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Second Generation Heliostat Evaluation Executive Summary

Heliostat Development Division

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SECOND GENERATION HELIOSTAT EVALUATION
EXECUTIVE SUMMARY

Heliostat Development Division
Sandia National Laboratories, Livermore

ABSTRACT

As technical manager of the Second Generation Heliostat development contracts for the Department of Energy, Sandia National Laboratories has evaluated five heliostat designs. Four of the heliostats are viable designs with unique approaches to the same generic design. The designs have varying amounts of risk and additional development required and minor design changes can benefit all of the designs. Detailed cost estimates indicate that the heliostat cost goal can be met at low production rates. This report is a condensed version of the Summary Report (SAND81-8034), which summarizes the evaluation and Sandia's conclusions. The evaluation pertains to the heliostats only and does not rate the contractors (ARCO, Boeing, Martin Marietta, McDonnell Douglas, and Westinghouse).

CONTENTS

ILLUSTRATIONS

ACKNOWLEDGMENTS

Sandia National Laboratories thanks the Users Panel and the Evaluation Review Committee members, as well as their respective companies, for many helpful suggestions and participation in the Second Generation Heliostat Evaluation.

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SECOND GENERATION HELIOSTAT EVALUATION
EXECUTIVE SUMMARY

1.0 Introduction

Sandia National Laboratories Livermore funded five contractors to develop Second Generation Heliostats:

- ARCO Power Systems (ARCO) (formerly Northrup Inc.)
- Boeing Engineering & Construction (BEC)
- Martin Marietta Corporation (MMC)
- McDonnell Douglas Astronautics Company (MDAC)
- Westinghouse Electric Corporation

The development supports the Department of Energy Solar Central Receiver Development Program. Each heliostat design was evaluated by Sandia with the assistance of a panel of potential users and a Review Committee (see Acknowledgments).

Each contractor completed a detailed mass production design for its heliostat, prepared a conceptual design for production of 50,000 heliostats per year, and estimated the price of installed heliostats in a 50 MW electrical power plant. With the exception of Westinghouse, each contractor built and tested two prototype heliostats. Sandia performed side-by-side testing at the Central Receiver Test Facility (CRFT) in Albuquerque, N.M. Independent analysis and testing were performed by Sandia to characterize the designs for proper operational modes, performance, survival and environmental loads, and wear and degradation under real-time and accelerated life-cycle tests.

This evaluation does not rate or rank the designs, and a Sandia preferred composite design is not proposed.

Additional information can be obtained from the Summary Report, SAND81-8034.

2.0 Conclusions and Recommendations

The results of the evaluation show that with low-risk design changes the four tested Second Generation Heliostats are viable designs. The Westinghouse heliostat evaluation could not be completed because prototype hardware was not fabricated and tested. The other four designs each have unique approaches to the same generic design with varying amounts of risk and additional development required. Although the inherent design weaknesses of previous designs have all been eliminated by one or more of the new approaches in the current designs, some relatively minor design changes or proven alternative approaches can benefit all the designs.

Because heliostat controls development was not emphasized during the Second Generation Heliostat Program, additional controls development is required for ARCO and Boeing. Additional development and/or design verification for component lifetimes is needed for all mirror modules and drive mechanisms. The reliance on adhesives and sealants is the major mirror module concern. Boeing's mirror module developed silver corrosion and cracks in the mirror while Martin Marietta's (MMC's) had core/skin bond failures and cracks. Both mirror module designs have unacceptable lifetimes. Inherent design problems with the drive mechanisms were identified for the ARCO and MMC drives. The ARCO stepper motor speed/torque characteristics are inadequate, and the feasibility of MMC's stow lock feature has not been demonstrated.

The contractors' installed heliostat cost estimates indicate that the DOE cost goal can be met at relatively low production rates with the normal expected learning after a few years of production. The cost of energy from a central receiver power plant continues to be attractive.

3.0 Heliostat Design Highlights

ARCO Power Systems--Photographs of the front and back of the ARCO heliostat are shown in Figure 3-1. The unique features of the design are the steel pipe for the foundation and pedestal and the silicone grease used to hold the two half-facet size mirrors to the sandwich-construction all-steel mirror support assembly. The grease also protects against silver corrosion and eliminates stresses in the glass due to differences in thermal expansion coefficients. The steel pipe foundation can be grouted into an augered hole or vibrated into the ground with a vibratory hammer; however, rocks will preclude vibratory hammer installation at some sites.

Boeing Engineering and Construction--Photographs of the front and back of the Boeing heliostat are shown in Figure 3-2. The unique features of the design are the glass/cellular-glass/glass mirror module sandwich and the unlubricated polymer nut on the elevation drive screw. The all-glass mirror module precludes defocusing and eliminates stresses in the glass due to thermal expansion coefficient differences. The polymer nut allows the linear actuator screw to operate without lubrication.

Martin Marietta Corporation--Photographs of the front and back of the Martin Marietta heliostat are shown in Figures 3-3. The unique features of the design are the locking mechanism (stow-lock) on the elevation drive and the polyisobutylene (PIB) used to hold the mirrors to the steel/paper-honeycomb/steel mirror support sandwich assembly. The stow-lock feature carries high wind loads that would normally be carried by the elevation

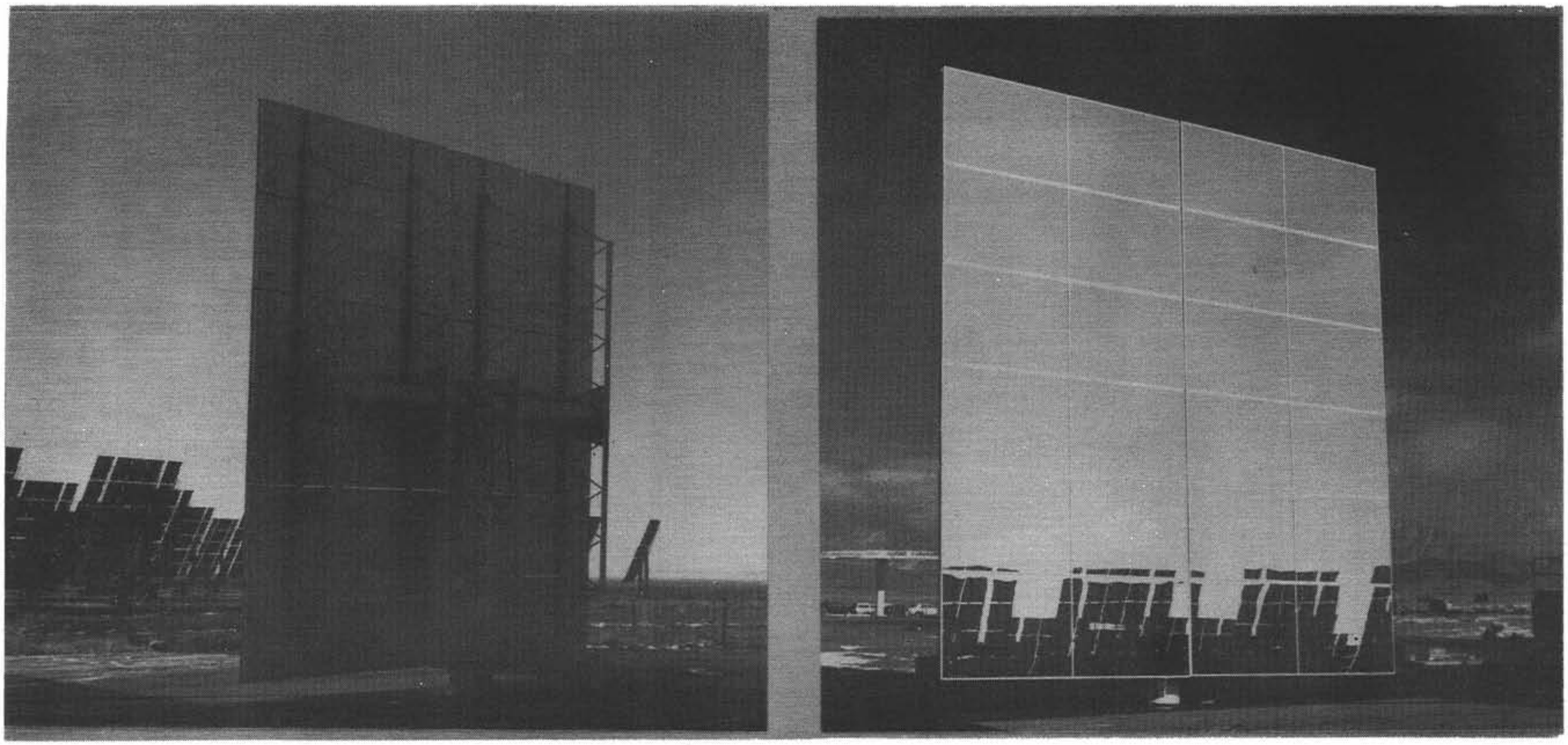

Figure 3-1. ARCO Second Generation Heliostat

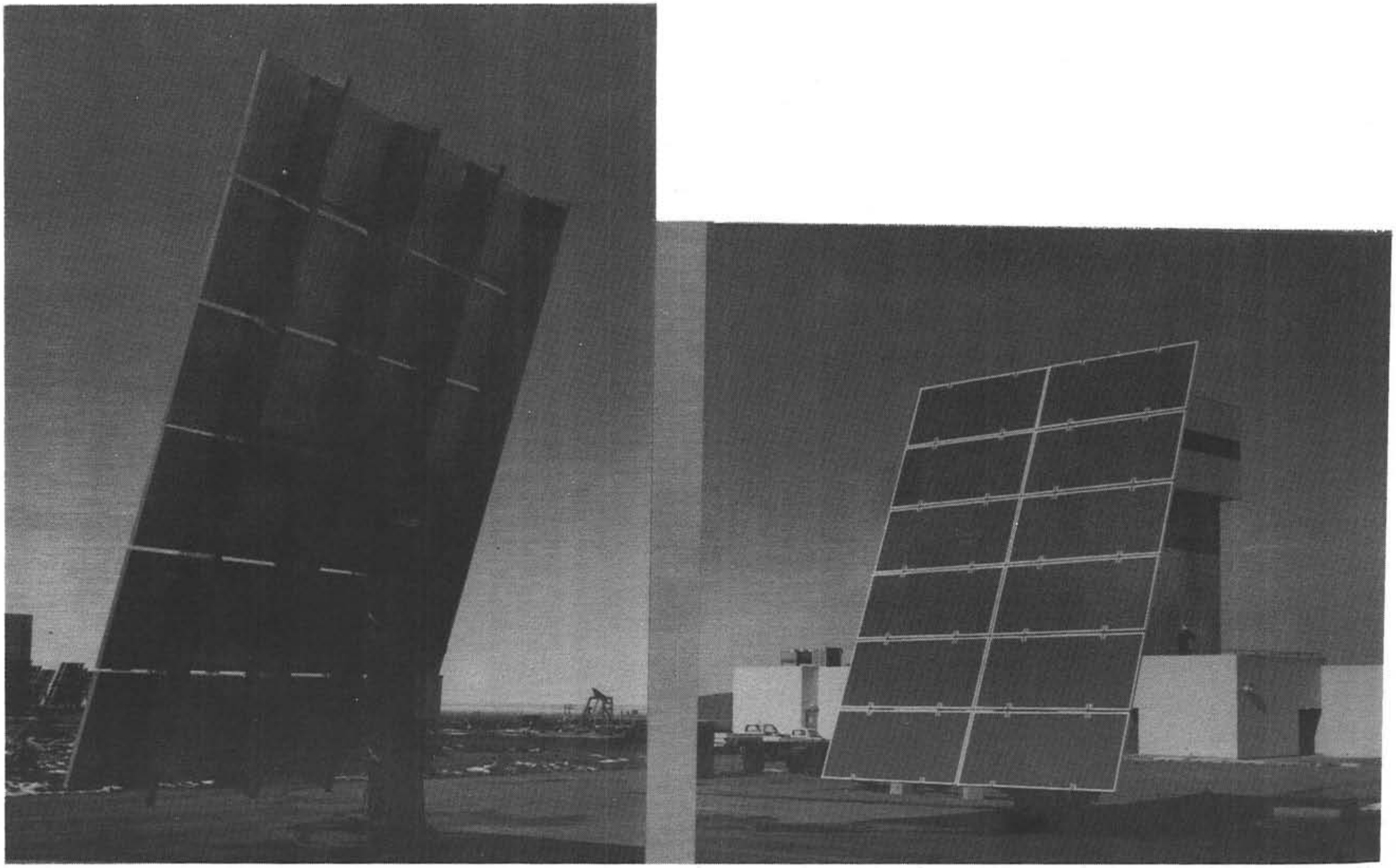

Figure 3-2. Boeing Second Generation Heliostat

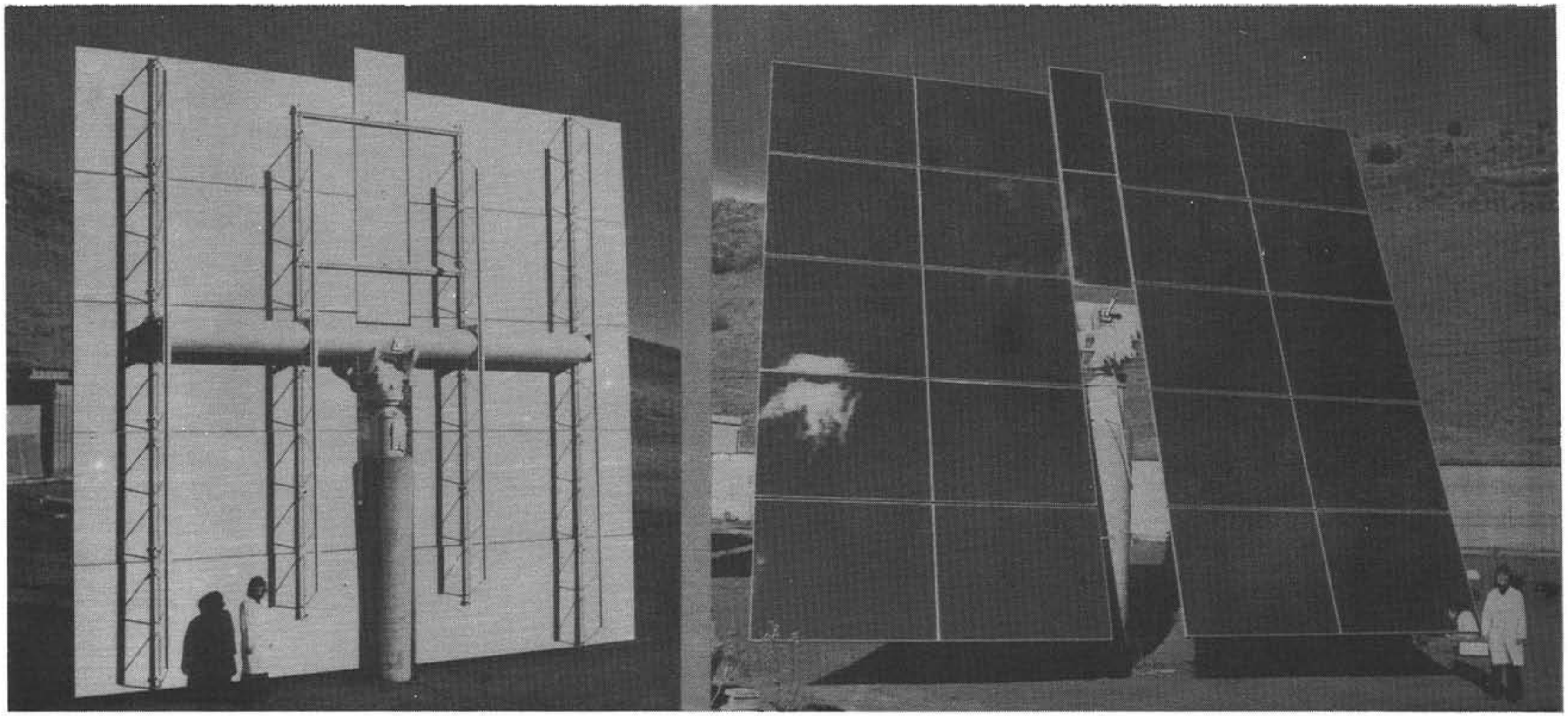

Figure 3-3. Martin Marietta Second Generation Heliostat

drive gears; thus the elevation gear strengths can be smaller. The PIB that holds the two half-facet size mirrors to the mirror support assembly acts as a non-rigid adhesive to preclude thermally induced stress in the glass. Mirror degradation protection is also provided by the PIB.

McDonnell Douglas Astronautics--Photographs of the front and back of the McDonnell Douglas heliostat are shown in Figure 3-4. The unique features of the design are the laminated mirrors, an environmentally sealed linear actuator, and a slip-joint pedestal/foundation interface. The mirrors are made of two pieces of glass that are laminated together like automobile windshields with an edge seal as added protection against mirror corrosion. The slip-joint pedestal/foundation makes it easy to change the foundation size or shape for different soil conditions and minimizes field installation time. The small amount of concrete above the ground simplifies the foundation installation by minimizing the forms and concrete curing problems when ambient temperatures are hot or cold.

Westinghouse Electric Corporation--The Westinghouse heliostat is shown in Figure 3-5. The unique features of the design are the first surface mirror, the large mirror area per heliostat, the stretched cable support structure, and the cable drives. The first surface silver mirror with a TiO_2 overcoat provides a high reflectivity while using conventional low-coat float glass. Low costs are due to the normal iron content in the glass and ease of manufacturing and handling due to its 6 mm thickness. The stretched cable support structure complicates the field assembly and may complicate mirror washing. The area is large, which reduces the number of heliostat controllers, heliostat field controllers, drive mechanisms, and power and control hook-ups to make and maintain.

4.0 Heliostat Cost Estimates

The user's cost (price) for installed heliostats was estimated by each contractor and independently evaluated by Sandia. The contractors were given a common set of cost estimating guidelines. They also provided operations and maintenance cost estimates for a 50 MWe heliostat field. Energy costs were determined by Sandia.

4.1 User's Cost for Installed Heliostats

Sandia has reviewed the cost estimates and adjusted them for omitted items and errors. The price for the Martin Marietta Pilot Plant heliostat has also been estimated by Battelle for a production rate of 50,000 per year. A summary of the price estimates follows.

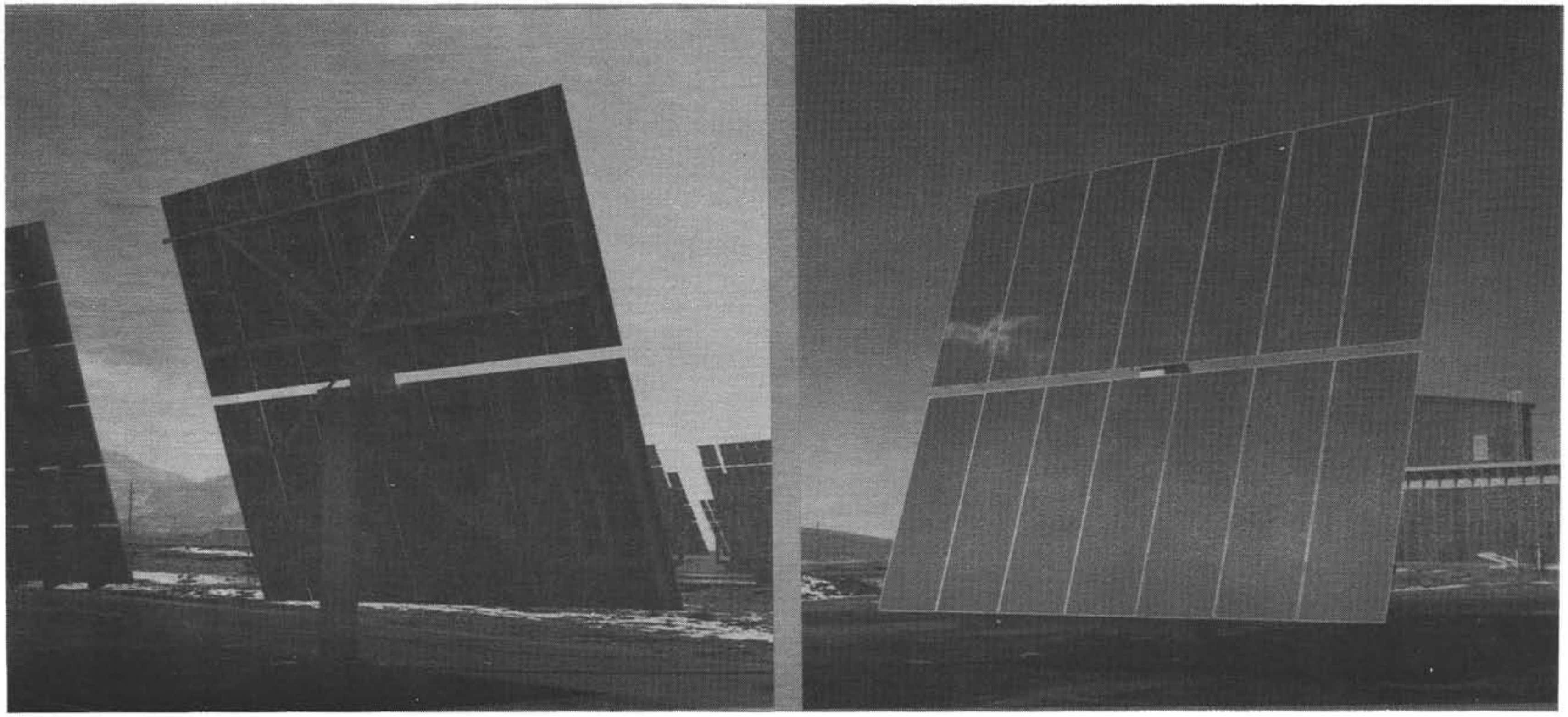

Figure 3-4. McDonnell Douglas Second Generation Heliostat

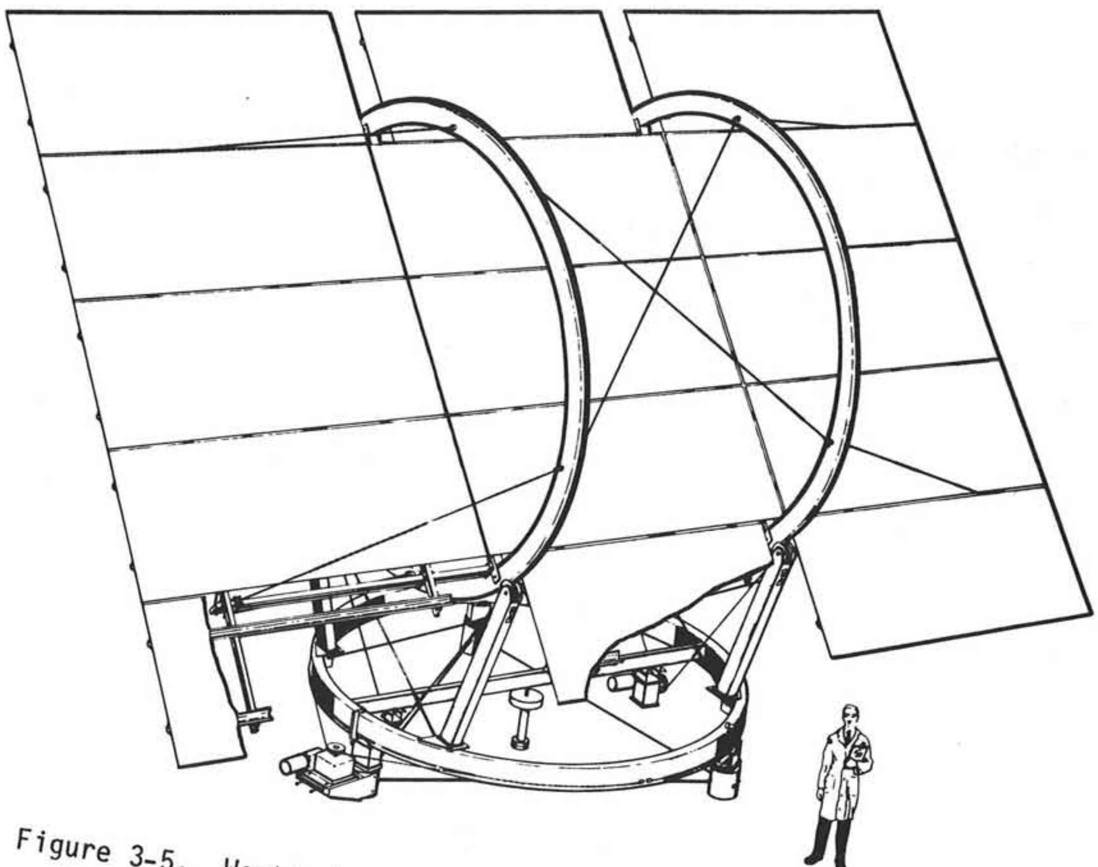

Figure 3-5. Westinghouse Second Generation Heliostat

Contractors' Estimates: Installed Heliostat Prices
First Year, $\$/m^2$ (April 1980)

	ARCO	BEC	MMC	MDAC	Barstow*
Reflective Assembly	33	47	35	34	63
Drive Assembly	45	41	35	28	51
Controls	14	16**	16	14	24
Support Structure	15	22	11	15	17
Foundation/Pedestal	11	21	12	20	18
Total Installed Price***	118	147	109	111	173

*Battelle Pacific Northwest estimate for a production rate of 50,000 heliostats per year.
**Estimated by Sandia; no estimate provided by BEC.
***Assembly/installation cost center apportioned to the above accounts.

4.2 Operations and Maintenance Costs

Operations and maintenance (O & M) costs for a 50 MWe heliostat field were also estimated by the contractors (see Summary Report). Component failure rates and repair times were used to make maintenance estimates. A range of annual O & M costs was obtained and reviewed by Sandia. Because all the expected costs were not provided by all the contractors, Sandia has made a nominal estimate that the annual operations and maintenance costs will be $100 per heliostat in 1980 dollars.

4.3 Energy Costs

Levelized energy costs have been calculated by Sandia for a 50 MW electric solar plant (37% capacity factor) and for an equivalent size plant for industrial process heat. The appropriate heliostat price, O & M cost, reflective areas and errors were used for each heliostat design. The economic assumptions and energy cost are shown below with a breakdown of the busbar energy cost contributors.

Economic Assumptions

	Electric Power	Thermal Power
Inflation Rate (%)	8	8
Levelizing Period (yrs)	30	20
Interest During Construction (%)	10	5
Fixed Charge Rate (%)	15.9	22.9

Levelized Energy Costs--April 1980 $'s

	ARCO	BEC	MMC	MDAC
Busbar Energy Costs (mills/kWhr)				
Capital	88	96	82	83
Heliostat O&M	10	16	8	11
Balance-of-Plant O&M	9	9	9	9
Total	107	121	99	103
Thermal Energy Costs ($/MBTU)				
Input to Receiver[1]	5.39	6.83	4.90	5.00
Base of Tower[2,3]	12.34	14.42	11.13	11.75

1. Does not include any O & M costs.
2. Receiver and piping losses, 22.4% annually.
3. Includes levelized O & M costs.

5.0 User Concerns

Comments received from the Users Panel regarding user concerns and recommendations are summarized below.

User Concerns

- Lack of documentation to develop realistic operating requirements
  - Washing
  - Dust build-up
  - Effects of agricultural, animal, and industrial chemicals
  - Long-term mirror life and reflectivity
  - Site selection criteria
- Lack of documentation on effects of component/subsystem failures
  - Dangers to workers
  - Reliability of emergency defocusing from receiver
  - Effect of one heliostat off-tracking
  - Power outages
  - Warranty plans (entire system, heliostats, and components)
- Lack of documentation to develop realistic maintenance requirements
  - Skill levels
  - Man-hours
  - Scheduled vs unscheduled
  - Times between maintenance

- Plant design impact (extra heliostats)
- Spare parts, inventory, availability, and replacement frequency
- Failure modes and effects analysis
- Reliability indices (these are currently based on component reliability; operating reliability is needed)

User Recommendations

- Heliostat suppliers, in partnership with utilities, industries, and other agencies, should install a few heliostats in the field at various sites.
- Sandia, in support of this effort, should collect, evaluate, and publish the operation, maintenance, and reliability data.
- For this new technology, information should be provided to the insurance industry for insurance codes and the following insurance:
  - Liability
  - Fire
  - Pressure Vessel
  - Business Interruption
  - Construction

6.0 Strengths, Design Concerns, and Potential Solutions

The Second Generation Heliostat strengths, design concerns, and potential solutions for the concerns are summarized below. The Westinghouse heliostat is not included because a prototype was not built and tested.

SECOND GENERATION HELIOSTAT EVALUATION SUMMARY

Heliostat	Strengths	Concerns	Potential Solutions
ARCO	• Low Risk Drive • Good Mirror Module Concept • Easy Maintenance • Simple Field Assembly	• Controls require development	• Update design based on test experiences; design and test (in progress
		• Stepper motor speed/torque characteristics are inadequate	• Change to induction or DC motor (in progress)
		• Rust and deterioration of controls due to water condensation inside of pedestal	• Provide ventilation (controls now outside pedestal)
		• Mirror module life difficult to demonstrate	• Field test at multiple sites for 3-5 years • Demonstrate accelerated life tests
		• Adhesives and sealants in mirror module require good quality control and acceptance tests are difficult to perform	• Adopt laminated glass for near-term applications • Develop & demonstrate cost-effective test and quality control methods
Boeing	• Low-risk azimuth drive • Simple, light-weight elevation drive	• Controls require development	• Update design based on test experience; design and test
		• Mirror module life is unacceptable	• Adopt alternate design (in progress) • Use laminated glass for near term applications

SECOND GENERATION HELIOSTAT EVALUATION SUMMARY (Cont'd)

<table>
<tr><th>Heliostat</th><th>Strengths</th><th>Concerns</th><th>Potential Solutions</th></tr>
<tr><td rowspan="2">Martin Marietta</td><td rowspan="2">• Simple field assembly
• Simple mirror canting adjustment
• Easy maintenance
• Fiber-optics immunity to electrical noise and lightning
• Operational flexibility of inverted stow</td><td>• Stow lock requires development</td><td>• Redesign to minimize sensitivity to dimensional tolerances
• Provide fail-safe locking method</td></tr>
<tr><td>• Mirror module life is unacceptable</td><td>• Adopt alternate design (in progress)
• Adopt laminated glass for near-term applications</td></tr>
<tr><td rowspan="3">McDonnell Douglas</td><td rowspan="3">• Low-risk laminated mirror module
• Low-risk drive
• Minimal field assembly
• Easy maintenance
• Fiber-optics immunity to electrical noise and lightning</td><td>• Cannot readily detect azimuth drive oil leaks</td><td>• Add deflector so oil exits pedestal</td></tr>
<tr><td>• Life of adhesive between glass and steel unknown</td><td>• Field test at multiple sites for 3-5 years
• Demonstrate accelerated life tests
• Develop attachment method with silicone adhesive or no adhesive</td></tr>
<tr><td>• Rust due to water condensation on inside of pedestal</td><td>• Improve ventilation</td></tr>
</table>

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