE tests, analysis, conservative design, use of industrial data for selected components, and supporting technology data. The application of these methods to verify the preliminary design requirements for the collector subsystem of the Pilot Plant lead directly to the SRE test program. Each part of the subsystem and the associated requirements were used to establish the methods by which compliance with requirements is verified. The verification analysis is contained in CDRL3, the MDAC Collector Conceptual Design Report.

The SRE tests identified by the verification analysis consisted of two basic types of tests, laboratory and field (or array) tests. Laboratory tests were used to verify structural functional requirements for deflection, strength,

and frequency; to verify reflector pointing accuracy and aerodynamic stability; to qualify the critical controls components and the reflective surface; to demonstrate control and structural life time, and to confirm analytical results. The field tests were used mainly to verify total collector subsystem requirements and to provide a working check on the chosen baseline design. A brief discussion of SRE test requirements follows:

- A. Collector Subsystem. Verify collector operational integrity. Verify collector modes, including sun tracking, emergency defocus, startup and shutdown, and stowage. Verify external interfaces. Verify shading and blocking relationships.
- B. Heliostat Assembly. Verify beam positioning and flux pattern. Verify strength, operational deflection, modal frequencies, and damping characteristics.
- C. Reflective Surface. Verify reflectivity, environmental survival, maintainability, and structural integrity.
- D. Structural Support. Verify operational deflections, survival strength and transportation/handling procedures.
- E. Drive Unit. Verify performance, reliability, strength, durability, and severe environment performance.
- F. Pedestal/Foundation. Verify survival strength and foundation stability.
- G. Beam Sensor Pedestal. Verify operational deflections, frequencies, and damping characteristics.
- H. Simulated Master Control. Verify the sun acquisition algorithm, synthetic track algorithm, and the field controller/master control interface logic and software.
- I. Field Controller. Verify the field controller software algorithm for normal track. This includes inputting data from the heliostat sensors, solving the transformation equations to determine motor drive requirements and outputting motor drive commands. Verify the field controller software algorithms for switching to/from synthetic track, for tracking through singularities, for emergency defocus, and for stowage. Verify compatibility of the field controller hardware with the heliostat drive motors and sensors. Verify the hardware and software for multiple heliostat control and operation through the full range of solar insolation. Determine the power required for each operation.

- J. Control Sensors. Verify beam sensor alignment techniques. Verify sensor performance and compatibility of sensor circuitry and the drive motors with the field controller circuitry. Verify beam sensor integrity in severe environments. Verify placement and operation of limit switches and position potentiometers.

6.2 SRE HARDWARE DESIGN AND FABRICATION

To support the SRE program, MDAC has designed, fabricated, and tested five complete heliostats of a noninverting, octagonal design; two heliostats of an inverting, rectangular design; a field controller capable of simultaneous control of five heliostats; a simulated master control; support and test equipment; and components for lower-level tests.

6.2.1 Summary of SRE Hardware

The heliostats fabricated and their use in the various experiments is shown in Table 6-1. The designations H1 through H6 refer to the noninverting octagonal heliostats. H5 is an incomplete heliostat, consisting of a reflector and drive unit mounted on a trailer for mobile tests at key field positions.

The designations IH1 and IH2 refer to the inverting, rectangular design. Variation 1 (for IH1) has a laminated glass reflector. Variation 2 (for IH1) has a laminated glass reflector on one side and a foam core reflector on the other side for testing of both configurations in the field. Similarly, IH2 employs both types of reflector for structural tests.

One field controller capable of controlling five heliostats simultaneously was constructed and installed in a mobile van. The van also contains a simulated master control in a NOVA 1200 computer, as well as various test and diagnostic equipment.

Heliostat array test hardware is discussed in Section 6.4.

Table 6-1
HELIOSTAT HARDWARE FABRICATED FOR SRE

Heliostat	Reflector	Test
● Noninverting Octagonal		
H1	First Surface	Structural Test Array Test
H2	First Surface	Controls Development Test Array Test
H3	First Surface	Array Test
H4	Laminated	Array Test
H5	Laminated	Mobile Array Test
H6	Laminated	Drive Unit Life Test
● Inverting Orthogonal		
IH 1, Variation 1	Laminated	Controls Development Test Array Test
IH 1, Variation 2	1/2 Laminated 1/2 Foam Core	Array Test
IH 2	1/2 Laminated 1/2 Foam Core	Structural Test

6.2.2 Noninverting Octagonal Heliostat

6.2.2.1 Configuration

The octagonal heliostat assembly consists of an octagonal mirror supported by radial beams which tie into a hub. The mirror substructure and hub are rotated by a drive unit. The assembly is supported by a conical pedestal and a reinforced concrete slab foundation. A typical octagonal heliostat at Naval Weapons Center is shown in Figure 6-1. The mirror image shows the backside of an adjacent octagonal heliostat.

6.2.2.2 Reflector

The reflective surface in the octagonal heliostat consisted of two types: first surface mirror with acrylic coating and laminated mirror. The base for the first surface mirror is 6.35 mm (1/4 in.) commercial float glass. The

Figure 6-1. Octagonal Heliostat

glass may have an iron content, and need not be free of cosmetic defects. Hence, the basic glass should be cheaper than the selected glass used for second surface mirrors. Defects which affect the long-term strength of the glass should be avoided.

The silver should be laid down in an about 800 Å thickness layer to provide optimum reflectance. A primer coating of a base polymer 5 micron (0.2 mil) thick is laid over the silver and cured. Then a top polymer coating 26 micron (1.0 mil) thick is laid on and cured.

The resulting coating has a high reflectivity (about 0.90) and a high degree of specularity. As the coating is to be applied in a commercial silvering facility, the result should be an excellent representation of the Pilot Plant and commercial reflective surface as presently defined. The coating applied represents commercial standards.

Laminated reflectors were also tested in the SRE octagonal heliostats. The first configuration was a 1/8-in. float glass second surface mirror laminated with polyvinyl butyral (PVB) to another 1/8-in. float glass (Figure 6-2). There are also thin layers of copper and mirror backing paint. A second laminated configuration used 3/32 in. plus 3/16 in. float glass. This laminate used a white acrylic backing paint.

In general, laminated mirrors are rugged but have the disadvantages of higher cost, nonflatness and susceptibility to backlighting. In the SRE tests, the laminated mirrors have generally performed better than the first surface mirror (whose acrylic coating was not durable in the desert environments encountered). (See Section 4.2.2 for a more detailed comparison between the laminated and foam sandwich mirrors, and Section 6.3.3.2 for detailed descriptions of the first surface and second surface mirror investigations.)

6.2.2.3 Reflector Support Structure

Specific Design Requirements/Loads

In addition to satisfying the survival environments for strength, the reflector support structural stiffness should satisfy the following mirror surface

Figure 6-2. Typical Laminated Second Surface Mirror

functional requirement: the maximum local rotation of the mirror surface shall not exceed 3.0 mr (0.17°) under the combined operational wind, temperature, and gravity loading; and 2.0 mr (0.11°) under the combined operational wind and temperature environments. Internal loads used for the stress analysis of various components were generated directly by NASTRAN.

Hardware Description

The SRE units use a reflector hub assembly which simulates the Pilot Plant design and a reflector segment design which is identical to the Pilot Plant design exception for detail design of the inboard attach fittings.

In the hub assembly, the deep drawn upper and lower shells are simulated by spot-welded sheet and angle assemblies which essentially duplicate the Pilot Plant design (Figure 6-3). The upper and lower face sheets are cut circular from sheet and stiffened by angle stiffeners rather than by formed beads. The outer cylindrical shell and the cross channels are formed from flat sheet. The upper and lower rings are made from structural angles and machined after assembly to the required dimensions. The internal support fittings and the outer support fittings are machined from bar stock. The lower skin, outer cylindrical shell, cross channels, lower ring, angle stiffeners, and internal fittings are assembled and joined by spot welding. The upper skin, upper ring and angle stiffeners are assembled as a unit, then joined to the lower assembly. The final assembly of the hub is made by joining the upper skin to the cross channels by means of rosette welds or rivets. Fusion welding attaches the upper ring to the cylinder. After assembly, the outer cylindrical surface of the rings is machined circular and perpendicular to the machined top surface. The key slot is machined parallel with the upper surface to provide accurate alignment for the reflector segments which bolt to the hub in field assembly. The attachment holes for the segments are drilled for an interchangeable clearance fit with respect to the segment hole pattern. Components of the hub assembly are shown in Figure 6-4.

The SRE assembly is the same as the Pilot Plant except for the beam attach fittings which are made from welded angle and bar stock to avoid the lead-time required for a forging (Figures 6-5 and 6-6). The ends of the fittings

Figure 6-3. SRE Reflector Hub Assembly

6-10

Figure 6-4. Reflector Hub Assembly

Figure 6-5. Reflector Segment

SRE REFLECTOR SEGMENT ATTACH FITTING

Figure 6-6. SRE Reflector Segment Attach Fitting

must be machined perpendicular to the reflector surface and the index pins installed parallel to the reflector surface. The attach holes are located for interchangeable clearance fit with respect to the hub assembly. The frame assembly is assembled flat within 1.52 mm (0.060 in.) to control bond thickness between the glass reflector and support structure. Plastic spacers are used between the steel frame and the glass plate to limit the minimum bond line thickness to 1.27 mm (0.050 in.).

Structural Analysis Results

The stress analysis results for the reflector support structure and hub are summarized in Tables 6-2 and 6-3. All applied loads and stresses were computed by NASTRAN. The margin of safety (MS) is defined as:

$$MS = \frac{\text{Allowable working stress}}{\text{Applied stress}} - 1.0$$

The critical load condition for strength calculations was the survival wind condition of 46.5 m/s (104 mph) at an angle of attack of 0.175 radian (10°). The maximum local mirror slope is less than 3.0 mr functional requirement.

6.2.2.4 Drive Unit

Each octagonal heliostat incorporates a drive unit which produces appropriate reflector motions for solar tracking, emergency slewing and routine reflector positionings. The following paragraphs summarize the drive unit requirements, hardware, and strength analysis.

Requirements

Performance requirements for the SRE octagonal heliostat drive unit are summarized in Table 6-4. The travel requirements of Table 6-4 were obtained from computer simulations of tracking motions. The Pilot Plant field layout and the baseline altitude/azimuth rotational axes were modeled in a digital computer simulation for a representative latitude (35 deg north) and over a range of seasonal conditions to determine drive unit angular deflection and rate requirements for tracking. These simulations indicate that the drive unit elevation axis must be capable of rotating from 0 deg (reflector horizontal) to 76.3 deg, and the azimuth axis must be capable of a full 360 deg of rotation to permit tracking when the sun is 10 deg or more

Table 6-2

STRUCTURAL ANALYSIS RESULTS: REFLECTOR SUPPORT ASSEMBLY, SURVIVAL WIND CONDITION

Component	Maximum Stress (psi) or Load	Allowable Stress (psi) or Load	Margin of Safety
Radial Beams			
Bending at Root	15,120	22,000	0.45
Flange Buckling at Root	15,120	>22,000	0.45
Web Buckling at End of Fitting (Post-Buckling Strength)	15,095	22,000	0.46
Lateral Instability (Bending Moment)	32,230 in. -lb	55,460 in. -lb	0.72
Attachment Fitting to Hub			
Spot Welds	356 lb	805 lb	1.26
Fillet Welds	4,626 lb	8,149 lb	0.76
Outer-Rim Square Tube	6,190	22,000	2.55
Clip Bending	15,390	22,000	0.43
Cross Beam	2,274	22,000	High
Short Beam Near Hub	9,590	22,000	1.29
Spot Welds Between Cross Beam and Radial Beam	586 lb	805 lb	0.37
Adhesive Bond	35.9 (Shear)	100	1.79
Glass	1,090	3,000	1.75

Table 6-3

STRUCTURAL ANALYSIS RESULTS: HUB ASSEMBLY, SURVIVAL WIND CONDITION

Component	Maximum Stress (psi)	Allowable Stress (psi)	Margin of Safety
Outer Rim	Axial + Bending 8,500	22,000	1.59
Peripheral Enclosure	Normal Shear 3,500 3,000	10,200 12,700	1.16
Cross Beam Web	Shear 6,970	14,400	1.07
Cross Beam Flange	Axial 8,460	22,000	1.60
Radial Stiffeners	Axial + Bending 4,200	22,000	4.24
Top and Bottom Enclosures	Compression 5,000	6,800	0.36

Table 6-4
DRIVE TRAIN REQUIREMENTS

	Azimuth	Elevation
Travel	± 225 deg	0 deg (horizontal) to 76.3 deg
Rate	5 deg/min	5 deg/min
Static load	5,300 Nm (47,000 in. -lb) while stowing in elevation	24,000 Nm (212,000 in. -lb, or 7,300 lb actuator load) horizontal stowage
Dynamic load	4,300 Nm (38,000 in. -lb)	10,500 Nm (93,000 in. -lb, or 3,200 lb actuator load) during stowage
<ul style="list-style-type: none"> • Design for cost-effective maintenance/replacement over 30-yr heliostat life. • Reflector shall remain in stowed position with power removed. 		

above the horizon. Implicit in the above requirements is the assumption that all drive units will be alike, and that each must therefore be capable of satisfying the deflection scenario for the entire field.

The heliostat deflection rate requirements specified in Table 6-4 are derived from defocus and stowage objectives. Computer simulations indicate that azimuth and elevation tracking rates throughout the field will not exceed 0.26 rad (15 deg) per hour except in a narrow singularity band in the southern portion of the field. The heliostats within this band will experience a temporary degradation of tracking accuracy while driving near singularities, but will regain their normal tracking accuracy within a few minutes after the high azimuth rate demand has subsided. The maximum azimuth drive rate requirement of 0.0872 rad (5 deg) per minute represents a compromise value providing a reasonably short time for slewing through poles, defocusing, hail storm positioning, and heliostat alignment for startup and routine maintenance positioning. The present elevation maximum rate requirement of 0.0872 rad (5 deg) per minute results from the need to slew to the horizontal position within 15 min in anticipation of high winds.

Drive unit torque requirements results primarily from aerodynamic and gravitational loading of the heliostat's movable reflector/substrate. Table 6-4 summarizes the azimuth and elevation static and dynamic torque requirements for the noted combinations of worst-case conditions.

The drive trains must be capable of reacting the static loads shown and must be able to position the reflective surface while exposed to the indicated dynamic loads. The maximum azimuth static load occurs after the wind velocity has exceeded the stowage initiation threshold of 17.9 m/s (40 mph). With the peak gust velocity envelope increasing at 0.58 m/s (1.3 mph) per minute, the reflective surface moves from a high initial elevation angle toward stowage, and the maximum azimuth static torque occurs at a critical combination of wind velocity, elevation angle, and yaw angle of attack. In contrast, the maximum elevation drive static load occurs after the reflector has come to rest in the stowed position. The wind velocity increases to the maximum design velocity including gusts of 46.5 m/s (104 mph), which in conjunction with an induced angle of attack of 0.175 rad (10 deg) produces the indicated elevation drive static load.

The specified azimuth dynamic load occurs at the 17.9 m/s (40 mph) maximum wind velocity under which solar tracking takes place. A combination of maximum reflector elevation angle and critical yaw angle of attack produces the indicated azimuth dynamic load. The maximum elevation dynamic load occurs after the wind velocity exceeds the threshold for stowage. The reflector, moving from an initial high elevation angle toward stowage, passes through a critical combination of wind velocity and angle of attack resulting in the indicated elevation dynamic load.

An MDAC-generated requirement that the reflector remain stowed with the power removed derives from a concern that aerodynamic loads are destabilizing; that is, they tend to produce higher attack angles, which produce higher loads. Thus, failure to impose this design constraint could result in catastrophic structural failures.

Hardware Description

Each heliostat incorporates azimuth and elevation drive mechanisms to produce movement of the reflective surface about its axes of rotation. The drive mechanisms are composed of motors, drive trains, position feedback transducers, limit switches, reflector-support bearings, and structural housings. The azimuth drive train is shown schematically in Figure 6-7. The input 230V, 3-phase, 42-frame, 4-pole AC torque motor drives an integral 30:1 gearhead, whose output shaft is coupled to a 15:1 worm reduction.

The worm reduction in turn is connected to the wave generator of a 242:1 harmonic drive, whose output produces reflector motion about the azimuth axis. Motor and reflector inertias, distributed drive train backlash, and compliance are represented schematically as lumped parameters for convenience. The worm gear reduction is required with the pulsed AC drive scheme to prevent dithering of the drive train under high external loads.

Figure 6-8 shows a schematic representation of the elevation drive train, which employs the same motor-gearhead as the azimuth train in the interest of commonality. The motor gearhead is attached to a linear screw jack having a 6:1 worm input and an output reduction through the acme-type screw of 9.52 mm (0.375 in.) per revolution. The antibackdrive nature of the screw jack is required with the pulsed AC input to avoid drive drain dithering and excessive power consumption under high external loads. In addition, the screw jack is capable of holding the reflector in the stowed position with power removed, provided that the aerodynamically induced vibration environment is not excessive. Planned testing will help to determine whether a supplemental elevation actuator lock will be required to achieve the MDAC-imposed objective of benign stowage with power removed. The transition from schematic to mechanical representation of the drive unit is facilitated by Figure 6-9 which shows the arrangement of the various elements comprising both drive trains. In addition, this figure shows the bolted interface between the drive unit and support pedestal, and the two elevation support bearings and elevation actuator rod end which comprise the three-point interface between the drive unit and the reflector substrate. The drive unit structure is simulated for SRE by flat plate elements cut to shape and joined

Figure 6-7. Azimuth Drive Schematic

Figure 6-8. Elevation Drive Schematic

Figure 6-9. Elevation-Azimuth Drive Unit

by fusion welding (Figure 6-10). This method of construction simulates the deep draw-pressed housing baselined to the Pilot Plant, but does not require the expensive dies. The turret bearing seat, the input drive shaft bearing seat, and upper harmonic drive mounting seat are machined parallel and concentric after welding to achieve alignment for the harmonic drive unit. The horizontal elevation axis uses self-aligning ball bushings to avoid close tolerance hole alignment.

Figure 6-11 is a cutaway view of a screw jack typical of the type employed in the actuator assembly. The jack shown is one of several vendor employed in the actuator assembly. The jack shown is one of several vendor options, differing from that employed in the elevation actuator assembly in the location of the mounting flange and the type of rod-end fitting. The drive motor is bracket-attached to the far end of the worm drive shown; a limit switch assembly is connected to the near end. The screw jack flange is bolted to a trunion block whose integral shaft ends support the complete assembly on bushings retained in the mount's actuator-support clevis. The drive unit assembly drawing (Figure 6-12) shows the remaining details of the azimuth and elevation drive trains.

Structural Analysis Results

Structural analysis was performed for each component of the drive unit for the critical survival wind condition. Loads for the analysis were determined from the reaction forces of the NASTRAN hub and segment model subjected to the various survival wind conditions. The critical reaction loads were then used in the analysis of the drive unit components. Conventional analysis techniques were used in the component analysis.

A summary of the structural analysis is presented in Table 6-5, including the critical component load, the resulting applied stress, the margin of safety at the critical load, and the load condition resulting in the critical component load. Elevation and azimuth motor mounts were analyzed for earthquake loads as well as survival winds. A similar table of margins of safety is shown in Table 6-6 for the drive unit mount housing.

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Figure 6-10. SRE Heliostat Mount/Actuator Structure

Figure 6-11. Elevation Drive Train

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Table 6-5 (Page 1 of 2)

SUMMARY OF MARGINS OF SAFETY FOR DRIVE UNIT COMPONENTS

Part	Applied Load/Stress	Allowable Load/Stress	Margin of Safety	Load Condition
Worm Gear and Worm	309 in. -lb Torque	402 in. -lb	0.3	6
Worm Shaft Bearing	206 lb (Axial)	225 lb	0.09	6
Worm Shaft Bushing	74 psi	7,500 psi	High	6
Coupling	27.5 in. -lb Torque	500 in. -lb	High	6
Upper Bearing, Harmonic Drive Shaft	272 lb	1,485 lb	4.46	6
Lower Bearing, Harmonic Drive Shaft	69 lb	1,485 lb	High	6
Elevation Axis Bearings	5,203 lb (Radial)	29,000 lb	4.57	5A
Actuator Clevis Bushing	4,230 psi	5,000 psi	0.18	5A
Shaft, Harmonic Drive	12,900 psi (Torsion)	13,200 psi	0.03	6
Shaft, Worm	14,900 psi (Bending)	19,800 psi	0.33	6
Base Plate	15,800 psi (Ring Bending)	19,800 psi	0.25	5C
Inner Retainer	11,900 psi (Thread Shear)	13,200 psi	0.11	5C
Outer Retainer	11,200 psi* (Ring Bending)	19,800 psi	0.18	5C

*Bolt preload = 8,500 lb.

Table 6-5 (Page 2 of 2)

SUMMARY OF MARGINS OF SAFETY FOR DRIVE UNIT COMPONENTS

Part	Applied Load/Stress	Allowable Load/Stress	Margin of Safety	Load Condition
Trunnion Shaft Bearing	2,115 psi	5,000 psi	1.36	3A
Motor Mount Azimuth	3,800 psi (Bending)	15,000 psi	High	Earthquake
Motor Mount Elevation	16,600 psi (Bending)	22,000 psi	0.32	Earthquake
Trunnion Flange	14,000 psi (Bending)	19,800 psi	0.41	7
Trunnion Shaft	4,650 psi (Shear)	13,200 psi	1.84	5
Retainer, Elevation Bearing	3,422 psi (Shear)	10,000 psi	1.92	Side Load

Table 6-6

STRUCTURAL ANALYSIS RESULTS: MOUNT HOUSING, SURVIVAL WIND CONDITION

Component	Maximum Stress/Load	Allowable Stress/Load	Margin of Safety
Machine Screw Jack (Duff-Norton Model 1805)	7,290 lb (Axial Load)	10,000 lb (5-Ton Capacity)	0.37
Side Load Moment*	2,410 in. -lb	3,600 in. -lb	0.49
Outer Shell	5,373 psi (Bending)	22,000 psi	3.10
Inner Shell	8,084 psi (Bending + Axial)	22,000 psi	1.72
Screw Jack Lug	3,262 psi (Shear)	14,400 psi	3.41
Elevation Pivot Lugs	10,620 psi (Shear)	14,400 psi	0.36
Welds	---	---	High
*For 60 mph operational condition.			

6.2.2.5 Pedestal/Foundation

Specific Design Requirements/Loads

The heliostat pedestal/foundation must sustain the operational and survival environment without exceeding the allowable material stress. The foundation will meet the requirements of ANSLA 58.1, Section 6.10 for overturning moment due to survival and operating wind loads.

Hardware Description

The pedestal/foundation for SRE is similar to that for the Pilot Plant (Figure 6-13). The pedestal is composed of a steel cone with attach angles at the top and bottom with eight bolt holes in each for attachment to the drive unit and the foundation. The foundation for SRE is circular and buried to a depth of 23 cm (9 in.) below grade with the base on the slab 40.6 cm (16 in.) below grade line. The base of the foundation is a flat slab 17.8 cm (7 in.) thick and 2.13m (84 in.) in diameter, reinforced with 9.5 mm (3/8 in.) diameter reinforcing rods. After the cone is attached to the foundation, the interior of the cone is filled with soil or sand to provide mass to resist overturning moments.

Structural Analysis Results

Analysis of the pedestal considered the elastic stability of the conical shell structure as well as the applied stress levels. The shell stability analysis used the method of NASA SP-8019, "Buckling of Thin-Walled Truncated Cones," to calculate critical loads for moment, axial compression, shear, and torsion. The allowable load was then determined as one-half the critical load. The applied stresses due to the various load conditions were calculated using the STAGS-C computer code. A summary of the structural analysis results is presented in Table 6-7.

Figure 6-13. Pedestal Foundation Assembly

Table 6-7

PEDESTAL AND FOUNDATION STRUCTURAL ANALYSIS SUMMARY

Part	Critical Load Condition (mph Wind)	Applied Stress or Load	Allowable Stress or Load	Margin of Safety
Attach Bolts	104	10,600 lb	11,700 lb	0.10
Upper Ring	104	15,350 psi (Bending) 6,450 psi (Tension)	24,000 psi (Bending) 22,000 psi (Tension)	0.06
Cone	104	17,500 psi	19,800 psi	0.13
Lower Ring	52	3,406 psi	22,000 psi	High
Anchor Bolts	52	20,900 psi	22,000 psi	0.05
Foundation				
Concrete				
Compression	52	490 psi	1,125 psi	1.29
Shear	52	32 psi	55 psi	0.72
Rebar				
Tension	52	22,015 psi	30,000 psi	0.36
Bond Stress	52	376 psi	500 psi	0.33
Overturning Moment	52	552,000 in. -lb	713,000 in. -lb	0.29
Soil Pressure	52	1,654 psf	3,000 psf	0.81

6.2.2.6 Sensor Post/Foundation

Specific Design Requirements/Loads

The sensor post/foundation must meet certain specific design requirements:

- A. Deflections/Rotations. Under an operational environment, the beam sensor rotation must be less than 1.0 mr for the single-pole configuration and 1.7 mr for the pole/boom configuration.
- B. Strength. There must be no structural damage from survival environments and from periodic forces due to vortex shedding.
- C. Frequency. The sensor post frequency must be greater than 2 Hz to preclude coupling with the control system.
- D. Foundation. The foundation shall meet overturning moment requirements of ANSIA 58.1 under the survival wind environment.

The design conditions used for the structural analysis under the operational environment are shown in Figure 6-14 and in Figure 6-15 for the survival environment.

Hardware Description

The SRE sensor post is the same as for the Pilot Plant. It provides support for the tracking beam sensor which must be positioned along the line of sight to the receiver from the center of each reflector. The post consists of a 6.1m (20 ft) steel pole set in a concrete foundation with its top 5.8m (19 ft) above ground. Due to the fact that the sensors must be mounted on the line of sight to the receiver, the poles near the base of the tower will have booms extending at a 45-deg angle from the top to position the sensor over the reflector. The basic straight pole will accommodate 63% of the field. Booms 1.27m (50 in.) long are required for 28% of the field while booms 2.80m (110 in.) long are required for 9% of the field (Figure 6-16). For the SRE fixed array, the maximum receiver target elevation angle will be about 35 deg, which will require the 1.27m (50 in.) boom.

The foundation for the pole is a steel reinforced concrete block which is sized to hold the pole stable against the maximum wind loads. The sensor pole for the mobile unit will be bolted to the bed of the trailer and be a telescoping straight pole to allow lowering the sensor for adjustment and servicing. The

WIND SPEED = 26 MPH
 TEMPERATURE DIFFERENTIAL = 2°F
 $C_D = 1.2$ COEFFICIENT OF THERMAL
 EXPANSION = 6.78×10^{-6} IN./IN./°F

Figure 6-14. Design Conditions-Deflection (Operational)

CONDITION 2

Figure 6-15. Design Conditions – Survival (Boom/Pole Configuration Critical)

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Figure 6-16. Sensor Pole Configuration

poles will be coated with a heat reflective paint to minimize thermal distortion. A typical sensor post/foundation is shown in Figure 6-17.

Structural Analysis Results

Structural analysis of the sensor post/foundation shows that it is adequate in stiffness and strength. Table 6-8 shows that, under operational conditions, the rotation is less than the allowable. The combination of wind and temperature effects will be evaluated during the SRE tests. Table 6-9 shows that, under survival wind conditions, all the margins of safety are positive.

The dynamic analysis used a NASTRAN finite element beam model and showed that for both sensor pole and pole/boom configurations: (1) the designs are acceptable for earthquake loads, which were less than the survival wind loads, (2) frequencies were above the 2 Hz requirements, and (3) vortex shedding loads were much less than the survival wind loads.

6.2.2.7 Electronics

The heliostat electronics, simulated master control, and field controller will be discussed in Subsection 6.2.4.

6.2.3 Inverting Rectangular Heliostat

6.2.3.1 Configuration

The inverting rectangular heliostat consists of two rectangular reflectors, separated by a 28-in. slot, and supported by a torque tube and four tapered cross beams. The reflector motion is controlled by an elevation/azimuth drive unit, which sits on top of a cylindrical pedestal and a reinforced concrete slab foundation. Figure 6-18 is an overall view of the inverting heliostat.

6.2.3.2 Reflector

The reflector design for the inverting heliostat consists of two types: a laminated mirror, 1/8-in. plus 1/8-in.; and a second surface mirror foam sandwich design, consisting of a 3/32-in. mirror, 2-in. Styrofoam, and backed by a 0.022-in. galvanized steel sheet.

Figure 6-17. Sensor Post/Foundation

Table 6-8

STRUCTURAL ANALYSIS RESULTS: ROTATIONS FROM
OPERATIONAL CONDITIONS (MR)

Effect	Condition 1 (Pole/Boom)	Condition 3 (Pole Only)
Boom Rotations from Wind	0.127	---
Pole Rotations from:		
Boom	0.375	---
Wind	0.680	0.680
Base Plate Rotation	0.059	0.047
Foundation Rotation	0.007	0.006
Total Rotation from Winds	1.248	0.733
Rotation from Temperature	1.04	0.57
Allowable	1.7	1.0

Notes:

1. Condition 2 not critical to operational environments.
2. Some combination of wind and temperature effects is applicable. These combinations will be evaluated during SRE tests.

Table 6-9

STRUCTURAL ANALYSIS RESULTS: SURVIVAL WIND CONDITION

Part	Maximum Stress (psi)	Allowable Stress (psi)	Margin of Safety
Boom	3,580	22,000	5.1
Pole	19,500	22,000	0.1
Base Plate	18,200	22,000	0.2
Anchor Bolts	13,800	20,000	0.4
Foundation			
Concrete	64	900	13.1
Rebar	6,340	18,000	1.8
Overturning Moment	---	---	0.05

Figure 6-18. Inverted Stowage Heliostat

6.2.3.3 Reflector Support Structure

The reflector (Figures 6-19, 6-20, 6-21) is composed of six rectangular glass panels bonded to longitudinal hat stiffeners. The panels are supported on eight transverse channel beams which extend at right angles from a main tubular support beam, which is bolted to the drive unit. A separate sensor reflector plate is attached to the center of the main beam.

The primary structural member of the support structure is a 10 in. diameter x 0.250 in. wall steel pipe. Provision for attachment to the drive unit is by means of two heavy fittings welded near the center. Ring flanges are also welded at four stations along the pipe to provide attachment for the eight beams which support the panels. After welding, the assembly is hot-dip galvanized for protection against corrosion.

The channel beams are tapered in depth from 14 in. to 6 in. and have 3-in. - wide flanges with a 0.5 in., 30-deg return lip. The parts are brake-formed from No. 11 gage (0.1196 in.) galvanized steel. The beams are attached by friction between the ring flanges and the channels. The bolts are installed in oversized holes, which allow adjustment of the beams on assembly to position the reflector panels in plane without precision holes. The clamp bolts are then torqued to 150 ft-lb to lock the beams in position.

The hat stiffeners for the reflector are break-formed parts, 3 in. wide and 1.56 in. deep, made from No. 16 gage (0.060 in.) hot-rolled steel in lengths of 112 in. and 101.25 in. In assembly, the stiffeners are bonded to the glass reflector plate and the front surface of the glass is supported on a surface table. The six attach points on the stiffeners are held in a plane parallel to the surface table during the bonding operation. On final assembly, attachment of the panels to the support beams is by means of six bolts through the upper flange of the beams and into nut plates inside the hat sections.

The sensor reflector is mounted to the main tubular beam by a welded triangular frame made from square steel tubing and attached with clips and brackets. Three adjusting screws bonded to the lower surface of the glass reflector panel attach the reflector to the steel frame so that its plane can be adjusted in position on assembly, as required for alignment of the heliostat.

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Figure 6-19. Inverted Heliostat Assembly

Figure 6-20. Inverted Heliostat Reflector Support Structure ($A = 408.3 \text{ ft}^2$)

Figure 6-21. Reflector Structure Details

The stress analysis results for the reflector support structure are summarized in Table 6-10. All margins of safety were positive. Applied loads and stresses were computed by NASTRAN. The critical load condition for strength calculations was the survival wind condition of 44.7 m/s (100 mph) at an angle of attack of 0.175 rad (10°). Bolt attachments and welds were satisfactory.

For the operational environment, the maximum local mirror slopes occurred at an angle of attack of 0.524 rad (30°). A summary of maximum local mirror slopes for each load condition is shown in Table 6-11. The allowable local mirror slope is 3 mr. During the most likely operational temperature environment of 23.9°C (75°F) warming up to 40°C (104°F), the worst slope is 2.97 mr. A cooldown to 0°C (32°F), representing only a small percentage of the total annual operating time, produced a condition whereby about 5% of the total mirror surface would exceed 3 mr. This small area will not significantly degrade the total efficiency of the system.

6.2.3.4 Drive Unit

The inverted heliostat's drive unit design is essentially the same as the Pilot Plant drive unit design described in Section 4.2.4, except for the minor differences noted in that section.

Major elements of the inverting drive unit including housings and supports were designed by MDAC. The castings and flame-cut supports were fabricated locally and machined by MDAC. These items were then shipped to the Compudrive Corporation, together with the large Timken bearings and seals, for installation of the orbdrive parts, final assembly, and acceptance testing. Two of the completed units were subjected to development/qualification tests at Compudrive, and two of the units were returned to MDAC for incorporation into complete heliostats for use in controls development and system tests at NWC and in heliostat structural tests at MDAC. The strength analysis of the inverting heliostat drive unit components is summarized in Table 6-12.

Table 6-10

STRUCTURAL ANALYSIS RESULTS: REFLECTOR SUPPORT STRUCTURE, SURVIVAL WIND CONDITION

Component	Load Condition or Attachment	Maximum Stress or Load	Allowable Stress or Load	Margin of Safety
Main Torque Tube	2, 2A	15,369 psi	24,000 psi	+0.56
	Bolt Attachment to Drive Unit	7,593 lb	19,596 lb (Tension)	+1.58
		9,779 lb	15,904 lb (Shear)	+0.63
	Tube-to-Drive Unit, Shoulder Weld Shear	91,120 in. -lb	580,880 in. -lb	High
	Tube-to-Beam	2,774 lb	3,942 lb	+0.43
Channel Beam	2A	12,823 psi	24,000 psi	+0.87
	Lateral Buckling	75,484 in. -lb	117,900 in. -lb	+0.56
	Web Crippling	12,823 psi	24,583 psi	+0.92
Hat Section	2A	24,000 psi	24,000 psi	0.00
Mirror Glass	1A	999 psi	3,000 psi	+2.00
Adhesive Bond	Shear	23 psi	100 psi	High
	Tension	6 psi	225 psi	High

Table 6-11

STRUCTURAL ANALYSIS RESULTS: REFLECTOR SUPPORT STRUCTURE,
OPERATIONAL WIND CONDITION

- 11.6 m/s (26 MPH), $\alpha = 30^\circ$
- $T_{REF} = 23.9^\circ\text{C}$ (75°F)

Temperature	Node No. With Max Slope ¹	Maximum Mirror Slope ² (mr)	
		Wind Parallel to Slot	Wind Perpendicular to Slot
$T = T_{REF} = 23.9^\circ\text{C}$ (75°F)	37	2.66	2.35
Warmup $T = 40^\circ\text{C}$ (104°F) ($\Delta T = 29^\circ\text{F}$)	36	2.97 (LC 1)	2.73 (LC 2)
Cooldown $T = 0^\circ\text{C}$ (32°F) ($\Delta T = -43^\circ\text{F}$)	43	3.85 ³ (LC 1A)	4.04 ³ (LC 2A)

Notes:

1. See node location in Figure 3-5 (CDRL6).
2. Allowable slope = 3 milliradians.
3. For each case, only about 5% of the total mirror surface area exceeds 3 mr; 95% of the area has slopes less than 3 mr.

6.2.3.5 Pedestal/Foundation

The pedestal is a thin-wall steel column, 20 in. in diameter and 108 in. long, with a 2-in. thick base plate for attachment to the foundation (Figure 6-22). The upper end has a 0.75-in. thick plate for attachment of the drive unit. An 8-in. section of thick wall, 20-in. diameter pipe is welded between the 2-in. base plate and the thin wall tube to strengthen the base area. Attachment to the concrete foundation is provided by eight 1.25-in. diameter anchor bolts equally spaced on a circle of 24-in. diameter.

Table 6-12

STRUCTURAL ANALYSIS RESULTS: DRIVE UNIT COMPONENTS, SURVIVAL CONDITION

Component	Applied Load or Stress	Allowable Load or Stress	Margin of Safety
Elevation Drive Housing			
Shear Pin, Bearing	33,720 psi	54,000 psi	+0.60
Attach Lug, Bending	20,040 psi	26,400 psi	+0.32
Attach Lug, Shear-Out	10,550 psi	16,000 psi	+0.52
Main Body, Bending + Torque	11,030 psi (shear)	16,000 psi	Interaction
	20,110 psi (bending)	26,400 psi	
Elevation Drive Bearings	28,860 lb (radial)	144,000 lb	High
Support, Shear Pins	84,470 psi	85,000 psi	+0.01
Azimuth Drive Housing			
Main Body, Bearing Cavity	22,980 psi	24,000 psi	+0.05
Base Leg, Bending + Shear	10,040 psi (bending)	26,400 psi	Interaction
	2,500 psi (shear)	16,000 psi	
Azimuth Bearings	61,570 lb (radial)	144,000 lb	+1.34
Azimuth Shaft			
Main Body, Bending	19,810 psi	26,400 psi	+0.33
Base Plate, Bending	13,250 psi	26,400 psi	+0.99

Figure 6-22. Pedestal/Foundation

The foundation is a 120-in. diameter by 12-in. thick steel-reinforced concrete pad with the base 32 in. below ground. The pad is covered with a 20-in. layer of back fill to increase the effective mass of the foundation. A center column of concrete extends up from the pad to 3 in. above ground line and contains the eight anchor bolts for attachment of the pedestal.

For the analysis of the pedestal, both conventional stress analysis methods and a NASTRAN finite element model were used. Table 6-13 is a summary of the results. For the survival environment, the pedestal was verified to have adequate strength in these areas: combined stresses, buckling, stress concentration due to the access hole, upper bolt attachment, top flange bending, and the base plate. A simple NASTRAN finite element model was made of the base plate region; results showed this region to have a margin of safety of +0.14.

The slab foundation analyzed also has adequate strength. This analysis is typical for the type of foundation shown. This foundation was sized prior to development of the final loads and is therefore quite conservative. The final Pilot Plant foundation design will reflect the updated loads and site soil properties so that a cost-effective design will be chosen.

6.2.3.6 Beam Sensor Pole/Foundation

The beam sensor pole/foundation for the inverted heliostat is the same as for the octagonal heliostat discussed in Section 6.2.2.6.

6.2.3.7 Electronics

The heliostat electronics, simulated master control, and field controller are discussed in Section 6.2.4.

6.2.4 Electronics

The electronics of the controls system consists of three parts: control sensor; simulated master control, and field controller.

6.2.4.1 Control Sensor/Heliostat Electronics

The elevation position signal is obtained from a single-turn potentiometer excited by +15V DC. The pot output is adjusted for +3.971V DC with the

Table 6-13

STRUCTURAL ANALYSIS RESULTS: PEDESTAL/FOUNDATION, SURVIVAL WIND CONDITION

Component	Applied Load or Stress	Allowable Load or Stress	Margin of Safety
Pedestal			
Combined Stresses	14,240 psi (bending) 1,347 psi (torsion) 226 psi (shear)	23,100 psi 14,000 psi 14,000 psi	Interaction +0.61
Shell buckling due to moment	462,400 in. -lb	1,452,400 in. -lb	
Stress concentration due to 8-in. diameter access hole	21,890 psi	23,100 psi	+0.06
Upper Bolt Attachment	68,320 psi	75,000 psi	+0.10
Top Flange Bending	20,920 psi	23,100 psi	+0.10
Base Plate	20,270 psi	23,100 psi	+0.14
Anchor Bolts	10,420 psi	22,000 psi	+1.11
Foundation			
Concrete			
Compression	968 psi	1,125 psi	+0.16
Shear	45 psi	55 psi	+0.22
Rebar			
Tension	29,900 psi	30,000 psi	+0.01
Bond Stress	305 psi	320 psi	+0.05
Overturning Moment	1,227,000 in. -lb	1,475,000 in. -lb	+0.20
Soil Pressure	1,316 psf	3,000 psf	+1.28

mirror in the horizontal position and amplified to 10V DC by an amplifier in the heliostat interface control box. The azimuth position is derived from a 3-turn potentiometer excited by +15 and -15V DC. The pot output is adjusted for 0V DC with the mirror rotated in the true south direction. The output is buffered (1.0 V/V amplification) by an amplifier in the heliostat interface control box.

The beam sensor design, which is based on the balanced-shadow concept, consists of two pairs of rectangular silicon detectors arranged on the arms of a cross. A square mask is positioned and sized so that sunlight passing the mask illuminates the outer edges of each detector. Vertical baffles are located so as to isolate each detector. An unbalance in signal between opposite pairs of detectors produces an error signal to the field controller. A fifth detector element at the center measures insolation to provide for automatic gain control (AGC) in the servo amplifiers.

Three-phase AC motors are used to drive the azimuth and elevation axes. The control of these motors is directed by the 3-phase motor controller located at the field controller. The drive excitation to the motors can be circumvented by the respective limit switches should either axes attempt to exceed the selected range of travel.

6.2.4.2 Simulated Master Control (SMC)

The SMC hardware consists of a 16-bit (Nova 1200) computer and the Communication Interface (CI) to arrange the 16-bit computer words into a 40-bit serial data stream for communication with the field controller (F/C).

The communication network between the SMC and F/C is a differential party line bus. A communications interface box containing the circuits necessary for a party line system is located at the SMC. The communication is via a 40-bit message serially transmitted on a party line. Conversation may only be started by the SMC.

The message is formatted such that it can address up to 128 F/Cs (bits 2-8), tells the F/C what data is requested or the command issued. Bits 17-32 are used to transmit the commanded data or the requested data. The complete description of the message format is shown in Table 6-14.

Table 6-14
MESSAGE FORMAT

Bit No. (s)	Description																		
1	Data Transmittal Request																		
2-8	7-bit FC address																		
9-11	3-bit message type																		
	<table> <tr> <th>Code</th><th>Function</th></tr> <tr> <td>000</td><td>Beam Sensor Bias Command</td></tr> <tr> <td>001</td><td>Transmit Solar Intensity and Heliostat Status to SMC</td></tr> <tr> <td>010</td><td>Spare</td></tr> <tr> <td>011</td><td>Receiver Pointing Angle</td></tr> <tr> <td>100</td><td>Mandatory Position Command</td></tr> <tr> <td>101</td><td>Transmit Heliostat Orientation to SMC</td></tr> <tr> <td>110</td><td>Optional Beam Sensor Track</td></tr> <tr> <td>111</td><td>F/C Emergency Slew</td></tr> </table>	Code	Function	000	Beam Sensor Bias Command	001	Transmit Solar Intensity and Heliostat Status to SMC	010	Spare	011	Receiver Pointing Angle	100	Mandatory Position Command	101	Transmit Heliostat Orientation to SMC	110	Optional Beam Sensor Track	111	F/C Emergency Slew
Code	Function																		
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011	Receiver Pointing Angle																		
100	Mandatory Position Command																		
101	Transmit Heliostat Orientation to SMC																		
110	Optional Beam Sensor Track																		
111	F/C Emergency Slew																		
12-16	Heliostat address (for the F/C addressed)																		
17-32	16-bits of data																		
33-36	Multiplexer address — used by MC to select one of 16 party lines																		
37	Message type expander (spare)																		
38-40	3 spares																		

Communications Interface (CI)

The SMC interface receives the 40-bit message from the SMC computer register in parallel form and serially transmits it down the party line. The serial reply from the F/C is arranged in the proper format for parallel transfer to the SMC. During the conversation time, the SMC is not required to remain at the interface. The communications interfaces can detect transmission errors, respond to retransmission requests, request retransmission, and flag the controller when a valid message is received. The F/C and SMC CI's are similar except for the address recognition feature required in the F/C.

Operation

The 40-bit message is loaded into the SMC CI register with a load command generated by the SMC; the command also initializes all the storage devices in the CI. The 40 bits are serially transmitted by a UART universal asynchronous receiver transmitter (UART) in 8-bit parcels.

The UART formats the 8 bits by adding a start bit (flags the receiver in the F/C's UART that a word has arrived), stop bit (signals end of word), and a parity bit (indicates the correct parity). The UART also checks for parity, overflow, and framing errors which may have occurred during the transmission; a flag is raised if an error is detected.

The loading of the UART and the controlling of the transmitter is controlled by an 8-bit burst clock. The first burst of 8 pulses is initiated by the MC load signal. The end of the burst enables the transmitter, and the completion of the transmission initiates the next burst. This cycle is repeated five times and then disabled. At the end of the five cycles, the original 40-bit message has been returned into the buffer register (this enables the CI to retransmit the same message without the assistance of the SMC). During the transmission period the receiver input is disabled because both the receiver and transmitter drivers are tied to the same bus. The transmission rate is 2 KHz, which is one-sixteenth of the oscillator frequency. (Transmission rates up to 12.5 KHz are possible.)

If the F/C communication interface detects a transmission error, it requests retransmission of that message by sending an 8-bit message with all zeros to the SMC CI. The all-zero message, which is created without the aid of the F/C, is initiated when the UART detects an error. The error flag clears the transmitter buffer register (creating 8 zero bits) and enables the transmitter. When the request is received by the SMC CI, it enables the burst clock to repeat the process of loading the UART with the original message. Should the F/C request still another retransmission of the original message, the request is denied and a flag (to the SMC) is set, indicating that the F/C did not receive the message. The SMC can then take interrogative measures to isolate the problem.

When a message is successfully assembled at the F/C CI and the address verification is made, the F/C processor is signaled that a message has been received. To acknowledge (to the SMC) that the message has been received, the F/C will send back the message it received if the F/C is not required to supply any information to the SMC, or the F/C will send back the information requested. In either case, the same 40-bit message format is used. The transmission circuits in the F/C are identical to the SMC. The burst clock is initiated by the F/C and the transmitter is enabled.

The SMC UART receiver also checks for transmission errors; however, when an error is detected the original message is sent to the F/C rather than a request for retransmission. The SMC is signaled when a valid message is assembled by the SMC CI.

The F/C is prevented from requesting retransmission when an emergency format is received. The F/C will maintain the emergency slew condition until reset by SMC.

6.2.4.3 Field Controller

Processor Operation

The field controller was designed with the capability of controlling 24 heliostats; however, only 5 heliostats were required for SRE. The operational tasks of the field controller processor are explained below for the controlling of 24 heliostats.

Each second of operation of the F/C is divided up into 8 segments of time (125 ms each). These segments are artificially identified as T0 through T7. During T0 and T4 the following sequence of operations occurs:

A. Data Acquisition

1. Azimuth position for heliostats 0-7.
2. Elevation position for heliostats 0-7.
3. Horizontal beam sensor error for heliostats 0-7.
4. Vertical beam sensor error for heliostats 0-7.
5. Solar intensity for heliostats 0-7.

- B. Motor drive commands are calculated for heliostats 0, 1, 2, and 3; (16, 17, 18, and 19 for T4.)
- C. Satisfies requests for loading the motor control RAM or communications with MC. Loading of the motor control RAM will be limited to those heliostats with updated calculations during the previous 0.5-sec period (one-half of the heliostats).

During T1 and T5 the following sequence of operations occurs:

- A. Data Acquisition
 - 1. Horizontal beam sensor error for heliostats 8-15.
 - 2. Vertical beam sensor error for heliostats 8-15.
- B. Calculation of motor drive commands for heliostats 4, 5, 6, and 7. (20, 21, 22, and 23 for T5.)
- C. Servicing of output and communication interrupts.

Segments T2 and T6 are similar to T1 and T4 except that the input data on heliostats 16-23 and control heliostats 8, 9, 10, and 11. T6 controls heliostat 24.

Segments T3 and T7 input data for heliostat 24. T3 controls heliostats 12, 13, 14, and 15. T7 does not control any heliostats.

Constants used in the coordinate conversion are calculated for one heliostat during time segments T6 and T7.

Three-Phase Controller

Three-phase AC motors are used to drive the azimuth and elevation axes. The directional control for each motor is achieved by switching two of the three phases. The control mode is proportional bang-bang with the F/C providing the logic signals and the power switching required for each of the 10 motors on the five heliostats. Two of the three phases (ϕ band and ϕ C) are being continuously switched in cyclic "bursts" to provide the directional control for the 3-phase motors. A burst consists of 14 60-Hz cycles with phasing sequence ABC or ACB. A null period (one AC cycle) between bursts is necessary to prevent damage to the TRIACs which perform the AC switching. The bursts are controlled by a logic network synchronized to ϕ A.

The field controller calculates the magnitude and direction of the required motor rotation to correct for a pointing error detected by the beam sensor (for closed-loop tracking mode) or by the gimbal position potentiometer (for position tracking mode). The 4-bit motor commands are coded to represent the desired magnitude and direction by the F/C and loaded (see Figure 6-23) into the motor controller interface memory (RAM) at the beginning of every other null period. The loading of the RAM is controlled by the address counter which assigns the RAM location in the following order: location 1 (elevation No. 1 command), location 2 (azimuth No. 1 command) ... location 9 (elevation No. 5 command) and location 10 (azimuth No. 5 command). The 4-bit motor command is coded as follows: Bit 1 (MSB), direction of rotation, and Bits 2 through 4 - magnitude of rotation.

The buss controller provides a 4-bit output (into the digital comparator) indicating the actual polarity (1 bit) of the 3 ϕ buss (ϕ ABC or ϕ ACB) and the number of AC cycles elapsed since the beginning of the present buss polarity (3 bits).

The other input to the digital comparator comes from the RAM outputs. It represents the desired buss polarity and the point within the cyclic "burst" in which the motor (selected by the address counter) should be turned on.

The address counter cycles through the 10 motor locations at a 50-KHz rate. The digital comparator generates an enable command to the output decoder when the two inputs to the comparator are identical.

The output decoder is synchronized to the RAM by the address counter and is turned on at the beginning of each null period. The enable signal from the digital comparator provides the drive command (for the motor addressed by the counter) to turn on the motor through the TRIAC switches. The motor remains turned on until the next null period at which time the decoder is turned off by the buss controller.

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Figure 6-23. SRE Field Controller Diagram

6.3 SRE ASSEMBLY, SUBASSEMBLY, AND COMPONENT TESTS

This section describes test results for the SRE assembly, subassembly, and component tests. These tests are divided into three categories: (1) controls development test, (2) structural tests of the octagonal and inverting heliostats, (3) environmental/qualification tests, which consists of those environmental/life cycle on both octagonal and inverting heliostat drive units, and various structure tests such as segment bonding tests, hail impact tests, and first- and second-surface mirror tests.

6.3.1 Controls Development Test

6.3.1.1 Test Objectives

The primary objectives of the collector controls development test was to verify the basic servo operation and to provide to the heliostat array tests proven hardware and software capable of meeting Pilot Plant performance requirements. Tests were performed to verify:

- A. Field Controller Hardware and Software. Including the microprocessor, the 3-phase AC reversing bus, the output 3-phase AC switching, the input multiplexer, the interface logic and the microprograms which control the field controller hardware.
- B. Field Controller/Simulated Master Control Interfaces. Including both the physical and functional parameters associated with the interface.
- C. Heliostat Hardware Interface. Including drive motors, position potentiometers, limit switches, and beam sensor.
- D. Operation Performance. Including the development of the microprograms executed in the field controller digital processor.

6.3.1.2 Test Specimen

The hardware and software for development testing of the collector controls consisted of a simulated master control, a field controller, and the appropriate noninverting or inverted stowage heliostat.

The simulated master control consists of an existing minicomputer (NOVA 1200), system software, and application programs. The system software provides the operator interface, controls the peripherals, and schedules the

execution of the application programs. The application programs simulate the functions which will be performed in master control for the Pilot Plant, such as calculating sun acquisition and synthetic track commands.

Functionally, the SRE field controller is the same as the Pilot Plant field controller. Physically, it is not a production design and contains circuitry for controlling 5 heliostats via the 25 controlled in the Pilot Plant. It is also housed in a van with controlled environment and has additional test points and program flexibility not required in the Pilot Plant design. The hardware interface with the simulated master control is at the output wires of the minicomputer, but the field controller software that controls the interface is the same as the Pilot Plant. The F/C operational software is identical to the Pilot Plant software.

6.3.1.3 Test Activities

Test activities performed to verify the collector controls for both heliostat designs are summarized in Table 6-15.

6.3.1.4 Test Results. Non-Inverting Octagonal and Inverted Stowage Heliostats

Test results were as follows:

- A. Field Controller Hardware and Software. Output motor control drive signal specification and AC reversing bus performance were established. Input multiplexer and analog to digital conversion circuitry performance were verified. The microprogrammed instructions that input sensor data and convert the data to motor drive signals using the transformation equations were verified for north field only.
- B. Field Controller/Simulated Master Control Interface. Hardware connector and pin assignments and control signal compatibility and timing were verified. Command and data formats were verified end-to-end from the simulated master control program to the control and monitoring of the individual heliostat input or output.
- C. Heliostat Hardware Interfaces. The direction of motor rotation with respect to AC phasing was established. Mirror position vs

Table 6-15 (Page 1 of 2)

CONTROLS DEVELOPMENT TEST MATRIX

Test Objective	Test Conditions	Measurements	Test Operations
F/C Hardware and Software Verification	As required	Output AC current cycles. DC power output. Numerical verification of transformation equation. Output AC phase sequence.	Input varying signals to test the multiplexer analog-to-digital converter section. Verify response time, accuracy and channel addresses. Drive each motor control output clockwise and counterclockwise. Verify phase relation and number of cycles applied. Execute each micro-programmable instruction including the transformation equation and verify logic and timing.
F/C Interface Verification	Connected F/C and SMC	Interface control signals.	Connect field controller and simulated master control and verify physical interface. Transfer individual instructions across interface both directions. Verify command and data formats and timing. Execute special test programs to verify end-to-end functional parameters and interface dynamics.
Heliostat Hardware Interface Verification	Partial Heliostat	Tracking Sensor Horizontal, Vertical, and insolation channel outputs. Drive potentiometer voltages.	Drive heliostat end-to-end on each axis and verify position vs potentiometer voltages. Verify limit switch operation. Scan tracking sensor across sun with varying solar radiation intensities. Verify sensor characteristics.

Table 6-15 (Page 2 of 2)

CONTROLS DEVELOPMENT TEST MATRIX

Test Objective	Test Conditions	Measurements	Test Operations
Operational Performance Verification	Heliostat located and aligned with Earth position reference. Heliostat connected to F/C	Tracking accuracy Point Accuracy Stability limits for System Gains	Using simulated master control programs command subsystem functions such as sun acquisition, synthetic track, stowage and emergency defocus. Verify dynamic performance. Operate in normal track mode then switch to/from synthetic track to normal track – verify control loop stability and logic switching to/from synthetic track. Move tracking sensor to different positions to force controls through worst-case tracking conditions – verify dynamics and stability of tracking through "poles." Run tests with heliostat connected to each of the five field-controlled heliostat interfaces – verify operation of each interface.

position potentiometer output was verified. Tracking sensor characteristic curves were obtained and overall system gain margins adjusted.

- D. Operational Functions. All major operational functions were verified with the heliostat elements, including sun acquisition, normal track, emergency defocus, stowage, and synthetic track. The algorithm for slewing through a tracking "pole" was not verified due to time constraints. Basic control-loop stability was verified.
- E. Closed Loop Stability. Both systems were designed to have 6- dB (factor of 2) gain margin to account for production/environmental variations with a nominal sensor gain of 312 mv/mr. The systems rely on friction for stability (i. e., no rate feedback). Maximum input sensitivity must be less than or equal to one-half the maximum surface motion per motor pulse (0.5 mr for noninverting, 1.0 mr for inverted stowage) to prevent limit cycling. System stability margin was determined empirically by introducing an error of 2 MRAD or more (by allowing solar drift to occur) and observing the return to tracking operation. The highest gain yielding stable operation (i. e., no limit-cycling) was halved and defined as the nominal system gain. Higher mechanical gain and wider surface motion per motor pulse variations in the inverted design resulted in reduced pointing accuracy.
- Phase margin in both systems is adequate as in the control region (<2.5 mr) mirror motion ceases before the error signals are sampled. Therefore, only current error data is used in determining the next corrective motor pulse. To date both systems have demonstrated stable performance in the field.
- F. Sensor Calibration. The beam sensors required calibration as part of the controls development test to establish stable overall system gains. Figures 6-24 and 6-25 show data obtained which verified the linearity, determined the total width of the sensor window, the width of the linear gain, the solar intensity gain, and the gain of the elevation and azimuth axes of the sensor.
- This sensor (No. 7) was used on the inverted stowage heliostat, IH-1. The calibration consisted of pointing the beam sensor at the sun and measuring the output voltage of both the elevation and

(A)

(B)

Figure 6-24. Sensor Calibration Curve — Narrow Range

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azimuth axes as the sun moved across the sky, which changed the beam incident angle relative to the stationary sensor at the solar drift rate of 15 deg/hr. For example, in Figure 6-24, Part A, the sensor output in volts vs the beam angle relative to the sensor normal is shown in a narrow range for the sensor elevation channel. As the incident beam angle changed from -0.472 mr to +0.472 mr, the output voltage varied linearly. There was no kink in the curve in the region about null, and therefore no control loop deadband or excessively high gain region encountered. In the range where most tracking errors are sensed, either of these nonlinearities could degrade tracking accuracy and/or control loop stability. The solar intensity output channel calibration is also shown. Both the output error signal magnitude and solar intensity output magnitude are dependent on the attenuating red filter on the face of the sensor. Any change in the spectral transmissivity characteristics of the filter will change the beam sensor calibration values for a given solar intensity. No degradation has been observed during the field tests. Figure 6-24B shows a similar curve for the azimuth channel. The normalized sensor gains are within 7% for the two channels. Figure 6-25 shows the performance of the sensor over its operating range for the azimuth channel. The data show that the sensor detects an error signal over a range of approximately $\pm 11^\circ$ about null (in either sensor axis); thus, a heliostat beam of sufficient solar irradiance striking the sensor window within this angle will result in the heliostat being brought onto track independent of the Master Control. In the linear range of $\pm 1.9^\circ$, the solar intensity is also sensed. If the solar intensity falls below the threshold value of 0.25 sun (or lower, if programmed into the field controller) tracking command would be transferred to the Master Control synthetic track.

It was noted during tests that the solar intensity can drop below 0.25 sun relatively frequently due to clouds; this causes a transfer from normal to synthetic track, which drives the beam 1-3 deg off of the target. When the solar intensity rises above the threshold value, normal track is reinitiated. However, our results showed that the energy onto the receiver will be increased, and power

consumption of the heliostats decreased if the threshold value is decreased. Although the tracking accuracy is degraded when the solar intensity drops, it is still more accurate at 1/8 and 1/16 sun than synthetic track, and motor power consumption due to switching from normal to synthetic track is minimized. We therefore reprogrammed the system for a 1/16 sun threshold.

Sensor No. 7 is typical of the SRE sensors fabricated for the test program. Sensor No. 6 was used in a series of environmental tests, including thermal cycling, dust chamber, and rain, and showed no degradation in performance or integrity. Sensor characteristics were as follows:

Linear Range: ± 1.9 mr

Linear Gain: $0.30 \text{ MV M}^2/\text{MR W}$

Wide Angle Acquisition Range: $\pm 11^\circ$

Solar Intensity Window: $\pm 3.44^\circ$

Solar Intensity Gain: $78 (\text{W/M}^2)/\text{V}$

6.3.1.5 Test Support Equipment

Collector controls testing required general-purpose test equipment such as dual-beam oscilloscopes, digital voltmeters, ammeters, ohmmeters, strip charts and counters. Pyreheliometers were used to calibrate beam sensor solar irradiance measurements.

6.3.1.6 Facilities

The test facilities used for the noninverting heliostat controls development tests were the Circuit Study Laboratory and the outdoor heliostat test facility, both located at MDAC-Huntington Beach. The inverted stow heliostat controls development test was conducted at the heliostat array test site, Randsburg, Wash. at NWC.

6.3.2 SRE Heliostat Structural Tests

6.3.2.1 Octagonal Heliostat

Test Objectives

There were three objectives of the SRE octagonal heliostat structural test. The first objective was to verify that the stiffness of the heliostat assembly exceeds its design limits when subjected to a simulated operational wind and gravity loading. Strains, deflections, and flatness variations were measured to verify analysis predictions. The second objective was to demonstrate that the heliostat assembly can withstand a simulated survival wind and gravity loading condition with no structural damage. The third objective was to measure the fundamental frequencies of the heliostat.

Approach

Any test setup is at best a simulation of the actual loading a heliostat may see in the desert. By correlating measured strains and deflections with the predicted in one test setup, we hope to place high confidence on the structural analysis method using the NASTRAN computer program, to be able to analyze other heliostat orientations.

The test specimen consisted of a pedestal, a drive unit, a hub, and eight reflector segments attached to a rigid floor in the MDAC Structures Laboratory. Seven of the segments were subjected to "coarse" loading at two points on each segment. The eighth and most highly loaded was subjected to "fine" loading over 18 areas. Most of the 22 strain gages and 8 displacement transducers were installed on the finely loaded segment where the best load simulation was possible. All height gage and laser profilometer measurements were made on this segment also. The structural test setup is shown in Figure 6-26.

Two static test conditions were applied by dead weight loading at the various loading points on the structure. The simulated operational wind loading was performed first, followed by simulated survival wind condition. After completion of the two static tests, a simple vibration test was conducted where the heliostat was excited manually and the fundamental frequencies were measured.

Figure 6-26. Octagonal Heliostat Structural Test Setup

Test Results

Deflection Data — Results of the deflection transducer measurements are shown in Table 6-16. These deflections were all measured in the fine segment (see Figure 6-27), and had the hub rigid body rotation removed from the raw data. The agreement with predicted values is good. The fact that the measured deflections were slightly greater than the predicted may be attributed to the actual glass thickness being 0.242 in. vs the 0.25 in. used in analysis. The height gage data were consistent with the displacement transducer data. The profilometer slope measurements were considered bad in the operational test, and acceptable in the survival test. However, some profilometer slope measurements at zero load were greater than the 3 mr allowable for the operational environment.

Strain Data — For the 11.6 m/s (26 mph) operational test, strain data measured were too small to allow for comparison with predicted values. Table 6-17 shows a comparison of strain data vs predicted for the 46.5 m/s (104 mph) survival test. For most of the locations, the agreement is reasonable.

Frequency Data — After completion of the static tests, the octagonal heliostat was subjected to vibration in the pitch and yaw modes. The agreement with the NASTRAN model predictions were good:

	<u>Pitch Oscillation</u>	<u>Yaw Oscillation</u>
Measured Frequency (Hz)	6.0	3.0
Predicted Frequency (Hz)	6.1	2.1

6.3.2.2 Inverted Heliostat

The test objectives and approach were essentially identical for the inverted heliostat and the octagonal heliostat structural tests. The inverted heliostat test specimen consisted of a pedestal, a drive unit, a reflector panel structural support, and a variety of reflector panels under consideration for the final design. Three laminated reflector panels and six foam-sandwich reflector panels were included on the test specimen. The sandwich reflector panels were located in the most highly loaded "fine" load distribution panel

Table 6-16

COMPARISON OF MEASURED AND PREDICTED DEFLECTIONS IN SRE OCTAGONAL
HELIOSTAT STRUCTURAL TEST

Disp Channel	Location	Operational (26 mph)		Survival (104 mph)	
		Measured (in.)	Predicted (in.)	Measured (in.)	Predicted (in.)
D21	Mirror	-0.025	-0.022	-0.29	-0.22
D22	Mirror	-0.028	-0.026	-0.34	-0.26
D23	Mirror	-0.028	-0.024	-0.32	-0.24
D24	Mirror	-0.032	-0.029	-0.38	-0.30
D25	Mirror	-0.016	-0.014	-0.14	-0.10
D26	Steel	-0.017	-0.023	-0.19	-0.20
D27	Steel	-0.023	-0.025	-0.26	-0.21

Figure 6-27. Segment Deflection Measurement Locations

Table 6-17

COMPARISON OF MEASURED AND PREDICTED STRAINS IN SRE
OCTANGONAL HELIOSTAT STRUCTURAL TEST 46.5 m/s (104 mph)
SURVIVAL WIND CONDITION

Strain Channel	Location	Measured Strain (μ in./in.)	Predicted Strain (μ in./in.)
S1	Root of Radial Beam "P," Above Top Flange	205	206
S2	Root of Radial Beam "P," Below Bottom Flange	-279	-304
S3	Root of Radial Beam "O," Above Top Flange	169	206
S4	Root of Radial Beam "O," Below Bottom Flange	-246	-304
S5A	Glass, Near Hub, Tangential	25	28
S5B	Glass, Near Hub, Radial	13	28
S6	Gross Beam, Above Top Flange	-10	-5
S7	Gross Beam, Below Bottom Flange	4	23
S8A	Pedestal Skin, Below Top Ring, Hoop	-16	82
S8B	Pedestal Skin, Below Top Ring, Meridional	220	256
S9A	Pedestal Skin, at Mid-Length, Hoop	-15	-15
S9B	Pedestal Skin, at Mid-Length, Meridional	47	47
S10A	Glass, Well Area, Tangential	24	37
S10B	Glass, Well Area, Radial	75	41
S11	Hub Top Rim, Above Angle, Tangential	81	96
S12	Hub Top Rim, Above Angle, Tangential	72	96
S13	Hub Bottom Cross Channel, Above Bottom Flange	7	56
S14	Hub Bottom Cross Channel, Above Bottom Flange	16	56
S15A	Hub Bottom Plate, Near Hole, Tangential	-60	-90
S15B	Hub Bottom Plate, Near Hole, Radial	-81	-133
S16	Radial Beam "A," Above Top Flange	136	155
S17	Radial Beam "A," Below Bottom Flange	-204	-269

locations. Eighteen points on each of these two panels were loaded. The remaining foam panels were loaded at two points each. The glass and hat stringer panels, which were twice as large as the foam panels, were loaded at four points (Figure 6-28).

Instrumentation consisted of 6 strain gages and 25 displacement transducers. In addition, height gage measurements were made on the "fine" load panels at 80 locations. Natural frequency data was obtained by recording appropriately located displacement transducers on an oscillograph with an accurate time base.

Test Results

The strains measured in the structure were low, as had been predicted by the NASTRAN analysis. Excellent agreement between measured strains and analysis predictions can be seen in Table 6-18 for the pedestal locations. More typical agreement for such low strain values was exhibited by the remaining strain gages on the reflector panel support beams.

Displacement measurements were made at various positions along the panel support beams and on the torque tube. The NASTRAN analysis assumed that the torque tube was fixed at the center of its length. Therefore, it was necessary to add rigid body translations and rotations of that point to the NASTRAN-predicted displacements in order to compare with test measurements. Two of the displacement measurements were chosen so that the rigid body motion of the torque tube could be easily determined. The test data correlates well with the NASTRAN predictions and torque tube rigid body motion combined as shown in Table 6-19.

Height gage readings were used to correlate displacement measurements and to determine slope changes due to wind loading. The slopes changes from wind loading only were less than 2 mr on the two panels measured, which is well within requirements.

Figure 6-28. Inverting Heliostat Structural Test Setup

Table 6-18

COMPARISON OF MEASURED AND PREDICTED STRAINS
FOR INVERTED HELIOSTAT STRUCTURAL TEST

Strain Gage Location	Operational Test 26-mph Wind		Survival Test 90-mph Wind	
	Predicted	Measured	Predicted	Measured
Pedestal	-26	-27	-172	-174
Pedestal	20	19	143	150
Upper Flange Inboard Support Channel	23	21	127	99
Lower Flange Inboard Support Channel	-22	-15	-126	-63
Upper Flange Outboard Support Channel	30	25	167	133
Lower Flange Outboard Support Channel	-30	-15	-168	-93
Note: All strains in $\mu\text{in.}/\text{in.}$				

Modal frequencies were determined by exciting the heliostat manually and recording its response in yaw, pitch, and roll modes. The results are compared to the predicted response below:

	<u>Predicted (Hz)</u>	<u>Measured (Hz)</u>
Reflector Yaw	1.64	0.87 - 1.5*
Reflector Pitch	2.52	2.8
Reflector Roll	4.36	3.2

*Varies with amplitude: 1.5 for large amplitude motion and 0.87 for small amplitude motion, typical for structures with nonlinear stiffness, like "slop" or free-play in the drive unit due to its use in the life cycle testing.

Table 6-19

COMPARISON OF MEASURED AND PREDICTED DISPLACEMENTS
FOR INVERTED HELIOSTAT STRUCTURAL TEST

Displ Gage No.	Operational Condition 26-mph Wind		Survival Condition 90-mph Wind	
	Predicted	Measured	Predicted	Measured
1	-0.300	-0.290	-2.878	-2.766
2	-0.017	-0.017	-0.005	-0.028
3	0.009	0.006	0.272	0.228
4	-0.022	-0.023	-0.051	-0.082
5	-0.078	-0.076	-0.662	-0.636
6	-0.217	-0.212	-2.057	-2.005
7	0.266	0.235	3.009	2.786
8	-0.276	-0.278	-2.764	-2.730
9	0.000	0.000	0.056	0.053
10	0.023	0.022	0.318	0.298
11	-0.059	-0.060	-0.584	-0.557
12	-0.195	-0.192	-1.953	-1.882
13	0.266	0.246	2.964	2.813
14	0.005	0.005	0.081	0.080
15	0.027	0.027	0.327	0.329
16	0.076	0.065	0.874	0.784
17	0.076	0.073	0.874	0.819
18	0.076	0.063	0.874	0.789
19	-0.276	-0.280	-2.764	-2.738
20	0.266	0.243	2.964	2.794
21	-0.300	-0.280	-2.878	-2.656
22	-0.017	-0.009	-0.002	0.055
23	0.009	0.014	0.269	0.307
24	0.266	0.246	3.009	2.862
25	0.001	0.055	0.000	0.319

Note: All displacements in inches.

6.3.3 Environmental/Qualification Tests

SRE environmental/qualification tests are divided into two main categories:

(1) environmental and life cycle tests of the drive unit, (2) miscellaneous structure tests, such as segment bonding test, hail impact tests, first surface mirror tests, and second surface mirror tests.

6.3.3.1 Drive Unit

Environmental Tests

Octagonal Heliostat Drive Unit Environmental Tests

- A. Test Objective. The collector subsystem is being designed for a 30-yr operating life under the climatic conditions at the site. The objective of the test was to subject the heliostat drive unit and control sensors to the extremes in environmental conditions anticipated during the operating life and verify the operability of the components under those conditions.
- B. Test Procedure. The detailed test procedure is described in Test Documentation Drawing (TDD) 1T50006. The basic test conditions, selected from MIL-STD-810C, included:
 - 1. Operating under ambient conditions to establish initial operating data for comparison.
 - 2. Operating under temperature extremes of -22°F and 140°F.
 - 3. Rain up to 2 in /hour under 40-mph wind.
 - 4. Icing created by a driving rain under temperature of -22°F.
 - 5. Dust concentration of 0.3 grams per cubic foot driven at 1,750 fpm.
 - 6. Post-test operating under ambient conditions.

Figure 6-29 is representative of those conditions provided in the noted TDD and shows the drive unit during icing tests.

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Figure 6-29. Inverting and Octagonal Drive Unit Environmental Tests

C. Test Results

The results of all environmental tests are reported in TDD 1T50006. A summary of the test results is shown in Table 6-20 and the following comments:

1. The drive unit functioned without failure or operating degradation throughout all tests.
2. Nominal azimuth slew rate is 0.1 deg/sec CW and CCW. Nominal elevation slew rate is 0.13 deg/sec hub up and hub down.
3. Total zero-load backlash is 0.13 mr in azimuth and 0.04 mr in elevation.
4. The rotational characteristics of the elevation and azimuth motors appeared to be nearly linear relative to the number of AC cycles applied during the pulse test. During the slew tests, the average running RPM, steady-state running current, and power factor were 1,732 rpm, 0.4 amp, and 0.36 respectively.
5. All differences in data between the initial and final tests are negligible and within the accuracy range of the measurement systems.
6. No dust entered the operating mechanisms during the dust test.
7. Water entered the actuator drive screw area during the rain test.

D. Test Conclusions

The drive unit and control sensor successfully withstood the test environments with the following exceptions:

1. The actuator boot installation should be modified to prevent water from entering the drive screw area.
2. Operation of the drive unit in elevation while solid ice is still present on the exterior of the actuator boot should be precluded to prevent damage to the boot.

Inverting Heliostat Drive Unit Environmental Tests

- A. Test Objective. The collector subsystem is being designed for a 30-yr operating life under the climatic conditions at the site. The

Table 6-20
OCTAGONAL HELIOSTAT DRIVE UNIT ENVIRONMENTAL TEST RESULTS

Test Activities		Test Data	
		Initial	Final
Slew Rate Measurements	Azimuth	0.1 deg/sec	0.1 deg/sec
	Elevation	0.13 deg/sec	0.13 deg/sec
Backlash Measurements	Azimuth	0.06 mr	0.07 mr
	Elevation	0.02 mr	0.05 mr
Pulse Measurements	Azimuth	1 pulse = 1.9 revolutions	N/R
		3 pulses = 7.4 revolutions	N/R
		14 pulses = 17.8 revolutions	N/R
	Elevation	1 pulse = 0.9 revolutions	N/R
		3 pulses = 3.0 revolutions	N/R
		14 pulses = 10.9 revolutions	14 pulses = 11.0 revolutions
Motor Characteristics (RPM/Current Amplitude/ Power Factor)	Azimuth	1,754/0.55/0.35	1,743/0.57/0.35
	Elevation	1,710/0.54/0.38	1,730/0.60/0.36

objective of the test was to subject the heliostat drive unit and control sensor to the extremes in environmental conditions anticipated during the operating life and verify the operability of the components under those conditions.

- B. Test Procedure. The detailed test procedure is described in Test Documentation Drawing (TDD) 1T48678. The basic test conditions, selected from MIL-STD-810C, included:
1. Operating under ambient conditions to establish initial operating data for comparison.
 2. Operating under temperature extremes of -22°F and 140°F .
 3. Rain up to 2 in. /hr under 40-mph wind.
Icing created by a driving rain under temperature of -22°F .
Dust concentration of 0.3 grams/ft³ driven at 1,750 ft/min.
Post test operating under ambient conditions.

Figure 6-29 is representative of those conditions provided in the noted TDD and shows the drive unit during icing tests.

- C. Test Results. The results of all environmental tests are reported in TDD 1T48678. A summary of the test results is depicted in Table 6-21 and in the following comments:
1. The drive unit functioned without failure or operating degradation throughout all tests.
 2. Nominal azimuth slew rate is 0.25 deg/sec CW and CCW.
Nominal elevation slew rate is 0.25 deg/sec hub up and hub down.
 3. Total zero load backlash is 0.4 mr in azimuth and 1.8 mr in elevation.
 4. The rotational characteristics of the elevation and azimuth motors appeared to be nearly linear relative to the number of AC cycles applied during the pulse test. During the slew tests the average running RPM, steady-state running current, and power factor were 1,784 rpm, 1.0 amp, and 0.36, respectively.
 5. All differences in data between the initial and final tests are negligible and within the accuracy range of the measurement systems.
 6. No dust entered the operating mechanisms during the dust test.

Table 6-21
INVERTING HELIOSTAT DRIVE UNIT ENVIRONMENTAL TEST RESULTS

Test Activities		Test Data	
		Initial	Final
Slew Rate Measurements	Azimuth	0.25 deg/sec	0.25 deg/sec
	Elevation	0.25 deg/sec	0.25 deg/sec
Backlash Measurements	Azimuth	0.3 mr	0.3 mr
	Elevation	1.8 mr	1.7 mr
Pulse Measurements	Azimuth	1 pulse = 2.0 revolutions	1 = 1.9 revolutions
		3 pulses = 5.8 revolutions	3 = 4.9 revolutions
		14 pulses = 11.8 revolutions	14 = 11.2 revolutions
	Elevation	1 pulse = 5.0 revolutions	1 = 4.0 revolutions
		3 pulses = 12.4 revolutions	3 = 8.8 revolutions
		14 pulses = 17.9 revolutions	14 = 19.1 revolutions
Motor Characteristics (RPM/Current Amplitude/ Power Factor)	Azimuth	1,780/1.42/0.42	1,775/1.52/0.34
	Elevation	1,788/1.45/0.29	1,792/1.56/0.37

- D. Test Conclusions. The drive unit and control sensors successfully withstood the test environments.

Octagonal Heliostat Drive Unit Life Cycle Test

- A. Test Objective. The collector subsystem is being designed for a 30 year operating life which corresponds to approximately 10,000 cycles of the drive unit and associated position transducers. The test objective was to verify the operational integrity of the system components under simulated full-life operations.
- B. Test Procedure. The life test procedure was based on the assumption that the fatigue life of bearing surfaces would limit the life of the drives. The number of test cycles was determined from the following relationships.

The endurance limits of the bearing surfaces are related to the cycling loads by the equation

$$N_2 = \left(\frac{L_1}{L_2} \right)^{\frac{10}{3}} N_1$$

which is a characteristic equation for roller bearings. N_1 is the endurance limit in cycles for the load, L_1 , and N_2 is the endurance limit in cycles for the load, L_2 . On the basis of the cumulative damage theory of cyclic loadings, the test load and number of test cycles were calculated from the equations

$$\frac{\eta_T}{N_T} = \frac{\eta_1}{N_1} + \frac{\eta_2}{N_2} + - - - - + \frac{\eta_i}{N_i}$$

and

$$\eta_T = \frac{\sum_i \eta_i L_i^{\frac{10}{3}}}{L_T}$$

The subscript T indicates a test parameter. The numerical subscripts indicate specific wind conditions.

η is the actual number of cycles that the load L is applied.

By this approach, the life test can be conducted using only one level of loading, and can be greatly accelerated by judicious selection of the test load.

The final step is to reduce the wind frequency distribution and the motions of the heliostat over a 30-yr period to a tabulation of loads and corresponding number of cycles which can be introduced into the above equations.

The complete test procedure is described in TDD 1T5003, summarized as follows:

1. Pretest inspections of operating mechanisms including measurements of the actuator screw shaft eccentricity were made.
2. All drive mechanisms and motors were monitored under no-load conditions.
3. Life-test loads were applied and the drive unit was operated for the required number of cycles.
4. During the tests the motor characteristics vs slew rate, under the simulated limit loads, was monitored to determine the drive unit efficiencies.

Figure 6-30 is representative of those conditions provided in the noted TDD and shows the drive unit loading arrangement.

C. Test Results. All test results are recorded in TDD 1T50003. A summary of the results is depicted in Table 6-22 and in the following comments:

1. Nominal slew rates were essentially unchanged from previous tests, i. e., azimuth slew rate is 0.1 deg/sec and elevation slew rate is 0.13 deg/sec.

Figure 6-30. Octagonal Heliostat Drive Unit Life Cycle Test

Table 6-22
OCTAGONAL HELIOSTAT DRIVE UNIT LIFE CYCLE TEST RESULTS

Test Activities		Test Data	
		Prior to Life Cycle Test	After Life Cycle Test
Screw Extended			
● Actuator Screw	To: -17 in.	0.168 in.	0.284 in.
Eccentricity/Displacement	To: -29 in.	0.366 in.	0.540 in.
● Pulse Measurements	Azimuth	1 Pulse = 0.88 Revolutions	1 = 1.02
		3 Pulses = 4.3 Revolutions	3 = 4.7
		14 Pulses = 11.7 Revolutions	14 = 11.9
	Elevation	1 Pulse = 1.7 Revolution	1 = 1.4
		3 Pulses = 5.9 Revolutions	3 = 5.9
		14 Pulses = 13.3 Revolutions	14 = 13.9
● RPM Measurements (Slew Rate)	Azimuth	1,765	1,735
	Elevation	1,724	1,724
● Backlash Measurements	Azimuth	0.13 mr	0.13 mr
	Elevation	0.04 mr	0.23 mr
● Slew Rate Measurements	Azimuth	12 min - 17 sec	12 min - 16 sec
	Elevation	5 min - 53 sec	5 min - 53 sec
● Heliostat Closed Loop	Tracking	Maximum Peak Tracking	
		Error for Azimuth and Elevation = 0.52 mr	

2. The eccentricity and backlash of the actuator screw increased during the test. The 0.003-in. increase in backlash corresponds to a total increase in deflection (in elevation angle) from 0.04 to 0.23 mr.
 3. The rpm, running current, and power factor showed no degradation during the tests.
 4. The peak errors during the automatic tracking test were 0.52 mr in both the elevation and azimuth directions.
 5. During the test runs, both the azimuth and elevation motor couplings became disengaged as a result of set screws backing off.
- D. Test Conclusions. All system components operated satisfactorily during the tests with the exception that the motor couplings should be redesigned to ensure positive engagement under load and vibration.

Inverting Heliostat Drive Unit Development and Life Tests

- A. Speed Ratio. Orbidrives of various sizes were tested to determine static and dynamic efficiencies and backdrive characteristics. The efficiency data is shown in Figure 6-31. On the basis of the above test results, a speed ratio of $1,000^{\pm 100}:1$ was selected for the second stage to ensure adequate backdrive margin. A dynamic efficiency of 34% and a static efficiency of 12% were predicted for the 1,000:1 speed ratio.
- B. Ultimate Load. An elevation drive unit was subjected to a static load of 250,000 in. -lb without failure, as required. The unit failed at a load of 300,000 in. -lb.
- C. Stiffness. The stiffness of all units were found to exceed the design requirement of 158,000 in. -lb/deg.
- D. Backlash. The backlash of every unit was less than 2 mr, which exceeds the specified design requirement but has subsequently been found to be adequate for the proposed closed loop scheme.
- E. First-Stage Efficiency. The initial efficiencies which were measured were too low. The desired efficiencies were achieved by

Figure 6-31. Orbidrive Speed Ratio Effects

replacing the MIL-G-23827A grease with Shell Alvania EP-2 grease loaded with 5% Molycote Z powder. A thrust bearing was added between the input eccentric and the housing to eliminate excessive wear.

- F. Second Stage Efficiency. The dynamic efficiency of the second-stage orbidrives was found to be 24% at 23,000 in. -lb, rather than the specified value of 34%. Subsequent evaluation revealed that the achieved efficiency was adequate for the proposed design. The static efficiency ranged from 13% to 15%, exceeding the requirement of 12%.
- G. Life Tests. The life test was defined by the process described previously for the elevation drive loads. Since the drive elements in the azimuth drive were the same as the drive elements in the elevation drive, and since the azimuth loads are much lower than the elevation loads, life tests were conducted under elevation loads only. The life test was defined as 323 cycles of a unidirectional load of 70,000 in. -lb, where a cycle consisted of 180 deg of rotation one way and then 180 deg of rotation in the opposite direction back to the starting point.

During the life test program, excessive wear was detected between the first-stage eccentric and its housing. A design change was made which installed a thrust bearing between the eccentric and its housing. This change eliminated the noted wear problem.

A life test was satisfactorily completed on a drive configuration which was lubricated with an 80-140 oil with an additive of 5% Molycote Z powder. Test results are summarized in Figures 6-32 and 6-33.

The rollers and cam of the above unit were replaced and it successfully completed a life test while lubricated with Alvania EP-2 grease. Test results are summarized in Figures 6-32 and 6-33.

Figure 6-32. Orbdrive Life Test Results

Figure 6-33. Orbdrive Life Test Results

The wear encountered during the above tests, in the form of increased backlash, is not the wear of a 30-yr life. The drives would have to be tested under a load which simulates the mirror gravity moment to accurately determine wear life. The total number of cycles in this test would have to equal the actual number of cycles applied over the 30-yr period. However, calculations, based on the L_{10} life test data, indicate that the azimuth and elevation backlash will increase less than 0.5 and 9 mr, respectively, over a 30-yr life.

H. Backdrive Margin. Backdrive margin of the second stage was demonstrated by a test which determined the amount of input torque required to start motion in the same direction as an applied load. The amount of input torque is a measure of the backdrive margin. The test results shown in Figure 6-34 indicate adequate margin against backdriving.

I. Conclusions and Recommendations. The orbidrive drive units, with the modifications which were made to the original configurations during the test program, will meet their design objectives. The modifications which were made are:

1. The drives were lubricated with Shell Alvania EP-2 grease with 5% Molycote Z powder added.
2. The joint between the reacting disc and reacting shaft of the azimuth second-stage was moved to a point just below the lower Timken roller bearing.
3. A thrust bearing was installed in both the first and second stages which will carry the axial loads of the cam eccentrics.

In addition, it is recommended that grease passages be incorporated in future designs of the second stages which connect the rollers to grease fittings. The grease passages will ensure that the rollers will be adequately greased during any relubrication operation.

Figure 6-34. Backdrive Test Results

6.3.3.2 Miscellaneous Structure Tests

Segment Bonding Tests

Stabond X-1894 polyurethane adhesive had been evaluated under MDAC funding and qualified for use in bonding front surfaced mirrors to steel structure. The tests included: (1) adhesion and shear modulus at room temperatures, 0°F, and +140°F, (2) desert aging studies with 100-hr and 1,000-hr outdoor exposure results showing no significant degradation (10,000-hr exposure results due in April 1977), and (3) tensile fatigue test run at room temperature, subjecting double-lap shear specimens to 10^6 cycles of 15 to 150 psi, run at 1,000 cycles per minute, with no specimen failure.

Under this contract MDAC initiated a program to obtain a fast curing adhesive to improve the efficiency and cost-effectiveness of the bonding process. The first candidate evaluated was Stabond X-2035 polyurethane. This product took 1-1/2 hr to develop sufficient cure to support 8 psi in shear and 3 hr to develop capability of supporting 8 psi in tension. This was a significant improvement over X-1894, which took about 18 hr at $72 \pm 2^\circ\text{F}$ to achieve the same state of cure. Both shear and tensile adhesion tests showed this product to be low in adhesion at both room temperature and at +140°F. Stabond reexamined this product and decided that it required an elevated temperature cure to improve its properties. The second candidate evaluated was Stabond X-2052. This product took 4 hr to cure at room temperature to develop sufficient strength to support 8 psi in shear and tension, and had acceptable room temperature and 0°F adhesion, but the +140°F adhesion was very low. MDAC decided to subject the adhesive double lap shear joint to an ambient temperature tensile fatigue test as described above, but all specimens failed adhesively to glass somewhere between 11,000 cycles and 148,000 cycles. Based on the failure of this adhesive in the fatigue test, all further evaluation of X-2052 adhesive has been discontinued.

Although Stabond X-1894 is qualified for pilot plant applications, additional development of a fast-curing adhesive is required to minimize Pilot Plant fabrication costs.

Hail Impact Tests

Heliostats will be occasionally subjected to hail impact throughout their 30-yr service life. Hail impact effects on the reflective surface/protective acrylic overcoating, and different types of glass/foam sandwiches were determined in this series of tests.

- A. Test Objectives. The main objectives of the hail tests were:
 - 1. To determine the effects of hail impact on the SRE baseline heliostat reflective surface protective coating.
 - 2. To determine if fracture or cracking of the inverted heliostat reflector occurs due to impact of 19 mm (0.75 in.) diameter hail stones at 20 m/s (65 fps) and 25 mm (1 in.) diameter hail stones at 23 m/s (75 fps).
- B. Approach. The tests simulated a severe hail storm by impacting the test specimens with the specified maximum diameter hail stone at nominal terminal velocity. The test specimens were representative of the full-scale hardware for both the baseline and inverted heliostats. A typical impact location diagram for our inverted heliostat specimen is shown in Figure 6-35.

Most of the specimens tested were different reflector designs for the inverted heliostat: 1/8-in. (or 3/16-in.) float glass with hat section stringers, 1/8-in. (also 3/32-in. and 3/17-in.) float glass plus Styrofoam sandwich, 3/32-in. ASG sheet glass plus Styrofoam sandwich. One 14 in. x 24 in. baseline heliostat specimen of 1/4-in. front surface mirror with acrylic coating was also tested. Survival means no damage sustained in a series of six shots at one velocity.

- C. Test Setup. The simulated hail impact tests were conducted in the MDAC Experimental Stress Analysis Laboratory. A schematic of the test setup is shown in Figure 6-36. A hail stone was made by freezing a piece of ice to the proper diameter using a special aluminum mold. The hail stone was then loaded into the launch tube. The manual valve was opened and the reservoir was pressurized to a predetermined value. The spring driven valve was opened and the pressure was released, driving the hail stone down

Figure 6-35. Typical Impact Location Diagram – Hall Impact Tests

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Figure 6-36. Schematic of Hail Test Setup

the launch tube to impact with the target. The launch tube had two electric eyes located a known distance apart at the target end. The electric eyes were connected to a timing device. The time for the hail stone to travel a known distance was measured and the velocity was determined. The hail impact test results are given in Table 6-23.

Table 6-23
HAIL IMPACT TEST RESULTS

Specimen	Survival Without Damage		Comments
	19 mm (3/4-in.) dia at 20 m/s (65 fps)	25 mm (1-in.) dia at 23 m/s (75 fps)	
1/4-in. Front Surface Mirror with Acrylic Coating	Yes	---	Not Tested
1/8-in. Float Glass Plus Hat Sections	Yes	No	
3/16-in. Float Glass Plus Hat Sections	Yes	Yes	1-in. at (a) 100 fps
0.083-in. PPG Float Glass Plus Foam Sandwich	No	---	
1/8-in. Float Glass Plus Foam Sandwich	Yes	Yes	1-in. at (a) 100 fps
3/32-in. Float Glass Plus Foam Sandwich	Yes	No	
3/16-in. Float Glass Plus Foam Sandwich	Yes	---	3/4-in. (a), at (b) 85 fps
3/32-in. ASG Sheet Glass Plus Foam Sandwich	Yes	No	
Note: (a) Test data			
(b) Has additional capability, greater than 1 in. at 100 fps			

First Surface Mirror Tests

Introduction. About mid 1976 it was discovered that considerable degradation of the reflectivity of the first surface mirrors for the thermal power system (TPS) had taken place. Moreover, the degradation had taken place over a relatively short period of time. It was, therefore, necessary to discover the cause(s) of the degradation and implement changes in the design necessary to obviate the problem. A preliminary microscopic examination of the acrylic first surface protective coating revealed considerable contamination. Particulate matter could be seen both embedded and imbibed in the coating. It was further discovered that some industrial cleaners could penetrate the acrylic film and react with the thin chemically deposited silver layer. The particulate contamination in or on the film was found to be typical shop-type dirt present in the acrylic coating materials and solvents and in the production area when the coatings were applied.

Having this information, a plan was devised to determine the cause of the rapid deterioration of the production mirrors' reflectivity.

First, determine whether the film is itself permeable to undesirable elements or whether foreign particulate matter allows "wicking" through the film. Sheldahl, the supplier of the production acrylic coating, was contracted by MDAC to run a series of coated mirror specimens using "dirty" coatings purposely contaminated with air and moisture and a series of "clean" coated mirror specimens. These were to be tested both at Sheldahl and MDAC.

Second, determine whether the clean Sheldahl acrylic coating is the best first surface mirror protective coating. Other suppliers had to be solicited for candidate protective coatings and tested by Sheldahl and MDAC.

Object. The object of this study is to determine the cause of the deterioration of the Sheldahl acrylic coating system and determine whether a superior system can be found, using the Sheldahl production acrylic coating 822-12A as a basis for comparison.

Procedure. Fifty float glass mirrors 5 in. x 5 in. x approximately 0.25 in. were prepared by Sheldahl with "clean" and "dirty" 822-2A acrylic coatings as follows:

One set of 10 "dirty" or contaminated mirrors was prepared with a coated film thickness of 0.001 in. The coatings were prepared with "as received" materials and were modified by the addition of the maximum amount of water allowed by solvent specification before application.

Four sets of 10 mirrors each were prepared with "clean" coatings, having final film thicknesses of 0.0005, 0.001, 0.0015, and 0.002 in., respectively. The procedure for preparation of pure materials for the "clean" coatings was as follows: Solvents to be used were dehydrated by mixing with molecular sieve materials in bottles and allowed to stand for 8 hr. After this time, the solvents were poured into a Gelman pressure rinser and pressurized to 20 psi using dry N₂. They were forced through membrane filters (using the smallest pore size consistent with the viscosity of the solvent) into clean bottles, and either purged with dry N₂ and sealed for later use, or used immediately to prepare coating solutions. In the latter case, the batch was then mixed and forced through a 0.45- μ m Alpha 6 membrane filter using the Gelman bottle at 40 psi. The resin solution was kept in clean bottles purged with dry N₂, or else used immediately.

Some of the original commercial float glass mirrors, manufactured by South Carolina Mirror Co. and coated with the "as received" Sheldahl 822-12A acrylic coating, were used as the control standards representing the first surface mirrors for the TPS. Several mirrors of this same lot were sent to coating suppliers for application of an abrasion-resistant coating (or overcoat) of the suppliers' recommended choice.

A third set of mirrors was manufactured by the Buchman Mirror Co. The chemically deposited silver of these mirrors was protected by a dry nitrogen atmosphere in heat-sealed polyethylene-coated aluminum foil bags. (Note: Specular reflectance of mirrors so packaged did not degrade after periods of up to 88 days.) Mirrors from this set were sent to suppliers for the

application of their recommended coatings and have been designated as "Other First Surface Coatings."

The abrasion-resistant or overcoated mirrors, as well as the other first surface-coated mirrors, were returned to MDAC for screening tests. The most acceptable of these were sent to Sheldahl for more precise measurements of reflectivity and abrasion resistance.

The abrasion-resistance tests conducted by Sheldahl were made on apparatus described in Sheldahl's report No. SER-60-231. Thirty grams of a specific Nevada sand were blown normally onto the test surface at 6 m/s. Optical measurements were made before and after abrasion, the loose sand being rinsed off with distilled water and the mirror allowed to air-dry before the final measurement.

All Sheldahl optical measurements were made on the Sheldahl Inc. specular spectrophotometer. The reflectance was measured at acceptance angles of 4, 8, and 16 mr at 10 wavelengths which correspond the mid-points of the 10% energy bands comprising the air mass 2 solar spectrum. All MDAC screening reflectivity measurements were made on a Sheldahl designed and manufactured portable reflectometer tester model SC223B. This instrument was designed to have an acceptance angle of 4 mr at a wavelength of approximately 561 nm. Considerable rework of the electronic circuitry on this instrument was necessary, however, to make it operable and to stabilize its output.

Some total reflectances were made early in the screening program to preclude the possibility that the portable reflectometer could not be made operable. These measurements were made on the Gier Dunkle mobile solar reflectometer MS-251.

In the screening of other first surface mirror coatings, as well as testing the Sheldahl "clean" and "dirty" coatings, two factors were felt to be of primary importance in the degradation of the mirror reflectance. First, the

permeability of the film to elements deleterious to a metallic silver surface; and second, the lack of resistance the film would have to an aggressive cleaning solution.

Some of the common constituents of the atmosphere are compounds of sulfur, and are among the most visual reactants with a silver surface. For this reason they were selected as detectors of film permeability. Several sulfide-type photographic toning formulations were examined but found to be too benign. The final choice was a 4% aqueous solution of ammonium sulfide. In a closed container the cleaned test mirrors were supported above the test solution and exposed to the humid vapors of ammonia and hydrogen sulfide. By removing mirrors from this environment in increasing time intervals, both visual and instrumental degradation of specular reflectance could be easily detected.

The second environment all mirrors will see is the periodic application of a cleaning solution. To accelerate this exposure and note its effect on film integrity, an industrial acid-type detergent solution was fortified with the addition of 0.4% by volume of 70% hydrofluoric acid. Initial tests on total immersion of specimen mirrors in the test detergent solution resulted in severe edge penetration, i. e., the protective film lifted from the edges and the silver was rapidly attacked. The test was, therefore, modified by using a small volume (25 ml) of acidified detergent mixture in a watch crystal fitted with a rubber gasket. The test solution was poured into the gasketed watch crystal, the test mirror, film down, placed upon the gasket, and the assembly inverted. The gasket and atmospheric pressure kept the test solution in place, and at the end of 16 hr a specular reflectance measurement was made on the treated area.

Normal 5% salt spray tests were run on screening test specimens for 450 hr, and reflectance measurements and arbitrary numerical ratings of appearance were made. Sheldahl "clean" and "dirty" coating test mirrors were exposed 240 hr, and their before and after specular reflectance measurements made.

Outdoor exposure specimens were adhesively bonded to aluminum mounting strips and horizontally positioned, silvered surface up, at Huntington Beach and China Lake. The tests are continuing.

To simplify the identification of the various protective coating systems, the test mirror specimens were given a numerical code as shown in Table 6-24.

Results. To determine a suitable treatment time in the 4% solution of ammonium sulfide, a series of exposure times versus specular reflectance (ρ) of the various vendor and Sheldahl production coatings was made. The curves in Figure 6-37 indicate that an exposure of 3 hr is sufficient to indicate the relative permeability of the coatings examined.

Figure 6-38 shows the results of a similar test to determine an effective exposure time of an acidified detergent solution on Sheldahl production and other first surface protective coatings. It would appear that a minimum exposure of 12 hr is necessary to give a significant data spread.

It is also interesting to note that, although the test media in Figure 6-37 is mildly alkaline and gaseous and that in Figure 6-38 is acid and aqueous, the materials under test retain their relative chemical resistances as measured by their specular reflectivities.

Table 6-25 is a summary of the test results of the relative permeability of candidate abrasion-resistant materials. Three of the eight materials tested were more resistant to sulfide reaction than the Sheldahl production coating. Only one of the three, however, exhibited the reflectivity of the control before exposure. Due to insufficient test material, with the exception of Specimen 107, acidified detergent tests were not run. The correlation between total and specular reflectance was poor at best before exposure and nonexistent after sulfide exposure. The subjective rating of salt spray resistance was found to have a fair degree of correlation with the portable reflectometer measurements.

Table 6-24
NUMERICAL CODE FOR TEST MIRROR SPECIMENS

Abrasion Resistant Coatings		
Specimen No.	Manufacturer	Product Designation
92	Owens Illinois	650
93	Owens Illinois	650 M
94	Sierracin	FX-103
95	Texstar	C-254
96	Texstar	2565-212
97	Swdflow	SWED 66A2CA
98	Minnesota Mining	3M ARC
107	Air Lock	C Resin
Control	Sheldahl	822-12A
Other First Surface Coatings		
99	Du Pont	500 S IMRON
100	Du Pont	326 L
101	Du Pont	RK3637
102	Sierracin	FX-103
103	Texstar	C-254
104	Texstar	C-254 Uncured
105	Owens Illinois	650
106	Owens Illinois	650 M
Aluminized Film		
108	Minnesota Mining	Acrylic/Al/Polyester
Sheldahl Upgraded Coatings		
	0.5 mil clean 822-12A	
	1.0 mil dirty 322-12A	
	1.0 mil clean 822-12A	
	1.5 mil clean 822-12A	
	2.0 mil clean 822-12A	
Control	Sheldahl Production 822-12A

Figure 6-37. Effects of Ammonium Sulfide Vapors on Specular Reflectance of First Surface Coatings

Figure 6-38. Effects of Acidified Detergent on Specular Reflectance of First Surface Coatings

Table 6-25

RELATIVE PERMEABILITIES OF ABRASION RESISTANT COATINGS (OVERCOATINGS)

Specimen No.	ρ Before Exposure*	ρ (NH ₄) ₂ S Exposure*	ρ HF-Detergent Exposure*	ρ and Salt Spray Rating	ρ Sheldahl Test** Before-After Abrasion
92	0.79-0.80 (0.92)	0.54-0.55 (C. 81)	--	0.02 7	
93	0.77 (0.92)	0.50 (0.80)	--	0.03 6	
94	0.77 (0.90)	0.47 (0.82)	--	0.39 4	
95	0.81-0.82 (0.91)	0.73 (0.88)	--	0.1 5	0.80 --
96	0.79 (0.92)	0.48-0.49 (0.78)	--	0.44 1	
97	0.72 (0.97)	0.55-0.56 (0.79)	--	0.39 2	
98	0.77 (0.92)	0.75-0.76 (0.93)	--	0.3 3	0.55*** 0.54***
107	0.77 (0.92)	0.70 (0.88)	0.49		
Control	0.80 (0.92)	0.50 (0.77)			

*Values in parenthesis are total reflectances measured on the Gier Dunkle solar reflectometer Model MS 251.

**Specimens 95 and 98 were selected as candidates for Sheldahl lab tests on the basis of least degradation to (NH₄)₂S, since insufficient test material was available to run HF resistance. Values for ρ are those measured for $\lambda = 561$ nm and 4 mrad acceptance angles.

***Specimen 98-1 (overcoated) had a ρ of 0.70. The values given above are from specimen 98-2.

Table 6-26 is a summary of the test results of the relative permeability of other first surface coatings. Two coatings equalled the reflectivity of the Sheldahl control before exposure. Five coatings were more resistant to sulfide attack than the Sheldahl control, and all eight of the coatings tested were superior in acidified detergent resistance. Good correlation is seen to exist between the numerical rating and instrumental measurements of salt-spray-tested specimens. Sheldahl test results agreed reasonably well with the portable reflectometer measurements.

Table 6-27 is the test data collected on the only metallized-film-bonded-to-glass mirror submitted. Its resistance to sulfide and salt spray was good, but it shows low abrasion resistance. The acidified detergent resistance is about average for the candidate materials tested. The Sheldahl reflectivity at 561 nm is much lower than the value obtained on the portable reflectometer. This would indicate some variability in the metallized film rather than instrumental differences, since good agreement can be found between most other values of reflectance for the Sheldahl specular spectrophotometer and the portable reflectometer.

Table 6-28 is the summarized test data for the "clean" and "dirty" first surface coatings produced and tested for reflectance and abrasion resistance at Sheldahl and for sulfide and acidified detergent permeability at MDAC. The relative performance of the various coatings was measured at MDAC by the portable reflectometer. Sheldahl reflectance values are those taken from their specular spectrophotometer. Only those values of reflectance at a wavelength of 561 nm and 4 mr are recorded. There is no clear trend to indicate a loss in reflectivity with increasing film thickness in the thickness range examined. Increasing film thickness does indicate more protection, hence less permeation of that media. The differences in reflectivity of "clean" and "dirty" 1-mil coatings are minor, if any. It is, therefore, doubtful at these film thicknesses and at the contamination level represented by the "dirty" coating that any film degradation results from film discontinuity or wicking due to particulate matter.

Conclusions. The Sheldahl production coating 822-12A and the experimental "clean" and "dirty" Sheldahl acrylic coatings exhibited the highest initial reflectances of any of the materials tested. After laboratory chemical exposure, however, 60% of the candidate first surface coating materials show

Table 6-26

RELATIVE PERMEABILITIES OF OTHER FIRST SURFACE COATINGS

Specimen No.	ρ Before Exposure	ρ (NH ₄) ₂ S Exposure	ρ HF-Detergent Exposure	ρ and Salt Spray Rating	ρ Sheldahl Test Before-After Abrasion
99	0.83 (0.91)	0.79 (0.89)	0.81 (0.90)	0.63 1	0.79 0.67
100	0.83 (0.91)	0.71 (0.87)	0.77 (0.91)	0.60 3	0.83 --
101	0.84 (0.92)	0.80-0.81 (0.91)	0.79 (0.91)	0.31-0.32 5	0.83 0.62
102	0.82 (0.92)	0.41 (0.73)	0.37 (0.94)	0.46 4	0.87 0.83
103	0.82 (0.91)	0.62 (0.88)	0.50 (0.95)	0.59 2	
104	0.82 (0.91)	0.52 (0.80)	0.56 (0.92)	0.21 6	0.82 0.82
105	0.84 (0.93)	0.4-0.5 (0.28)	0.60 (0.94)	0.19	
106	0.59 (0.92)	0.3 (0.30)	0.54 (0.87)	0.08	
Control	0.84 (0.92)	0.44 (0.73)	0.35 (0.84)		

Table 6-27

RELATIVE PERMEABILITIES OF ALUMINIZED FILM BONDED TO GLASS

108	0.83 (0.86)	0.83	0.61 (0.70)	0.83	0.74	0.58
Control	0.82 (0.92)	0.71	0.36 (0.83)			

Table 6-28

RELATIVE PERMEABILITY OF SHELDAHL "CLEAN" AND "DIRTY" FIRST SURFACE COATINGS

Film Thickness	Condition	ρ Before Exposure	ρ (NH ₄) ₂ S Exposure	ρ HF-Detergent Exposure	ρ Salt Spray 240 hrs	ρ Sheldahl Values Before-After Abrasion	
0.0005 in.	Clean	0.82 (0.92)	0.10 (0.35)	0.17 (0.88)	0.52	0.86	--
0.0010 in.	Dirty	0.89 (0.94)	0.46 (0.74)	0.25 (0.93)	0.86	0.85	0.83
0.0010 in.	Clean	0.85 (0.93)	0.34 (0.65)	0.31 (0.88)	0.86	0.87	0.84
0.0015 in.	Clean	0.79 (0.92)	0.62 (0.83)	0.32 (0.90)	0.84-0.85	0.87	--
0.0020 in.	Clean	0.81 (0.98)	0.55 (0.80)	0.49 (0.92)	0.85-0.86	0.85	0.84
Control		0.81 (0.92)	0.36 (0.68)	0.19 (0.57)	0.59		

more sulfide resistance than the Sheldahl production coating used on the heliostat for the central receiver. All of the coatings tested exhibited more detergent resistance than the Sheldahl material. The Sheldahl production coating 822-12A can, therefore, be easily outperformed if some sacrifice in reflectance is made.

Overcoating the Sheldahl production coating does little to enhance its performance. Other combinations, however, might be more successful, i. e., the most abrasion-resistant coating, Specimen 102, as measured by the Sheldahl specular spectrophotometer*, might be used to overcoat a more chemically resistant film, such as that represented by No. 99, 100, or 101. This system would probably reduce the initial reflectance far below an acceptable level, however, even assuming the film combination was compatible.

The fact that increasing the film thickness of the Sheldahl "clean" and "dirty" coatings increases its laboratory-tested environmental resistance, and that there is little difference between 1-mil "clean" and "dirty" coatings, is strong evidence to support the view that the original failure of the central receiver heliostat first surface mirrors was a combination of insufficient film thickness and chemical resistance. Particulate contamination at the levels tested appears to have little effect on the mode of failure. To provide more reliability for the first surface concept, thicker, more impervious coating materials must be used. This will necessarily reduce the reflectivity and not necessarily solve the edge attack all films are susceptible to.

Finally, the question of long-term utility must be answered by field testing. To date, short-term field testing results (100 days) are not encouraging.

Second Surface Mirror Tests

This subsection describes the component level tests for the second surface mirror program. A series of 11 different tests of the foam sandwich core reflector was conducted on various sizes of specimens. A summary of the test type, test specimen size and number, and location of tests is shown in Table 6-29. Detailed descriptions and results for each test follow:

*See Sheldahl Report No. SER 1005-60.

Table 6-29
COMPONENT LEVEL TEST MATRIX

Test Type	Test Specimen Size (In.)	Test Specimen Number	Conductor/Location
1. Flatness	42.5 x 114 42.5 x 114	1D40004-1 Ser 3 1D40004-507 Ser 4 1D40004-511 TS Ser 1	MDAC-Huntington Beach
2. Thermal/ Backlighting	42.5 x 30	1D40004-511 TS Ser 1 1D40004-513 TS Ser 1	MDAC-Huntington Beach
3. Thermal Cycle	42.5 x 30	1D40004-511 TS Ser 1	MDAC-Huntington Beach
4. Thermal Distortion	42.5 x 114	1D40004-507 Ser 4	MDAC-Huntington Beach
5. Washing	Full Heliostat	1D40002 Var 003 and 004	MDAC-China Lake, CA
6. Reflectivity	5 x 5	See Note	Sheldahl Northfield, MN
7. Exposure	5 x 5	1S, 2S, 1F, 2F	MDAC, Fort Irwin, CA
8. Salt Spray	5 x 5	3S, 4S, 3F, 4F	MDAC-Huntington Beach
9. Accelerated UV	3 x 3	6S, 7S, 8S, 6F, 7F, 8F	Sandia, Albuquerque
10. Compatibility	N/A	N/A	PPG, East Point, GA Glidden, Atlanta, GA
11. Creep	2 x 24	B1, B2	MDAC-Huntington Beach

NOTE: These specimens will consist of 2-1/8 in. sheet glass mirrors,
2-3/32 in. sheet glass mirror and 2 pieces of 0.0217 galvanized
sheet steel.

A. Flatness Tests

1. Test Objective. To measure the flatness of foam sandwich core panels for design verification.
2. Test Specimens and Instrumentation. One 42.5 in. by 30 in. float glass panel and two full-scale panels 42.5 in. by 114 in. were measured. One full-scale panel was made with 1/8 in. sheet glass and one panel with 3/32 in. float glass. The 42.5 in. by 30 in. panel was instrumented with six thermocouples. No instrumentation was installed in the full-scale panels.
3. Test Procedure. The panels were set on a surface table with the four attach points in a plane. Measurements taken at approximately 40 points on the surface in a grid of 12 inch spacing for the full-scale panels. For the small panel, 30 measurements were taken on the surface in a grid of 6-in. spacing. Measurements were taken with a transit and were accurate to ± 0.001 in.
4. Test Results. Typical flatness measurements are shown in Figure 6-39. The worst vertical deflection was 0.035 in. at one corner.

B. Thermal/Backlighting Test

1. Test Objective. To determine maximum temperature and gradients due to front surface exposure and backlighting.
2. Test Specimen and Instrumentation. Test panels 30 x 42.5 in. with six thermocouples each were used. One test panel was made with 1/8 in. sheet glass and the other with 3/32 in. float glass.
3. Test Procedure. Panels were placed outdoors with the mirror facing the sun. Temperature of the glass foam and steel were monitored for two "sunny" days to determine maximum temperature and gradients due to front surface exposure. The tests were repeated with the steel backing sheet facing the sun to determine maximum temperature and gradients due to backlighting.
4. Test Results. The thermal backlighting test results are summarized in Table 6-30.

6-115

TOP VIEW
(ALL MEASUREMENTS IN IN.)

PART NO. ID 40004-507
SER NO. 4
INSP
DATE 2/11/77

Figure 6-39. Typical 42.5 x 114-in. Panel Flatness Measurements

Table 6-30
THERMAL BACKLIGHTING TEST RESULTS

Test Panel Glass Type	Glass Facing Sun		Steel Facing Sun	
	Max Temp(°F)	Max ΔT(°F)	Max Temp(°F)	Max ΔT(°F)
3/32-in. float glass	79	10	112	38
1/8 in. sheet glass	76	5	111	41

ΔT = Temperature differential between glass and steel.

C. Thermal Cycle Tests

1. Test Objectives. To determine if thermal cycling of foam sandwich core panels causes binding delamination or distortion.
2. Test Specimen and Instrumentation. One 42.5 in by 30 in. float glass panel with six thermocouples was tested.
3. Test Procedure. First, this panel had flatness measurements as outlined in Test No. 1. Then, the panel was placed in a temperature and humidity chamber where it was subjected to the following temperature cycles: -20°F to 120°F for 60 cycles at relative humidity of 50% at 70°F. The thermocouples were monitored to determine compliance with the above temperature ranges. After undergoing these tests, the panel was inspected for delamination and measured again for flatness.
4. Test Results. After thermal cycling, flatness measurements showed no significant differences compared to pretest values. However, a crack originated at an edge flaw and propagated across the specimen width. No delamination or edge seal degradation was seen.

D. Thermal Distortion

1. Test Objective. To determine the amount of thermal "curl" or distortion caused by the operational temperature range.
2. Test Specimen. One full-scale 42.5 in by 114 in float glass panel that has been measured for flatness was used.
3. Test Procedure. The test panels were placed on a flat surface in an oven. The temperature of the panel was allowed to equilibrate at 104°F and then 32°F. Flatness measurements

were then taken at both temperatures. These were then compared with the flatness measurements at room temperature to determine the amount of thermal distortion.

4. Test Results. The measured deflection due to thermal distortion was about twice the predicted value. As a result, tests were conducted in the range 30°F to 120°F to measure the coefficients of thermal expansion for the glass and steel used in the specimen. The measured glass α was 3.9×10^{-6} in./in./°F versus the 4.8×10^{-6} in./in./°F used in analysis (obtained from glass manufacturers). The measured steel α was 6.3×10^{-6} in./in./°F versus the analytical value of 6.8×10^{-6} in./in./°F

E. Washing Tests

1. Test Objective. To determine the effects of various washing solutions on the mirror and foam sandwich core reflector structure.
2. Test Specimen. Full-scale panels at the NWC test facility were used for these tests.
3. Test Procedure. Several washing solutions were tested. The heliostats were washed at various times of the day to determine the optimum time of day to wash. The effectiveness of each solution was evaluated by visual inspection and by measuring specular reflectance efficiency before and after washing. Any deleterious effects of washing on the mirror or core structure or edge seal was noted.
4. Test Results (See washing results in Section 6.4.4).

F. Reflectivity Tests

1. Test Objective. To determine the specular and total reflectance efficiencies of 1/8 in. sheet and 3/32-in. float glass second mirror and galvanized sheet steel.
2. Test Specimens. The specimen size for these tests was 5 in. by 5-in. Two 1/8-in. sheet glass mirror specimens, two 3/32-in. float glass mirror specimens, and two 0.0217 galvanized sheet steel specimens were measured.
3. Test Procedure. Specular and total reflectance efficiencies were measured by Sheldahl Corporation for each specimen. In addition, the specular and total reflectance efficiency of the

galvanized face sheet was measured to evaluate any possible backlighting problems.

4. Test Results (see Table 4-7 of Volume III, Book 1).

G. Exposure

1. Test Objectives. To determine if desert exposure has any deleterious effects on the foam sandwich mirror panels.
2. Test Specimens. Four 5 x 5 in. specimens were tested for exposure. Two specimens were made with 1/8-in. sheet glass and two were 3/32-in. float glass.
3. Test Procedure. The four specimens were mounted on an exposure rack at Fort Irwin, California and exposed to a desert environment. Periodic inspections at 2-mo intervals for a period of 6 mo were made to evaluate exposure effects.
4. Test Results (specimens were installed on 22 February 1977).

H. Salt Spray

1. Test Objectives. To determine if a damp salt environment will seriously affect the foam core sandwich mirror.
2. Test Specimen. Four 5 in. x 5 in. test specimens were used for these tests. Two used 1/8-in. sheet glass and two used 3/32-in. float glass.
3. Test Procedure. The four specimens were placed in a salt spray chamber and subjected to 400 hr of salt spray. The specimens were then removed and inspected for edge seal degradation/leaking or silver degradation.
4. Test Results. After 400 hr of salt spray, no degradation was noted in the mirror or edge seal.

I. Accelerated Ultraviolet

1. Test Objectives. To determine the effects of ultraviolet radiation on the foam core sandwich mirror.
2. Test Specimens. Six 3 in. x 3 in. specimens will be used for these tests. Three will contain 1/8-in. sheet glass and three will contain 3/32-in. float glass mirrors.
3. Test Procedure. The specimens will be sent to Leroy Reinhart at Sandia. He will subject the specimens to accelerated UV. Any damage or degradation will be noted.
4. Test Results. UV radiation tests began in February 1977. Results show no damage or degradation.

J. Compatibility

1. Test Objective. To determine compatibility of adhesives with mirror backing paints.
2. Test Specimens. No fabricated specimens are required for these tests.
3. Test Procedure. Samples of the polyurethane adhesive were sent to Glidden and PPG, the two major mirror backing paint manufacturers. They performed tests to determine if the adhesives are compatible with their mirror backing paint.
4. Test Results. The polyurethane adhesive was compatible with the Glidden and PPG gray alkyd melamine paints; no degradation was observed. However, some deterioration was observed for the Glidden white acrylic paint.

K. Creep Tests

1. Test Objective. To measure creep deflecting of the foam sandwich core under shear loading at two temperatures.
2. Test Specimens. Two 2 in. x 24 in. float glass beams were tested for creep.
3. Test Procedure. The beams were simply supported with 22 in. between supports. A 20-lb. weight was put at the center of the span. Deflection measurements at the center of the span were made initially and at the following intervals:

1/2 hr for the first 2 hrs

1 hr from 2 to 6 hr

Twice daily - 8:00AM and 4:00PM
from 6 to 72 hr

These tests were performed at room temperature ($\approx 75^{\circ}\text{F}$) and an elevated temperature of 120°F . One specimen was tested at each temperature.

4. Test Results. Creep test results and analyses of the Styrofoam IB showed that over a period of 30 yr, creep will cause an additional mirror rotation of 0.6 mr, which is acceptable. The creep analysis used a temperature-time shift factor and average desert day and night temperatures for each month of the year summed over 30 yr.

6.4 SRE HELIOSTAT ARRAY SUBSYSTEM TESTS

A series of engineering and extended life tests of five noninverting heliostats and one inverted stowage heliostat were conducted at the Naval Weapons Center, Randsburg Wash Test Site, China Lake, under operational and environmental conditions representative of Pilot Plant field conditions.

Tests were conducted with the heliostats emplaced and with the noninverting heliostat mounted on a mobile trailer. The mobile heliostat can be controlled up to 1,500 ft from a mobile test van. The mobile test van housed the heliostat control system (master control and field controller), peripheral data recording equipment, and the digital image radiometer TV system. Weather data monitoring, including solar insolation was also provided at the site. The heliostats directed the reflected solar insolation onto an instrumented target suspended approximately 70m high, between two towers 120m high. A view of the field is shown in Figure 6-40; the layout is shown in Figure 6-41.

Test activities included determination of reflective surface performance, heliostat tracking performance, effects of environmental exposure, and operations/maintenance procedures. Tests were performed from October 1976 through March 1977. Test results are discussed below.

6.4.1 Reflective Surface Performance

The objectives of the reflective surface performance tests were to determine the beam flux distribution, beam power, and reflector surface flatness. Beam distribution, reflector flatness, and power data were obtained using the digital image radiometer. Flatness measurements were also made with coaligned beam sensors and photographs of the beam images.

6.4.1.1 Noninverting Heliostat Beam Flux Distribution

The beam patterns for the canted (5 mr) Sheldahl acrylic coated heliostats (H1 and H2 in the emplaced position), are shown in Figure 6-42, Parts A and B. The canted (5 mr) laminate glass heliostat beam patterns are shown in Figure 6-42, Part C for the emplaced heliostat (H4) and in Figure 6-42, Part D for mobile heliostat H5, at the M1 field position.

Figure 6-40. Heliostat Array Test Site

NOTES:

UNLESS OTHERWISE SPECIFIED

1. LOCATE, STAKE & MARK POINTS C.P., N, E, W, H1, H2, H3, H4, H5, H6, H7, H8, D1, D2, H1, H2, H3, H4, H5, S1, S2, S3, S4, S5, S6, S7
2. DUST BUILDUP APPARATUS (IT47480) TO BE INSTALLED WITHIN 200 FT OF NWC CAMERA STA #3 (NOT SHOWN)
3. 240 VOLT 3Ø POWER MAY BE SUPPLIED FROM POWER PAD NORTH WEST OF TOWER #1
4. CAMERA STA #1 (NOT SHOWN) WILL HOUSE WEATHER INSTRUMENTATION

(A) EMPLACED HELIOSTAT H1 BEAM (SHELDAHL ACRYLIC)

(B) EMPLACED HELIOSTAT H2 BEAM (SHELDAHL ACRYLIC)

(C) EMPLACED HELIOSTAT H4 BEAM (LAMINATE GLASS)

(D) HELIOSTAT H5 BEAM FOR M1 POSITION
(LAMINATE GLASS)

Figure 6-42. Non-Inverting Heliostat Beam Images

6.4.1.2 Inverted Heliostat Beam Flux Distribution

The beam pattern for the emplaced inverted stowage heliostat, canted 5mr, is shown in Figure 6-43, Part A. Two reflector designs were tested on this heliostat: foam core panels (on the right side, facing the heliostat) and laminate glass (on the left side, facing the heliostat).

The distinctive tail beneath the elliptical image is from the lower portion of the beam sensor mirror. This misalignment was not seen in earlier tests of IH-1 with the reflector segments uncanted because the image was larger.

The initial foam core panels, as installed on IH-1, exhibited some severe beam nonuniformities. The effect was first noted when reflectance measurements were made and were found to vary between 60% and 116%, indicating a significant beam focusing and defocusing at distances of the order of 1.5 ft to 5.0 ft. The degree of beam nonuniformity observed indicated that a significant power loss due to beam spreading was possible, especially at distances of the order of several hundred feet or more. Therefore, tests were performed with the digital image radiometer (DIR) to compare the incident power on the target from the foam core and laminate panels, as well as compare the incident power with the theoretical incident power.

The accuracy of the DIR has been shown to be better than 2% (see Section 6.4.5.3). A known solar irradiance was reflected onto the target by four thoroughly clean 30 x 30 in. mirrors of known reflectivity positioned close to the target such that no significant power could be lost by wide-angle-beam spreading or attenuation. Power determined by the DIR agreed with the reflected power to within 1.3%.

High accuracy is expected for the comparison between the foam core and laminate panels since the measurements were made within 15 min of each other, the solar insolation was constant, and all pertinent system parameters (dark-current, lens setting, target position, temperature, etc) were constant. The test was performed by covering the foam core panel, recording the beam power while the heliostat was tracking, and then removing the covering and recording the total power. The beam distribution is normally

(A) HELIOSTAT IH-1 INVERTED STOW
(LAMINATE/FOAM CORE)

(B) MULTIPLE AIM STRATEGY (H1, H2, H4, IH1)

Figure 6-43. Inverted Heliostat Beam Images

presented as a computer output of 3,600 points (60 x 60 array) covering the portion of the target on which the beam is directed. For convenience, the irradiance distribution has been presented as three-dimensional plots in Figures 6-44 and 6-45 for the laminate panel and total heliostat reflector area (foam core and laminate.) The calibration curve generated for these runs is given for completeness in Figure 6-46. The noted depressions are the locations of the 2-in. diameter holes (with a 3-in. -dia black circle) at which the Hycal pyrhelimeters are mounted. The beam spread of the foam core relative to the laminate can be seen qualitatively. Measurements of the beam dimensions for the laminate were 3.81m and 4.03m (x,y) and for the foam core and laminate, 6.39m and 4.49m (x,y). Clearly, the foam core beam spread was significantly greater than the laminate. Intensity profiles are shown in Figures 6-47 and 6-48. Intensity is divided into 10 increments and displayed to demonstrate beam size and shape.

Power measurements obtained with the DIR are presented in Table 6-31, with corresponding theoretical values from the MDAC program CONCEN. The CONCEN program used the reflectivity as determined by pyrhelio-meter measurement made immediately prior to energy measurements. (The pyrhelimeter was moved to avoid shading and blocking.) Atmospheric attenuation has also been included. Although no data is available on visibility, we are certain the visibility was equal to or greater than 50 km, and therefore, the attenuation is 1.0 to 1.5% for a 200m slant range distance from the heliostat to the target. Comparison of the DIR power for the laminate panels with the theoretical power is good, especially in view of the uncertainty of the integrated average reflectivity of the panels (see Section 6.4.4.4). Reflectance measurements made at one spot on a mirror have been found to vary by ± 1 to $\pm 3\%$ when taken at widely spaced points. In addition, dust often tends to accumulate on edges, further dropping the average reflectivity. It is therefore reasonable to find that the measured power for the laminate is approximately 4% less than the theoretical power. However, additional wide angle beam-spreading losses due to the laminate mirror being dirty, as well as out-of-flatness effects, cannot be ruled out. The reflectivity measurement made with the pyrhelimeter corresponds to an aperture of 17.5 mr, which corresponds to a spread of 12 ft at the 680 ft slant range distance between the heliostat and target.

DATE= 15 110 80 80

FILE= 12

PEAK INTENSITY = 3,066 W/M²

HYCAL LOCATION

MAX VALUE = 158 MIN VALUE = 29 INTENSITY = 12.778 KWATTS

6-127

Figure 6-44. Laminate Glass Mirror Beam Distribution (IH-1)

6-128

Figure 6-45. Laminate and Foam Core Beam Distribution (IH-1)

Figure 6-46. Digital Image Radiometer Calibration Curve

Figure 6-47. Intensity Profile for Laminate Mirror (IH-1)

6.39M

CR39A
VOL III-2

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4.49M

Figure 6-48. Intensity Profile for Laminate and Foam Core (IH-1)

TABLE 6-31

THEORETICAL AND MEASURED POWER INCIDENT ON TARGET FOR
INVERTED HELIOSTAT FOAM CORE AND LAMINATE PANELS

	Power (KW)			
	Laminate Panels/ Sensor Mirror	Laminate Panels Only	Foam Core Panels Only	Total Reflector (Laminate, Foam Core, Sensor Mirror)
Theoretical Power CONCEN, 79% Reflectivity				
o No atmospheric attenuation	13.51	12.00	13.00	26.51
o Minimum attenuation, no aerosols (-1.0%)	13.37	12.85	12.85	26.22
o 50 km visibility (-1.5%)	13.30	12.79	12.79	26.09
o 23 km visibility (-2.5%)	13.17	12.66	12.66	25.83
Measured power from digital image radiometer	12.80 ± 1.86%	12.33	11.63	24.6 ± 1.3%
Percent difference of theoretical and measured power ($P_T - P_M/P_T$)				
o No atmospheric attenuation	5.2 %	5.1 %	10.5 %	7.2 %
o Minimum attenuation, no aerosols (-1.0%)	4.2 %	4.0 %	9.5 %	6.2 %
o 50 km visibility (-1.5%)	3.7 %	3.6 %	9.1 %	5.7 %
o 23 km visibility (-2.5%)	2.8 %	2.6 %	8.1 %	4.8 %
Percent measured power loss of foam core panels due to beam spreading, relative to laminate panel measured power		$\frac{12.33 - 11.63}{12.33} = 5.7\%$		

Test Conditions

Date: 4/4/77

Time: 1:30 PM

Heliostat: IH1, emplaced,
foam core and laminateSolar Insolation: 960 w/m²

Laminate Reflectivity: 79%

Foam core reflectivity: Unknown
estimated as 79%

Target Height: 220 ft, Distance: 680 ft

Area of laminate panels = 18.62m²Area of foam core panels = 18.62m²Area of sensor mirror = 0.72m²NOTE: Atmospheric attenuation determined for 200m slant range. Visibility on 4/5/77 was equal to
or greater than 50 km.

Thus, some portion of the reflected irradiance measured by the pyrhelio-meter may fall outside of the DIR scan on the target, or be spread to such a low intensity as to be indistinguishable from background irradiance falling on the target. For example, the DIR with a lens adjustment to measure a four-sun peak intensity has a sensitivity of approximately 10W/m^2 . Since the area outside the main beam on a DIR scan is about equal to the main beam area, approximately 1% of the total beam power could fall outside this main beam and be undetected relative to the background irradiance.

A comparison between the initial foam core panels and the laminated panels shows that the foam core incident power is 5.7% less than the laminate incident power and the foam core power is 9.5% less than the theoretical power. This loss also explains the difference between the total incident power measured and the theoretical power prediction for the total reflector area of IH-1 for minimum atmospheric attenuation, which differed by 6.2%. Later tests of acceptable foam core panels showed similar performance with the laminated panels.

6.4.1.3 Multiple Aim

Figure 6-43, Part B shows heliostats H1, H2, H4, and IH-1 aligned on the target. H4 is uppermost, H1 is at the bottom, and H2 and IH-1 overlap in the middle. There has been no significant shifting of the relative positions of these beams due to sensor misalignment for approximately 1 mo.

6.4.1.4 Heliostat Flatness Tests

On 2/22/77, a test was performed to determine surface flatness of a portion of IH-1, for the uncanted laminated glass. An instrument sensor, similar to the tracking beam sensor, but without noise filtering (low-pass 1/4 Hz) was mounted on a tripod facing the lower left corner of the heliostat and coaligned with the tracking sensor. Throughout the day, the heliostat tracked such that the spot seen by the instrument sensor moved across the surface as shown in Figure 6-49. The instrument sensor was monitored to determine the reflected beam angle as the spot seen by the sensor moved over the heliostat surface. During this test, the mirror surface normal was approximately 25 deg from horizontal. Figure 6-49 shows that the

INSTRUMENT SENSOR READING RELATIVE TO POLE-MOUNTED TRACKING SENSOR		
POSITION	ELEVATION (MR)	AZIMUTH (MR)
1	0	0
2	0	0
3	4	0.8
4	4	1.3
5	4.6	1.8
6	6.2	1.8

Figure 6-49. Surface Out-of-Flatness, Lower Left Hand Corner of IH-1 Laminate Glass Panel

elevation error increased to 6.2 mr relative to the initial position, with the error increasing as the spot moved across the bonded hatsection. The corresponding deflection of Points 3 and 4 relative to Point 2 is approximately 0.016 in. (assuming a linear profile for the glass between Points 2 and 3 and between 3 and 4. Similarly, the additional deflection of Point 6 relative to Point 4 is 0.066 in., and thus the total deflection of Point 6 relative to Point 2 is approximately 0.023 in.

It should be emphasized that coaligning the instrument sensor on the sun image reflected from the panel with the beam sensor aligned on the sun reflected from the sensor mirror does not mean that the two sensors are parallel. Therefore, the maximum error detected is not necessarily out-of-flatness relative to the sensor mirror, but the out-of-flatness of Point 6 relative to Point 1. Also, the observed error cannot be completely attributed to the panel, since the sensor mirror is not perfectly flat and some variation in beam angle will occur as the beam sensor alignment point on the sensor mirror changes. For this test, the sensor mirror slope variation was estimated to be less than 1.0 mr. This method of determining relative reflector out-of-flatness for installed panels under field conditions is accurate to within ± 0.5 to 1.0 mr, since the beam sensors are sensitive to slope errors well within ± 0.25 mr, the sensors are steady for the low wind conditions encountered, and the relative slopes between the tracking sensor and an instrument sensor are readily determined at a given time from strip chart data. However, the method is time-consuming and would require multiple sensors to evaluate the overall surface flatness. Therefore, further tests of this type were discarded in favor of obtaining beam distribution data from the digital image radiometer and beam image photographs.

On 3/28/77, a series of photographs were taken of the reflected beam patterns of the initial foam core panels and the laminated panels. Figure 6-50 shows a series of photographs that reveal striations in the beam image, focusing, and defocusing, and a distinctive box pattern from the foam core, corresponding to distortion areas of the glass roughly 2 ft x 2 ft. An estimate of the beam focusing/defocusing effect at 17 ft is shown in Figure 6-50, Part E; the resulting maximum slope error corresponds to a

(A) FOAM CORE 3 FT 9 IN. 13:20

(B) LAMINATE 4 FT 3 IN. 13:25

(C) FOAM CORE 9 FT 6 IN. 13:30

(D) LAMINATE 6 FT 6 IN. 13:35

Figure 6-50. Inverted Stow Heliostat Reflected Beam Patterns (Page 1 of 2)

(E) FOAM CORE 17 FEET 13:40 BOTTOM HALF FIRST PANEL,
TOP HALF SECOND PANEL

(F) LAMINATE 23 FEET 13:45 TOP OF FIRST PANEL,
BOTTOM OF SECOND PANEL SHOWN BY POINTER

(G) FOAM CORE 38 FEET 13:55 SIGNAL MIRROR, LAMINATE,
DARK AREA BELOW SIGNAL MIRROR

(H) FOAM CORE NEXT TO TOP PANEL 60 FEET 14:05

Figure 6-50. Inverted Stow Heliostat Reflected Beam Patterns (Page 2 of 2)

half-angle of approximately 24 mr. The degree of beam spread and focusing/defocusing for the laminate glass was noticeably less, as seen by comparing, for example, images E and F. Images of acceptable foam core panels showed a uniform pattern similar to the laminated panels.

6. 4. 1. 5 Backlighting and Shadowing

Backlighting and shadowing pose potential glass breakage and deformation problems from stresses set up in the reflectors due to variations in solar insolation. The emplaced heliostats were subjected to backlighting and shadowing for approximately 2 mo. There was no evidence of deformation and no breakage resulting from backlighting or shadowing.

6. 4. 2 Collector Tracking Performance

A series of tests were conducted of both the noninverting and inverted stow heliostats to determine tracking accuracy, stability, power consumption, and operation over a range of solar insolation values. The master control algorithms were verified.

6. 4. 2. 1 Beam Pointing, Noninverting Heliostat

Figure 6-51 is a composite of beam sensor errors for a noninverting (H3) heliostat under quiescent wind conditions in the north field for several times of day. A sensor calibration is included. This calibration consists of interrupting drive to the heliostat and allowing error to accumulate for a period of time. The sensor output in mv/mr can then be determined. It may be observed that under the relatively benign conditions, peak tracking errors are less than 0.5 mrad, with a mean value on the order of 1/8 mr lagging (each axis). (See Section 6.4 for wind effects.) An interesting sonic boom effect (-0.5 mr to + 0.3 mr) is also noted.

6. 4. 2. 2 Beam Pointing, Inverted Stow heliostat

Beam pointing data for the alternate (IH-1) heliostat under quiescent wind conditions in the north field is shown in Figure 6-52. A peak tracking error on the order of 0.75 mrad is observed. The mean tracking error is approximately 0.5 mrad lagging. Inconsistency in surface motion per drive pulse (friction variations) make mean error interpretation more difficult.

Figure 6-51. H3 - Non-Inverting Heliostat 11/23/76 - North Field - No Wind

Figure 6-52. IH-1 - Inverted 4/6/77 - North Field - No Wind

6. 4. 2. 3 Closed-Loop Stability

Both systems were designed as a part of the controls development tests to have 6 db of gain margin with a nominal sensor gain of 312 mv/mr. To date, both systems have demonstrated stable performance in the field, for wind, solar insolation, and tracking angle variations encountered.

6. 4. 2. 4 Operation Over Insolation Range

Tests performed on noninverting and inverted stow heliostats using neutral density filters to attenuate reflected sunlight at the sensor indicated that peak tracking errors of about 1.5 mr would occur at light levels of approximately 0.25 suns using typical SRE beam sensors. Testing was performed with winds of less than 10 knots. Since SRE beam sensors were typically on the low side (250-270 mv/mr) of the desired (320 mv/mr) sensor gain, additional error reduction in proportion to the sensor gain ratios can be expected.

Figure 6-53 shows SRE tracking sensor errors and solar intensity variations for the inverted heliostat during passage of a cloud. Solar intensity for a bright clear day should be approximately 10V. Cloud passage was noted by a gradual reduction in solar intensity (8V to 5V - not shown) and then a fairly sharp reduction and recovery (5V to 1.5V to 6.5V) as the thicker part of the cloud body passed over.

Sensor error output signals are proportional to error and solar intensity. In three areas the chart has been annotated and the absolute error in mv/mr shown. Peak tracking errors on the order of 1 mr may be observed.

6. 4. 2. 5 Multiple Heliostat Control

No degradation in tracking performance was observed with multiple heliostats under control. One through five heliostats were simultaneously controlled. Figure 43. Part B shows multiple images on the target.

6. 4. 2. 6 Severe Position Track

Severe position tracking (i. e. , "pole" position in South field) has yet to be demonstrated.

Figure 6-53. Cloud Passage — IH1 Tracking — North Field — No Wind

6. 4. 2. 7 Energy Consumption

The energy consumption (motor drive) of the noninverting and inverted stow heliostats exclusive of field controller consumption was determined for various operational modes including acquisition, track, and stowage. The field controller has a nearly constant power consumption of approximately 30W, assuming 25 heliostats are controlled.

Figures 6-54 and 6-55 show noninverting heliostat H4 energy consumption and power consumption respectively during an all day tracking test run on 2/2/77 with negligible wind conditions. Energy consumption was monitored at mode transition times and at regular 1-hr intervals. By observing a watt-hour meter inserted in the 240Vac line, relatively high energy consumption is noted while going to and from stowage. Energy consumption during the tracking is lower and relatively constant. In the first half-hour considerably higher energy consumption is noted (see Figure 6-55 for ease of interpretation). This is due to the fact that wide angle acquisition (transition from sun in field of view to track, not shown in Figure 6-55) requires several minutes at approximately half of the acquisition power consumption of mandatory commanded position. Mandatory commanded position requires that each affected motor be pulsed twice each second, whereas wide-angle acquisition requires that each affected motor be pulsed once each second. Variations during the day are due to a combination of (1) elevation motion direction (gravity moment helping or hindering), (2) temperature, and (3) tower and sensor pole shadowing in the 11 AM to 2 PM area. In general, power consumption will increase somewhat from the measured values as more motion occurs in the elevation axis for South, East, and West field positions and for summer, when the sun elevation angle is greater.

Figure 6-56 displays inverted stow heliostat energy consumption for various amounts of elevation axis motion. The motions simulate (1) inverted stowage (-90°) to acquisition (18°), (2) end of track (18°) to vertical stowage (90°), (3) vertical stowage (90°) to acquisition (18°), and (4) end of track (18°) to inverted stowage (-90°). Bringing the heliostat from inverted stowage (-90°) to acquisition (18°) consumed considerably more energy than the other increments of motion. Exclusive of the differences

Figure 6-54. Energy and Power Consumption, Heliostat H4 (Non-inverting)

Figure 6-55. Energy and Power Consumption, HelioStat H4 (Non-inverting)

Figure 6-56. IH1 Elevation Commanded Position Energy Consumption

between the net elevation angles through which the heliostat moved for the four simulated cases, the additional energy consumption for slewing from inverted stow to acquisition is required to overcome the gravity moment and the relatively high friction and viscosity of the initially cold drive train.

Assuming an overall plant electrical generating efficiency of 25%, a conservative estimate of power required to operate the heliostats (including field controller power) is less than 1%.

6.4.2.8 Backlash/Compliance Test

The objective of the backlash/compliance test was to obtain mechanical/structural data for elevation and azimuth drive unit deflections under imposed loads.

Noninverting Heliostat, Azimuth

The noninverting heliostat, H2, was placed in the horizontal stow position and a steel cable and spring scale affixed to the lifting lug on the outboard mirror segment. The cable was affixed to an aerial ladder which was positioned to place a controllable load parallel to the reflector surface and normal to the moment arm from the heliostat azimuth drive unit centerline. A dial indicator was affixed to the drive unit housing and a reference surface attached to the top of the pedestal. Loads were then applied in increments of 50 lb, from 0 to 200 lb, alternating the directions (clockwise and counterclockwise). Loads were applied by rotating the ladder. Data were taken for 2 or 3 complete cycles to verify data repeatability. Readings were taken from the dial indicator at each imposed load.

Noninverting Heliostat Elevation

A steel cable was affixed to the two outboard segment lifting lugs and a spring scale attached at the midpoint of the cable. Loads were manually applied sequentially, both at the front of the heliostat (opposite the linear actuator) and at the rear (on the same side as the linear actuator); a front load, therefore, tended to extend the actuator, while a rear load compressed it. Dial indicator readings were taken in a similar manner, as before, but with the indicator reoriented. Following these tests, the antibacklash mechanism was adjusted to minimize backlash and the test repeated.

Inverted Stow Heliostat, Azimuth

A steel cable was attached to the aerial ladder and the spring scale attached at the outer end of the torque tube. Loads were applied sequentially, as for the baseline.

Inverted Stow Heliostat, Elevation

The inverted stow heliostat in the face up stowage position has a gravity moment of 28,000 in. -lb. With the heliostat in this position, sufficient load could not be applied to offset this moment. Therefore, tests were performed with the heliostat in a position that minimized the gravity moment.

Results

Results are shown in Figures 6-57 and 6-58. The harmonic drive (Figure 6-57, Part A) does not exhibit appreciable backlash (< 0.5 mr) since it is a pre-loaded, compliant mechanism. However, friction in the unit (possibly between splines) introduces a hysteresis effect. Thus, a load applied and released is followed by an incomplete nonlinear relaxation of the unit to an angular position somewhat greater than the position prior to the load application. The maximum uncertainty associated with this effect for a relatively high load of 24,000 in. -lb is approximately ± 0.5 mr, as shown in Figure 6-57, Part A. It was further found that this hysteresis effect produces a position uncertainty that is approximately proportional to applied load in the range of 6,000 to 18,000 in. -lb, and increases rapidly at 24,000 in. -lb. The linear actuator shows low backlash (0.12 mr) prior to adjustment, and 0.07 mr following backlash adjustment, and has linear stiffness (Figure 6-57, Part B). The inverted stow heliostat exhibited approximately 0.8 mr of mechanical backlash in azimuth, Figure 6-58, Part A. The backlash in elevation was 1.1 mr, Figure 6-58, Part B.

6.4.2.9 Heliostat Slew Rates

The objective of this test was to determine heliostat slew rates. These data serve as a basis for comparing heliostat performance variations that may occur, such as tracking accuracy or stability, and the data verify the degree to which the design slew rates have been achieved.

Figure 6-57. Backlash/Compliance Test

A - IH1, AZIMUTH AXIS

B - IH1, ELEVATION AXIS

Figure 6-58. Backlash/Compliance Test

Measurements of slew rates were made for each emplaced heliostat in both elevation and azimuth. An inclinometer was affixed to the reflector support structure for elevation slew rate tests. The heliostat was then commanded to slew and time and position measurements recorded. A similar procedure was followed for azimuth, except angular readings were made from scribed marks on the drive unit.

The four noninverting heliostats had an initial mean and standard deviation azimuth rotation rate of 4.945 ± 0.096 deg/min on 11/12/76. The average limit switch positions in azimuth for the four heliostats were $237^\circ \pm 8^\circ$ both clockwise and counterclockwise, following the same installation procedure for each of the heliostats. The heliostat surface normal elevation slew rate is a function of position for a constant jack screw extension and retraction rate, but the average mean and standard deviation slew rates (jack screw retracing and extending) were 5.9 ± 0.65 deg/min for four heliostats. Adjusting the anti backlash screw on heliostats H2 and H4 on 12.21.76 to minimize backlash reduced the elevation slew rate 4.8%.

The inverted stow heliostat azimuth rate was 11.7 ± 0.3 deg/min and the elevation rate was 10.4 ± 1.5 deg/min; the elevation rate increased approximately 18% as the motor warmed up from 30°F to approximately 75° to 100° .

6.4.3 Master Control

The Master Control developed for the SRE heliostat array tests simulates the Pilot Plan heliostat control functions by commanding the field controller to perform the required heliostat control tasks. The hardware consists of a minicomputer (NOVA 1200), Master Control to field controller interface unit, CRT display, operator keyboard, digital output real-time clock, and master control program storage on magnetic tape cassettes. These elements are housed in the heliostat mobile test van with the field controller.

The software for master control consists of system software and the application program. The system software consists of a FORTRAN IV Compiler, FORTRAN and SYSTEM libraries, service program editor assembler, and the relocatable binary loader.

The source application program is primarily written in the FORTRAN language for ease of program modification with the special hardware control instructions (for the clock, video interface, field controller interface, and the A/D converter control) written in in-line assembly language for program execution speed and flexibility.

The Pilot Plant control functions are programmed in a modular fashion with each specific task contained in its own subroutine. The Executive Routine provides overall control and scheduling of the real time operations through operator instigated commands. Included in the control functions are the field location inputs to the field controller, sun acquisition and synthetic track, heliostat biased track, mandatory positioning, stowage positioning, and emergency elevated synthetic track. Parameter modification and on-line display of heliostat performance such as the instantaneous gimbal angles, solar insolation and tracking errors are also controlled by the Executive Routine.

The SRE field controller is functionally similar to the Pilot Plant field controller. The major elements are Master Control interface logic, a microprocessor, an analog input section, and an AC motor drive section. A manual interface panel is included to load the microprograms, aid in troubleshooting the field controller hardware and software, and operate the heliostats independent of the Master Control.

The Master Control machine and the field controller communicate over a bidirectional party line system. Conversation must be initiated by Master Control. The master control may transmit field position constants and optional or mandatory position commands or request heliostat status information. Commands may be applicable to one or all of the heliostats under the command of the field controller. Message correctness is verified before execution.

Initial tests consisted of mandatory position verification. Within the accuracy of the gimbal axes potentiometers, mandatory position commands were executed without fail. The most common mandatory command is stowage. Other mandatory commands include positioning for maintenance (such as washing positions, actuator replacement, potentiometer alignment, etc) and emergency defocus.

Master control/field compatibility tests were next performed. The general nature of these tests consisted of acquiring and tracking the sun under master control direction, then comparing the optional synthetic track commands, updated every 3 min, with the achieved tracking angles. Master control initially transmits field position constants (target azimuth and elevation coordinates). Proper receipt of these was verified. Optional initial

acquisition commands were then received by the field controller. These commands cause the heliostat to slew to the transmitted coordinates, but allow the option to go to track when the sun falls within the sensor field of view. Two difficulties were encountered during these tests. In general, the noninverting heliostats had no difficulty except when the outer row of heliostats went to track prior to any inner row motion. Under these circumstances, reflected light from the second row struck the front row sensor resulting in confusion. This anomaly can be avoided by activating all heliostats simultaneously or activating the close-in heliostats first. The second acquisition anomaly occurs when wide angle acquisition with the alternate heliostat tracks into the void between mirrors (azimuth correction before elevation) which means that the beam sensor is pointed above or below the sensor mirror. Normally, the sensor would be pointed below the sensor mirror. This anomaly can be avoided by using initial mandatory position commands and after the coordinates have been achieved, releasing the heliostats to track. In our tests, once tracking was achieved, comparison of synthetic track commands and achieved tracking positions differed by no more than 2 bits (5° azimuth and 1.5° elevation).

Data requests were initiated by Master Control and the results compared with field controller data. Data conformity was observed.

One mode of emergency defocus was demonstrated. In this mode all heliostats are pointed at a spot above the target, thereby avoiding random dispersal of focused beams. The beams are held there by a mandatory (can not be overridden by beam sensor commands) modified synthetic track algorithm. From this point heliostats may be returned to track or independently stowed depending on the nature of the emergency. For North field heliostats such a defocus algorithm results primarily in elevation motion. Cross-axes terms will result in more complex motion in other field positions. As expected, the test showed that the noninverting heliostats and the inverted stow heliostat moved to the commanded position CA point arbitrarily chosen to be 100' above the target) at the respective elevation slew rates of 6 deg/min and 10 deg/min.

6.4.4 Environmental/Extended Life Effects

The environmental conditions affecting heliostat performance encountered at Randsburg, Wash and the Pilot Plant site at Daggett are similar as shown by available meteorological data of Table 6-32 for the weather stations closest to Daggett and Randsburg, Wash. Randsburg, Wash and Daggett have similar soil, vegetation, solar insolation, winds, humidity, temperature, rainfall, topography, and are 45 mi apart at the same elevation, 650m. However, because California has experienced a particularly dry and benign winter, data obtained to date on dust buildup rates, washing effectiveness, sensor pole/pedestal stability, wind effects, and integrity of certain subassemblies may not be truly representative. Environmental effects and performance data should span at least a full year to be fully applicable and valid for establishing requirements, costs, and plans for the Pilot Plant. Additional performance monitoring is, therefore, recommended to validate and increase the data base obtained to date. Data obtained to date is presented in the following sections.

6.4.4.1 Reflective Surface Integrity

Two laminate glass noninverting heliostats, three Sheldahl acrylic coatings (822-12A) noninverting heliostats, and an inverted stow heliostat with one side laminate and the other side foam core were installed at Randsburg, Wash.

The adverse effects observed, exposure periods and probable causes are summarized in Table 6-33.

Judging from the pinholes, stains, and delamination (especially as a result of a light snowfall) of the Sheldahl acrylic, this surface has not exhibited sufficient integrity for a 30-yr life. No adverse effects have been observed with the laminate panels although they have not yet been exposed to desert high-temperature conditions or icing. The foam core panels have exhibited a waviness that caused reflected beam variations, focusing, and defocusing which made field measurements of reflectivity invalid (reflectivity varied 60% depending on location of pyrliometers). This effect was not due to environmental exposure. Two of the foam core panels cracked following a

Table 6-32
METEOROLOGICAL SUMMARY

Mean Percentage of Days Per Month For Occurrence of Various Meteorological Phenomena, From Daily Observations									
Station	Location	Elevation	Distance From Pilot Plant Site	Thunder- Storms	Rain/ Drizzle	Snow/Sleet/ Freezing Rain	Fog	Dust/ Sand	Years of Observation
Naval Weapons Center	Indian Wells Valley, CA	760M	65 Mi	0.9	9.6	0.5	0.7	1.2	20
Edwards Air Force Base	Western Mojave Desert Near Mojave	770M	56 Mi	1.2	9.6	0.9	1.9	1.6	19
George Air Force Base	Western Mojave Desert Near Victorville	960M	36 Mi	1.7	10.1	1.4	2.3	1.0	18
Kirtland Air Force Base	Albuquerque, NM	1780M	--	10.2	22.9	6.9	2.7	1.2	26
NOTES:									
Data Compiled from Aerospace Tapes.									
Blowing Dust/Sand Reported only when Visibility is less than 1 km.									
Daggett Elevation, 660M									
Randsburg, Wash Elevation, 650M									

Table 6-33

REFLECTIVE SURFACE INTEGRITY

Heliostat	Reflector Surface	Exposure Period/Location	Adverse Effect Observed	Cause
H1	Sheldahl acrylic	August-September, 1976/ Structures Laboratory, MDAC- Huntington Beach	Minor pinholes (1/16-1/8 in.)	Exposure
		Mid-October 1976 to April 1977/ Heliostat Array, Randsburg Wash	Moderate pinholes (1/8-3/8 in.) Stains Delamination (6 in. wide, 3 in. long)	Exposure, including rain, dust, washing Unknown
H2	Sheldahl acrylic	July-September 1976/Solar Integration Laboratory, Huntington Beach	Moderate pinholes (1/8 in. - 3/8 in.) Stains	Exposure, including rain, dust, washing
		Mid-October 1976 to April 1977/ Heliostat Array, Randsburg Wash	Extensive pinholes (>1/2 in.) Stains	Exposure including rain, dust, washing (CB 120 one time, A69M subsequent)
H3	Sheldahl acrylic	Mid-October 1976 to April 1977/ Heliostat Array, Randsburg Wash	Total delamination of four segments	Snowfall (~2 in.) on 3/25/77. Wet surface has very low adhesive peel strength.
			Moderate pinholes, stains	Exposure, including rain, dust, washing
H4	Laminate	Mid-October, 1976 to April 1977/ Heliostat Array, Randsburg Wash	No adverse effect observed	
H5	Laminate	December 1976 to April, 1977/ Heliostat Array, Randsburg Wash. Mobile heliostat	No adverse effect observed	
IH-1	Laminate	December 1976 to April 1977/ Heliostat Array, Randsburg Wash	No adverse effect observed	
IH-1	Foam Core 3/32 in. glass	March-April 1977/Heliostat Array, Randsburg Wash	Two panels cracked	Apparently due to a 1-hr thermal cycle (130°F) to 75°F) with cracks originating at small chips at edge.
			Beam error pattern (~ 25 mr for portion of surface) ~6 to 10% power loss at target	Nonuniform application of adhesive between foam core and 3/32 in. glass suspected.
			Streaking/surface contamination	Rain water and rinse water washed material from edge sealant onto glass.

thermal cycle from 75°F to approximately 130°F and back to 75°F over a period of 1 hr. with the cooling occurring in approximately 10 min. (This condition was encountered when a plastic tarp was placed over the foam core for a power measurement comparison between the foam core and laminate glass). Both cracks initiated at a glass edge having a small initial chip. Streaking and surface contamination of the glass were observed as shown in Figure 6-59.

6.4.4.2 Wind Effects on Heliostat Performance

The objectives of the test activity were to (1) determine heliostat tracking accuracy for operational wind conditions encountered, (2) compare the performance of the noninverting and inverting heliostats for similar wind conditions, and (3) verify heliostat integrity for survival wind conditions. Survival wind conditions (>60 mph) were not encountered during the test period, but the other objectives were met. Typical results are presented in the following paragraphs.

Tracking accuracy data were obtained directly from the heliostat's tracking beam sensor and in some cases an additional instrument beam sensor. Wind speed and direction were measured with a wind indicator mounted on a 20-ft pole in front of heliostat H1 (see Figure 6-40). This particular wind indicator did not respond well to sudden large changes in wind direction, occasionally spinning completely around or stalling the speed indicator. Therefore, correlations of tracking accuracy with wind speed and direction are approximate, especially for gusting conditions.

A number of typical tracking conditions are discussed below for different wind speed, direction, gust variations, and for the two types of heliostat at different surface angles with respect to wind and gravity load. Tracking errors are presented for filtered and unfiltered beam sensors, and as maximum peak-to-peak, mean error, and time-averaged peak-to-peak errors. The noninverting heliostat is compared with the inverting heliostat for similar wind conditions and heliostat tracking angles. Data are presented showing the heliostat motor commands and corresponding beam response, and the beam-pointing error variations for solar drift conditions (no active tracking).

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STREAKING DUE TO RAINFALL ON IH-1 IN INVERTED STOW
POSITION — APRIL 2, 1977

STREAKING OF FOAM CORE PANEL FOLLOWING CB-120 WASH
AND RINSE WITH DEIONIZED WATER — APRIL 7, 1977

Figure 6-59. Streaking of Foam Core Panel

Figure 6-60 shows the tracking performance on 12/10/76 of a noninverting heliostat (H1) as indicated by its tracking beam sensor for winds of 10 to 20 knots approximately parallel to the reflector surface. The horizontal tracking error is predominantly to the right of null, indicating that the heliostat motion lags behind the required motion for perfect tracking, with an occasional correction overshoot to the other side. Similarly, the elevation error lags behind the required downward motion corresponding to this time of day. The maximum peak-to-peak error in azimuth is 1.0 mr, and in elevation, 0.5 mr. The corrective motor pulses are also shown. For these special commands (field position, time of day, low wind, etc.) a corrective azimuth motor pulse is made, on the average, approximately once every 3 sec, and a corrective elevation motor pulse every 10 sec. The wind speed and direction during this period show the wind approximately parallel to the surface and thus, the results are not "worst case." An estimate of the average peak error to the right and left of null was made to define an average error band. The error band in azimuth is 0.6 mr and in elevation it is 0.25 mr. An independent estimate was also made of the mean error $\pm$ a deviation about mean; this mean error was $0.6 \text{ mr} \pm 0.4 \text{ mr}$.

Figure 6-61 shows the tracking performance of the non-inverting heliostat, H1 and the inverting heliostat, IH-1, for the wind conditions shown in Figure 6-60. The tracking errors for both heliostats are relatively low: 0.6-mr error band for IH-1 in both azimuth and elevation, compared to 0.6 mr in azimuth and 0.25 mr in elevation for H1. A solar drift case is shown for each to illustrate the oscillatory error occurring with no heliostat corrective motor pulses. The near-parallel 10-20 knot winds induce approximately the same errors in either heliostat about the mean beam position as when the heliostat is tracking. The noninverting heliostat mean error in azimuth was estimated at $0.3 \pm 0.3 \text{ mr}$ and in elevation, $0.25 \pm \text{mr}$. The inverting heliostat mean error was $0.6 \pm 0.4 \text{ MR}$.

Figure 6-62 shows the results for higher winds, again near-parallel to the heliostat surface, i.e., nominal wind coming from 260° (WSW) for surface at 252° to 256° . In this case, the noninverting heliostat error band is 0.4 in azimuth and 0.1 mr in elevation, whereas the inverting heliostat error band

Figure 6-60. Noninverting Heliostat (H1) Tracking Performance with 10-20 Knot Near-Parallel Winds
6-160

Figure 6-61. Noninverting Heliostat (H1) Tracking Performance Compared to Inverting Heliostat (IH-1) for 10-20 Knot Near-Parallel Winds

Figure 6-62. Noninverting Heliostat (H1) Tracking / Performance Compared to Inverting Heliostat (IH-1) for 10-30 Knot Winds

is 1.8 mr in azimuth and 0.5 mr in elevation; in addition, the percentage of time the heliostat error exceeded ± 1.0 mr about null was determined. Heliostat IH-1 error was greater than ± 1 mr for 45% of the time, whereas the H1 error was greater than ± 1 mr for only 1% of the time. Maximum peak errors for IH-1 are also relatively high, reaching a value of 3.0 mr in azimuth and 2.5 mr in elevation for several seconds. The mean error for H1 was 0.4 ± 0.4 mr in both axes, and the mean error for IH-1 is 0.9 ± 0.7 mr in azimuth and 0.25 ± 0.25 mr in elevation.

Figure 6-63 shows tracking performance for IH-1 on 4/1/77, after approximately 4 mo of exposure. There is no noticeable degradation in tracking performance due to wear. However, wind condition variations reveal a number of interesting system responses. The isolated cases presented here were selected as being representative both in terms of the heliostat tracking accuracy variations and in the wind gust variations encountered in the desert. For this test, an additional instrument beam sensor was mounted next to the tracking beam sensor. Both sensors were aligned on the sensor mirror. The additional sensor was unfiltered and therefore can be used to measure the heliostat wind-induced oscillations more accurately than the filtered (1/4 Hz) tracking sensor. Typically, the filtered sensor output signal was attenuated and therefore its error signals were somewhat lower than the unfiltered instrument sensor. For most of the test period, the average error band was 0.75 to 1.2 mr in azimuth and 0.25 mr in elevation. However, for the mirror normal at 36° , the IH-1 reflector is balanced, i.e., the CG is directly above the elevation axis. With low-gravity loads, wind speed or direction changes can cause larger rotations about the elevation axis. In one case, the wind indicator showed a 10-knot wind gusting from west to south and back to west with the azimuth and elevation errors increasing to greater than 5 mr. The mean error indicated by the filtered sensor throughout this test was 0.75 ± 0.75 mr in azimuth and 0.25 ± 0.5 mr in elevation.

Figure 6-64 shows the results for 10-20 knot winds with somewhat higher error bands. Winds are still from the west, fluctuating approximately $\pm 15^\circ$ to 20° . The maximum angle of attack is of the order of 30° to 35° , the highest encountered during the tracking tests. The average error band for the filtered sensor is 1.25 mr in azimuth and 1.0 mr in elevation compared

Figure 6-63. Inverting Heliostat (IH-1) Tracking Performance for 6-18 Knot Winds

Figure 6-64. Inverting Heliostat (IH-1) Tracking Performance for 10-22 Knot Winds
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to 2.2 mr in azimuth and 1.6 mr in elevation for the unfiltered sensor. Maximum peak-to-peak errors of -2.5 to +4.0 mr in azimuth and -2.0 to +2.8 mr in elevation were recorded. However, the filtered error exceeded ± 2 mr only 1% to 2% of this test period, but exceeded ± 1 mr approximately 20 to 30% of the test period. The mean error was 0.6 ± 1.0 mr in azimuth and 0.5 ± 0.75 mr in elevation as indicated by the filtered sensor.

Figure 6-65 shows the results for somewhat higher wind speeds. The average error band for the filtered sensor is 1.75 mr in azimuth and 1.25 mr in elevation for a 24-knot wind from the west, compared to 3.0 mr in azimuth and 2.0 mr in elevation for the unfiltered sensor. Maximum peak-to-peak errors of -5 to +5 mr were recorded in both axes. At 1 PM, the filtered error exceeded ± 1 mr approximately 50% of the test period, and exceeded ± 2 mr approximately 10% of the test period. The mean error was 0.6 ± 0.9 mr in azimuth and 0.25 ± 0.75 mr in elevation, as indicated by the filtered sensor for the nominal 20-knot winds. The mean error in elevation increased for the 24-knot wind and is estimated as 0.25 ± 0.9 mr.

An attempt was made to compare error bands found for additional typical selected cases too numerous to incorporate in this report. Within the limits of the wind speed and direction uncertainties, certain conclusions can be reached. Table 6-34 shows IH-1 tracking errors tabulated against wind speed for near-parallel wind conditions for both filtered and unfiltered sensors. These results are compared with more limited tracking data for the noninverting heliostat, H1, which has shown a tracking error band less than 1 mr throughout the operational wind speeds. Although the wind conditions encountered are not worst-case, the data consistently indicate that the higher backlash and lower stiffness of the IH-1 drive trains result in higher tracking errors than for H1. The mean lagging error in azimuth appear to be approximately 0.6 mr, with the variation about this mean increasing as the wind speed increases.

6.4.4.3 Pedestal Sensor Pole Stability

Measurements were made periodically to assess the effects of wind loads, foundation settling, temperature variation, rainfall, etc., on the beam

Table 6-34

TIME-AVERAGED ERROR BAND FOR
INVERTING HELIOSTAT, IH-1 NEAR-PARALLEL WINDS

Wind Speed (Knots)	Azimuth Error		Elevation Error		RSS Error $\sqrt{(\text{Az Error})^2 + (\text{El Error})^2}$	
	Filtered Sensor (mr)	Unfiltered Sensor (mr)	Filtered Sensor (mr)	Unfiltered Sensor (mr)	Filtered Sensor (mr)	Unfiltered Sensor (mr)
10 $\pm$ 5	0.75	1.0	0.25	0.25	0.8	1.0
15 $\pm$ 5	1.2	1.0	0.3	0.25	1.6	1.0
20 $\pm$ 5	1.1	1.7	0.75	1.0	1.3	2.0
25 $\pm$ 5	1.8	3.0	1.25	2.0	2.2	3.6

sensor pole and pedestal angular stability. Data on tilting immediately following installation and for a 6-mo period was obtained. Measurements were made with a vernier inclinometer, accurate to within 0.25 mr at designated spots on the sensor poles and pedestals of all the heliostats to determine E-W and N-S tilting. In summary, the mechanical tilting of the four baseline and inverted stow sensor poles was $0.8 \text{ mr} \pm 0.6 \text{ mr}$, with no discernable shifting due to foundation settling immediately following installation. Similarly, the tilting of the pedestals was $0.67 \pm 0.24 \text{ mrad}$. Data are plotted in Figures 6-66 and 6-67.

6.4.4.4 Washing Effectiveness/Reflectivity degradation

The objectives of this test were: (1) to obtain reflectivity data for extended periods under desert conditions typical of those for the 10-megawatt Pilot Plant, (2) correlate the data with the weather conditions encountered, and (3) periodically wash the heliostat and determine washing effectiveness.

Reflectance data have been obtained for approximately 4 mo, three washing tests have been conducted and the heliostats have been washed naturally by rain, snow, and frost.

Reflectivity Measuring Technique

Heliostat reflectivity is measured using three Eppley normal incidence pyrhelimeters before and after each washing, and periodically (every 1 to 3 wk, weather permitting). Two of the pyrhelimeters have 1° (17.5 mr) apertures; the third has the standard $5^\circ 43'$ (100 mr) aperture and is equipped with a filter wheel and three Eppley filters.

The 1° and $5^\circ 43'$ pyrhelimeters are mounted parallel to each other on a support placed between the heliostat and the target. The heliostat is placed on track (accurate to within 0.5-1.0 mr). The 1° pyrhelimeter is then aligned parallel with the reflected beam. The reflected solar insolation is measured for both the 1° and $5^\circ 43'$ pyrhelimeters. During this time, a second 1° pyrhelimeter mounted on a tracking equatorial mount is used to measure incoming solar insolation. The ratio of the reflected solar insolation to the incident solar insolation is the mirror reflectivity for a 17.5-mr aperture.

Figure 6-66. Sensor Pole Angular Sway

Figure 6-67. Heliostat Pedestal Angular Sway

Smaller apertures (i. e., 8 mr) would lower the reflectivity. Periodically, the two 1° pyrliometers are both pointed at the sun and the solar insolation values compared. In all cases, agreement has been within 1%. Multiple measurements are made at a convenient spot on the mirror, care being taken to avoid bird droppings and other nontypical, heavily soiled areas. Measurements were also made at several additional spots (approximately 1-3 ft apart) to determine the variation in reflectivity over the surface.

Measurements made at six different locations on the bottom segment of each of the three acrylic surface heliostats showed a standard deviation of reflectivity of $\pm 2.5\%$; the glass mirror had approximately $\pm 1\%$ standard deviation, but greater variations have been observed. Measurements could not be made with the available equipment on the upper portions of the heliostat, and therefore, greater reflectivity variations may be present, but undetected. For example, heliostat H2 has three visually noticeable swaths of what appears to be a permanent "staining" that is darker than the lower part of the heliostat, where measurements were made with the pyrliometers. These variations should be noted for comparisons of energy received at the target with respect to expected energy values. Total energy received relative to the reflectivity value at one point may differ by several percent, for both the glass and acrylic heliostats.

Washing Technique

The procedure for cleaning the heliostat by washing and rinsing the reflective surface encompasses the following steps:

1. Take a reflectance measurement of the reflective surface immediately prior to washing.
2. Position each reflector near vertical, approximately 70°, in a manner which avoids excessive irradiation of the surroundings.
3. Rotate the reflector so that it faces the direction of Northwest for early morning washing, North for mid-day washing, and Northeast for afternoon washing. This orientation minimizes spotting of the surface due to drying of the wash solution and minimizes glared.
4. Spray the entire reflective surface with a washing solution. Application is made quickly and evenly (see Figure 6-68).

APPLICATION OF WASH SOLUTION

OVERSPRAY OF HELIOSTAT

HELIOSTAT RINSING

FINAL STAGE OF RINSE

Figure 6-68. Heliostat Washing

5. At the end of the specified soak time for the washing solution (approximately 1 min) rinse the reflective surface thoroughly with deionized water.
6. Take a reflective measurement of the reflective surface when the surface is dry.

Reflectivity/Wash Results

Five emplaced heliostats have been monitored from 9-18 December 1976 until 8 April 1977. Three of the heliostats have acrylic first surface mirrors and are the noninverting, eight-petal design, normally stowed horizontally, face up. A fourth noninverting emplaced heliostat has a laminate glass second surface mirror. The fifth is the inverted stow laminate glass heliostat. These heliostats are designated H1, H2, H3, and H4, and IH-1, respectively. A fifth noninverting laminate heliostat, mounted on a trailer 1,100 ft from the target has been exposed, but not washed for 4 mo to determine maximum reflectance loss.

Results obtained to date are presented in Figures 6-69 through 6-73.

Figures 6-69 and 6-70 show that heliostats H1 and H2 (acrylics) were washed on 18 December 1976 with reflectivity increased by 13.5 % and 5.3%, respectively. These heliostats arrived at the site in a soiled condition, and both had been used for tests at Huntington Beach. Both heliostats were washed with McGean Chemical A69M, a chemical cleaning agent shown to be compatible with acrylics.

Figures 6-71 to 6-73 show that heliostats H3, H4 and IH-1 were washed on 9 December 1976, with reflectivity increased by 9.1, 13.8, and 3.4% respectively. McGean Chemical Co. A69M was used for H3, and CB 120 for H4 and IH-1.

For the initial wash, relatively large amounts of wash and rinse solution were used to obtain as high an initial reflectivity as considered practically achievable. Results are presented in Table 6-35. However, these results are not directly applicable to Pilot Plant, since the amounts used, wash time, etc., are probably not compatible with Pilot Plant economics.

Figure 6-69. Heliostat H1 Reflectivity/Weather H1 (Page 1 of 2)

Figure 6-69. Heliostat H1 Reflectivity/Weather H1 (Page 2 of 2)

Figure 6-70. Heliostat H2 Reflectivity/Weather (Page 1 of 2)

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Figure 6-70. Heliostat H2 Reflectivity/Weather (Page 2 of 2)

Figure 6-71. Heliostat H3 Reflectivity/Weather (Page 1 of 2)

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Figure 6-71. Heliostat H3 Reflectivity/Weather (Page 2 of 2)

Figure 6-72. Heliostat H4 Reflectivity/Weather (Page 1 of 2)

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Figure 6-72. Heliostat H4 Reflectivity/Weather (Page 2 of 2)

Figure 6-73. Heliostat IH-1 Reflectivity/Weather (Page 1 of 2)

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Figure 6-73. Heliostat IH-1 Reflectivity/Weather (Page 2 of 2)

Table 6-35

WASHING EFFECTIVITY RESULTS, 12/9/76 AND 12/17/76

Helio- stat No.	Prewash Reflect- ance	Postwash Reflect- ance	Reflect- ance Increase	Application Time		Solution Quantity		Solution Type		Nozzle Type		Waiting Period
	R1	R2	ΔR	Wash	Rinse	Wash	Rinse	Wash	Rinse	Wash	Rinse	--
	%	%	%	Min	Min	Gal	Gal	--	Water	GPM	GPM	Min
H1	67.78	81.29	13.51	4.07	3.80	5.25	12.50	A69M	D.I.	1	5	1.0
H2	64.89	70.20	5.31	5.98	5.75	6.40	15.00	A69M	D.I.	1	5	6.0
H3	77.25	86.34	9.09	5.50	3.43	9.25	10.50	A69M	D.I.	1	5	15.0
H4	72.07	85.89	13.82	3.92	2.45	6.63	10.25	CB120	D.I.	1	5	5.0
IH1	78.25	81.64	3.39	5.47	3.27	5.25	10.50	CB120	D.I.	1	5	2.0

H3, H4, IH1 washed on 9 December 1976

H1, H2 washed on 17 December 1976

A69-M dilution 1:10

CB 120 dilution 1:20

The five heliostats were washed on 15 March 1977 and reflectivity measurements made before and after. Results are summarized in Table 6-36. An effort was made to use minimum amounts of wash/rinse solution and to apply the solutions rapidly. For H4, wash solution was applied in 1 min, followed by a 1-min dwell time to loosen the accumulated dust, and then deionized water rinse was applied for 2 min. A final wash was performed on 7 April 1977, but there was insufficient time to accurately measure the wash quantities. The technique used was similar to the above cases.

Based on our experience to date, it is likely that with proper equipment, wash solution can be applied in less than 1 min (i. e., 30-45 sec), followed by a 1-min dwell time, and a 2-min rinse. These times do not include positioning of the trucks, sprayers, etc. It also appears that 1 gal of wash solution and 5 to 6 gal of deionized water are minimal quantities. Both washing solutions (A69M and CB120) appear to be effective, with CB120 more so.

Reflectivity Degradation

The rate of decrease in heliostat reflectivity under actual desert field conditions has been monitored since early December 1976. Results are summarized in Table 6-37. Results for December and January indicate that reflectivity of both the acrylic and glass mirrors can be degraded by 6 to 8% in 2 to 3 wk and can remain essentially constant for approximately the same period. We have also noted a surprising difference during this period between heliostats H2 and H3, which are side by side and would be expected to show more closely similar reflectivity curves. H2 decreased from 70% to 64% between 17 December 1976 and 3 January 1977, whereas H3 decreased slightly, from 83.6% to 82.8%.

It is also interesting to note that IH-1 and H4 show a similar rate of reflectivity degradation, even though IH-1 was kept in the face down stowage position for approximately three-fourths of this time, both day and night, to establish what was expected to be a baseline minimum degradation rate for near-continuous inverted stow relative to continuous face-up stow.

Table 6-36

WASHING EFFECTIVITY RESULTS, 3/15/77

Heliostat No.	Prewash Reflectance	Postwash Reflectance	Reflectance Increase	Application Time		Solution Quantity		Solution Type		Nozzle Type	
	R1	R1	ΔR	Wash	Rinse	Wash	Rinse	Wash	Rinse	Wash	Rinse
	%	%	%	Min	Min	Gal	Gal	--	Water	GPM	GPM
H1	65.88	78.24	12.36	1.0	5.0	1.50	14.00	A69M	D.I.	1	5
H2	56.08	76.50	20.42	1.0	3.7	1.25	8.75	A69M	D.I.	1	5
H3	69.23	87.46	18.23	1.0	3.0	0.75	8.0	A69M	D.I.	1	5
H4	73.31	87.65	10.69	1.0	2.0	1.25	5.75	CB120	D.I.	1	5
IH1	76.80	86.5	8.30	1.4	2.8	1.60	7.75	CB120	D.I.	1	5
IH1'	72.16*	86.60	14.44								

Waiting period between wash and rinse = 1 minute

IH1' = 3/32 in. float glass (foam core)

IH1 = 1/4 in. float glass (laminated)

H4 = Laminated glass

H1, H2, H3 = Acrylic coating

*Reflectivity of IH1' as received from
plant following fabrication

Table 6-37
SUMMARY OF HELIOSTAT REFLECTIVITY VARIATIONS

Heliostat No.	Reflectivity (%)														
	12/9/76	12/9/76	12/17/76	12/17/77	1/3/77	1/14/77	1/28/77	2/4/77	2/15/77	3/2/77	3/14/77	3/15/77	4/1/77	4/7/77	4/8/77
H1	N/A	N/A	67.78	81.29	N/A	77.49±0.3	N/A	76.61±0.5	75.37±1.0	67.33±0.5	65.88±0.1	78.24±0.5	77.95±0.9	71.28±0.5	83.22
H2	N/A	N/A	64.89	70.20	64.28±2.1	74.13±1.5	66.45±0.8	65.15±0.7	70.15±0.5	67.03±1.0	56.08±0.7	76.50±0.4	71.90±0.5	66.89	68.13
H3	77.25	86.34	83.53	N/A	82.80±2.3	85.53±0.19	81.85±2.2	79.71±0.5	78.11±1.0	75.40±0.4	69.23±0.2	87.46±1.5	N/A	N/A	N/A
H4	72.07	85.89	78.18	N/A	83.62±1.6	37.65±0.76	83.51±0.2	80.37±0.6	81.79±1.1	73.79±0.4	73.31±1.6	84.00±1.3	81.56±1.8	80.4	85.43
IH1	78.25	81.64	83.92	N/A	81.92±1.1	86.49±0.19	85.05±0.2	85.78±0.1	85.53±0.2	N/A	76.80±0.8	85.10±0.01	81.25±1.5	82.09	80.04
Comment	Dirty	Washed	Dirty	Washed	Rain	Frost during week of 1/10 cleaned surfaces					Dust storm	Washed	Snow on 3/25/77 cleaned surfaces	Washed	

Heliostat No.	Exposure Time (Days)	Time Averaged Reflectivity (%)	Degradation (%)
H1	113	$\bar{\zeta} = 75.46$	7.76
H2	113	$\bar{\zeta} = 68.37$	8.13
H3	97	$\bar{\zeta} = 80.47$	6.99
H4	121	$\bar{\zeta} = 81.10$	6.55
IH1	121	$\bar{\zeta} = 83.30$	3.19*

*NOTE: IH-1 was stowed in the face down position for most of the test period ($\approx 2/3$ of exposure time).

From 3 January to 14 January 1977, H2 showed a 10% increase (due to rain and frost) whereas H3, being initially cleaner, showed a 2.5% increase. These variations illustrate the need for monitoring more than one heliostat, and for cautious use of data obtained for relatively short periods.

Comparing the 14 March 1977 prewash reflectivity measurements of Table 6-37 with the 2 March 1977 data shows that H1 lost 1.5% and H4 was essentially unchanged, whereas H2 lost 11% and H3 lost 7.2%. These variations in degradation rate for neighboring heliostats has not been explained. Better agreement is found on comparing data from 15 February and 14 March 1977. In this period, heliostat IH-1 can be included; IH-1 had been disassembled on 1 March and reassembled on 4 March and was therefore not available for reflectivity measurements on 2 March. For the period 15 February to 14 March, heliostats H1, H2, H3, H4, and IH-1 had degradation rates of 9%, 14%, 9%, 8%, and 9%, respectively, for an average degradation of approximately 10%. February and March had higher wind conditions than December and January, and there was a dust storm on 9 March; such conditions would be expected to cause an increase in the reflectivity degradation rate.

Snow fell on 2 March and heliostats H1, H2, H3, and H4 were positioned near-vertical to observe the cleaning effect. Visually, H4 was cleaned as well as any washing case. Therefore, it is assumed that the reflectivity of H4 following the snowfall was near its maximum value of 88%. Between 25 March and 1 April, H4 thus lost approximately 5% reflectivity in 7 days, but during the next week the reflectivity remained essentially constant.

There is insufficient information at this time to draw reliable conclusions as to dust buildup and attendant reflectance degradation, but the data available from December to April can be time-averaged to estimate the effective heliostat reflectivity. Results summarized in Table 6-34 show that the three noninverting acrylics (H1, H2, and H3) lost approximately 7 to 8% and the noninverting laminate lost 6.5%. The period between either washing or natural cleaning by frost, rain, and snow was roughly 1 mo for the test period.

Therefore, within the limits of available data, the time-averaged reflectivity for the noninverting heliostats can be estimated to be 6 to 8% less than the maximum reflectivity, if the heliostats are cleaned approximately once each month. A similar conclusion cannot yet be reached for the inverting heliostat. Since IH-1 was inverted both day and night for approximately three-fourths of the period from mid-December to mid-January, and approximately half the period from mid-January to April, the observed 3.2% time averaged degradation is most likely too low, and the resulting value would be expected to fall between 3.2% and the 6.5% value of H4.

Frost

During the week of 10 January to 17 January 1977, a heavy frost was deposited on the mirrors; frost is an additional reflectance degradation effect, but it can be a very effective method of cleaning the mirrors. The ambient temperature/humidity data corresponding to the week of frost is shown in Figure 6-74. We have noted that the heliostat radiates to the night sky, and reaches a temperature of the order of 2.5°F less than the ambient temperature, as seen in Figures 6-75 and 6-76. Since the heliostat thermocouple is located underneath the steel channel, the glass surface should have a temperature somewhat lower than that measured. Therefore, the top surface of the glass may be approximately 3°F less than the ambient temperature. Determination of the number of heavy frosts to be encountered for a particular site should account for this temperature difference, rather than using ambient temperature data alone.

The frost formed on the mirrors is shown in Figure 6-77 with the times noted. Approximately 30 min after bringing the heliostat onto track, the laminated mirrors (both the inverted and baseline designs) were cleared of frost. As the frost melted, the water and ice mixture flowed off the mirror, carrying off dirt and dust and cleaning the mirrors more effectively than the initial wash for heliostats H2, H4, and IH-1; H3 was cleaned as effectively as the initial wash, and H1 was cleaned somewhat less effectively. The glass mirrors, mirrors, H4 and IH-1, were cleaned more effectively than the acrylics because the water/ice mixture could flow easily on the surface.

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Figure 6-74. Temperature/Humidity Data 1/10/77 to 1/17/77

Figure 6-75. Nocturnal Temperature Variation

Figure 6-76. Nocturnal Temperature Variation

(A) FROST ON INVERTED STOW AT 7:45 AM

(B) FROST AT 8:15 AM

(C) FROST ON H1, H2, H3, H4 AND IH-1 ESSENTIALLY
CLEAR AFTER 30 MINUTES (8:35 AM)

FROST ON H3 (ACRYLIC) COMPARED TO H4 (LAMINATE)
8:40 AM

Figure 6-77. Frost on Heliostats

On the acrylic mirrors, the time required to cause substantial melting was approximately 1 hr. The water tended to bead up and remain in place, which decreased the washing effect. The difference in time required to melt the frost is primarily due to the nonwetting effect of water on the acrylic, but the additional absorption of radiation in the glass of the second surface laminate may be a more than a negligible effect. Noticeable scattering of the reflected light due to the water beads was evident after 2.5 hr (10:30 AM).

These times correspond to the North field heliostats on track. For heliostats in the eastern and southern portion of the field, the mirrors would be approximately horizontal and the frost melting rate and cleaning effectiveness would be reduced. If frost is shown to occur frequently for a site, the loss in energy may have to be considered and adjustments made in the field configuration and number of heliostats.

It has also been noted on all occasions in which frost and dew form on the mirror surfaces that the region directly above the structural supports does not tend to accumulate frost or dew as readily as the mirror surface outside of this region (see Figure 6-77). The effect is evident whether the structure is bonded to the glass or directly beneath it. Also, the areas immediately outside the structural member area accumulate a noticeable dust film, apparently due to the condensation depositing airborne dust particles and capturing wind-blown dust.

Rain/Snow

Rain has been observed to both improve and exacerbate the dust buildup problem. There was a relatively heavy rain on 5 and 6 January 1977. The total quantity measured was 1.26 in. Since the baseline heliostats were stowed horizontally, the dirt/dust could not be washed off as effectively as in a near-vertical storage position. It was our visual observation that the rain had not cleaned the mirrors, and had left them with a "spotty" appearance. The improvement in reflectivity noted following the rain is in fact due more to the following frost, which effectively cleaned the mirrors. The inverted heliostat had been stowed face-down during this period. It was observed that accumulated dirt from the mirror support structure was washed onto

the mirror surface, causing substantial smearing over the surface within 1 ft to 2 ft of the outer edge of the mirror panels. It is apparent that both the baseline and inverted heliostats should be stowed near-vertically during substantial rain storms to obtain maximum rinsing of the reflective surface.

Approximately 2 in. of snow fell on 25 March 1977. The baseline heliostats were placed in a near-vertical position to determine if the snow would clean the surface. It was observed that snow slid off of the glass surface of H4, resulting in a very clean surface; although measurements could not be made, it was visually obvious that snow was a highly effective cleaning agent for glass. The snow did not tend to slide off of the acrylic surface, and in fact caused heliostat H3 to delaminate.

Sand/Dust Storm

A rather severe sand/dust storm was encountered on 9 March 1977, the only one of its kind during the test period. Photographs taken during the storm are shown in Figure 6-78. Reflectance data was obtained on 2 March and on 14 March; therefore the loss due to the sand/dust storm can only be approximated. It was visually observed that a fine dust was deposited on the surface by the storm, but measurements could not be taken until 5 days later.

The reflectance loss for H1, H2, and H3 after the dust storm was observed to be 1.45%, 10.95%, and 7.17% respectively; the corresponding mean and standard deviation is $6.52 \pm 4.78\%$. These measurements were taken in a relatively small area (6 in. x 6 in) of the bottom panel of each heliostat. We have observed a spread in reflectance of the order of $\pm 2.3\%$ for acrylics. Thus, we conclude that the dust storm caused an appreciable degradation in reflectivity of the acrylics, although the relatively low loss for H1 relative to H2 and H3 is unexplained.

The reflectivity of the laminate glass baseline heliostat (H4) remained essentially unchanged (0.5% loss, which is within standard deviation for reflectivity loss), which indicates that glass tends to stay substantially cleaner than the acrylic for dust storm conditions.

(A) HELIOSTAT H1 DURING WIND TEST

(B) WIND GUSTS TO 48 KNOTS, 1:42 PM

(C) HELIOSTAT H1 DURING WIND TEST

(D) DUST TO EAST OF FIELD, MOBILE HELIOSTAT
500 FEET AWAY COMPLETELY OBSCURED

Figure 6-78. Sand/Dust Storm, March 9, 1977, Randsburg, Wash.

Reflectivity data obtained at near-normal incidence/reflectance angles may not adequately describe the total loss. One set of data was obtained for the incident solar irradiance approximately 40° from the mirror surface, compared to the near-normal case. The reflectivity for the baseline acrylic heliostat (H3 on 14 March 1977) was $57.85\% \pm 0.6\%$ at 40° from the surface and $69.23 \pm 0.2\%$ at approximately 80 deg from the surface for a loss of 11%. The angular effect for the glass mirror was $60.23 \pm 2.1\%$ at 40 deg, vs $73.3 \pm 1.6\%$ at approximately 80 deg, for a difference of 13%.

6.4.4.5 General Extended Life/Environmental Effects

A number of adverse life/environmental effects were observed and are summarized in the following paragraphs.

Junction Box

The junction box allowed small quantities of water and dust to accumulate. The positioning of the J-box on the baseline heliostat was better than that of the inverted stow heliostat (IH-1), which was at ground level. Sufficient dust/water accumulated in the IH-1 J-box to apparently cause an electrical short which caused the fuses in the motor drive electronics to blow. The J-box should therefore be reconfigured to avoid this problem. Suggested changes include mounting the box vertically, three feet or more above the ground, and providing one to two small (1/8-1/4 in.) drain holes, or weather sealing the box.

Relays

Some of the relays used in the azimuth limit switch circuitry of both heliostats were mechanically unsound and failed. They were bypassed or repaired in the field, but should be reconfigured if used for Pilot Plant.

Flex Coupling

The motor/gear box shaft flex coupling is attached with machine screws. These have come loose on occasion and should be reconfigured or replaced by pins for Pilot Plant.

Position Potentiometers

The position potentiometers posed occasional difficulties due to slippage and alignment. These should be reconfigured for Pilot Plant and a more positive shaft attachment used.

Beam Sensor

The beam sensor windows have accumulated a dust film due to airborne dust, rain, and wash solution overspray during 3 mo of exposure in the field, but there has been no noticeable performance degradation. Periodic cleaning will probably be required for Pilot Plant, but not more frequently than once every 2-4 mo. In addition, one sensor window accumulated condensation on the inside surface, which could cause a degradation in performance. Weathertight sealing of the sensor should be considered as a design requirement.

Beam Sensor Mount

The beam sensor mount problems encountered were: rust, component loss, misalignment. Rusting of the adjustment screws and mount threads must be eliminated since periodic manual adjustments will be required. The mount has a ball bearing about which vernier swivel adjustments are made. This ball can fall out when the adjustment screws are loosened. Birds sitting on the sensor have dislodged the mount and caused a 10-30 deg misalignment. This poses a potential safety problem, as well as an energy loss, since the heliostats track according to the sensor commands, which countermand synthetic track command.

Three Phase Motor

The azimuth motor of a baseline heliostat (H1) burned out; although the cause has not yet been determined, it is suspected that water accumulated in the windings.

Lubricant Leakage

Minor lubricant leakage was observed in the motor gear boxes, the linear actuators, and the harmonic drive. No leakage was sufficient to require "topping off" of the lubricant.

Cables

No problems were encountered with the cables, which were strung on the ground (not entrenched).

6.4.5 Installation and Maintenance

During collector hardware installation and testing at the Naval Weapons Center (NWC), a substantial amount of installation and maintenance data were collected. This section presents a compilation of those data, along with a report of the procedure used at NWC for the assembly/installation of the heliostats.

6.4.5.1 Heliostat Assembly/Installation

The following assembly/installation activities were accomplished in accordance with Drawings 1T47293, Site Plan, and 1T49882, Heliostat Assembly.

The flow of assembly/installation tasks, as performed at NWC, is shown in Figure 6-79. The following paragraphs describe the activities which took place in reference to the tasks in the flow diagram, Figure 6-79.

Install Heliostat Foundation

Standard surveying techniques were used to establish the location for each heliostat foundation. Foundation holes were dug and foundation rebar emplaced. Anchor J-bolts were wired to the rebar framework. The rebar assembly was aligned such that the North and South bolts were within tolerance. Concrete was poured and the bolt hole alignment confirmed. A template was available for this operation. The foundation hole was back-filled.

Install Heliostat Pedestal

The pedestals were positioned over the foundation by a crane and lowered onto the J-bolts; nuts and washers were attached and torqued to specifications. The pedestals were filled with sand using a crane and concrete bucket.

Install Hub/Mount Assembly

The existing Nike trailer was used for the reflector assembly. It did not require any modification for the assembly operation other than additional

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Figure 6-79. Flow of Heliostat Assembly/Installation

scaffolding and electrical grounding. The hub/mount assembly was placed on the trailer pedestal using a crane and a hub/mount lifting sling. It was then bolted to the trailer pedestal and positioned in azimuth for installation of the first segment. Positioning was required so that the rotation required to accommodate installation of eight segments did not overrun the azimuth limit switch.

Install Reflector Segments

Each segment was removed from its shipping crate and hoisted into a horizontal position adjacent to the hub/mount using the mobile crane and a lifting sling. An adjustable table was used to hold the segment while aligning the bolt holes and bolts. After each segment was installed, the mount was rotated 45 deg so that the next segment could be installed. These activities are shown in Figure 6-80. The hub and mount assembly can support the maximum offset load of the side-by-side segments, and the trailer/pedestal installation can also support this load.

Install Reflector on Pedestal

After completing the reflector segment-hub-drive unit assembly, the unit was hoisted into place by crane and bolted to the pedestal mounting flange. After the four fixed heliostats had been emplaced, the fifth unit was assembled in the manner noted above. Upon completing the assembly, this unit was hoisted clear of the trailer by crane and a pedestal extension installed. Then the crane was used to swing the heliostat onto the trailer pedestal and the pedestal extension was bolted to the pedestal flange. These activities are shown in Figure 6-81.

Connect Power and Control Cables

The pedestal J-box was installed on the pedestal using self-tapping screws. Power and control cables from the heliostat drive motors, potentiometers, and limit switches were then connected to terminal strips within the J-box. After the incoming cables were laid in place, they were also connected into the J-box. The length of the cable between the J-box and the top of the heliostat was adjusted to provide a loop of slack cable sufficient to compensate for heliostat azimuthal movement. This was done prior to connecting the cable into the junction box. The incoming cable was laid on the ground with no trenching except in areas of vehicle traffic.

(A) ASSEMBLY TRAILER POSITIONED NEAR PEDESTAL

(B) POSITIONING OF MOBILE CRANE

(C) REMOVAL OF SEGMENT

(D) SEGMENT POSITIONING

Figure 6-80. Heliostat Field Assembly

(I) REMOVAL OF DRIVE UNIT/REFLECTOR ASSEMBLY

(J) POSITIONING ABOVE PEDESTAL

(K) ATTACHMENT TO PEDESTAL

(L) REMOVAL OF LIFTING SLING

Figure 6-81. Heliostat Field Assembly

Install Sensor Pole Foundation

The sensor pole foundations installed at NWC were of two designs. One design incorporated anchor bolts which interfaces with a flange on the pole. The other design incorporated a stub pipe cast into the foundation to which the pole was welded. Both foundations were installed in a fashion similar to the heliostat foundation.

Install Sensor Pole

Because of the different foundation designs, the poles were installed either by being bolted to the foundation or welded to the cast-in pipe stud. In both instances the poles were positioned vertically, $90^\circ \pm 1.5$. An inclinometer was used to measure the verticality of the poles. Also, the point of measurement on each pole was marked so that test readings to detect pole movement from vertical could be taken at the same point.

Install Sensor and Sensor Mount

An aerial ladder was used for access to the sensor location on the sensor pole. Although sensor booms were installed on the poles, they were not used at NWC. The sensor mount was hoisted to the work location on the ladder using a small rope. The sensor mount U-bolts were placed over the pole, the mount installed, positioned, and secured using the attaching nuts. Then the sensor was lifted to the work location, installed on the mount and aligned, grossly, on the target.

Connect Sensor Cable

Again using the aerial ladder to gain access to the sensor, the interconnecting cable between the sensor and the heliostat pedestal junction box was uncoiled and one end mated with the sensor. The cable was then secured to the pole by wrapping tape around the pole and cable as required. The other end of the cable was connected to a terminal strip within the pedestal junction box.

Make Electrical Checks

Continuity checks were made on all leads. Then power was turned on, and using the manual control unit and a digital voltmeter each heliostat and sensor combination was checked out for:

Power Phasing	Sensor Signal Error Polarity
Command Response	Sensor AGC Level
Motor Operation	Potentiometer Polarity

Set Limit Switches and Potentiometers

Starting with the heliostat in a horizontal position, the azimuth and elevation limit switches were checked for proper setting, and were reset as required, and the azimuth and elevation potentiometers were set to the proper reference. These operations were accomplished as follows:

- The heliostat was driven to a position of $-1\ 1/2^\circ$ from horizontal. A vernier inclinometer was used to determine this position. The limit switch was adjusted to open the power circuit, and this setting was verified by moving the heliostat away from the limit switch and driving it back again until the limit switch opened.
- The heliostat was positioned to a 0° (horizontal) position. Then while measuring the elevation potentiometer output with a digital voltmeter, the potentiometer shaft was rotated to obtain a reading of +3.971 V. When this reading was obtained, the potentiometer shaft was locked. Part of the potentiometer circuit is a gain amplifier mounted in the pedestal junction box. After adjusting the potentiometer, the gain amplifier was adjusted to provide an output of +10V. As a check of potentiometer output polarity, the heliostat was slewed down to confirm that there was a voltage drop in the output reading. An increase in voltage would have signified reversed polarity.
- The heliostat was then driven to a position of 78° deg (approaching a vertical position). With it in this position the other end of the elevation limit switch was adjusted, and the setting verified.
- The first step in setting the azimuth potentiometer was to position the heliostat so that it faces due South. At NWC the reference used was a string drawn from the center of the heliostat pedestal to the center of the sensor pole foundation. This string provided a true North-South reference because the two foundations locations were surveyed to be in such a position. Then, with the heliostat in a close to vertical elevation position, it was slewed on azimuth until the center of the bottom segment was directly over the string. This established a South facing position for the heliostat. With the heliostat in this position, the potentiometer shaft was rotated as necessary to obtain a 0.00V reading on the digital voltmeter. When this reading was obtained, the potentiometer shaft was locked

in place. Polarity was checked by slewing the heliostat clockwise and then counterclockwise in azimuth. Proper polarity will result in a plus voltage output as the heliostat moves clockwise and a negative voltage output as it moves counterclockwise.

- Setting of the azimuth limit switches was accomplished by slewing the heliostat from a South-facing position approximately 235°deg clockwise and then 235°deg counterclockwise. With the heliostat in each of these positions the azimuth limit switches were adjusted to open the drive motor power circuit.

Align Beam Sensor

The beam sensors at NWC were aligned on the target by the simple method of adjusting the sensor position so that the reflected beam was centered on the target. This was accomplished by commanding the heliostat to a near-track angle using the master control and field controller. When the beam was on or near the target, the heliostat was commanded to track. While the heliostat was in a track mode, a technician positioned next to the sensor, on an aerial ladder, adjusted the heliostat in two axes until the beam was centered on the target. The sensor was then locked in position.

6.4.5.2 Assembly/Installation Timelines

During the assembly/installation of the heliostats and sensor pole assemblies at NWC, data relative to how much time was required to accomplish the tasks were collected. These data have been refined and are presented in Figure 6-82. for the sensor pole assembly, and Figure 6-83 for the heliostat.

6.4.5.3 Maintenance Time Lines

During the NWC tests certain essential maintenance data were collected. These data have also been refined and are presented in Figure 6-84.

6.4.5.4 Sensor Alignment

The beam sensor alignment procedure is shown in Table 6-38. These procedures can normally be followed without difficulty. When the synthetic track angles result in the beam missing the target prior to normal track acquisition, the workman may not know where the reflected beam is and therefore will not know which direction to adjust the beam sensor to bring the beam onto the

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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. SENSOR POLE ASSY 1D40025	3 NEXT HIGHER ASSY. HELIOSTAT ASSY 1D40001	4 QTY. REQ. 1	5 DOC. CONT. NO.	12 DESCRIPTION OF REPT. INSTALL THE HELIOSTAT SENSOR POLE ASSY INCLUDING SENSOR ALIGNMENT
6 WBS NO.	7 REQUIREMENT INSTALL	8 ANNUAL FREQ. NA	9 MONTHS NA	10 MILE YEAR NA	11 MAINT. CODE NA

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL ET.	17 PERSONNEL MAN-MIN			
		0	10	20	30	40	50	60	70	80	90		TOTAL	H	I	S
0010	UNLOAD EQUIPMENT - POLE, SENSOR, MOUNT & CABLE	■										2	1	1		4
0020	POSITION HUISTING EQUIPMENT	■										1		1		1
0030	INSTALL POLE LIFTING STRAP	■										1	1			1
0040	HUIST POLE & LOWER ONTO FOUNDATION	■										1	1	1		2
0050	INSTALL ANCHOR NUTS		■									2	1			2
0060	LEVEL POLE			■								2	1	1		4
0070	TORQUE ANCHOR NUTS				■							2		1		2
0080	POSITION & ERECT AERIAL LADDER					■						3	1	1		6
0090	MOUNT LADDER						■					1	1	1		2
0100	INSTALL SENSOR MOUNT							■				5	1	1		10
0110	INSTALL SENSOR								■			2	1	1		4
0120	INSTALL CABLE									■		2	1	1		4
0130	ROUGH ALIGN SENSOR										■	1	1	1		2
0140	TAPE CABLE TO POLE											9	1	1		18
0150	RUN CABLE TO PEDESTAL JUNCTION BOX											1	1	1		2
0160	MAKE ELECTRICAL CONNECTIONS IN JUNCTION BOX											12		1		12
0170	MAKE ELECTRICAL CHECKS											10	1	1		20
0180	DRIVE HELIOSTAT ONTO TARGET											8		1		8
												Σ				

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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. SENSOR POLE ASSY. ID40025	3 NEXT HIGHER ASSY. HELIOSTAT ASSY. ID40001	4 QTY. REQ. 1	5 DOC. CONT. NO.	12 DESCRIPTION OF REQ.: INSTALL THE HELIOSTAT SENSOR POLE ASSY INCLUDING SENSOR ALIGNMENT
6 WBS NO.	7 REQUIREMENT INSTALL	8 ANNUAL FREQ. N.A.	9 N.A.	10 MO./YEAR N.A.	11 MAINT. CODE N.A.

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13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL EST.	17 PERSONNEL MAJ-MTH			
		5	10	20	30	40	50	B	I	S	TOTAL					
0180	CONTINUED															
0190	POSITION AERIAL LADDER											1	1	1	2	
0200	MOUNT LADDER											1	1	1	2	
0210	ALIGN SENSOR											2	1	1	4	
0220	SECURE AREA & EQUIPMENT											5	1	1	10	
0230	RETURN HELIOSTAT TO STOW POSITION											3	1	1	6	
Σ												77				128

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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. HELIOSTAT 1T47591	3 NEXT HIGHER ASSY. COLLECTOR FIELD 1T49886	4 QTY. REQ. NA	5 DOC CONT NO. NA	12 DESCRIPTION OF REPT.: ASSEMBLE/INSTALL HELIOSTAT											
6 WBS NO.	7 REQUIREMENT INSTALL	8 ANNUAL FREQ. NA	9 NA	10 MOES/YEAR NA	11 MAINT. CODE NA											
13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL ET.	17 PERSONNEL MAY-MIN			
		10	20	30	40	50						B	I	S	TOTAL	
0010	UNLOAD EQUIPMENT											20	4	1		100
0020	POSITION HOISTING EQUIPMENT											5		2		10
0030	HUIST PEDESTAL											2	4	1		10
0040	INSTALL SAND BARRIER											3	2		1	9
0050	LOWER PEDESTAL ONTO FOUNDATION											1	4	1		5
0060	INSTALL ANCHOR NUTS											6	2			12
0070	LEVEL PEDESTAL											12	2			24
0080	TORQUE ANCHOR NUTS											4	1	1		8
0090	PUT SAND IN PEDESTAL											43	3	1		172
0100	INSTALL HUB/MOUNT ON ASSY FIXTURE											12	2	1	1	40
0110	ROTATE HUB/MOUNT CLOSE TO LIMIT SWITCH											35		1		35
0120	REMOVE SEGMENT FR CRATE-INSTALL ON FIXTURE											6	2	1	1	24
0130	ATTACH SEGMENT TO HUB											8	2	1	1	32
0140	ATTACH CLIP TO SEGMENT TIP											3	2	1	1	12
0150	ROTATE HELIOSTAT 45°											2	2	1	1	9
0160	REPEAT 0120-0150 7 TIMES (7x19=133)											133	2	1	1	532
												Σ				
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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. HELIOSTAT IT47891	3 NEXT HIGHER ASSY. COLLECTOR FIELD IT47896	4 QTY. N/A	5 DOC CONT NO. N/A	12 DESCRIPTION OF REPAIR ASSEMBLE/INSTALL HELIOSTAT	
6 VBS NO.	7 REQUIREMENT INSTALL	8 ANNUAL FREQ. N/A	9 A N/A	10 HOURS/YEAR N/A	11 MAINT. CODE N/A	
13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME -- MINUTES 10 20 30 40 50			16 TOTAL ET.	17 PERSONNEL MAY-MIN B I S TOTAL
0160	CONTINUED					
0160	CONTINUED					
0170	INSTALL HELIOSTAT LIFTING SLING				15	2 2 1 75
0180	TRANSFER HEL. FR FIXTURE TO PEDESTAL				12	3 2 1 72
0190	INSTALL PEDESTAL JUNCTION BOX				45	1 1 90
0200	MAKE ELEC. CONNECTIONS IN JUNCTION BOX				53	1 53
0210	MAKE ELECTRICAL CHECKS				20	1 1 40
0220	POSITION HELIOSTAT AT -15° ELEVATION				4	2 1 12
0230	SET ELEV. UPPER LIMIT SWITCH				7	2 1 21
0240	POSITION HELIOSTAT AT 0° ELEVATION				4	2 1 12
0250	SET ELEVATION POTENTIOMETER				6	2 1 18
0260	POSITION HELIOSTAT AT 75° ELEVATION				15	2 1 45
0270	SET ELEV. LOWER LIMIT SWITCH				4	2 1 12
0280	POSITION HEL. SOUTH FACING				5	2 1 15
0290	SET AZIMUTH POTENTIOMETER				12	2 1 36
0300	ROTATE HEL. 135° CLOCKWISE				47	2 1 141
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1. SYSTEM COLLECTOR	2. ITEM NAME/PART NO. GEAR MOTOR 1T47284	3. NEXT HIGHER ASSY. ELEV. ACTUATOR 1T47334	4. QTY. RIII ONE	5. DOC CONT NO MSA 1010 1010-1	12. DESCRIPTION OF REPT. 1 FOLLOWING VERIFICATION OF ELEVATION ACTUATOR GEAR MOTOR MALFUNCTION, REMOVE & REPLACE GEAR MOTOR. THIS IS A LEVEL 1 (ON-LINE) CORRECTIVE MAINTENANCE TASK.										
6. WGS NO.	7. REQUIREMENT REMOVE & REPLACE	8. ANNUAL FREQ 2	9. 10. 1986/1987	11. MAINT. CODE 1P11											
13. TASK NO.	14. TASK DESCRIPTION	15. ELAPSED TIME - MINUTES			16. TOTAL										
		10	20	30	40	50	60	70	80	90	100				
0010	ACQUIRE REPLACEMENT GEAR MOTOR	[Bar chart showing time from 0 to 10 minutes]										0:10	1		10
0020	ASSEMBLE TOOLS & EQUIPMENT	[Bar chart showing time from 0 to 10 minutes]												1	10
0030	DRIVE TO WORK AREA	[Bar chart showing time from 0 to 10 minutes]										0:10	1	1	20
0040	POSITION WORK STAND	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0050	CONNECT MANUAL CONTROL UNIT	[Bar chart showing time from 0 to 10 minutes]										0:03	1	1	6
0060	REMOVE UPPER J-BOX COVER	[Bar chart showing time from 0 to 10 minutes]										0:02	1	1	4
0070	DISCONNECT MOTOR LEADS AT J-BOX	[Bar chart showing time from 0 to 10 minutes]										0:01		1	1
0080	REMOVE CONDUIT FITTING AT MOTOR	[Bar chart showing time from 0 to 10 minutes]											1		1
0090	WITHDRAW MOTOR LEADS FROM CONDUIT	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0100	REMOVE MOTOR MOUNTING CAP SCREWS	[Bar chart showing time from 0 to 10 minutes]										0:02	1	1	4
0110	REMOVE MOTOR FROM HOUSING	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0120	REMOVE COUPLING HALF FROM MOTOR	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0130	REMOVE MOUNT PLATE FROM MOTOR	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0140	INSTALL MOUNT PLATE ON RPLMT. MOTOR	[Bar chart showing time from 0 to 10 minutes]										0:02	1	1	4
0150	INSTALL COUPLING HALF ON RPLMT. MOTOR	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0160	POSITION GEAR MOTOR IN HOUSING	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
0170	INSTALL MOTOR MOUNTING CAP SCREWS	[Bar chart showing time from 0 to 10 minutes]										0:02	1	1	4
0180	ADJUST & SECURE MOTOR SHAFT COUPLING	[Bar chart showing time from 0 to 10 minutes]										0:01	1	1	2
PAGE 1 OF 2							Σ	0:40				80			
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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. EL DR MOTOR/REDUCER 1D40010/1B40094-1	3 NEXT HIGHER ASSY. DRIVE UNIT ASSY 1D40093	4 QTY. REQ. 1	5 DOC. CONT. NO. MSA-1010.1010-1	12 DESCRIPTION OF REPT. FOLLOWING VERIFICATION OF ELEVATION DRIVE MOTOR/REDUCER MALFUNCTION REMOVE AND REPLACE MOTOR/REDUCER.
6 VRS. NO.	7 REQUIREMENT REMOVE/REPLACE	8 ANNUAL FREQ. λ	9 λ	10 HRS/YEAR	11 MAINT. CODE 1 PU

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES						16 TOTAL ET.	17 PERSONNEL MAX-MIN			
		10	20	30	40	50	H		I	S	TOTAL	
0010	ACQUIRE REPLACEMENT DRIVE MOTOR/REDUCER	★	★	★	★	★	★	10	1			10
0020	ASSEMBLE TOOLS & EQUIPMENT	★	★	★	★	★	★			1		10
0030	DRIVE TO WORK AREA		★	★	★	★	★	10	1	1		20
0040	CONNECT MANUAL CONTROL UNIT			★	★	★	★	3	1	1		6
0050	DRIVE REFLECTOR TO CONVENIENT POSITION (IF REQ'D)			★	★	★	★	4	1	1		8
0060	POSITION WORK STAND			★	★	★	★	1	1	1		2
0070	DISCONNECT MOTOR FLEET WIRING			★	★	★	★	4	1	1		8
0080	REMOVE ATTACHING HARDWARE & MOTOR			★	★	★	★	4	1	1		8
0090	POSITION MOTOR ON MOUNT & INSTALL ATTACH HDW			★	★	★	★	6	1	1		12
0100	RECONNECT MOTOR WIRING			★	★	★	★	6	1	1		12
0110	CHECK ELEVATION DRIVE OPERATION					★	★	4	1	1		8
0120	DISCONNECT MANUAL CONTROL UNIT					★	★	2	1	1		4
0130	RECONNECT PEDESTAL FLEET CABLES					★	★	2	1	1		4
0140	REMOVE WORK STAND					★	★	2	1	1		4
0150	VERIFY REFLECTOR OPERATION	★	★	★	★	★	★	4	1			4
0160	LOAD TOOLS & EQUIPMENT	★	★	★	★	★	★	2	1	1		8
0170	DRIVE TO MAINTENANCE FACILITY	★	★	★	★	★	★	10	1	1		20
								Σ				

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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. ACTUATOR 1747334	3 NEXT HIGHER ASSY. DRIVE UNIT 1747314	4 QTY. REQ. 1	5 DOC. CONT. NO. MSA 101010-2	12 DESCRIPTION OF REPT.: FOLLOWING VERIFICATION OF ELEVATION ACTUATOR MALFUNCTION REMOVE & REPLACE ACTUATOR. THIS IS A LEVEL ONE (ON-LINE) CORRECTIVE MAINTENANCE ACTION					
6 WBS NO.	7 REQUIREMENT REMOVE/REPLACE	8 ANNUAL FREQ. λ	9	10 MOES/YEAR	11 MAINT. CODE 1 PLU					
13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES			16 TOTAL ET.	17 PERSONNEL MAN-MIN				
		10.	20	30	40	50	B	I	S	TOTAL
0010	ACQUIRE REPLACEMENT ACTUATOR									
0020	ASSEMBLE TOOLS & EQUIPMENT									
0030	DRIVE TO WORK AREA									
0040	POSITION WORK STANDS									
0050	CONNECT MANUAL CONTROL UNIT									
0060	INSTALL SAFETY LINK									
0070	REMOVE GEAR MOTOR WITH BRACKET									
0080	SECURE MOTOR TO MOUNT									
0090	REMOVE LIMIT SWITCH									
0100	SECURE LIMIT SWITCH TO MOUNT									
0110	REMOVE CLEVIS BOLT									
0120	LOOSEN BOOT RETAINING WIRES									
0130	REMOVE ACTUATOR RETAINING BOLTS									
0140	REMOVE ACTUATOR FROM TRUNION									
0150	REMOVE COUPLING HALF FROM ACTUATOR									
0160	INSTALL COUPLING HALF ON REPLACEMENT ACT.									
0170	POSITION BOOT									
0180	POSITION ACTUATOR IN TRUNION									
						Σ	46			92

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1 SUBSYSTEM	2 ITEM NAME/PART NO. ACTUATOR IT 47324	3 NEXT HIGHER ASST.	4 QTY. REQ.	5 DOC. CONT. NO.	12 DESCRIPTION OF REPT.
6 VBS NO.	7 REQUIREMENT	8 ANNUAL FREQ.	9 λ	10 MO./YEAR	11 MAINT. CODE

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL ET.	17 PERSONNEL MAX-MIN			
		10	20	30	40	50	B	I	S	TOTAL						
0190	INSTALL ACTUATOR RETAINING BOLTS											2	1	1		4
0200	ATTACH REFLECTOR TILTING ROPES											4	1	1	1	12
0210	REMOVE SAFETY LINK											1	1	1	1	3
0220	POSITION REFLECTOR HORIZONTAL											2	1	1	1	6
0230	INSTALL SAFETY LINK											1	1	1	1	3
0240	FIT CHECK ACTUATOR SCREW TO CLEVIS											2	1	1	1	6
0250	TIGHTEN ACTUATOR RETAINING BOLTS											1	1	1	1	3
0260	REMOVE SAFETY LINK											1	1	1	1	3
0270	POSITION REFLECTOR TO 12°											2	1	1	1	6
0280	INSTALL SAFETY LINK											1	1	1	1	3
0290	MANUALLY EXTEND ACTUATOR SCREW											2	1	1	1	6
0300	FIT CHECK ACTUATOR SCREW TO CLEVIS											1	1	1	1	3
0310	INSTALL SPACERS & CLEVIS BOLT											2	1	1	1	6
0320	TIGHTEN CLEVIS BOLT											1	1	1	1	3
0330	REMOVE REFLECTOR TILTING ROPES											2	1	1	1	6
0340	REINSTALL GEAR MOTOR											2	1	1		4
0350	REINSTALL LIMIT SWITCH											2	1	1		4
0360	REMOVE SAFETY LINK											1	1	1		2
											Σ 76				175	

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Figure 6-84 (Sheet 8 of 15)

1. SYSTEM COLLECTOR	2. ITEM NAME/PART NO. GEAR MOTOR IT 47284	3. NEXT HIGHER ASST. DRIVE UNIT IT 47314	4. QTY. REQ. ONE	5. DOC. COST NO. MSA/010 2010-1	12. DESCRIPTION OF REQ.: Following VERIFICATION OF AZIMUTH GEAR MOTOR MALFUNCTION, REMOVE & REPLACE MOTOR. THIS IS A LEVEL 1 (ON-LINE) CORRECTIVE MAINTENANCE TASK.				
6. VBS NO.	7. REQUIREMENT REMOVE & REPLACE	8. ANNUAL FREQ. λ	9. MONTH/YEAR	10. MAINT. CODE 1PL					
13. TASK NO.	14. TASK DESCRIPTION	15. ELAPSED TIME - MINUTES			16. TOTAL ET.	17. PERSONNEL MAN-MIN			
		10	20	30	40	50	18. TOTAL		
0010	ACQUIRE REPLACEMENT GEAR MOTOR	[Gantt bar from 0 to 10]					0:10	1	10
0020	ASSEMBLE TOOLS & EQUIPMENT	[Gantt bar from 0 to 10]						1	10
0030	DRIVE TO WORK AREA	[Gantt bar from 10 to 20]					0:10	1	20
0040	POSITION WORK STAND	[Gantt bar from 20 to 21]					0:01	1	2
0050	CONNECT MANUAL CONTROL UNIT	[Gantt bar from 21 to 24]					0:03	1	6
0060	REMOVE UPPER J-Box COVER	[Gantt bar from 24 to 26]					0:02	1	4
0070	DISCONNECT MOTOR LEADS AT J-Box	[Gantt bar from 26 to 27]					0:01	1	1
0080	REMOVE CONDUIT FITTING AT MOTOR	[Gantt bar from 27 to 28]						1	1
0090	WITHDRAW MOTOR LEADS FROM CONDUIT	[Gantt bar from 28 to 29]					0:01	1	2
0100	TILT REFLECTOR TO ≥ 45° (AR)	[Gantt bar from 29 to 33]					0:04	1	8
0110	REMOVE DRIVE UNIT COVER	[Gantt bar from 33 to 35]					0:02	1	4
0120	REMOVE MOTOR MOUNTING CAPSCREWS	[Gantt bar from 35 to 37]					0:02	1	4
0130	REMOVE GEAR MOTOR FROM HOUSING	[Gantt bar from 37 to 38]					0:01	1	2
0140	REMOVE COUPLING HALF FROM MOTOR	[Gantt bar from 38 to 39]					0:01	1	2
0150	REMOVE MOUNT PLATE FROM MOTOR	[Gantt bar from 39 to 40]					0:01	1	2
0160	INSTALL MOUNT PLATE ON RPLMT. MOTOR	[Gantt bar from 40 to 42]					0:02	1	4
0170	INSTALL COUPLING HALF ON RPLMT. MOTOR	[Gantt bar from 42 to 43]					0:01	1	2
0180	POSITION GEAR MOTOR IN HOUSING	[Gantt bar from 43 to 44]					0:01	1	2
PAGE 1 OF 2						Σ	43	86	
PREPARED BY: _____						DATE: _____			

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Figure 6-84 (Sheet 10 of 15)

LOGISTIC SUPPORT ANALYSIS
MAINTENANCE TASK ANALYSIS
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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. AZ DR MOTOR/REDUCER ID40010/ID40099-511	3 NEXT HIGHER ASSY. DRIVE UNIT ASSY ID40098	4 QTY. REQ. 1	5 DOC. CONT. NO. MSA 10102010-1	12 DESCRIPTION OF REPT. FOLLOWING VERIFICATION OF AZIMUTH DRIVE MOTOR/REDUCER MALFUNCTION, REMOVE AND REPLACE UNIT. THIS IS A LEVEL 1 (ONPLINE) CORRECTIVE MAINTENANCE TASK.
6 VBS NO.	7 REQUIREMENT REMOVE/REPLACE	8 ANNUAL FREQ.	9 A	10 MO./YEAR	11 MAINT. CODE 1 PU

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES						16 TOTAL ET.	17 PERSONNEL MAT-MIN.			
		10	20	30	40	50	B		I	S	TOTAL	
0010	ACQUIRE REPLACEMENT DRIVE MOTOR/REDUCER	■						10	1			10
0020	ASSEMBLE TOOLS & EQUIPMENT	■								1		10
0030	DRIVE TO WORK AREA		■					10	1	1		20
0040	CONNECT MANUAL CONTROL UNIT			■				3	1	1		6
0050	DRIVE REFLECTOR TO HORIZONTAL			■				10	1	1		20
0060	POSITION WORK STAND				■			1	1	1		2
0070	REMOVE DRIVE MOTOR COVER				■			2	1	1		4
0080	DISCONNECT MOTOR ELEC WIRING				■			6	1	1		12
0090	REMOVE ATTACHING HARDWARE & MOTOR				■			6	1	1		12
0100	POSITION MOTOR IN HOUSING & INSTALL ATTACH HDW.				■			8	1	1		16
0110	RECONNECT MOTOR WIRING	■						8	1	1		16
0120	CHECK AZIMUTH DRIVE OPERATION		■					4	1	1		8
0130	INSTALL DRIVE MOTOR COVER		■					2	1			2
0140	DISCONNECT MANUAL CONTROL UNIT		■								1	2
0150	RECONNECT PEDESTAL ELEC. CABLES		■					2	1	1		4
0160	REMOVE WORK STAND		■					2	1	1		4
0170	VERIFY REFLECTOR DRIVE OPERATION		■					4	1			4
Σ												

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LOGISTIC SUPPORT ANALYSIS
MAINTENANCE TASK ANALYSIS
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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. EL. POTENTIOMETER MODEL 152	3 NEXT HIGHER ASSY. PED. ELECT INST 1340028	4 QTY. REQ. 1	5 DOC. CONT. NO. MSA 104Q10-1	12 DESCRIPTION OF REPT.: ADJUST POTENTIOMETER TO SPECIFIED OUTPUT WITH REFLECTION IN HORIZONTAL POSITION
6 VHS NO.	7 REQUIREMENT ADJUST	8 ANNUAL FREQ. λ	9	10 HRS/YEAR	11 MAINT. CODE

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL ET.	17 PERSONNEL MAX-MIN			
		10.	20	30	40	50	8	I	S	TOTAL						
0010	ASSEMBLE TOOLS AND EQUIPMENT											10	1	1		20
0020	DRIVE TO WORK AREA											10	1	1		20
0030	CONNECT MANUAL CONTROL UNIT											3	1	1		6
0040	DRIVE REFLECTOR TO 90° POSITION											8	1	1		16
0050	VERIFY 90° POSITION WITH INCLINOMETER											1	1	1		2
0060	POSITION WORK STAND											1	1	1		2
0070	REMOVE EL DRIVE ASSY COVER											1	1			1
0080	OPEN PED. J-BOX COVER													1		1
0090	READ POT OUTPUT AND ADJUST TO 3.97V											4	1	1		8
0100	VERIFY/ADJUST AMPLIFIER OUTPUT IS 10V											2	1	1		4
0110	REPLACE DRIVE ASSY & J-BOX COVERS											1	1	1		2
0120	REMOVE WORK STAND											1	1	1		2
0130	DISCONNECT MANUAL CONTROL UNIT											2	1	1		4
0140	CONNECT PEDestal CABLES											2	1	1		4
0150	VERIFY HORIZONTAL OPERATION											4		1		4
0160	LOAD TOOLS & EQUIPMENT											2	1	1		8
0170	DRIVE TO MAINTENANCE FACILITY											10	1	1		20
0180	STORE TOOLS & EQUIPMENT											10	1	1		20
											Σ	72				144

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LOGISTIC SUPPORT ANALYSIS
MAINTENANCE TASK ANALYSIS
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1 SUBSYSTEM COLLECTOR	2 ITEM NAME/PART NO. BEAM SENSOR 1T47414	3 NEXT HIGHER ASST. SENSOR POLE INST 1T47248	4 QTY. REQ. 1	5 DOC CONT NO. MSA-105010-1 -2	12 DESCRIPTION OF REQ.: Following Verification of Beam Sensor Malfunction Remove and Replace Sensor. This is a Level One (on-line) corrective maintenance action.
6 VBS NO.	7 REQUIREMENT REMOVE/REPLACE	8 ANNUAL FREQ. λ	9	10 MCH/YEAR	11 MAINT. CODE 1PU

13 TASK NO.	14 TASK DESCRIPTION	15 ELAPSED TIME - MINUTES										16 TOTAL FT.	17 PERSONNEL MAN-MIN			
		10	20	30	40	50	B	I	S	TOTAL						
0010	ACQUIRE REPLACEMENT BEAM SENSOR	■										10	1			10
0020	ASSEMBLE TOOLS & EQUIPMENT	■												1		10
0030	DRIVE TO WORK AREA		■	■	■	■						10	1	1		20
0040	POSITION & ERECT AERIAL LADDER			■								3	1			3
0050	MOUNT LADDER & DISCONNECT SENSOR CABLE			■								2	1			2
0060	REMOVE ATTACHING BOLT AND SENSOR				■							3	1			3
0070	OBTAIN AND INSTALL REPLACEMENT SENSOR					■						4	1			4
0080	CONNECT SENSOR ELECT CABLE					■						1	1			1
0090	CONNECT MANUAL CONTROL UNIT			■										1		2
0100	DRIVE MIRROR ON TARGET & PLACE IN AUTO TRACK			■	■	■								1		11
0110	ALIGN SENSOR AND LOCK IN PLACE					■						3	1	1		6
0120	DISCONNECT MAN. CONT UNIT						■					2	1	1		4
0130	VERIFY MIRROR TRACKING OPERATION							■				4		1		4
0140	REMOVE AERIAL LADDER							■					1			1
0150	LOAD TOOLS AND EQUIPMENT								■				3			3
0160	DRIVE TO MAINTENANCE FACILITY									■		10	1	1		20
0170	STOW TOOLS AND EQUIPMENT										■	10	1	1		20
												Σ 62				124

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Table 6-38
SENSOR ALIGNMENT PROCEDURE/EVALUATION

Procedure

- Sensor mounted on pole at prescribed location and oriented along line-of-sight to receiver $\pm 5^\circ$
- Heliostat(s) commanded to near-track angle via master control/field controller
- Workman on mobile ladder adjusts knurled vernier alignment screws while heliostat is on normal track, and observes beam movement onto target
- Spring-bolt tightened and final adjustments made to alignment screws
- Heliostat commanded to stowage position (radio link to master control)

Evaluation

- Total time ~ 3 to 6 min, 1 man to adjust, 1 man to drive mobile ladder
 - Alignment accuracy limited by workman's ability to judge beam position on target. Can easily adjust to within ± 0.5 ft at 650 ft, or ± 0.77 MR, for clearly defined edge of beam. Alignment error of the order of ± 1 -1.5 MR for more diffuse beam
-

target. In this case, a hand-held beaded glass screen signal mirror is useful. The mirror can be used two ways. The mirror can be placed against the reflector and a second workman then directs the workman adjusting the beam sensor. The workman adjusting the beam sensor can also look through his signal mirror at the heliostat sensor mirror such that his mirror is parallel to the heliostat (as noted by the infinitely receding images). The actual reflected beam position in either case is seen through the signal mirror as a bright spot in the sky in the vicinity of the target, and it is then an easy task to properly adjust the beam sensor angle.

One difficulty encountered, which must be addressed for any subsequent beam sensor design requirements, is the necessity for aligning the sensor onto the relatively small projected area portion of sensor mirror for worst-case heliostat angles. This area is approximately 6 in. in diameter for the inverted heliostat; therefore, the accuracy of positioning the sensor pole and the positioning of the sensor mount on the pole prior to vernier alignment must be sufficiently accurate to allow vernier adjustment to be made such that the sensor mirror will always reflect onto the sensor, rather than the panels. We encountered problems of this type in our field tests, and it was necessary to construct a boom to support the beam sensor such that the sensor mirror, beam sensor, and target lay on the same line-of-sight.

6.4.5.5 Digital Image Radiometer (DIR)

MDAC has developed a high-speed digital irradiance measuring and recording instrument. The system is shown in Figure 6-85. The system consists of a TV vidicon with a 16-320 mm zoom lens and neutral density filters, a digitizer for converting analog video signals to digital format, 16 A/D converter channels for processing analog instrumentation signals, a CRT display, operator keyboard, video monitors to observe the beam on the target, a NOVA 1200 mini-computer, and a three-drive cassette tape unit for data recording and program storage. The target is a 40 x 40 ft flat steel structure painted with a high-temperature white paint specifically selected for its near Lambertian reflectance characteristics, which minimizes glare and provides uniform reflection. The target is instrumented with four Hycal thermopile pyrliometers with 20 apertures which measure incident solar irradiance from the mirrors at the target.

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Figure 6-85. Digital Image Radiometer Block Diagram

The system is fully operational to acquire and record beam intensity data to an accuracy of approximately 2%. Determinations of the beam intensity distribution (3,600 data points) are presented for the beam in watts/m², and calculations made of the beam centroid, total power, and total energy over the test period. Complete scenes are scanned in less than 2 sec. The system is automatically correlated whenever data is taken since Hycal thermopile pyrhelimeters mounted on the target simultaneously record the incident light at various points on the target for a range of irradiance values. These values establish a calibration curve for the incident light irradiance versus the digitized video output signal for the region immediately surrounding the Hycal.

Beam-intensity data and peripheral data are recorded on cassette tape. Preliminary data reduction is performed by the operator on site using the NOVA 1200 computer. Data acquired is verified during the test and conditions corrected if necessary, and thus costly test repetitions are avoided.

An error analysis of the DIR was performed and results are summarized in Table 6-39. The analysis indicated that power measurements at a given point on the target could be obtained with an accuracy of the order of 1.8 to 2.6% or better, using careful test procedures. Two error sources which can be minimized by test procedure, but pose operational problems are: (1) vidicon dark-current variation due to ambient temperature changes, and (2) target motion due to wind. The dark-current problem is presently avoided by allowing a 1-hr warmup of the vidicon, using a hand-held heat gun to warm it on cold mornings, and applying ice bags on hot days. These procedures, although workable, are time-consuming and require close manual monitoring of the dark current. It will be necessary for future extensive use of the DIR to add an environmental enclosure, capable of maintaining the vidicon temperature constant to within $\pm 2.5^{\circ}$ to 5° F, depending on the video output curve sensitivity to dark-current. Target motion poses no problem on quiescent days, but during February and March, winds caused sufficient target motion to make system calibration a difficult and time consuming operation. This problem can be eliminated by increasing the scan speed from approximately two seconds to 1/30 sec. For future extensive use of the DIR, a faster scan speed should be developed to minimize time-dependent effects such as solar drift and wind motion.

Table 6-39 (Page 1 of 2)
DIGITAL IMAGE RADIOMETER

Error Analysis		
Parameter	Error Source/Magnitude	Resulting Irradiance Error (%)
A. Random		
● Eppley N. I. P.	Temperature/ $\pm 5^{\circ}\text{C}$	± 0.2
	Linearity/ $\pm 0.5\%$	± 0.5
● Hycal Pyrheliometer	Temperature/ $\pm 5^{\circ}\text{C}$	± 0.2
	Linearity/ $\pm 0.5\%$	± 0.5
● Target Angle	Wind shifts/ $\pm 0.5'$ in 20 (± 1.43 deg)	$< \pm 0.04$ to 0.8 for quasi-lambert surface
● Hycal Angle	Wind shifts/ ± 1.43 deg	± 0.04 to 0.8
● Hycal/Digital Eye Calibration	Target motion/ ± 3 in./sec	± 0.3
● Target Reflectivity	Paint nonuniformity	$\pm 1 - \pm 1.8$ (max.)
● Recorded Signal	Amplifier and cable noise (40 microvolts out of 3 millivolts)	± 1.25
● Recorded Signal	Amplifier gain inaccuracy	± 0.1
$\pm 1.8\% \leq \text{RSS error} \leq 2.6\%$		
B. Systematic (Controlled by Test Procedure)		
● Vidicon Dark Current	Temperature/ ± 1 nano amp for 12 nano amp nominal	± 4.5
● Vidicon Output Current	Tube uniformity	± 1
● Hycal Pyrheliometer	Variations in background light level (0.050 - 0.150 MV out of 3 MV, for 1 sun)	$\pm 1.67\%$ 1 sun $\pm 0.17\%$ 10 suns

Table 6-39 (Page 2 of 2)
DIGITAL IMAGE RADIOMETER

Error Analysis		
Parameter	Error Source/Magnitude	Resulting Irradiance Error (%)
● Beam Motion	Tracking correction/~1 MR/sec for 0.5 sec = > 0.5 ft, 2 sec scan. 1,000 deg from target	0.6 - 1.25% Increase or decrease in beam area scanned
● Beam Motion	Wind/0.5-2 MR shift for 1-2 sec	0.6% - 10% increase or decrease in beam area scanned
C. Inherent		
● Sensitivity	Digital eye range (0 to 255)	±0.2
Conclusions		
1.	Assuming all systematic errors except vidicon tube non-uniformity are eliminated by test procedure, total RSS error is:	
	$\pm 2\% \leq \text{RSS error} \leq \pm 2.8\%$	
2.	Including all errors except maximum beam motion due to wind, total RSS error is:	
	$\pm 5\% \leq \text{RSS error} \leq \pm 5.7\%$	
3.	Including all errors noted above	
	$\pm 5.3\% \leq \text{RSS error} \leq \pm 11.5\%$	

A test was performed to verify the accuracy of the DIR. Four clean 30 in. $\times$ 30 in. mirrors were used to reflect sunlight onto the target at a distance of 80 ft and power measurements made with the DIR. The mirror reflectivity, relative angles, and solar insolation were determined, and thus, the incident power on the target. Positioning the mirrors close to the target eliminated losses due to wide angle scattering and atmospheric attenuation which could occur for the normal heliostat to target distances of 200m. Thorough cleaning of the mirrors eliminated the ± 1 to $\pm 3\%$ uncertainty due to reflectance variations. The solar insolation value and reflectivity values for a clean mirror are accurate to within ± 0.5 and $\pm 1.0\%$, respectively. The mirror projected areas were known to within $\pm 1\%$. Therefore, the RSS error for the mirror reflected power was accurate to approximately $\pm 1.5\%$.

The test setup is shown in Figure 6-86, which depicts the mirrors mounted to reflect onto the target. The corresponding DIR three-dimensional plots of the beam intensity distribution are shown in Figures 6-87 and 6-88. The calibration curve is shown in Figure 6-89. It is interesting to note that the power measurements repeated for the same solar insolation value and mirror, target, and sun angles, were identical at 1,791W although the beam distribution was different. The measured power must be decreased by 2% to 1.755W to account for a bias in the DIR A/D converters which are used to record the Hycal pyrliometer analog signals. (There was insufficient time to adjust or replace these A/D converters; therefore, they were calibrated against known input voltages to establish a calibration correction factor.) The power shown in Figures 6-87 and 6-88 is total power.

The net incident power is found by subtracting the background level of 40W/m^2 for the area of 1.15m^2 . The net incident power is thus $1,755 - 46 = 1,709\text{W}$ compared to the calculated reflected power of $1,687 \pm 25\text{W}$. The agreement for this test is 1.3%, which is within the experimental error for the calculated reflected power. This test therefore indicated that DIR power measurements are accurate to within the theoretically determined value of ± 1.8 to 2.6% .

(A)

(B)

(C)

(D)

Figure 6-86. Digital Image Radiometer Verification Test

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Figure 6-87. 3D Plot of Beam Intensity

DATE= 10 12 50 36 FILE= 45

PEAK INTENSITY = 4,106 W/M²

HYCAL LOCATION

MAX VALUE = 245 MIN VALUE = 39 INTENSITY = 1.791 KWATTS

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Figure 6-88. 3D Plot of Beam Intensity

Figure 6-89. Calibration Curve for DIR Verification

Appendix A
COLLECTOR SUBSYSTEM
REQUIREMENTS SPECIFICATION
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1.0 SCOPE

This specification establishes the performance, design, and test requirements for the Pilot Plant collector subsystem.

2.0 APPLICABLE DOCUMENTS

The equipment, materials, design, and construction of the collector subsystem shall comply with all Federal, state, local, and user standards, regulations, codes, laws, and ordinances which are currently applicable for siting in Dagget, California and for utility, determined by the Southern California Edison Company. These shall include but not be limited to the government and non-government documents itemized below. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, state, county or municipal codes, laws or ordinances, that applicable requirement which is the most stringent shall take precedence.

The following documents which were in effect on the date of request for proposal form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

2.1 GOVERNMENT DOCUMENTS

2.1.1 Specifications

DD-G-451 C, Glass, plate, sheet, figured (float, flat, for glazing, corrugated, mirrors and other uses).

DD-M-0041 1b (GSA-FSS), Mirrors, Glass.

Regulations of the Occupational Safety and Health Administration (OSHA).

Regulations of the California Occupational Safety and Health Administration (CAL/OSHA) - if required.

2.1.2 Standards

NFPA Bulletin No. 78 (ANSI C5.1), Lightning Protection Code.

Federal Test Method Standard No. 101B for "Preservation, Packaging, and Packaging Materials: Test Procedures," January 15, 1969.

MIL-STD-454, Standard General Requirements for Electronic Equipment.

MIL-STD-889, Dissimilar Metals.

MIL-STD-1261A, Welding Procedures for Constructional Steels.

MIL-STD-1472, Human Engineering Design Criteria.

2.1.3 Other Publications

AFSC-Design Handbook on Electromagnetic Compatibility, DH1-4

Checklist of General Design Criteria, CH1-X

Instrumentation Grounding and Noise Minimization Handbook, AFRPL-TR-65-1

National Motor Freight Classification 100B - Classes and Rules Apply on
Motor Freight Traffic

Uniform Freight Classification 11 - Railroad Traffic Ratings Rules and
Regulations

CAB Tariff 96 - Official Air Transport Rules Tariff

CAB Tariff 169 - Official Air Transport Local Commodity Tariff

R. H. Graziano's Tariff 29 - Hazardous Materials Regulations of the
Department of Transportation

CAB Tariff 82 - Official Air Transport Restricted Articles Tariff

2.2 NON-GOVERNMENT DOCUMENTS

2.2.1 Standards

National Electrical Manufacturers Association (NEMA) Standards Manual of
Steel Construction, 7th Edition, 1974, American Institute of Steel
Construction.

Building Code Requirements for Reinforced Concrete, ACI 318-71, American
Concrete Institute.

Uniform Building Code - 1973 Edition, Vol I by International Conference of
Building Officials.

National Electrical Code, NFPA 70-1975 (ANSI C1-1975)

American National Standards Institute ANSI A58.1-1972, "Building Code
Requirements for Minimum Design Loads in Buildings and other Structures."

2.2.2 Other Publications

A Ground Lightning Environment for Engineering Usage, Stanford Research
Institute Project No. 1834.

"Wind Forces on Structures," ASCE Paper No. 3269 Transactions, American
Society of Civil Engineers, Vol 126, Part II, 1961.

2.0 REQUIREMENTS

3.1 COLLECTOR SUBSYSTEM DEFINITION

The collector subsystem is composed of an array of heliostats and supporting power and control elements which interact with the master control. The heliostat array reflects solar radiation onto the elevated absorber (boiler/superheater) of the receiver subsystem in a manner which satisfies receiver incident heat flux requirements. In addition, the collector subsystem executes alternative drive modes in response to commands from the master control for emergency defocusing of the reflected energy or to protect the heliostat array against environmental extremes. The heliostat is properly positioned for repair or maintenance in response to either master control or local commands.

The collector subsystem shall be capable of scaling to a commercial central receiver power generation system of approximately 100 MWe by the expansion of the field in accordance with scaling laws.

The collector subsystem components are:

(A) Heliostat

- (1) Reflective surface (includes glass, silver, mirror backing, foam core and steel rear face sheet.
- (2) Structural support
- (3) Drive unit (motors, drive trains, bearings, housings)
- (4) Control sensors (beam sensor, position transducers).
- (5) Pedestals and foundations for drive unit and beam sensor.
- (6) Heliostat cabling

(B) Heliostat Controller

- (1) Controller
- (2) AC/DC power supplies
- (3) AC motor control electronics

(C) Field Controller

- (1) Controller
- (2) AC/DC power supplies
- (3) Heliostat controller interface electronics
- (4) Master control interface electronics

3.1.1 Collector Subsystem Diagram

Figure A-1 represents the collector functional elements and Figure A-2 shows the collector subsystem electrical elements and interfaces.

3.1.2 Interface Definition

3.1.2.1 Collector/Physical Site

The physical arrangement and boundaries of the array of heliostats shall be optimized to concentrate the requisite solar energy on the receiver absorber in the most cost-effective manner. The final subsystem arrangement shall reflect balanced consideration of heliostat shading, blocking, and geometric parameters to produce an optimal heliostat field layout. A representative layout is shown in Figure A-3 with the corresponding heliostat locations defined in Appendix B of this Volume (3). Heliostat and beam sensor pedestal foundations shall be consistent with site-peculiar stratigraphy and surface soil conditions.

3.1.2.2 Collector/Receiver Subsystem

The collector subsystem shall concentrate at least 95% of the redirected energy onto the receiver absorber.

3.1.2.3 Collector/Electrical Power Generation Subsystem

The collector subsystem and the ES shall be interconnected by the power grid. The EPGS shall be capable of supplying (TBD) kVA at 240 V, 3-phase to the subsystem from two independent power sources.

3.1.2.4 Collector/Master Control

A two-way digital data communication grid shall be used to interconnect the field controllers and the master control. Communication may be effected by mandatory commands, transfer of information, and information requests. All heliostats and field controllers shall be uniquely addressable.

3.1.2.5 Collector Subsystem Internal Interfaces

Principal interfaces of the heliostats within the collector subsystem involve the field controller and the heliostat controllers. Each heliostat controller provides signal conditioning of the beam sensor error signals, the beam

Figure A-1. Collector Functional Diagram

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Figure A-2. Power and Data Distribution – Collector Field Network

GENERAL NOTES

A POWER HOUSE AND AUXILIARIES

- 1 RECEIVER TOWER AND FOUNDATION
- 2 POWER HOUSE
- 3 THERMAL STORAGE SUBSYSTEM
- 4 CONDENSATE STORAGE TANKS
- 5 ASSEMBLY, AS NOTED
- 6 DIESEL GENERATOR
- 7 WATER TREATING BLDG
- 8 ACID STORAGE TANK
- 9 LIME SOFTENER
- 10 CLEARWELL, COVERED
- 11 SEWAGE UNIT
- 12 AUX TRANSFORMER
- 13 MAIN TRANSFORMER
- 14 RECEIVER PANELS LAYDOWN AREA
- 15 POWER AND CONTROL CABLE TRENCH
- 16 BURIED PIPE LANE
- 17 TREATED WATER AND FIRE PUMPS
- 18 ROCK-FILLED CATCH BASIN
- 19 LUBE OIL STORAGE TANK
- 20 CONDENSATE STORAGE TANKS
- 21 FUEL OIL TANK

B SOUTH ACCESS ROAD IS 11M (36 FT) WIDE

C EAST, WEST, AND NORTH ACCESS ROADS ARE 5.5M (18FT) WIDE EACH

D ⊗ = HELIOSTAT EXCLUSION CIRCLE

PREPARED BY COMPUTERIZED MAPPING MCDONNELL DOUGLAS CORPORATION	MDAC 10MW CENTRAL RECEIVER COLLECTOR FIELD LAYOUT	
	DATE 4-21-77	APPROVED BY <i>[Signature]</i>

Figure A-3. Ten-MW Central Receiver Collector Field Layout
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sensor radiation intensity signal and the gimbal position transducers of its associated heliostat. The output of the beam sensor is used to calculate the azimuth and elevation motor commands which must be applied to correct for errors in the mirror orientation. This coordinate conversion calculation and AC motor drive command calculations are accomplished in the field controller. The gimbal position transducers are used during synthetic tracking mode (coarse track) where the orientation of the mirror is determined by the master control. If required, they can also be used in the digital processor to correct the aiming point of the beam sensor.

3.2 CHARACTERISTICS

3.2.1 Performance

The collector subsystem shall reflect solar radiation onto the elevated absorber of the receiver subsystem with a maximum beam pointing error of 2.5 mrad standard deviation whenever the insolation exceeds 300 W/m^2 and the sun is more than 15° above the horizon, under the normal operational environmental conditions specified in Para 3.2.6.

The collector subsystem shall be capable of concentrating 38.3 MWth radiant energy on the absorber at 2 p.m. local sun time on a clear day at winter solstice and 43.0 MWth at noon local sun time on a clear day at equinox for a solar insolation of 950 W/m^2 , with a peak flux density not to exceed 0.3 MW/m^2 . The collector subsystem shall be capable of emergency defocusing upon command of the master control at a rate equal to or greater than that which would linearly reduce peak incident radiation on the receiver to less than 3% of initial value within 120 sec. The subsystem shall perform synthetic heliostat track under control of the master control during obscuration (shadowing) so that normal tracking is resumed within 180 sec after removal of the obscuration.

Automatic nonoperational heliostat slewing provisions shall be incorporated so that the entire array of heliostat reflectors can be (1) aligned horizontally within 15-minutes to accommodate high winds and sand or dust storm conditions, and (2) aligned in any preferred orientation within 15 minutes to facilitate

cleaning or maintenance. The elevation and azimuth gimbals shall remain in their last commanded positions for all operating and non-operating conditions when electrical power is removed.

The collector subsystem shall be designed in such a manner that normally unirradiated portions of the receiver subsystems are not exposed to heat fluxes greater than 3 kW/m^2 at any time. Reflectance of clean heliostat reflective surfaces shall exceed 91% average over an air mass 2 solar spectrum and within 4-mrad cone. A surface life of 30 yr is required, and surface degradation rate shall be minimized. The optical spreading due to surface waviness and specular dispersion shall be less than 0.08 deg. The heliostat structural support shall be designed to prevent reflective surface deflection from exceeding 1.7 mrad standard deviation under the normal operational wind and temperature conditions specified in Para 3.2.6. An override provision shall be included in the drive unit to permit manual feathering of the reflector at the heliostat.

3.2.2 Physical Characteristics

The maximum heliostat weight shall be governed by cost, transportation, and servicing constraints, structural requirements, and power consumption of the drive components. Reflector shape limitations shall be imposed only by the collector field layout, shadowing and blocking constraints, and servicing requirements. The heliostats shall be spaced in the field to permit access by service vehicles, control and power lines, and maintenance personnel.

The foundation design shall include consideration of soil stratigraphy, preservation of vegetation, and geological phenomena. Physical security provisions shall be included for the collector field to protect against damage by animals, sabotage, or vandalism.

3.2.3 Reliability

High reliability shall be achieved in the collector subsystem design by providing adequate operating margins, maximizing the use of proven standard parts, and using conservative design practices so that the reliability performance shall not affect the capability to achieve the availability specified in Para 3.2.5 when operated in the environments specified in Para 3.2.6.

Single-point failures that disable the automatic mode of system operation shall be eliminated wherever practical. In cases where it is impractical to eliminate such failure modes, suitable devices shall be used to detect and signal the occurrence of a failure.

3.2.4 Maintainability

The collector subsystem shall be designed so that required service can be accomplished by persons having normal skills using a minimum of non-standard tools or special equipment.

The collector subsystem shall be designed to provide data indicating malfunctions and fault isolation information on critical components. Critical components are those components that, because of failure risk, downtime, or effect on overall Pilot Plant performance, materially affect the system availability, or the system safety with respect to the reflected beam in the surrounding air space or on the ground within the collector field.

Items which do not have a redundant mode of operation shall have the maximum capability for on-line repair or replacement. These items might include, for example, sensors and actuators. The collector subsystem shall be designed so that potential maintenance points can be easily reached, the reflector can be readily cleaned, replaceable components such as electronic modules and sensors can be readily replaced, and elements subject to wear or damage can be easily serviced or replaced.

3.2.5 Availability

The collector subsystem shall operate in accordance with Para 3.2.1 performance requirements 99% of its scheduled operating time based on reliability and maintainability exclusive of insolation conditions. Determinations of availability shall be based on a period of one year.

3.2.6 Environmental Conditions

The environmental conditions described in Tables A-1 and A-2 are representative of the site characteristics and the transportation and operating environments to be encountered by the collector subsystem. For design purposes, design allowable stresses shall be used commensurate with

Table A-1
OPERATIONAL ENVIRONMENTAL CONDITIONS

Environment	Requirement	Source																		
Gravity	1 g	--																		
Ambient Air Temperature	0 to 49° C (32 to 120° F)	MDAC																		
Winds:																				
1. Wind Speed	11.6 m/s (26 mph) includes 1.3 gust factor	MDAC																		
2. Wing Speed Frequency	<table><tr><th>Speed (m/s)</th><th>Frequency (%)</th></tr><tr><td>0-2</td><td>29</td></tr><tr><td>2-4</td><td>21</td></tr><tr><td>4-6</td><td>19</td></tr><tr><td>6-8</td><td>14</td></tr><tr><td>8-10</td><td>8</td></tr><tr><td>10-12</td><td>5</td></tr><tr><td>12-14</td><td>3</td></tr><tr><td>> 14</td><td><1</td></tr></table>	Speed (m/s)	Frequency (%)	0-2	29	2-4	21	4-6	19	6-8	14	8-10	8	10-12	5	12-14	3	> 14	<1	ERDA
Speed (m/s)	Frequency (%)																			
0-2	29																			
2-4	21																			
4-6	19																			
6-8	14																			
8-10	8																			
10-12	5																			
12-14	3																			
> 14	<1																			
3. Stowage Initiation Speed	16.1 m/s (36 mph)	MDAC																		
4. Wind Rise Rate During Stowage	0.01 m/s ² (1.3 mph/min). Helio-stat shall withstand, without catastrophic failure, a maximum wind of 22.4 m/s (50 mph) from any direction.	ERDA																		
5. Wind Profile	Use Power Law Velocity Profile: $V_Z = V_{10m} \left(\frac{Z}{10m} \right)^{0.15}$ where: V_Z = mean wind velocity at height Z V_{10m} = reference wind velocity at height of 10m 0.15 = power law exponent for flat open country	ERDA																		

availability and performance requirements to ensure operation in accordance with Para 3.2.1 during and/or after exposure to these conditions, as appropriate, for the 30-yr life of the system.

All critical (frangible) components of the collector subsystem shall be designed or packaged so the conditions described in Para 3.2 of the annex do not induce a dynamic environmental condition which exceeds the structural

Table A-2
SURVIVAL ENVIRONMENTAL CONDITIONS

Environment	Requirement	Source
Gravity	1 g	--
Ambient Air Temperature	-30 to 60°C (-22 to 140°F)	ERDA
Winds:		
1. Maximum Wind Speed Stowed	40.2 m/s (90 mph) with ±10 deg angle of attack	ERDA
2. Align Elevation Axis with Mean Wind Vector	For γ = angle from elevation axis: $\gamma = \pm 26$ deg No Damage Any γ No Catastrophic Failures	MDAC
3. Wind Profile	Use Power Law Velocity Profile: $V_Z = V_{10m} \left(\frac{Z}{10m} \right)^{0.15}$	ERDA
Earthquake	0.25 g peak (see horizontal and vertical response spectra in Section 3.1.2)	MDAC
Snow/Ice	250 Pa (5 psf) snow load 50 mm (2 in.) ice load	ERDA
Hail	Survive at any orientation: 19 mm (3/4 in.) at 20 m/s (65 ft/s) Survive at stowed position: 25 mm (1 in.) at 23 m/s (75 ft/s)	ERDA
Rain	Average annual rainfall - 100 mm (4 in.)	ERDA
Dust Devils	With wind speeds up to 17 m/s (40 mph)	ERDA

capability of the component. All components shall be designed to withstand handling/hoisting inertial loads up to 2 g's considering number, location, and type of hoisting points. The maximum pressure exerted by the base of the pedestal foundation subsurface footing upon the soil shall not exceed 0.07 MN/m² (1,500 psf) at 0.6m (2') depth and 0.23 MN/m² (5,000 psf) at 1.5m (5') depth.

The collector subsystem shall satisfy all performance and operational requirements in sustained surface winds up to 8.9 m/s (20 mph) at all elevation angles with gust velocities up to 11.6 m/s (26 mph). The subsystem shall continue to operate in surface winds including gust velocities up to 16.1 m/s (36 mph). The heliostats shall survive in a nonoperational state a 22.4 m/s (50 mph) wind at the worst azimuth and angle of attack conditions. The heliostat shall also survive peak wind gust speeds up to 40.2 m/s (90 mph) without damage.

Practices recommended in ANSI A58.1-1972, ASCE Paper 3269, Vol 126 and the Uniform Building Code, 1973, Vol 1 shall be employed in designing the collector subsystem for winds. The natural wind environment specified in Tables A-1 and A-2 produces a vibratory response both from the oscillatory nature of the gusts and from periodic vortex shedding. The collector subsystem shall be designed to withstand and/or operate when subjected to the loads produced by this vibration. The actual loads must be computed taking into account structural configuration and dynamic characteristics, and the computed structural velocities associated with the winds. The structure will be designed to minimize the coupling between the structure and the environmentally induced forces.

The heliostats shall be stowed face down in anticipation of major storms and in the event of slowly rising winds above 12.5 m/s (28 mph). In the event of rapidly increasing, unforecasted gust speeds above 16.1 m/s (36 MPH), face up stowage will be acceptable. Subsystem components shall be protected from electrostatic charging and discharging in sand and dust storms. Lightning will be handled by protection means such as air terminals, transient suppression, shielding, and grounding. The subsystem elements shall withstand the maximum earthquake environment described in Annex 1* without structural damage or yielding.

3.2.7 Transportability

Collector subsystem components shall be designed for transportability within applicable Federal and state regulations by highway and railroad carriers using standard transport vehicles and materials handling equipment. Whenever feasible, components shall be segmented and packaged to sizes that

*"Pilot Plant Environmental Conditions, "Volume 2, Annex 1, Central Receiver Solar Thermal Power System, Phase 1, Preliminary Design Baseline Report, MDC G6040, January 1976.

are transportable under normal commercial transportation limitations in accordance with Table A-3. Subsystem components that exceed normal transportation limits (Table A-3) shall be transportable with the use of special routes, clearances, and permits.

Table A-3
TRANSPORTATION LIMITS

Transportability Limits for Normal Conditions (Permits Not Required)

	Truck	Rail
Height:	13 ft 6 in. above road	16 ft 0 in. above rail
Width:	8 ft 0 in.	10 ft 6 in.
Length	55 ft 0 in. - Eastern States 60 ft 0 in. - Western States	60 ft 6 in.
Gross Weight:	73,280 lb; 18,000 lb/axle	200,000 lb

Transportability Limits for Special Conditions

	Truck	Rail
Height:	14 ft 6 in. above road	16 ft 0 in. above rail
Width:	12 ft 0 in.	12 ft 0 in.
Length:	70 ft 0 in.	80 ft 6 in.
Gross Weight:	100,000 lb; 18,000 lb/axle	400,000 lb

The design requirements for component packaging and tiedown techniques shall be compatible with the limit load factors indicated in Table A-4.

All critical (frangible) components shall be designed or packaged such that the conditions described in Table A-4 do not induce a dynamic environmental condition which exceeds the structural capability of the component. These conditions reflect careful handling and firmly constrained (tied down) transporting via common carrier. All components shall be designed to withstand handling/hoisting inertial loads up to 2 g's considering the number, location and type of hoisting points.

Handling shock will result from normal handling drops of large packaged equipment. Corresponding acceleration peak may be of the order of 7 g's vertical and 4 g's horizontal with a sinusoidal profile and a duration of 10 to 50 milliseconds.

Table A-4
LIMIT LOAD FACTORS

Vibration		
Transportation Mode	Amplitude (G _{op})	Frequency Range (Hz)
Highway	±0.6	1 - 85
	±0.9	85 - 300
Air	±0.05 in D. A.	3 - 38
	±2.0	38 - 1,000
Rail	±1.0	1 - 100
	±1.6	100 - 1,000

Shock Load Factors

Transportation Mode	Acceleration (G)		
	Longitudinal	Lateral	Vertical
Air	±3.0	±2.5	±2.0
Highway	±3.5	±2.0	±3.0
Rail			
Rolling	±3.0	±0.75	±3.0
Humping (Hydro cushion car)	±3.0	±2.0	±3.0

Smaller components shall be properly packaged to prevent structural damage during normal handling. The handling shocks for these components are a function of the weight and dimensions of the packaged item. Structural analyses shall be performed for critical items to establish the structural integrity of the packaged component for the shock levels experienced in the shipping package. The drop height noted in Table A-5 shall be used as design guidelines for the packaged item.

3.3 DESIGN AND CONSTRUCTION

Commercial design and construction standards relevant to the intended use of the collector subsystem components and structures shall be employed. Where applicable, the Uniform Building Code (1973 ed), the American Institute of Steel Construction's Manual of Steel Construction (7th ed), and the American Concrete Institute's Building Code Requirements for Reinforced Concrete shall be used. ANSI A58.1-1972 and ASCE paper No. 3269, Wind

Table A-5
DROP HEIGHT DESIGN GUIDELINES

Gross Weight Not Exceeding (lb)	Dimensions of Any Edge, Height, Diameter (in.)	Free Fall Height of Drop on Corners, Edges, or Flat Faces (in.)
50	36	22
100	48	16
150	60	14
No Limit	No Limit	

Forces on Structures (ASCE Transactions, Vol 126, Part II, 1961) shall be used during design when determining loading due to winds. For electrical components, the National Electrical Code (ANSI C1), the National Electrical Manufacturers Association (NEMA) and MIL-STD-454 standards for electronic equipment shall be used. The heliostat and the sensor pedestals shall be installed within 1 deg of vertical and shall not deviate from that alignment (exclusive of seismic effects) at rates exceeding 0.2 and 0.1 deg per year, respectively.

3.3.1 Materials, Processes, and Parts

To the maximum extent possible, standard materials and processes, and off-the-shelf components shall be used. Wherever possible, commercial specifications shall be employed.

The glass to be used for mirror panels shall be made by the float process. The glass iron content shall be the minimum consistent with the Pilot Plant production volume. The reflective surface of the heliostat shall be chemically deposited silver, with copper and backing paint consistent with good commercial mirroring practice. The mirror shall be supported by a styrofoam core with a sheet steel back face. Dissimilar materials as defined by MIL-STD-889 shall not be used in direct contact with one another in such a way as to cause galvanic corrosion.

3.3.2 Electrical Transients

The subsystem operation shall not be adversely affected by external or internal power line transients caused by normal switching or fault clearing

functions which result in fewer than six cycles of the fundamental frequency (100 ms) and 1.7 PU voltage (1.7 per unit or 170%).

3.3.3 Electromagnetic Radiation

The collector subsystem control wiring shall be designed to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference.

3.3.4 Nameplates and Product Marking

All deliverable end items shall be labeled with a permanent nameplate listing, as a minimum, manufacturer, part number, change letter, serial number, and date of manufacture.

3.3.5 Workmanship

The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the selected site and the utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidence of the status available for examination. Where skill levels or details of workmanship are not specified, the work shall be accomplished in accordance with the level of quality currently maintained in the construction and assembly of commercial power plants. All work shall be finished in a manner that presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a uniform appearance.

3.3.6 Interchangeability

Items with a common function shall be provided with standard tolerances and connector locations to permit interchanging them for servicing. Components with similar appearance but different functions shall incorporate protection against inadvertent erroneous installation. All heliostats shall be interchangeable regardless of their position in the heliostat array.

3.3.7 Safety

The collector subsystem shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Electrical components shall be insulated and grounded. All components with elevated

temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements, and safety override controls/interlocks shall be provided for servicing. All pertinent OSHA rules and regulations shall be observed.

3.3.8 Human Engineering

The collector subsystem shall be designed to facilitate manual operation, adjustment, and maintenance as needed and provide the optimum allocation of functions between personnel and automatic control. The collector subsystem design shall provide electrical and electronic packaging which ensures rapid repair and replacement, adequate lighting for night maintenance, placarding of hazardous work areas, and equipment for item removal and handling. MIL-STD-1472, Human Engineering Design Criteria, shall be used as a guide in designing equipment.

3.4 DOCUMENTATION

3.4.1 Characteristics and Performance

Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves shall be provided, where applicable.

3.4.2 Instructions

Instructions shall cover assembly, installation, alignment, adjustment, checking, lubrication, maintenance, and operation of the collector subsystem. All instructions shall include references to applicable subsystem engineering data and guides to troubleshooting instruments and controls. All phases of collector subsystem operation shall be addressed including startup, normal and synthetic tracking operation, on-line and off-line maintenance, shutdown, contingency operation, and emergency operations.

3.4.3 Construction

Engineering and assembly drawings shall be provided to show the equipment construction, including assembly and disassembly procedures. Engineering data, wiring diagrams, and parts lists shall be provided.

3.5 LOGISTICS

Table A-6 shows elements required to support the collector subsystem.

Table A-6
COLLECTOR SUBSYSTEM SUPPORT ELEMENTS

Maintenance

- (1) Support and test equipment
- (2) Technical publications
- (3) Field service
- (4) Data file

Supply

- (1) Spares, repair parts, and consumables
- (2) Transportation, handling, and packaging

Facilities

3.5.1 Maintenance

Maintenance activities are categorized as Level 1, on-line maintenance; Level 2, off-line, on-site maintenance; or Level 3, off-line, off-site maintenance.

3.5.1.1 Level 1, On-Line Maintenance

Table A-7 shows the scheduled and unscheduled maintenance activities which shall be identified for the collector subsystem in Program Phase 1.

Table A-7
MAINTENANCE ACTIVITIES
(Phase 1)

Visual inspection
Remove and replace
Repair in place
Adjust
Align
Calibrate
Lubricate
Paint
Transport

3.5.1.2 Level 2, Off-Line On-Site Maintenance

Table A-8 shows the maintenance activities which shall be identified in the maintenance plan during Program Phase 2.

Table A-8
MAINTENANCE ACTIVITIES
(Phase 2)

Fault verification
Fault isolation to a removable item
Remove and replace a faulty item
Verify acceptable repaired item
Repair designated subtiered items
Servicing
Lubrication
Visual inspection
Transportation

3.5.1.3 Level 3, Off-Line Off-Site Maintenance

Level 3 maintenance activities are performed at the equipment supplier's facility. Frequencies and turnaround times shall be determined during Program Phase 2.

3.5.2 Supply

The following criteria shall be used for selecting and positioning spares, repair parts, and consumables.

3.5.2.1 Protection Level

Items shall be packaged in accordance with the requirements of Para 5.0.

3.5.2.2 Demand Rate

The mean-time-between-maintenance-actions shall be the initial basis for spares determinations. The quantities and mix shall be such that there is a 90% probability of a part being available on demand.

3.5.2.3 Pipeline

Pipeline quantities shall be determined on the basis of system location, demand rate, and repair cycle times. Resupply methods, distribution, and location of system stocks shall be determined after site selection.

3.5.2.4 Procurement and Release for Production

Long-lead-time supply items shall be procured or drawings released early enough for the items to be on-site 30 days prior to initial operation. Other items shall be procured or released lead time away so as to minimize

obsolescence due to design changes, except where significant cost savings can be achieved by acquiring items concurrent with production.

3.5.2.5 Minimum/Maximum Levels

Minimum and maximum quantities of spares and repair parts to be stocked shall initially be determined by use of predicted failure rates. These levels are to be adjusted as actual usage rates are established.

3.5.3 Facilities and Facility Equipment

Detail facility requirements shall be identified for the selected Dagget site. These facilities criteria shall establish the detail placement of the collector subsystem and its physical and functional interfaces with the site and other system level elements.

The collector field criteria shall define: the specific area and the location of subsystem equipment; the tolerances and limitations of foundation base placement and elevation; access roadways, soil surface control requirements; the quantity, placement and distribution of support utilities; area lighting; communications; personnel service facilities; maintenance and storage shops; area fencing; reference benchmarks and other survey and alignment aids; site security provisions; maintenance equipment support installations and all criteria agreements necessary for architectural engineering definition and design.

3.6 PERSONNEL AND TRAINING

3.6.1 Personnel

The Pilot Plant is to be installed, checked out, and tested by contractor personnel and then taken over and operated as a Commercial Plant by utility personnel. Operation and maintenance personnel requirements shall be satisfied by recruiting from the established utility labor pool. Specific skills and number of persons required for Pilot Plant operation are (TBD).

3.6.2 Training

Unique aspects of the collector subsystem dictate a need for training existing utility people but do not establish a need for new skills or trades. The types and numbers of utility personnel requiring training, along with the unique tasks, are shown in Table A-9.

Table A-9
PERSONNEL TRAINING

Type	No.	Unique Task
(TBD)	(TBD)	Reflector repair and handling Heliostat removal and replacement Heliostat alignment Heliostat handling and transport Heliostat component repair and servicing Sensor removal and replacement Field controller maintenance Safety requirements Emergency operations Others (TBD)

3.7 PRECEDENCE

The order of precedence of collector subsystem requirements and characteristics shall be as follows:

- (A) Performance (including scalability to Commercial power levels)
- (B) Capability to withstand natural environmental conditions
- (C) Cost.

The precedence of specific characteristics and requirements shall be established based on system cost-effectiveness sensitivity analyses. This specification has precedence over documents referenced herein. The contractor shall notify the procuring activity of each instance of conflicting or apparently conflicting requirements within this specification or between this specification and a referenced document.

0 QUALITY ASSURANCE PROVISIONS

4.1 GENERAL

4.1.1 Responsibility for Tests

All tests shall be performed by the contractor. These tests may be witnessed by ERDA or its representatives or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirements is required.

4.1.2 General Test Requirements

Tests shall be conducted in accordance with a test plan to be prepared by the contractor and approved by ERDA. Specific required tests are identified in Para 4.2. Tests shall be classified in the test plan as:

- (A) Acceptance tests for the purpose of verifying conformance to design and determining acceptability of the product for further operations or for delivery, or
- (B) Qualification tests for the purpose of verifying the adequacy of design and method of production to yield a product conforming to the requirements.

Acceptance tests and qualification tests shall be defined for verification as indicated in Para 4.3. The test of the collector subsystem in conjunction with another subsystem is regarded as a system test and shall conform to the Pilot Plant System Requirements specification.

4.1.3 Previous Tests

Maximum use shall be made of test data available from the subsystem research experiments and hardware tests already completed. Where conformance to this specification can be established at less cost by analysis of such data, tests shall not be repeated.

4.2 SPECIFIC TEST REQUIREMENTS

4.2.1 Subsystem Performance Tests

The following tests of the installed subsystem shall be performed before Pilot Plant system testing. Tests shall be performed cumulatively until the entire field is tested.

4.2.1.1 Installed Heliostat Test

Each installed heliostat shall be tested and adjusted as necessary for beam intensity and centroid of the image to indicate conformance to requirements of (TBD).

4.2.1.2 Tracking and Beam Quality

A representative sampling of heliostats shall be tested for tracking accuracy of 1.7 mrad standard deviation and beam error of 2.5 mrad standard deviation. Tests shall be performed while the sun is at an altitude of more than 15 deg with insolation exceeding 300 W/m². Valid data for the test shall be those taken under the environmental conditions specified for normal operation in 3.2.6.

4.2.1.3 Slew-off and Stowage

Each cell (24 heliostats) shall be operated by command simulating master control to demonstrate (1) horizontal alignment, (2) alignment at a pre-selected angle from horizontal, and (3) stowage position, starting from the operating position at the time of test. Realignment in each case shall be achieved within 15 min from time of command.

4.2.2 Validation Sample

The contractor shall assemble, install, align, and check out one complete heliostat and field controller in an area of his choice to validate production, installation, and checkout (acceptance) practices. If the closed-loop system is selected, a sensor shall be installed and aligned during this validation.

4.2.3 Environmental Tests

The beam sensor, drive unit, and control sensors shall be subjected to high and low temperature from -30 to +60°C (-22 to 140°F), rain, icing, and blowing dust in accordance with Drawing 1 T50006.

Reflector panels shall be subjected to the following qualification tests:

- (A) Impact by hail per Dwg 1 T50005
- (B) Thermal cycle - 20°F to +120°F for 60 cycles with relative humidity of 50% at 70°F
- (C) Salt fog test of 400 hours per MIL-STD-810B
- (D) Accelerated ultraviolet per (TBD)
- (E) Compatibility of adhesive with the mirror-backing paint, using salt fog test of 400 hours per MIL-STD-810B
- (F) Rain, snow and frost tests per (TBD).

4.2.4 Materials and Processes Control Tests

Materials and processes shall be controlled in accordance with their specifications as invoked in the specification or drawing for assemblies, sub-assemblies and components using the materials and processes.

4.2.5 Life Tests

The drive unit shall be subjected to performance life tests in accordance with Drawing 1 T50003. Dust erosion tests for the mirror shall project less than 1% loss of reflectivity over an equivalent 30 yr.

4.2.5.1 Mean Time Before Failure/Replacement

The estimates for MTBF and MTBR shall be made as described in section 4.2.12 of Vol III of this report (Pilot Plant Availability).

4.2.6 Engineering Critical Component Qualification Tests

Components for which reliability data are not available shall be subjected to sufficient qualification testing to estimate their impact on the MTBF of the overall device.

4.3 VERIFICATION OF CONFORMANCE

The contractor shall verify that the requirements of Sections 3 and 5 are fulfilled by the methods given in Table A-10. The methods of verification are defined as follows:

- (A) Inspection - Examination and measurement of product.
- (B) Analysis - Examination of the design and associated data, which may include relevant test information.
- (C) Similarity - Demonstration or acceptable evidence of the performance of a product which is sufficiently similar to permit conformance to be inferred.
- (D) Test - Functional operation or exposure under specified conditions to evaluate product performance.
- (E) Demonstration - Exhibition of the product or service in its intended modes and conditions.

4.3.1 Hardware Acceptance for Pilot Plant

The contractor shall provide a system by which conformance of hardware to the design will be verified prior to initiation of subsystem-level tests. This verification of conformance shall include proof-by-assembly and the inspection of records. A record shall be made of each inspection or test performed and of the verification. In addition, evidence shall be maintained of satisfactory accomplishment of inspections and tests required by codes and standards that apply to the collector subsystem.

Table A-10 (Page 1 of 5)

COLLECTOR SUBSYSTEM REQUIREMENT VERIFICATION MATRIX

Verification Methods		Test Categories	
1. Inspection		A. Acceptance Test	
2. Analysis		B. Qualification Test (including life	
3. Similarity		tests and critical component	
4. Test		qualification)	
5. Demonstration			
N/A denotes "not applicable"			
Requirements (paragraph)	Verification Method	Test Category	Remarks
3.1 Collector Subsystem Definition	2	N/A	
3.1.1 Collector Subsystem Diagram	N/A	N/A	
3.1.2 Interface Definition	N/A	N/A	
3.1.2.1 Collector/Physical Site	2	N/A	
3.1.2.2 Collector/Receiver Subsystem	2	N/A	
3.1.2.3 Collector/Electrical Power Generation Subsystem	N/A	N/A	See EPGS Subsystem specification.
3.1.2.4 Collector/Master Control	N/A	N/A	See Master Control Subsystem Specification
3.1.2.5 Collector Subsystem Internal Interfaces	N/A	N/A	

Table A-10 (Page 2 of 5)

COLLECTOR SUBSYSTEM REQUIREMENT VERIFICATION MATRIX

Verification Methods		Test Categories	
1. Inspection		A. Acceptance Test	
2. Analysis		B. Qualification Test (including life tests and critical component qualification)	
3. Similarity			
4. Test			
5. Demonstration			
N/A denotes "not applicable"			
Requirements (paragraph)	Verification Method	Test Category	Remarks
3.2 Characteristics	N/A	N/A	
3.2.1 Performance	2,4	A	See 4.2.1.
3.2.2 Physical Characteristics	1,2	N/A	
3.2.3 Reliability	2	N/A	
3.2.4 Maintainability	2	N/A	
3.2.5 Availability	2	N/A	
3.2.6 Environmental Conditions	1,3,4	B	See 4.2.3 Environmental Qualification of Controllers Required
3.2.7 Transportability	2	N/A	
3.3 Design and Construction	1,2	N/A	
3.3.1 Materials, Processes, and Parts	1,2	N/A	Test requirements as in subordinate specifications

COLLECTOR SUBSYSTEM REQUIREMENT VERIFICATION MATRIX

<u>Verification Methods</u>	<u>Test Categories</u>
1. Inspection	A. Acceptance Test
2. Analysis	
3. Similarity	B. Qualification Test (including life
4. Test	tests and critical component
5. Demonstration	qualification)

N/A denotes "not applicable"

Requirements (paragraph)	Verification Method	Test Category	Remarks
3.3.2 Electrical Transients	1, 2, 4	B	Test to be accomplished at system level.
3.3.3 Electromagnetic Radiation	2, 4	B	Test to be accomplished at system level.
3.3.4 Nameplates and Product Marking	1	N/A	
3.3.5 Workmanship	1	N/A	
3.3.6 Interchangeability	2	N/A	
3.3.7 Safety	1, 2	N/A	
3.3.8 Human Engineering	1, 2	N/A	
3.4 Documentation	N/A	N/A	
3.4.1 Characteristics and Performance	1, 2	N/A	
3.4.2 Instructions	1, 2	N/A	
3.4.3 Construction	1, 2	N/A	

Table A-10 (Page 4 of 5)
COLLECTOR SUBSYSTEM REQUIREMENTS
VERIFICATION MATRIX

Verification Methods		Test Categories	
1. Inspection		A. Acceptance Test	
2. Analysis		B. Qualification Test (including life tests and critical component qualification)	
3. Similarity			
4. Test			
5. Demonstration			
N/A denotes "not applicable"			
Requirements (paragraph)	Verification Method	Test Category	Remarks
3.5 Logistics	2	N/A	
3.5.1 Maintenance	2	N/A	
3.5.2 Supply	2	N/A	
3.5.3 Facilities and Facility Equipment	1	N/A	
3.6 Personnel and Training	N/A	N/A	
3.6.1 Personnel	2	N/A	
3.6.2 Training	2	N/A	
3.7 Precedence	2	N/A	
5.1 General	1,2	N/A	
5.2 Preservation and Packaging	1,2	N/A	
5.3 Packing	1,2	N/A	

Table A-10 (Page 5 of 5)

COLLECTOR SUBSYSTEM REQUIREMENT VERIFICATION MATRIX

<u>Verification Methods</u>	<u>Test Categories</u>
1. Inspection	A. Acceptance Test
2. Analysis	
3. Similarity	B. Qualification Test (including life
4. Test	tests and critical component
5. Demonstration	qualification)

N/A denotes "not applicable"

Requirements (paragraph)	Verification Method	Test Category	Remarks
5.4 Handling and Transportability	1,2	N/A	
5.5 Marking	1	N/A	

5.0 PREPARATION FOR DELIVERY

5.1 GENERAL

Packaging for collector subsystem components shall provide adequate protection during shipment by common carrier from supplier to the first receiving activity for immediate use or temporary storage.

5.2 PRESERVATION AND PACKAGING

Subsystem components that may be harmed when exposed to the normal transportation and handling environments (Para 3.2.6) shall be protected by inert environments, barrier materials, or equivalent techniques.

5.3 PACKING

Shipping containers and their cushioning devices shall ensure protection of collector subsystem components when exposed to the shock and vibrations loads defined in Para 3.2.6. Containers shall meet, as a minimum, the requirements in the following regulations as applicable to the mode of transportation utilized.

- (a) National Motor Freight Classification (Highway Transportation)
- (b) Uniform Freight Classification (Railroad Transportation)
- (c) CAB Tariff 96 and 169 (Air Transportation)
- (d) R. M. Graziano's Tariff 29 (For Dangerous Articles Surface)
- (e) CAB Tariff 82 (For Dangerous Articles Air)

5.4 HANDLING AND TRANSPORTABILITY

Containers with gross weights exceeding 60 pounds shall have skids and other provisions for handling by standard materials handling equipment. When feasible, container sizes and configurations shall be compatible with efficient utilization of transport vehicles.

5.5 MARKING

Unless otherwise specified, container marking shall be standard commercial practice.

Appendix B

HELIOSTAT LOCATION SUMMARY REPORT

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HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 1

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1	17.74, 59.41	14	-17.74, 59.41
2	28.82, 54.89	15	-28.82, 54.89
3	38.84, 48.33	16	-38.84, 48.33
4	47.4, 39.96	17	-47.4, 39.96
5	54.2, 30.11	18	-54.2, 30.11
6	58.97, 19.13	19	-58.97, 19.13
7	61.55, 7.44	20	-61.55, 7.44
8	59.81, -16.33	21	-59.81, -16.33
9	55.56, -27.52	22	-55.56, -27.52
10	49.23, -37.69	23	-49.23, -37.69
11	41.07, -46.45	24	-41.07, -46.45
12	31.38, -53.47	25	-31.38, -53.47
13	20.51, -58.51	26	-20.51, -58.51

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.2

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
27	13.32, 68.01	41	-13.32, 68.01
28	26.14, 64.18	42	-26.14, 64.18
29	37.99, 57.96	43	-37.99, 57.96
30	48.42, 49.58	44	-48.42, 49.58
31	57.05, 39.35	45	-57.05, 39.35
32	63.55, 27.65	46	-63.55, 27.65
33	67.68, 14.92	47	-67.68, 14.92
34	68.3, -11.71	48	-68.3, -11.71
35	64.78, -24.62	49	-64.78, -24.62
36	58.84, -36.61	50	-58.84, -36.61
37	50.7, -47.24	51	-50.7, -47.24
38	40.68, -56.1	52	-40.68, -56.1
39	29.14, -62.88	53	-29.14, -62.88
40	16.51, -67.3	54	-16.51, -67.3

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.3

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
55	7.34, 75.64	70	-7.34, 75.64
56	21.74, 72.82	71	-21.74, 72.82
57	35.33, 67.29	72	-35.33, 67.29
58	47.61, 59.24	73	-47.61, 59.24
59	58.1, 48.99	74	-58.1, 48.99
60	66.44, 36.91	75	-66.44, 36.91
61	72.29, 23.45	76	-72.29, 23.45
62	75.45, 9.12	77	-75.45, 9.12
63	73.32, -20.02	78	-73.32, -20.02
64	68.1, -33.74	79	-68.1, -33.74
65	60.35, -46.2	80	-60.35, -46.2
66	50.34, -56.93	81	-50.34, -56.93
67	38.46, -65.55	82	-38.46, -65.55
68	25.15, -71.72	83	-25.15, -71.72
69	10.89, -75.22	84	-10.89, -75.22

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.4

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
85	15.8,80.67	99	-15.8,80.67
86	31.01,76.13	100	-31.01,76.13
87	45.06,68.75	101	-45.06,68.75
88	57.44,58.81	102	-57.44,58.81
89	67.67,46.67	103	-67.67,46.67
90	75.38,32.79	104	-75.38,32.79
91	80.27,17.7	105	-80.27,17.7
92	81.02,-13.89	106	-81.02,-13.89
93	76.84,-29.21	107	-76.84,-29.21
94	69.79,-43.43	108	-69.79,-43.43
95	60.14,-56.03	109	-60.14,-56.03
96	48.25,-66.55	110	-48.25,-66.55
97	34.56,-74.58	111	-34.56,-74.58
98	19.58,-79.83	112	-19.58,-79.83

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 5

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
113	13.18,90.24	127	-13.18,90.24
114	26.09,87.39	128	-26.09,87.39
115	38.45,82.7	129	-38.45,82.7
116	60.5,68.25	130	-60.5,68.25
117	69.73,58.79	131	-69.73,58.79
118	77.49,48.09	132	-77.49,48.09
119	88.01,23.91	133	-88.01,23.91
120	90.54,10.94	134	-90.54,10.94
121	86.72,-28.25	135	-86.72,-28.25
122	81.72,-40.48	136	-81.72,-40.48
123	75.01,-51.87	137	-75.01,-51.87
124	57.04,-71.16	138	-57.04,-71.16
125	46.16,-78.66	139	-46.16,-78.66
126	34.3,-84.5	140	-34.3,-84.5

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.6

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
141	7.14,98.24	161	-7.14,98.24
142	21.26,96.18	162	-21.26,96.18
143	34.94,92.09	163	-34.94,92.09
144	47.89,86.08	164	-47.89,86.08
145	59.83,78.25	165	-59.83,78.25
146	70.51,68.78	166	-70.51,68.78
147	79.71,57.87	167	-79.71,57.87
148	87.24,45.74	168	-87.24,45.74
149	92.93,32.65	169	-92.93,32.65
150	96.68,18.87	170	-96.68,18.87
151	98.03,-9.57	171	-98.03,M9.57
152	95.62,-23.64	172	-95.62,-23.64
153	91.2,-37.21	173	-91.2,-37.21
154	84.86,-50	174	-84.86L-50
155	76.74,-61.75	175	-76.74,-61.75
156	67.01,-72.19	176	-67.01,-72.19
157	55.87,-81.12	177	-55.87,-81.12
158	43.56,-88.34	178	-43.56,-88.34
159	30.34,-93.71	179	-30.34,-93.71
160	16.47,-97.11	180	-16.47,M97.11

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 7

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
181	15.23, 104.29	201	-15.23, 104.29
182	30.15, 101	202	-30.15, 101
183	44.43, 95.58	203	-44.43, 95.58
184	57.78, 88.15	204	-57.78, 88.15
185	69.92, 78.87	205	-69.92, 78.87
186	80.58, 67.94	206	-80.58, 67.94
187	89.56, 55.58	207	-89.56, 55.58
188	96.65, 42.05	208	-96.65, 42.05
189	101.71, 27.64	209	-101.71, 27.64
190	104.64, 12.65	210	-104.64, 12.65
191	103.88, -17.81	211	-103.88, -17.81
192	100.22, -32.64	212	-100.22, -32.64
193	94.45, -46.79	213	-94.45, -46.79
194	86.69, -59.95	214	-86.69, -59.95
195	77.12, -71.85	215	-77.12, -71.85
196	65.92, -82.24	216	-65.92, -82.24
197	53.34, -90.91	217	-53.34, -90.91
198	39.64, -97.66	218	-39.64, -97.66
199	25.11, -102.37	219	-25.11, -102.37
200	10.05, -104.92	220	-10.05, -104.92

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.3

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
221	8.06, 110.91	241	-8.06, 110.91
222	24.108.58	242	-24.108.58
223	39.45, 103.97	243	-39.45, 103.97
224	54.06, 97.17	244	-54.06, 97.17
225	67.54, 88.34	245	-67.54, 88.34
226	79.6, 77.65	246	-79.6, 77.65
227	89.99, 65.33	247	-89.99, 65.33
228	98.48, 51.64	248	-98.48, 51.64
229	104.91, 36.86	249	-104.91, 36.86
230	109.14, 21.31	250	-109.14, 21.31
231	110.67, -10.8	251	-110.67, -10.8
232	107.95, -26.69	252	-107.95, -26.69
233	102.96, -42.01	253	-102.96, -42.01
234	95.81, -56.45	254	-95.81, -56.45
235	86.64, -69.71	255	-86.64, -69.71
236	75.65, -81.5	256	-75.65, -81.5
237	63.08, -91.58	257	-63.08, -91.58
238	49.18, -99.73	258	-49.18, -99.73
239	34.25, -105.79	259	-34.25, -105.79
240	18.6, -109.63	260	-18.6, -109.63

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 9

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
261	16.8, 114.98	281	-16.8, 114.98
262	33.24, 111.34	282	-33.24, 111.34
263	48.98, 105.37	283	-48.98, 105.37
264	63.7, 97.18	284	-63.7, 97.18
265	77.08, 86.96	285	-77.08, 86.96
266	88.84, 74.9	286	-88.84, 74.9
267	98.73, 61.27	287	-98.73, 61.27
268	106.55, 46.36	288	-106.55, 46.36
269	112.13, 30.47	289	-112.13, 30.47
270	115.36, 13.94	290	-115.36, 13.94
271	114.53, -19.64	291	-114.53, -19.64
272	110.49, -35.99	292	-110.49, -35.99
273	104.12, -51.58	293	-104.12, -51.58
274	95.58, -66.09	294	-95.58, -66.09
275	85.02, -79.21	295	-85.02, -79.21
276	72.68, -90.67	296	-72.68, -90.67
277	58.81, -100.22	297	-58.81, -100.22
278	43.7, -107.67	298	-43.7, -107.67
279	27.68, -112.85	299	-27.68, -112.85
280	11.08, -115.67	300	-11.08, -115.67

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.10

NO. LOCATION (METERS)

301 13.55, 124.06
 302 26.94, 121.86
 303 40.01, 118.21
 304 64.59, 106.79
 305 75.8, 99.14
 306 86.12, 90.33
 307 103.58, 69.61
 308 110.53, 57.95
 309 116.17, 45.61
 310 123.18, 20.05
 311 124.59, 7.25
 312 124.57, -7.61
 313 119.99, -34.32
 314 115.55, -47.15
 315 109.75, -59.42
 316 94.33, -81.71
 317 84.91, -91.47
 318 74.47, -100.14
 319 51.1, -113.86
 320 38.43, -118.73
 321 25.32, -122.21

NO. LOCATION (METERS)

322 -13.55, 124.06
 323 -26.94, 121.86
 324 -40.01, 118.21
 325 -64.59, 106.79
 326 -75.8, 99.14
 327 -86.12, 90.33
 328 -103.58, 69.61
 329 -110.53, 57.95
 330 -116.17, 45.61
 331 -123.18, 20.05
 332 -124.59, 7.25
 333 -124.57, -7.61
 334 -119.99, -34.32
 335 -115.55, -47.15
 336 -109.75, -59.42
 337 -94.33, -81.71
 338 -84.91, -91.47
 339 -74.47, -100.14
 340 -51.1, -113.86
 341 -38.43, -118.73
 342 -25.32, -122.21

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 11

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
343	7.17, 131.7	370	-7.17, 131.7
344	21.43, 130.15	371	-21.43, 130.15
345	35.43, 127.05	372	-35.43, 127.05
346	49.02, 122.45	373	-49.02, 122.45
347	62.02, 116.41	374	-62.02, 116.41
348	74.3, 108.98	375	-74.3, 108.98
349	85.69, 100.27	376	-85.69, 100.27
350	96.07, 90.38	377	-96.07, 90.38
351	105.32, 79.41	378	-105.32, 79.41
352	113.31, 67.51	379	-113.31, 67.51
353	119.97, 54.81	380	-119.97, 54.81
354	125.22, 41.46	381	-125.22, 41N46
355	128.85, 28.2	382	-128.85, 28.2
356	131.05, 14.94	383	-131.05, 14.94
357	131.02, -15.19	384	-131.02, -15.19
358	128.6, -29.33	385	-128.6, -29.33
359	124.65, -43.12	386	-124.65, -43.12
360	119.23, -56.4	387	-119.23, -56.4
361	112.41, -69.01	388	-112.41, -69.01
362	104.25, -80.81	389	-104.25, -80.81
363	94.86, -91.65	390	-94.86, -91.65
364	84.35, -101.41	391	-84.35, -101.41
365	72.84, -109.96	392	-72.84, -109.96
366	60.47, -117.22	393	-60.47, -117.22
367	47.38, -123.1	394	-47.38, -123.1
368	33.74, -127.51	395	-33.74, -127.51
369	19.69, -130.42	396	-19.69, -130.42

HELICSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.12

NO. LOCATION (METERS)

397 15.14, 138.58
 398 30.09, 136.11
 399 44.69, 132.04
 400 58.76, 126.41
 401 72.14, 119.28
 402 84.67, 110.74
 403 96.19, 100.9
 404 106.58, 89.85
 405 115.7, 77.75
 406 123.46, 64.73
 407 129.76, 50.94
 408 134.52, 36.55
 409 137.7, 21.73
 410 139.2, 7.39
 411 139.14, -8.51
 412 137.39, -23.56
 413 134.02, -38.34
 414 129.07, -52.67
 415 122.59, -66.37
 416 114.66, -79.29
 417 105.37, -91.27
 418 94.84, -102.17
 419 83.18, -111.86
 420 70.55, -120.23
 421 57.08, -127.18
 422 42.93, -132.62
 423 28.28, -136.5

NO. LOCATION (METERS)

425 -15.14, 138.58
 426 -30.09, 136.11
 427 -44.69, 132.04
 428 -58.76, 126.41
 429 -72.14, 119.28
 430 -84.67, 110.74
 431 -96.19, 100.9
 432 -106.58, 89.85
 433 -115.7, 77.75
 434 -123.46, 64.73
 435 -129.76, 50.94
 436 -134.52, 36.55
 437 -137.7, 21.73
 438 -139.2, 7.39
 439 -139.14, -8.51
 440 -137.39, -23.56
 441 -134.02, M38.34
 442 -129.07L-52.67
 443 -122.59, M66.37
 444 -114.66, -79.29
 445 -105.37, -91.27
 446 -94.84, -102.17
 447 -83.18, -111.86
 448 -70.55, -120.23
 449 -57.08, -127.18
 450 -42.93, -132.62
 451 -28.28, -136.5

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.12 (CONT.)

NO. LOCATION (METERS)

424 13.29,-138.77

NO. LOCATION (METERS)

452 -13.29,M138.77

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 13

NO.	LOCATION (METERS)
453	7.99, 146.78
454	23.88, 145.05
455	39.49, 141.6
456	54.63, 136.47
457	69.12, 129.73
458	82.8, 121.46
459	95.5, 111.75
460	107.07, 100.72
461	117.37, 88.5
462	126.29, 75.24
463	133.71, 61.08
464	139.55, 46.2
465	143.74, 30.78
466	146.23, 14.99
467	146.02, -16.93
468	143.32, -32.69
469	138.92, -48.05
470	132.88, -62.85
471	125.27, -76.91
472	116.18, -90.06
473	105.72, -102.14
474	94, -113.01
475	81.18, -122.55
476	67.39, -130.64
477	52.81, -137.19
478	37.6, -142.11
479	21.95, -145.35

NO.	LOCATION (METERS)
480	-7.99, 146.78
481	-23.88, 145.05
482	-39.49, 141.6
483	-54.63, 136.47
484	-69.12, 129.73
485	-82.8, 121.46
486	-95.5, 111.75
487	-107.07, 100.72
488	-117.37, 88.5
489	-126.29, 75.24
490	-133.71, 61.08
491	-139.55, 46.2
492	-143.74, 30.78
493	-146.23, 14.99
494	-146.02, -16.93
495	-143.32, -32.69
496	-138.92, -48.05
497	-132.88, -62.85
498	-125.27, -76.91
499	-116.18, -90.06
500	-105.72, -102.14
501	-94, -113.01
502	-81.18, -122.55
503	-67.39, -130.64
504	-52.81, -137.19
505	-37.6, -142.11
506	-21.95, -145.35

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 14

NO. LOCATION (METERS)

507 16.83, 154.08
 508 33.46, 151.35
 509 49.69, 146.82
 510 65.34, 140.55
 511 80.22, 132.63
 512 94.14, 123.14
 513 106.95, 112.19
 514 118.5, 99.91
 515 128.65, 86.45
 516 137.28, 71.97
 517 144.28, 56.64
 518 149.58, 40.64
 519 153.11, 24.16
 520 154.82, 7.4
 521 154.71, -9.46
 522 152.77, -26.2
 523 149.02, -42.63
 524 143.51, -58.56
 525 136.31, -73.8
 526 127.49, -88.16
 527 117.16, -101.48
 528 105.45, -113.6
 529 92.49, -124.38
 530 78.44, -133.69
 531 63.46, -141.41
 532 47.74, -147.47
 533 31.44, -151.78

NO. LOCATION (METERS)

535 -16.83, 154.08
 536 -33.46, 151.35
 537 -49.69, 146.82
 538 -65.34, 140.55
 539 -80.22, 132.63
 540 -94.14, 123.14
 541 -106.95, 112.19
 542 -118.5, 99.91
 543 -128.65, 86.45
 544 -137.28, 71.97
 545 -144.28, 56.64
 546 -149.58, 40.64
 547 -153.11, 24.16
 548 -154.82, 7.4
 549 -154.71, -9.46
 550 -152.77, -26.2
 551 -149.02, -42.63
 552 -143.51, -58.56
 553 -136.31, -73.8
 554 -127.49, -88.16
 555 -117.16, -101.48
 556 -105.45, -113.6
 557 -92.49, -124.38
 558 -78.44, -133.69
 559 -63.46, -141.41
 560 -47.74, -147.47
 561 -31.44, -151.78

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 14 (CONT.)

NO. LOCATION (METERS)

534 14.78, -154.29

NO. LOCATION (METERS)

562 -14.78, -154.29

HFLIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 15

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
563	10.95, 162.73	590	-10.95, 162.73
564	26.5, 160.93	591	-26.5, 160.93
565	41.8, 157.65	592	-41.8, 157.65
566	62.55, 150.63	593	-62.55, 150.63
567	76.69, 143.94	594	-76.69, 143.94
568	90.14, 135.93	595	-90.14, 135.93
569	107.54, 122.63	596	-107.54, 122.63
570	118.8, 111.76	597	-118.8, 111.76
571	128.96, 99.86	598	-128.96, 99.86
572	141.18, 81.68	599	-141.18, 81.68
573	148.35, 67.77	600	-148.35, 67.77
574	154.17, 53.24	601	-154.17, 53.24
575	159.91, 32.1	602	-159.91, 32.1
576	162.25, 16.63	603	-162.25, 16.63
577	161.76, -20.86	604	-161.76, -20.86
578	159.02, -36.27	605	-159.02, -36.27
579	154.81, -51.34	606	-154.81, -51.34
580	146.53, -71.62	607	-146.53, -71.62
581	139, -85.33	608	-139, -85.33
582	130.18, -98.26	609	-130.18, -98.26
583	115.84, -114.82	610	-115.84, -114.82
584	104.3, -125.39	611	-104.3, -125.39
585	91.8, -134.81	612	-91.8, -134.81
586	72.91, -145.9	613	-72.91, -145.9
587	58.59, -152.21	614	-58.59, -152.21
588	43.73, -157.13	615	-43.73, -157.13
589	22.29, -161.57	616	-22.29, -161.57

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 16

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
617	7.61, 171.66	654	-7.01, 171.66
618	20.97, 170.51	655	-20.97, 170.51
619	34.8, 168.24	656	-34.8, 168.24
620	48.4, 164.84	657	-48.4, 164.84
621	61.67, 160.35	658	-61.67, 160.35
622	74.53, 154.79	659	-74.53, 154.79
623	86.9, 148.2	660	-86.9, 148.2
624	98.69, 140.62	661	-98.69, 140.62
625	109.82, 132.11	662	-109.82, 132.11
626	120.23, 122.72	663	-120.23, 122.72
627	129.83, 112.52	664	-129.83, 112.52
628	138.57, 101.56	665	-138.57, 101.56
629	146.38, 89.93	666	-146.38, 89.93
630	153.23, 77.7	667	-153.23, 77.7
631	159.05, 64.95	668	-159.05, 64.95
632	163.81, 51.77	669	-163.81, 51.77
633	167.49, 38.25	670	-167.49, 38.25
634	170.05, 24.47	671	-170.05, 24.47
635	171.48, 10.53	672	-171.48, 10.53
636	170.91, -17.47	673	-170.91, -17.47
637	168.92, -31.34	674	-168.92, -31.34
638	165.8, -45	675	-165.8, -45
639	161.58, -58.36	676	-161.58, -58.36
640	156.29, -71.34	677	-156.29, -71.34
641	149.95, -83.84	678	-149.95, -83.84
642	142.62, -95.78	679	-142.62, -95.78

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.16 (CONT.)

NO. LOCATION (METERS)

643 134.34,-107.09
 644 125.17,-117.68
 645 115.16,-127.49
 646 104.38,-136.45
 647 92.92,-144.51
 648 80.83,-151.6
 649 68.2,-157.68
 650 55.13,-162.72
 651 41.68,-166.67
 652 27.96,-169.51
 653 14.05,-171.22

NO. LOCATION (METERS)

680 -134.34,-107.09
 681 -125.17,-117.68
 682 -115.16,-127.49
 683 -104.38,-136.45
 684 -92.92,-144.51
 685 -80.83,-151.6
 686 -68.2,-157.68
 687 -55.13,-162.72
 688 -41.68,-166.67
 689 -27.96,-169.51
 690 -14.05,-171.22

HF LIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 17

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
691	14.71, 179.9	727	-14.71, 179.9
692	29.32, 178.1	728	-29.32, 178.1
693	43.74, 175.12	729	-43.74, 175.12
694	57.87, 170.97	730	-57.87, 170.97
695	71.61, 165.69	731	-71.61, 165.69
696	84.88, 159.3	732	-84.88, 159.3
697	97.58, 151.85	733	-97.58, 151.85
698	109.63, 143.39	734	-109.63, 143.39
699	120.95, 133.98	735	-120.95, 133.98
700	131.47, 123.68	736	-131.47, 123.68
701	141.11, 112.55	737	-141.11, 112.55
702	149.81, 100.68	738	-149.81, 100.68
703	157.52, 88.13	739	-157.52, 88.13
704	164.18, 75	740	-164.18, 75
705	169.75, 61.37	741	-169.75, 61.37
706	174.18, 47.33	742	-174.18, 47.33
707	177.46, 32.98	743	-177.46, 32.98
708	179.56, 18.4	744	-179.56, 18.4
709	180.16, -11.01	745	-180.16, -11.01
710	178.67, -25.66	746	-178.67, -25.66
711	175.98, -40.14	747	-175.98, -40.14
712	172.12, -54.35	748	-172.12, -54.35
713	167.12, -68.19	749	-167.12, -68.19
714	161.01, -81.59	750	-161.01, -81.59
715	153.82, -94.44	751	-153.82, -94.44
716	145.62, -106.66	752	-145.62, -106.66

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.17 (CONTIN)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
717	136.44,-118.17	753	-136.44,-118.17
718	126.35,-128.9	754	-126.35,-128.9
719	115.43,-138.77	755	-115.43,-138.77
720	103.73,-147.72	756	-103.73,-147.72
721	91.35,-155.68	757	-91.35,-155.68
722	78.36,-162.61	758	-78.36,-162.61
723	64.84,-168.45	759	-64.84,-168.45
724	50.9,-173.18	760	-50.9,-173.18
725	36.61,-176.75	761	-36.61,-176.75
726	22.09,-179.14	762	-22.09,-179.14

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 18

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
763	7.74, 189.74	800	-7.74, 189.74
764	23.18, 188.48	801	-23.18, 188.48
765	38.47, 185.96	802	-38.47, 185.96
766	53.5, 182.21	803	-53.5, 182.21
767	68.17, 177.24	804	-68.17, 177.24
768	82.39, 171.1	805	-82.39, 171.1
769	96.06, 163.81	806	-96.06, 163.81
770	109.09, 155.44	807	-109.09, 155.44
771	121.4, 146.03	808	-121.4, 146.03
772	132.89, 135.65	809	-132.89, 135.65
773	143.51, 124.37	810	-143.51, 124.37
774	153.17, 112.26	811	-153.17, 112.26
775	161.81, 99.4	812	-161.81, 99.4
776	169.37, 85.88	813	-169.37, 85.88
777	175.81, 71.79	814	-175.81, 71.79
778	181.07, 57.23	815	-181.07, 57.23
779	185.13, 42.28	816	-185.13, 42.28
780	187.96, 27.05	817	-187.96, 27.05
781	189.54, 11.64	818	-189.54, 11.64
782	188.92, -19.31	819	-188.92, -19.31
783	186.71, -34.64	820	-186.71, -34.64
784	183.27, -49.74	821	-183.27, -49.74
785	178.61, -64.51	822	-178.61, -64.51
786	172.75, -78.86	823	-172.75, -78.86
787	165.75, -92.67	824	-165.75, -92.67
788	157.65, -105.87	825	-157.65, -105.87

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.18 (CONT.)

NO. LOCATION (METERS)

789 148.49,-118.37

790 138.35,-130.08

791 127.29,-140.92

792 115.38,-150.83

793 102.71,-159.73

794 89.35,-167.57

795 75.39,-174.29

796 60.93,-179.86

797 46.07,-184.23

798 30.91,-187.37

799 15.53,-189.26

NO. LOCATION (METERS)

826 -148.49,-118.37

827 -138.35,-130.08

828 -127.29,-140.92

829 -115.38,-150.83

830 -102.71,-159.73

831 -89.35,-167.57

832 -75.39,-174.29

833 -60.93,-179.86

834 -46.07,-184.23

835 -30.91,-187.37

836 -15.53,-189.26

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 19

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
837	16.24, 198.64	873	-16.24, 198.64
838	32.38, 196.65	874	-32.38, 196.65
839	48.3, 193.36	875	-48.3, 193.36
840	63.9, 188.78	876	-63.9, 188.78
841	79.07, 182.94	877	-79.07, 182.94
842	93.72, 175.89	878	-93.72, 175.89
843	107.74, 167.67	879	-107.74, 167.67
844	121.05, 158.33	880	-121.05, 158.33
845	133.55, 147.94	881	-133.55, 147.94
846	145.16, 136.56	882	-145.16, 136.56
847	155.81, 124.27	883	-155.81, 124.27
848	165.42, 111.16	884	-165.42, 111.16
849	173.93, 97.31	885	-173.93, 97.31
850	181.28, 82.81	886	-181.28, 82.81
851	187.43, 67.76	887	-187.43, 67.76
852	192.33, 52.26	888	-192.33, 52.26
853	195.95, 36.41	889	-195.95, 36.41
854	198.26, 20.32	890	-198.26, 20.32
855	198.93, -12.16	891	-198.93, -12.16
856	197.28, -28.33	892	-197.28, -28.33
857	194.31, -44.32	893	-194.31, -44.32
858	190.05, -60.01	894	-190.05, -60.01
859	184.53, -75.3	895	-184.53, -75.3
860	177.78, -90.08	896	-177.78, -90.08
861	169.85, -104.27	897	-169.85, -104.27
862	160.78, -117.77	898	-160.78, -117.77

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.19 (CONT.)

NO. LOCATION (METERS)

863 150.65, -130.48

864 139.51, -142.33

865 127.45, -153.22

866 114.54, -163.1

867 100.86, -171.89

868 86.52, -179.54

869 71.6, -186

870 56.2, -191.21

871 40.43, -195.16

872 24.39, -197.8

NO. LOCATION (METERS)

899 -150.65, -130.48

900 -139.51, -142.33

901 -127.45, -153.22

902 -114.54, -163.1

903 -100.86, -171.89

904 -86.52, -179.54

905 -71.6, -186

906 -56.2, -191.21

907 -40.43, -195.16

908 -24.39, -197.8

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 20

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
909	8.54, 209.23	943	-8.54, 209.23
910	25.56, 207.83	944	-25.56, 207.83
911	42.42, 205.06	945	-42.42, 205.06
912	58.99, 200.92	946	-58.99, 200.92
913	75.17, 195.44	947	-75.17, 195.44
914	90.85, 188.67	948	-90.85, 188.67
915	105.92, 180.63	949	-105.92, 180.63
916	120.29, 171.4	950	-120.29, 171.4
917	133.86, 161.03	951	-133.86, 161.03
918	146.54, 149.58	952	-146.54, 149.58
919	158.24, 137.14	953	-158.24, 137.14
920	168.89, 123.79	954	-168.89, 123.79
921	178.42, 109.61	955	-178.42, 109.61
922	186.76, 94.7	956	-186.76, 94.7
923	193.86, 79.17	957	-193.86, 79.17
924	199.67, 63.1	958	-199.67, 63.1
925	204.14, 46.62	959	-204.14, 46.62
926	207.26, 29.83	960	-207.26, 29.83
927	209.01, 12.84	961	-209.01, 12.84
928	209.27, -7.38	962	-209.27, -7.38
929	208.31, -21.29	963	-208.31, -21.29
930	205.89, -38.2	964	-205.89, -38.2
931	202.09, -54.85	965	-202.09, -54.85
932	196.95, -71.14	966	-196.95, -71.14
933	190.49, -86.95	967	-190.49, -86.95
934	182.77, -102.19	968	-182.77, -102.19

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.20 (CONT.)

NO. LOCATION (METERS)

935 173.84,-116.75

936 163.74,-130.53

937 152.56,-143.44

938 140.36,-155.39

939 127.23,-166.32

940 113.25,-176.13

941 98.52,-184.78

942 83.13,-192.19

NO. LOCATION (METERS)

969 -173.84,-116.75

970 -163.74,-130.53

971 -152.56,-143.44

972 -140.36,-155.39

973 -127.23,-166.32

974 -113.25,-176.13

975 -98.52,-184.78

976 -83.13,-192.19

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.21

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
977	15.66, 219.04	1009	-15.66, 219.04
978	32.16, 217.23	1010	-32.16, 217.23
979	55.39, 212.5	1011	-55.39, 212.5
980	68.28, 208.72	1012	-68.28, 208.72
981	83.85, 202.96	1013	-83.85, 202.96
982	105.23, 192.74	1014	-105.23, 192.74
983	116.83, 185.95	1015	-116.83, 185.95
984	130.53, 176.59	1016	-130.53, 176.59
985	148.81, 161.49	1017	-148.81, 161.49
986	158.41, 152.09	1018	-158.41, 152.09
987	169.44, 139.69	1019	-169.44, 139.69
988	183.51, 120.62	1020	-183.51, 120.62
989	190.54, 109.17	1021	-190.54, 109.17
990	198.24, 94.47	1022	-198.24, 94.47
991	207.27, 72.55	1023	-207.27, 72.55
992	211.32, 59.74	1024	-211.32, 59.74
993	215.23, 43.61	1025	-215.23, 43.61
994	218.59, 20.99	1026	-218.59, 20.99
995	219.46, 7.79	1027	-219.46, 7.79
996	219.29, -11.75	1028	-219.29, -11.75
997	217.04, -33.44	1029	-217.04, -33.44
998	214.59, -46.65	1030	-214.59, -46.65
999	210.45, -62.72	1031	-210.45, -62.72
1000	202.47, -85.04	1032	-202.47, -85.04
1001	196.89, -97.26	1033	-196.89, -97.26
1002	188.98, -111.85	1034	-188.98, -111.85

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.21 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1023	175.82,-131.57	1035	-175.82,-131.57
1004	167.45,-142.08	1036	-167.45,-142.08
1005	156.24,-154.32	1037	-156.24,-154.32
1006	138.7,-170.26	1038	-138.7,-170.26
1007	128.03,-178.42	1039	-128.03,-178.42
1008	114.19,-187.58	1040	-114.19,-187.58

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.22

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1041	9.4, 230.41	1081	-9.4, 230.41
1042	23.48, 229.4	1082	-23.48, 229.4
1043	37.46, 227.54	1083	-37.46, 227.54
1044	51.31, 224.82	1084	-51.31, 224.82
1045	64.96, 221.26	1085	-64.96, 221.26
1046	78.37, 216.87	1086	-78.37, 216.87
1047	91.49, 211.67	1087	-91.49, 211.67
1048	104.26, 205.68	1088	-104.26, 205.68
1049	116.65, 198.92	1089	-116.65, 198.92
1050	128.59, 191.42	1090	-128.59, 191.42
1051	140.06, 183.19	1091	-140.06, 183.19
1052	151, 174.29	1092	-151, 174.29
1053	161.38, 164.72	1093	-161.38, 164.72
1054	171.15, 154.55	1094	-171.15, 154.55
1055	180.28, 143.79	1095	-180.28, 143.79
1056	188.74, 132.5	1096	-188.74, 132.5
1057	196.49, 120.71	1097	-196.49, 120.71
1058	203.5, 108.46	1098	-203.5, 108.46
1059	209.75, 95.82	1099	-209.75, 95.82
1060	215.22, 82.81	1100	-215.22, 82.81
1061	219.88, 69.49	1101	-219.88, 69.49
1062	223.72, 55.91	1102	-223.72, 55.91
1063	226.72, 42.13	1103	-226.72, 42.13
1064	228.87, 28.18	1104	-228.87, 28.18
1065	230.17, 14.13	1105	-230.17, 14.13
1066	230.08, -15.48	1106	-230.08, -15.48

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.22 (CONT.)

NO. LOCATION (METERS)

1067 228.88,-28.12
 1068 226.73,-42.07
 1069 223.73,-55.85
 1070 219.9,-69.43
 1071 215.24,-82.75
 1072 209.78,-95.76
 1073 203.53,-108.41
 1074 196.52,-120.65
 1075 188.77,-132.45
 1076 180.32,-143.74
 1077 171.19,-154.5
 1078 161.42,-164.68
 1079 151.05,-174.24
 1080 140.11,-183.16

NO. LOCATION (METERS)

1107 -228.88,-28.12
 1108 -226.73,-42.07
 1109 -223.73,-55.85
 1110 -219.9,-69.43
 1111 -215.24,-82.75
 1112 -209.78,-95.76
 1113 -203.53,-108.41
 1114 -196.52,-120.65
 1115 -188.77,-132.45
 1116 -180.32,-143.74
 1117 -171.19,-154.5
 1118 -161.42,-164.68
 1119 -151.05,-174.24
 1120 -140.11,-183.16

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.23

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1121	17.23,240.98	1159	-17.23,240.98
1122	31.94,239.48	1160	-31.94,239.48
1123	46.53,237.08	1161	-46.53,237.08
1124	60.94,233.79	1162	-60.94,233.79
1125	75.12,229.62	1163	-75.12,229.62
1126	89.02,224.6	1164	-89.02,224.6
1127	102.59,218.74	1165	-102.59,218.74
1128	115.78,212.05	1166	-115.78,212.05
1129	128.53,204.57	1167	-128.53,204.57
1130	140.8,196.33	1168	-140.8,196.33
1131	152.54,187.35	1169	-152.54,187.35
1132	163.72,177.67	1170	-163.72,177.67
1133	174.27,167.33	1171	-174.27,167.33
1134	184.18,156.36	1172	-184.18,156.36
1135	193.4,144.8	1173	-193.4,144.8
1136	201.89,132.7	1174	-201.89,132.7
1137	209.63,120.11	1175	-209.63,120.11
1138	216.58,107.06	1176	-216.58,107.06
1139	222.73,93.62	1177	-222.73,93.62
1140	228.03,79.82	1178	-228.03,79.82
1141	232.49,65.72	1179	-232.49,65.72
1142	236.07,51.38	1180	-236.07,51.38
1143	238.77,36.85	1181	-238.77,36.85
1144	240.58,22.18	1182	-240.58,22.18
1145	241.49,7.42	1183	-241.49,7.42
1146	241.49,-7.36	1184	-241.49,-7.36

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.23 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1147	240.59,-22.11	1185	-240.59,-22.11
1148	238.78,-36.79	1186	-238.78,-36.79
1149	236.09,-51.32	1187	-236.09,-51.32
1150	232.51,-65.66	1188	-232.51,-65.66
1151	228.06,-79.76	1189	-228.06,-79.76
1152	222.75,-93.56	1190	-222.75,-93.56
1153	216.61,-107	1191	-216.61,-107
1154	209.66,-120.05	1192	-209.66,-120.05
1155	201.93,-132.65	1193	-201.93,-132.65
1156	193.44,-144.75	1194	-193.44,-144.75
1157	184.22,-156.31	1195	-184.22,-156.31
1158	174.32,-167.28	1196	-174.32,-167.28

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.24

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1197	10.34, 253.39	1233	-10.34, 253.39
1198	25.82, 252.28	1234	-25.82, 252.28
1199	41.2, 250.23	1235	-41.2, 250.23
1200	56.43, 247.24	1236	-56.43, 247.24
1201	71.44, 243.33	1237	-71.44, 243.33
1202	86.19, 238.5	1238	-86.19, 238.5
1203	100.61, 232.79	1239	-100.61, 232.79
1204	114.66, 226.2	1240	-114.66, 226.2
1205	128.28, 218.76	1241	-128.28, 218.76
1206	141.42, 210.51	1242	-141.42, 210.51
1207	154.03, 201.47	1243	-154.03, 201.47
1208	166.06, 191.67	1244	-166.06, 191.67
1209	177.47, 181.15	1245	-177.47, 181.15
1210	188.22, 169.96	1246	-188.22, 169.96
1211	198.26, 158.13	1247	-198.26, 158.13
1212	207.56, 145.71	1248	-207.56, 145.71
1213	216.08, 132.74	1249	-216.08, 132.74
1214	223.8, 119.28	1250	-223.8, 119.28
1215	230.67, 105.37	1251	-230.67, 105.37
1216	236.68, 91.07	1252	-236.68, 91.07
1217	241.81, 76.42	1253	-241.81, 76.42
1218	246.03, 61.49	1254	-246.03, 61.49
1219	249.33, 46.33	1255	-249.33, 46.33
1220	251.7, 30.99	1256	-251.7, 30.99
1221	253.12, 15.54	1257	-253.12, 15.54
1222	253.13, -15.48	1258	-253.13, -15.48

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.24 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1223	251.71,-30.93	1259	-251.71,-30.93
1224	249.34,-46.26	1260	-249.34,-46.26
1225	246.05,-61.43	1261	-246.05,-61.43
1226	241.83,-76.36	1262	-241.83,-76.36
1227	236.71,-91	1263	-236.71,-91
1228	230.7,-105.31	1264	-230.7,-105.31
1229	223.83,-119.22	1265	-223.83,-119.22
1230	216.12,-132.69	1266	-216.12,-132.69
1231	207.6,-145.66	1267	-207.6,-145.66
1232	198.3,-158.08	1268	-198.3,-158.08

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.25

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1269	18.95,264.92	1304	-18.95,264.92
1270	35.11,263.27	1305	-35.11,263.27
1271	51.15,260.63	1306	-51.15,260.63
1272	66.99,257.01	1307	-66.99,257.01
1273	82.58,252.43	1308	-82.58,252.43
1274	97.87,246.91	1309	-97.87,246.91
1275	112.78,240.46	1310	-112.78,240.46
1276	127.28,233.12	1311	-127.28,233.12
1277	141.3,224.9	1312	-141.3,224.9
1278	154.79,215.83	1313	-154.79,215.83
1279	167.7,205.96	1314	-167.7,205.96
1280	179.98,195.32	1315	-179.98,195.32
1281	191.59,183.95	1316	-191.59,183.95
1282	202.48,171.89	1317	-202.48,171.89
1283	212.61,159.18	1318	-212.61,159.18
1284	221.95,145.88	1319	-221.95,145.88
1285	230.45,132.04	1320	-230.45,132.04
1286	238.1,117.7	1321	-238.1,117.7
1287	244.85,102.92	1322	-244.85,102.92
1288	250.69,87.75	1323	-250.69,87.75
1289	255.58,72.25	1324	-255.58,72.25
1290	259.52,56.49	1325	-259.52,56.49
1291	262.49,40.51	1326	-262.49,40.51
1292	264.48,24.38	1327	-264.48,24.38
1293	265.47,8.16	1328	-265.47,8.16
1294	265.48,-8.09	1329	-265.48,-8.09

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.25 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1295	264.49,-24.31	1330	-264.49,-24.31
1296	262.5,-40.44	1331	-262.5,-40.44
1297	259.54,-56.42	1332	-259.54,-56.42
1298	255.6,-72.19	1333	-255.6,-72.19
1299	250.71,-87.68	1334	-250.71,-87.68
1300	244.88,-102.85	1335	-244.88,-102.85
1301	238.13,-117.63	1336	-238.13,-117.63
1302	230.49,-131.98	1337	-230.49,-131.98
1303	221.99,-145.83	1338	-221.99,-145.83

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.26

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1339	11.37, 278.47	1370	-11.37, 278.47
1340	28.38, 277.25	1371	-28.38, 277.25
1341	45.28, 275	1372	-45.28, 275
1342	62.01, 271.71	1373	-62.01, 271.71
1343	78.51, 267.41	1374	-78.51, 267.41
1344	94.72, 262.11	1375	-94.72, 262.11
1345	110.57, 255.83	1376	-110.57, 255.83
1346	126.01, 248.59	1377	-126.01, 248.59
1347	140.98, 240.41	1378	-140.98, 240.41
1348	155.42, 231.34	1379	-155.42, 231.34
1349	169.27, 221.41	1380	-169.27, 221.41
1350	182.5, 210.64	1381	-182.5, 210.64
1351	195.04, 199.08	1382	-195.04, 199.08
1352	206.85, 186.78	1383	-206.85, 186.78
1353	217.88, 173.78	1384	-217.88, 173.78
1354	228.1, 160.13	1385	-228.1, 160.13
1355	237.47, 145.88	1386	-237.47, 145.88
1356	245.95, 131.09	1387	-245.95, 131.09
1357	253.5, 115.8	1388	-253.5, 115.8
1358	260.11, 100.08	1389	-260.11, 100.08
1359	265.74, 83.99	1390	-265.74, 83.99
1360	270.38, 67.58	1391	-270.38, 67.58
1361	274.01, 50.91	1392	-274.01, 50.91
1362	276.61, 34.06	1393	-276.61, 34.06
1363	278.18, 17.08	1394	-278.18, 17.08
1364	278.18, -17.01	1395	-278.18, -17.01

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.26 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1365	276.62,-33.99	1396	-276.62,-33.99
1366	274.02,-50.84	1397	-274.02,-50.84
1367	270.4,-67.5	1398	-270.4,-67.5
1368	265.77,-83.92	1399	-265.77,-83.92
1369	260.14,-100.01	1400	-260.14,-100.01

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.27

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1401	23.69, 290.74	1429	-23.69, 290.74
1402	38.56, 289.14	1430	-38.56, 289.14
1403	53.34, 286.78	1431	-53.34, 286.78
1404	76.36, 281.53	1432	-76.36, 281.53
1405	90.7, 277.24	1433	-90.7, 277.24
1406	104.79, 272.23	1434	-104.79, 272.23
1407	126.47, 262.86	1435	-126.47, 262.86
1408	139.78, 256.03	1436	-139.78, 256.03
1409	152.73, 248.52	1437	-152.73, 248.52
1410	172.33, 235.35	1438	-172.33, 235.35
1411	184.17, 226.21	1439	-184.17, 226.21
1412	195.53, 216.47	1440	-195.53, 216.47
1413	212.4, 199.94	1441	-212.4, 199.94
1414	222.37, 188.78	1442	-222.37, 188.78
1415	231.76, 177.13	1443	-231.76, 177.13
1416	245.33, 157.8	1444	-245.33, 157.8
1417	253.1, 145.02	1445	-253.1, 145.02
1418	260.2, 131.85	1446	-260.2, 131.85
1419	270.01, 110.37	1447	-270.01, 110.37
1420	275.32, 96.38	1448	-275.32, 96.38
1421	279.9, 82.13	1449	-279.9, 82.13
1422	285.63, 59.22	1450	-285.63, 59.22
1423	288.29, 44.5	1451	-288.29, 44.5
1424	290.19, 29.66	1452	-290.19, 29.66
1425	291.53, 9.86	1453	-291.53, 9.86
1426	291.56, -8.88	1454	-291.56, -8.88

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 27 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1427	290.73, -23.81	1455	-290.73, -23.81
1428	287.85, -47.26	1456	-287.85, -47.26

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 23

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1457	19.49, 305.38	1489	-19.49, 305.38
1458	33.48, 304.16	1490	-33.48, 304.16
1459	47.4, 302.31	1491	-47.4, 302.31
1460	61.22, 299.81	1492	-61.22, 299.81
1461	74.91, 296.69	1493	-74.91, 296.69
1462	88.44, 292.94	1494	-88.44, 292.94
1463	101.79, 288.57	1495	-101.79, 288.57
1464	114.92, 283.6	1496	-114.92, 283.6
1465	127.81, 278.03	1497	-127.81, 278.03
1466	140.44, 271.87	1498	-140.44, 271.87
1467	152.76, 265.14	1499	-152.76, 265.14
1468	164.76, 257.85	1500	-164.76, 257.85
1469	176.42, 250.02	1501	-176.42, 250.02
1470	187.71, 241.67	1502	-187.71, 241.67
1471	198.6, 232.8	1503	-198.6, 232.8
1472	209.07, 223.44	1504	-209.07, 223.44
1473	219.1, 213.62	1505	-219.1, 213.62
1474	228.67, 203.34	1506	-228.67, 203.34
1475	237.76, 192.63	1507	-237.76, 192.63
1476	246.34, 181.52	1508	-246.34, 181.52
1477	254.41, 170.03	1509	-254.41, 170.03
1478	261.95, 158.18	1510	-261.95, 158.18
1479	268.93, 145.99	1511	-268.93, 145.99
1480	275.34, 133.5	1512	-275.34, 133.5
1481	281.18, 120.73	1513	-281.18, 120.73
1482	286.42, 107.7	1514	-286.42, 107.7

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.28 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1483	291.06,94.45	1515	-291.06,94.45
1484	295.09,81	1516	-295.09,81
1485	298.49,67.37	1517	-298.49,67.37
1486	301.27,53.61	1518	-301.27,53.61
1487	303.41,39.73	1519	-303.41,39.73
1488	304.91,25.77	1520	-304.91,25.77

HELICSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.29

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1521	13.06,319.93	1554	-13.06,319.93
1522	27.72,319	1555	-27.72,319
1523	42.33,317.39	1556	-42.33,317.39
1524	56.85,315.11	1557	-56.85,315.11
1525	71.24,312.17	1558	-71.24,312.17
1526	85.49,308.58	1559	-85.49,308.58
1527	99.56,304.33	1560	-99.56,304.33
1528	113.42,299.44	1561	-113.42,299.44
1529	127.03,293.92	1562	-127.03,293.92
1530	140.39,287.78	1563	-140.39,287.78
1531	153.44,281.04	1564	-153.44,281.04
1532	166.17,273.71	1565	-166.17,273.71
1533	178.56,265.79	1566	-178.56,265.79
1534	190.56,257.32	1567	-190.56,257.32
1535	202.17,248.31	1568	-202.17,248.31
1536	213.35,238.77	1569	-213.35,238.77
1537	224.08,228.73	1570	-224.08,228.73
1538	234.33,218.21	1571	-234.33,218.21
1539	244.1,207.23	1572	-244.1,207.23
1540	253.35,195.81	1573	-253.35,195.81
1541	262.07,183.98	1574	-262.07,183.98
1542	270.23,171.77	1575	-270.23,171.77
1543	277.83,159.19	1576	-277.83,159.19
1544	284.84,146.27	1577	-284.84,146.27
1545	291.25,133.05	1578	-291.25,133.05
1546	297.05,119.55	1579	-297.05,119.55

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 29 (CONT. I)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1547	302.22, 105.79	1580	-302.22, 105.79
1548	306.75, 91.82	1581	-306.75, 91.82
1549	310.64, 77.65	1582	-310.64, 77.65
1550	313.88, 63.31	1583	-313.88, 63.31
1551	316.45, 48.85	1584	-316.45, 48.85
1552	318.36, 34.28	1585	-318.36, 34.28
1553	319.6, 19.63	1586	-319.6, 19.63

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.30

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1587	21.39, 335.12	1618	-21.39, 335.12
1588	36.74, 333.78	1619	-36.74, 333.78
1589	52.02, 331.75	1620	-52.02, 331.75
1590	67.18, 329.01	1621	-67.18, 329.01
1591	82.21, 325.58	1622	-82.21, 325.58
1592	97.06, 321.47	1623	-97.06, 321.47
1593	111.7, 316.68	1624	-111.7, 316.68
1594	126.12, 311.22	1625	-126.12, 311.22
1595	140.26, 305.1	1626	-140.26, 305.1
1596	154.11, 298.35	1627	-154.11, 298.35
1597	167.64, 290.96	1628	-167.64, 290.96
1598	180.81, 282.97	1629	-180.81, 282.97
1599	193.6, 274.37	1630	-193.6, 274.37
1600	205.99, 265.2	1631	-205.99, 265.2
1601	217.94, 255.47	1632	-217.94, 255.47
1602	229.43, 245.2	1633	-229.43, 245.2
1603	240.44, 234.42	1634	-240.44, 234.42
1604	250.94, 223.14	1635	-250.94, 223.14
1605	260.91, 211.39	1636	-260.91, 211.39
1606	270.33, 199.2	1637	-270.33, 199.2
1607	279.19, 186.59	1638	-279.19, 186.59
1608	287.46, 173.58	1639	-287.46, 173.58
1609	295.12, 160.21	1640	-295.12, 160.21
1610	302.16, 146.5	1641	-302.16, 146.5
1611	308.56, 132.49	1642	-308.56, 132.49
1612	314.31, 118.19	1643	-314.31, 118.19

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 32 (CONT.)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1613	319.4, 103.65	1644	-319.4, 103.65
1614	323.82, 88.88	1645	-323.82, 88.88
1615	327.56, 73.93	1646	-327.56, 73.93
1616	330.61, 58.83	1647	-330.61, 58.83
1617	332.96, 43.6	1648	-332.96, 43.6

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO.31

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1649	14.33, 351.11	1679	-14.33, 351.11
1650	30.42, 350.08	1680	-30.42, 350.08
1651	46.45, 348.32	1681	-46.45, 348.32
1652	62.39, 345.82	1682	-62.39, 345.82
1653	78.19, 342.59	1683	-78.19, 342.59
1654	93.82, 338.64	1684	-93.82, 338.64
1655	109.26, 333.98	1685	-109.26, 333.98
1656	124.47, 328.62	1686	-124.47, 328.62
1657	139.41, 322.56	1687	-139.41, 322.56
1658	154.06, 315.83	1688	-154.06, 315.83
1659	168.39, 308.43	1689	-168.39, 308.43
1660	182.37, 300.37	1690	-182.37, 300.37
1661	195.95, 291.69	1691	-195.95, 291.69
1662	209.13, 282.39	1692	-209.13, 282.39
1663	221.87, 272.5	1693	-221.87, 272.5
1664	234.13, 262.04	1694	-234.13, 262.04
1665	245.91, 251.02	1695	-245.91, 251.02
1666	257.17, 239.47	1696	-257.17, 239.47
1667	267.88, 227.42	1697	-267.88, 227.42
1668	278.04, 214.89	1698	-278.04, 214.89
1669	287.6, 201.91	1699	-287.6, 201.91
1670	296.56, 188.5	1700	-296.56, 188.5
1671	304.9, 174.7	1701	-304.9, 174.7
1672	312.59, 160.52	1702	-312.59, 160N52
1673	319.63, 146.01	1703	-319.63, 146.01
1674	325.99, 131.2	1704	-325.99, 131.2

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 31 (CONTN)

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1675	331.67, 116.1	1705	-331.67, 116.1
1676	336.64, 100.76	1706	-336.64, 100.76
1677	340.91, 85.21	1707	-340.91, 85.21
1678	344.46, 69.48	1708	-344.46, 69.48

HELIOSTAT LOCATION SUMMARY REPORT FOR CIRCLE NO. 32

NO.	LOCATION (METERS)	NO.	LOCATION (METERS)
1709	23.46, 367.55	1735	-23.46, 367.55
1710	40.3, 366.09	1736	-40.3, 366.09
1711	57.05, 363.85	1737	-57.05, 363.85
1712	73.69, 360.85	1738	-73.69, 360.85
1713	90.16, 357.09	1739	-90.16, 357.09
1714	106.45, 352.58	1740	-106.45, 352.58
1715	122.52, 347.33	1741	-122.52, 347.33
1716	138.32, 341.34	1742	-138.32, 341.34
1717	153.84, 334.63	1743	-153.84, 334.63
1718	169.03, 327.22	1744	-169.03, 327.22
1719	183.86, 319.12	1745	-183.86, 319.12
1720	198.31, 310.35	1746	-198.31, 310.35
1721	212.34, 300.93	1747	-212.34, 300.93
1722	225.92, 290.87	1748	-225.92, 290.87
1723	239.03, 280.2	1749	-239.03, 280.2
1724	251.63, 268.94	1750	-251.63, 268.94
1725	263.71, 257.11	1751	-263.71, 257.11
1726	275.22, 244.74	1752	-275.22, 244.74
1727	286.16, 231.85	1753	-286.16, 231.85
1728	296.5, 218.48	1754	-296.5, 218.48
1729	306.21, 204.65	1755	-306.21, 204.65
1730	315.28, 190.38	1756	-315.28, 190.38
1731	323.68, 175.72	1757	-323.68, 175.72
1732	331.4, 160.68	1758	-331.4, 160.68
1733	338.42, 145.31	1759	-338.42, 145.31
1734	344.73, 129.63	1760	-344.73, 129.63