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10 MW_e Solar Thermal Central Receiver Pilot Plant Mirror Module Corrosion Torque Tube Damage and Vent Tube Assessment Survey July 1985 and July 1986

M. A. Danzo, R. L. Velazques, and C. L. Mavis

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10 MW_e SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MIRROR MODULE CORROSION TORQUE TUBE DAMAGE AND VENT TUBE ASSESSMENT SURVEY JULY 1985 AND JULY 1986

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ABSTRACT

This report documents the results of the July 1985 and July 1986 surveys of mirror module corrosion and torque tube damage at the 10 MW_e Solar Thermal Central Receiver Pilot Plant. It also assesses the effect of vent tubes on the corrosion growth rate. Results show that 0.052% and 0.061% of the total reflective area of the heliostat field was corroded in 1985 and 1986, respectively. However, the corrosion growth rate is much less than in previous years, primarily because of the effect of mirror module vent tubes.

In the July 1984 survey, 35 torque tubes were damaged due to impact with the gear box. The 1985 survey showed that 14 of those same torque tubes were re-damaged. In addition, 9 newly dented ones were found. In the July 1986 survey, 39 torque tubes were dented, of which 4 were redented from 1985. The denting is caused when the gear-drive travels past the limit switch due to a shorted diode in parallel with the limit switch.

SOLAR THERMAL TECHNOLOGY
FOREWORD

The research described in this report was conducted within the U.S. Department of Energy's Solar Thermal Technology Program. This program directs efforts to incorporate technically proven and economically competitive solar thermal options into our nation's energy supply. These efforts are carried out through a network of national laboratories that work with industry.

In a solar thermal system, mirrors or lenses focus sunlight onto a receiver where a working fluid absorbs the solar energy as heat. The system then converts the energy into electricity or uses it as process heat. There are two kinds of solar thermal systems: central receiver systems and distributed receiver systems. A central receiver system uses a field of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a receiver mounted on a tower. A distributed receiver system uses three types of optical arrangements--parabolic troughs, parabolic dishes, and hemispherical bowls--to focus sunlight onto either a line or point receiver. Distributed receivers may either stand alone or be grouped.

This evaluation report is one of a series of reports designed to cover topics of interest on the 10 MW_e Solar Thermal Central Receiver Pilot Plant, at Barstow, California. These reports provide information obtained or developed during the two-year Test and Evaluation period or during the three year Power Production period when the plant was undergoing various engineering tests or demonstrating power production; During both periods, evaluation efforts were under the direction of Sandia National Laboratories. For a list of reports, contact the Solar Energy Department, 6220, Sandia National Laboratories, Albuquerque, New Mexico 87185.

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1985 Summary

1. The total corrosion area of the entire heliostat field increased from 32,208 square inches in July 1984 to 57,279 square inches in July 1985 while the corrosion growth rate decreased from 92% per year to 78% per year in the same time period. 0.052% of the total reflective surface of the collector field is corroded. This is equivalent to the surface area of approximately one heliostat.

2. Forty-eight percent of all modules have some amount of corrosion, but 262 heliostats are corrosion-free.

3. Fifty-eight percent of all corrosion occurs in the northeast quadrant of the field. The mirrors in this quadrant have the majority of the corrosion because they were produced before improved manufacturing techniques were incorporated to improve the water tightness of the mirror module edge seals.

4. There was a 167% increase in the corrosion growth rate in right side mirror modules, but only a 32% rate increase in left side modules in the last year. Right side modules experienced a pronounced growth rate change due to the lack of vent tubes on these modules. Although these rates are markedly different, right side and left side corrosion are approximately equal.

5. Of 1984's 35 damaged torque tubes, 14 were re-dented and an additional 9 newly dented torque tubes were found in 1985.

6. Ninety-eight randomly selected heliostats were surveyed before the performance of the full field evaluation. The values obtained in this sample survey were nearly the same as those obtained from the full field survey. This suggests that it is not necessary to survey the entire field to determine the trend in heliostat corrosion.

7. Mirror modules with vent tubes installed experienced a 53% increase in corrosion, while those modules without vent tubes showed a 188% increase. Thus, vent tubes appear to have mitigated the corrosion growth rate.

8. Although venting appears to inhibit corrosion, the decision to vent more modules must be based on the predicted length of future plant operation.

1986 SUMMARY

1. The 98 randomly selected heliostats and not the entire field was surveyed this year as recommended from 1985 because of the similarity of these two fields. Therefore, the 98 heliostat field survey results were extrapolated into terms of the entire field results and compared to the previous year's results.

2. The total corrosion area of the entire heliostat field has increased from 57,279 square inches in July 1985 to an extrapolated 71,026 square inches in July 1986, while the corrosion growth rate decreased from 78% per year to 24% per year in the same time period. Of the total reflective surface of the collector field, 0/061% is corroded. This is equivalent to the surface area of approximately 1-1/8 heliostat.

3. Fifty-seven percent of all modules have some amount of corrosion, while 130 heliostats are corrosion-free.

4. Sixty-two percent of all corrosion occurs in the northeast quadrant of the field. The mirrors in this quadrant have the majority of the corrosion because they were produced before improved manufacturing techniques were incorporated to improve the water tightness of the mirror module edge seals.

5. There was a 48% increase in the corrosion growth rate in right side mirror modules, but only a 1% rate increase in left side modules in the last year. Right side modules experienced a pronounced growth rate increase due to the lack of vent tubes on these modules.

6. Mirror modules with vent tubes show a 14% increase in corrosion, those without vent tubes (below the serial number 17,000) show a 64% increase. Thus, vent tubes appear to have mitigated the corrosion growth rate.

7. By the year 2011, it is predicted that the total corrosion will amount to 8 heliostats; this is a very small percentage of the entire field and would not lower the plant's efficiency. Although venting appears to inhibit corrosion, the decision to vent more modules should be based on a drastic increase in the corrosion growth rate from the current .015% per year.

10 MW_e SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT MIRROR MODULE CORROSION, TORQUE TUBE DAMAGE, AND VENT TUBE ASSESSMENT SURVEY, JULY 1985 AND JULY 1986

Introduction

Silver corrosion on mirror modules at the Solar Thermal Central Receiver Pilot Plant was first discovered in February, 1982, several measures have been employed to halt its rapid spread over the reflective surface. These include a change from a horizontal to a vertical stow position for all heliostats and the installation of vent tubes in badly corroded mirror modules. The mirror modules of the entire field were spot checked in 1982 and surveyed completely in July 1983, July 1984, and July 1985. In July 1986, a randomly selected group of 98 heliostats was surveyed to represent the entire field.

Torque tube damage was first noticed in December, 1983 when a heliostat drive gear box failed due to torque tube impact with the gear box. Subsequent surveys in January and July of 1984, July of 1985, and in July 1986, found more torque tubes to have sustained damage.

This report describes the current level of corrosion, assesses the methods used to combat corrosion and predicts future corrosion levels. Results of the torque tube damage survey are also addressed.

Background

Mirror Module Corrosion

Figure 1 shows a pilot plant heliostat with two corroded mirror modules. Each heliostat has twelve mirror modules consisting of a metal pan which forms five of the module's six surfaces. The sixth surface is the glass mirror which is supported by the aluminum honeycomb structure contained within the pan. Because expansion of air contained within the pan would place a high load on the adhesive that holds the mirror assembly together, the pan was originally equipped with a small vent. However, shortly after initial plant operation, the glass mirror silver surface was found to be corroding. It was then determined that the originally installed vents did not have sufficient capacity. The test found that when the mirror module was suddenly cooled by a simulated rain, a differential pressure between the atmosphere and the pan's interior existed for a sustained period. As a consequence, any moisture accumulation along the edge seal leaked into the module through edge seal imperfections.

Corrosion appeared to be more prevalent on those heliostats having mirror modules that had been produced before July 1, 1981, when production changes had been made to improve the edge seals. This improved module design exists in module serial numbers above 17,000. For additional background, see References 1 and 2.

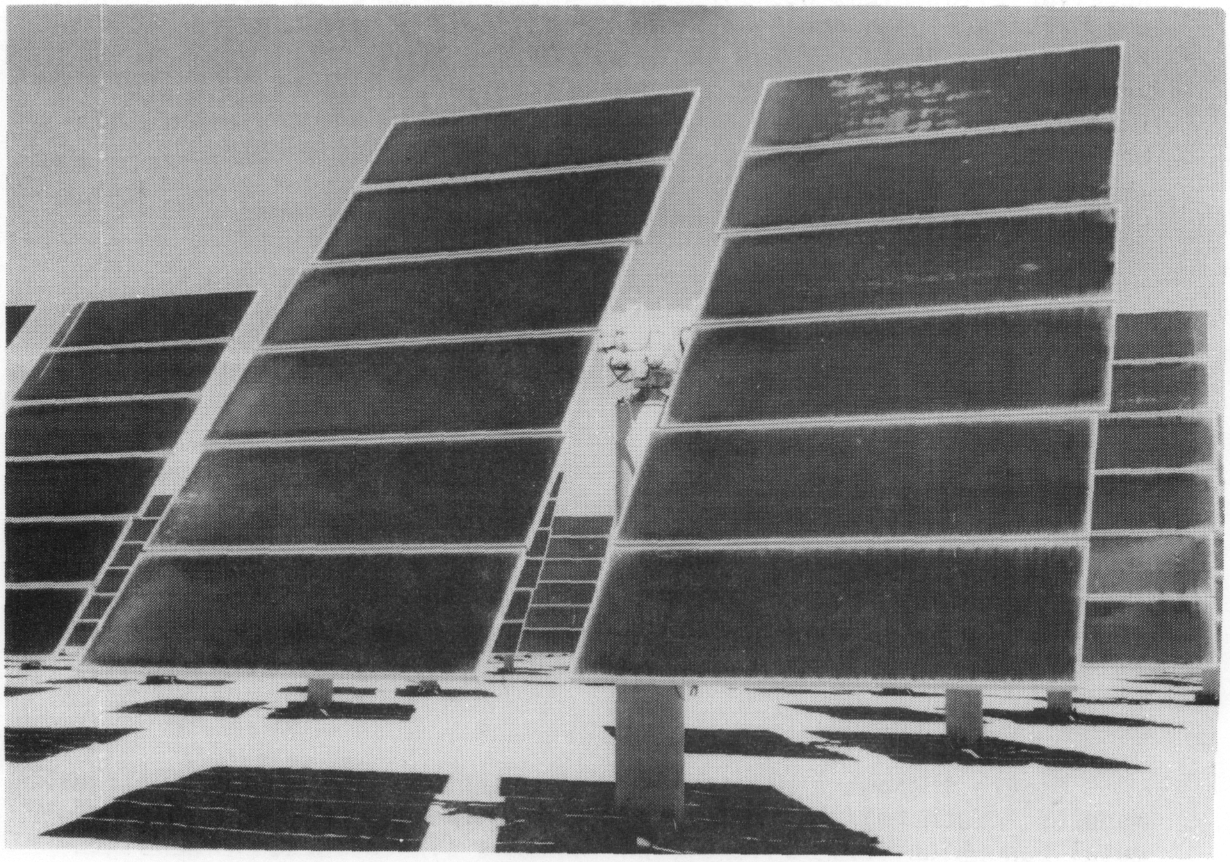


Figure 1. Pilot Plant Heliostats

1984 Major Conclusions

1. The total reflective surface of the heliostat field showed corrosion of 0.029% - an increase from 0.015% in 1983.

2. Some amount of corrosion was evident on 27% of all modules.

3. The northeast quadrant of the field contained 64% of all the corrosion.

4. Sixty-seven percent of all the corrosion is located on the left side (odd numbered) modules.

5. Thirty-five heliostats have some amount of damage to their torque tubes because the drive assemblies went beyond their limit switches.

6. During the fabrication of the heliostats, the reflective area was reduced 2.1% less than design because of the installation of mirror edge seals.

The July 1984 complete collector field survey results indicated that the collector field was 0.029% corroded instead of the predicted value (July 1983 survey) of 0.15% (References 1 and 2). The decrease in the rate of corrosion was attributed, in part, to the change in heliostat stow position. The stow position was changed in January 1983 from the horizontal face down position to a vertical stow position, thus minimizing water contact with the reflective silver surface. In addition, 10,036 mirror modules were fitted with four 0.5" diameter vent tubes to help dry out mirror modules and thus retard the corrosion rate. Installation of the vents was completed in May 1984. It was then concluded that complete collector field corrosion surveys should be conducted in July 1985 and July 1986 to determine the effects of the revised stow procedure and the installation of vent tubes on corrosion.

Vent Tube Installation

In February 1983, Sandia National Laboratories, Livermore, CA., began conducting tests on several vent designs suitable for retrofitting the mirror modules to minimize the spread of corrosion. Vents serve to "open up" the air space inside the mirror modules to the surrounding air to initially facilitate drying and thereafter minimize moisture accumulations. They also help to reduce the intake of water through the edge seals by eliminating the vacuum formed inside the mirror modules as a result of thermal and barometric effects (Reference 1).

Based on test results that showed reduced water in vented modules and no vacuum upon cooling, Sandia designed a vent assembly suitable for retrofitting the mirror modules. It is a silicone rubber stopper (#4 size) containing a 1/2" bent aluminum tube. A bent tube was used so that water from rain and washing could not enter the module.

Vent installation began in March and ended in May 1984. Four vents were "corked" into each mirror module through holes drilled at the sides; two vents were placed on the inboard side, while the other two were placed on the outboard side. To date, 10,036 mirror modules have been vented. The locations of the vented modules are:

NE Quadrant: All mirror modules in rows 8 - 29, except Row 17

SE Quadrant: All left side mirror modules

NW Quadrant: All left side mirror modules in Rows 24 - 29

SW Quadrant: All left side mirror modules in Rows 2 - 16

These particular modules were chosen since the better clamping procedure was not used when they were manufactured. As a result, they were more corroded than the remaining mirror modules. To determine the effect of vent tubes on the corrosion growth rate, the corrosion on vented and unvented modules was compared during the 1985 and 1986 summer corrosion surveys.

Torque Tube Damage

Heliostat drive gear box No.1851 failed in December 1983 during operation of the collector field. The gear box inspection found the main ring and pinion gears to have stripped teeth. The detailed inspection of heliostat control components, including the elevation limit switch, failed to show the cause for the heliostat's overtravel which resulted in the impact of the mirror assembly torque tube with the gear box. The impact led to the overstress and failure of the gear box gears. At this time, it was tentatively concluded, that the elevation limit switch, whose connector is exposed to wind born dust and rain water, became temporarily shorted, allowing the gear box to overtravel. Subsequent to the gear box failure, station operators, based on ground level observation in 1984, estimated the presence of twenty-one dented torque tubes and ten torque tubes which had minor scratches. The effort to identify a specific control component responsible for the failure of gear box 1851 was unsuccessful. It was determined appropriate to resurvey the collector field for torque tube damage during the planned July 1984 collector field corrosion survey. It was felt that the results of a second torque tube damage survey would help determine if the damage was, in fact, related to the original heliostat installation and start-up in 1982, or due to a continuing control system problem.

Findings from the July 1984 survey showed the majority of the damage to come from the torque tube impacting with the gear box, on the side opposite from the motors, which could have occurred when the "up" limit switches failed to open. Most of the heliostats damaged in this way had only 1/2" to 1" diameter dents in their torque tubes. It was suggested that the failure of the limit switches may have been due to a short circuit caused by water in the limit switch connector. However, when three of the damaged heliostats were run to their full limits to test this hypothesis, all heliostats were successfully halted by their limit switches. From this result, and by noting that all the dents were accompanied by heavy rust, it seemed possible that the damage was caused when the heliostats were first installed and were operated with a manual controller.

Red paint was sprayed onto the torque tube dents at the end of July 1984 to determine if the limit switches were failing regularly. If the torque tube impacts with the gear box, the red paint will be chipped, suggesting that a repeating control system problem exists. In July 1985 a torque tube damage survey was conducted to determine whether damage was done early in the start-up of the collector field or is, in fact, a continuing control system problem.

Results

1985 Corrosion Survey

The July 1985 corrosion survey was accomplished in the same manner as the previous surveys. Identical corrosion survey data sheets, developed by Sandia, were used for all surveys. The pattern of corrosion was drawn onto the data sheet, and the number of square inches of corrosion on each mirror module was estimated. Some error was introduced by visually estimating the area of corrosion. This error was assumed to be 5% during previous surveys. However, the mean error during calibration studies conducted before the survey began, was calculated and found to be 15%. After further practice in estimating corrosion area, error was again calculated at only 6%. This year's larger error in corrosion estimation may be a direct result of having a different person performing the survey. Also, the 1983 and 1984 surveys only assumed an error value, while the 1985 survey actually calculated it.

The total amount of corrosion in square inches is presented in Table I for the July 1983, July 1984, and July 1985 surveys. The percent increases in corrosion from July 1984 to July 1985 are also noted.

TABLE I-- Heliostat Corrosion Update, July 1985

	JULY 1983	JULY 1984	JULY 1985	% INCREASE
TOTAL CORROSION	16,807	32,208	57,279	78
LEFT-SIDE	14,280	21,427	28,456	32
RIGHT-SIDE	2,527	10,781	28,822	167
***************BY QUADRANTS***************				
NORTHEAST				
TOTAL CORROSION	10,905	20,629	33,236	61
LEFT-SIDE	9,428	13,334	16,500	24
RIGHT-SIDE	1,477	7,295	16,735	129
NORTHWEST				
TOTAL CORROSION	2,291	3,880	11,399	194
LEFT-SIDE	1,735	2,287	5,453	138
RIGHT-SIDE	556	1,593	5,946	273
SOUTHEAST				
TOTAL CORROSION	2,007	4,471	6,711	50
LEFT-SIDE	1,711	3,142	2,690	- 14
RIGHT-SIDE	296	1,329	4,021	203
SOUTHWEST				
TOTAL CORROSION	1,604	3,228	5,933	84
LEFT-SIDE	1,406	2,664	3,813	43
RIGHT-SIDE	198	564	2,119	276

Note: All numbers are square inches of corrosion.

The data is tabulated into left-side and right-side mirror modules and by collector field quadrants. The percent increases for left-side and right-side modules are markedly different. Left-side module corrosion has only increased 32%, while right-side module corrosion has increased 167%. Although the percent increases are different, the total areas of corrosion in square inches are extremely similar; right-side corrosion accounts for 28,822 square inches, while the left-side accounts for 28,456 square inches of corrosion. The July 1984 survey showed a sharp increase in right-side mirror corrosion, but failed to explain it. This report suggests that the pronounced increase was a result of insufficient venting, as vent tubes were mainly installed in left-side modules. Since they are still lacking vent tubes, it appears that right-side mirror module corrosion will keep increasing at a pronounced rate. This rate should be employed when predicting future corrosion growth rates. Table I also shows that the northwest quadrant experienced the greatest increase in corrosion. The July 1984 survey showed only 12% of the total corrosion in the northwest quadrant. However, the present survey found the same quadrant to now account for 20% of the total corrosion. A decrease in corrosion occurred in the southeast quadrant in the left-side modules. This is only due to estimation error, as silver corrosion does not decrease. This point is further discussed later in a separate section in this report.

Figure 2 illustrates the actual and predicted logarithmic growth from the 1985 and previous surveys. Lines representing left-side, right-side, and total corrosion growth rates intersect at the value 0.052% of reflective area corroded. This shows again, that the right-side corrosion is now approximately the same as left-side corrosion. Left-side corrosion accounts for 49.6% of total corrosion whereas, right-side corrosion accounts for 50.4% of the total corrosion. Thus, 0.052% of both left-side and right-sides reflective areas are corroded. This serves to explain the intersection of left-side, right-side, and total corrosion growth rates. Ultimately, the collector field experienced a 78% increase in corrosion from July 1984 to July 1985.

The incidence of corrosion on individual mirror modules is presented in Table II. In July 1984, 27% of the mirror modules had some amount of corrosion on them; this increased to 48% for July 1985. The data also shows that corrosion incidence is greater on right side and lower mirror modules. The percent increase in incidence of corrosion decreases from top to bottom modules in both left and right sides. Also, right-side modules experienced much greater percent increases than left-side ones.

The July 1984 data showed that corrosion was becoming less localized away from the mirror edges and spreading over the entire face of the mirror module, especially right-side ones.

Although corrosion is becoming more evenly distributed over the modules, July 1985 data suggests the corrosion remains concentrated along the mirror edges. Corrosion is heaviest along edges located furthest away from the original vents.

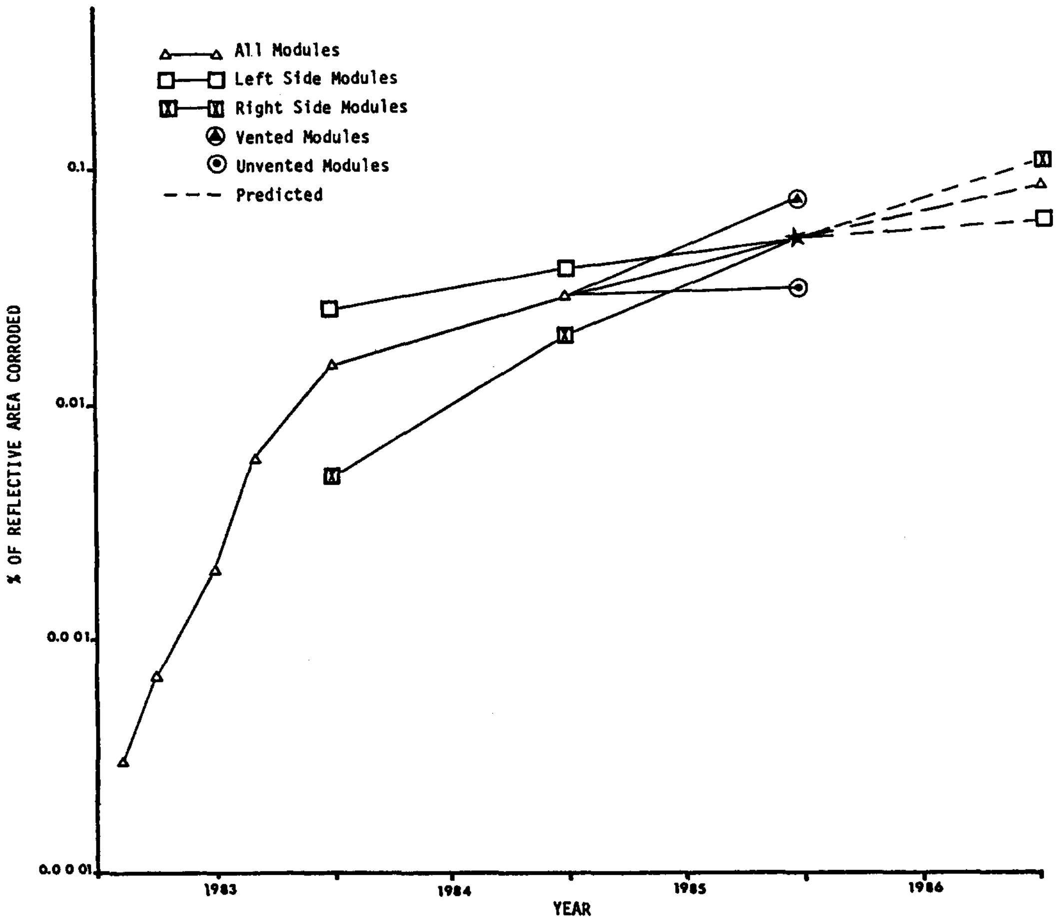


Figure 2. Actual and Predicted Mirror Module Corrosion

TABLE II - Incidence of Corrosion on Modules

- THESE NUMBERS REPRESENT THE NUMBER OF TIMES CORROSION WAS FOUND ON THAT PARTICULAR MODULE

MODULE	JULY 1984	JULY 1985	% INCREASE
LEFT-SIDE			
1	406	830	104
3	450	691	54
5	514	686	33
7	602	787	31
9	688	793	15
11	736	847	15
RIGHT-SIDE			
2	369	916	148
4	381	942	147
6	391	902	131
8	437	1,004	130
10	504	1,026	104
12	509	1,018	100
TOTALS	5,987	10,442	74

- 48 PERCENT OF ALL MODULES HAVE SOME TYPE OF CORROSION

Comparison Between Sample Survey of 98 Heliostats and Full Field Survey

This section compares results of the 1985 complete collector field survey and the subset (sample) survey consisting of 98 randomly chosen heliostats. The goal of this comparison is to show that only a sample of the collector field needs to be surveyed to obtain a statistically significant account of the corrosion in the collector field. This can eliminate the time and expense of surveying the entire field in subsequent years. Table III lists a summary of the comparisons between the entire field and sample surveys while Table IV compares the results.

Entire field results showed a 78% increase in the total square inches of corrosion while sample survey results yielded a similar value of 74%. The entire field survey yielded a 32% increase for left-hand side modules while the sample survey showed a 28% increase. However, rate increase values for right-hand side modules were not as similar; the entire field value was 167% while the sample value was 182%. Although right-hand side rate increases are different, they still both suggest that right-hand side modules corroded at a much greater rate than left-hand side modules.

Further similarity in survey values exists between the percentages of the total reflective area of the collector field that is corroded. The field value was calculated to be 0.052% in contrast to the sample value of 0.050%. In addition, the entire field survey showed that 58% of all the corrosion occurs in the northeast quadrant. However, the sample survey value was found to be 66%. Although these values are somewhat different, they still suggest that the northeast quadrant contains most of the corrosion.

According to the field survey, the amount of corrosion (in square inches) of left side and right side modules has approached each other (28,456 and 28,822, respectively). Sample data shows the same trend; left-hand modules contained 1,512 square inches of corrosion, while right-hand side modules contained 1,434 square inches.

The left-hand side modules of the southeast quadrant in the field survey showed a decrease in corrosion (-14.38%). This was probably due to errors in estimating corrosion area between the two different surveyors. This is supported by the negative value (-9.6%) also reported by the sample survey. The correlation between this finding suggests the following:

1. The 1985 estimation of corrosion was consistent throughout the survey (or at least in the southwest quadrant) and

2. The 1984 survey over-estimated, or the 1985 survey under-estimated corrosion in that quadrant.

Table V shows the comparison of incidence of corrosion between the sample and field surveys. Results show that left-hand side modules have a greater percent increase in incidence of corrosion on modules located at the top of the heliostat. However, modules located at the bottom of the heliostat contain the highest incidence of corrosion. In contrast, incidence of corrosion on right-hand side modules fails to correlate between the two surveys. Field survey data shows that the largest percent increase in incidence of corrosion occurs in the modules located at the top of the heliostat and decreases toward the bottom. Sample survey data suggests a more even distribution of incidents among modules. No decreasing trend in incidence from top to bottom of the heliostat is present.

Ultimately, this comparison between surveys illustrates, through similarities between % increases in corrosion, similar negative value, and mirror module incidence that it is not necessary to survey the entire collector field annually. Instead, a full field survey should be completed every two years for the next six years and then every three years afterwards. Meanwhile, the sample survey of 98 heliostats should be performed annually. However, the results of such a survey should not be interpreted as decisive, but the trends in corrosion it uncovers should be noted for comparison to subsequent surveys.

Table III-- Summary of the Comparisons Between the Complete Field and Sample Field Surveys

	Statistic	Complete Field	Sample Field
1.	% increase in total corrosion	78	74
2.	% increase in left-side modules	35	28
3.	% increase in right-side modules	164	182
4.	% of total reflective area corroded	0.052	0.050
5.	% of total corrosion that northeast accounts for	58	66
6.	% decrease in corrosion of southeast left-side modules	-14	-10
7.	% of all modules that have same type of corrosion.	48	53
8.	Is a decrease evident in the incidence of corrosion on modules from top to bottom?	yes	yes

Table IV-- Corrosion Update of Sample Survey, 1985

	July 1984	July 1985	% of Increase	Actual % Increase From Full Field
Survey				
Total Comparison	1,691	2,974	74	78
Left Side	1,182	1,513	28	32
Right Side	509	1,434	182	167
		By Quadrant		
Northeast				
Total Comparison	1,112	1,948	75	61
Left Side	741	965	30	24
Right Side	371	983	165	129
Northwest				
Total Comparison	100	252	152	194
Left Side	76	117	55	138
Right Side	24	134	488	273
Southeast				
Total Comparison	278	379	36	50
Left Side	190	172	-10	-14
Right Side	88	207	136	203
Southwest				
Total Comparison	201	369	83	84
Left Side	175	259	48	43
Right Side	26	110	322	271

Table V-- Incidence of Corrosion on Modules
Complete Field vs Sample Field Surveys

Module	July 1984	July 1985	Sample Survey % Increase	* Complete Survey % Increase
Left Side				
1	19	40	110.52	104.43
3	25	39	56.00	53.56
5	26	37	42.31	33.46
7	37	48	29.72	30.73
9	37	48	29.72	15.26
11	43	52	20.93	15.01
Right Side				
2	20	58	190.00	148.23
4	21	64	204.76	147.24
6	18	56	211.11	130.69
8	21	62	195.24	129.74
10	29	59	103.44	103.57
12	21	63	200.00	100.00
TOTALS	317	626	97.48	74.41

Introduction To The 98 Heliostat Sample Survey Field

In the summer of 1985 the comparison between values obtained in the complete field survey and values of the 98 heliostat field survey showed very similar results. Therefore, in 1986 the same 98 heliostats will provide a good indication of the degree and trend of corrosion of the entire collector field.

The advantages of surveying these 98 heliostats are the reduced time, relative accuracy, and reduced cost involved. It is considerably less time consuming to survey the 98 heliostats rather than the entire field of 1818 heliostats. The entire field survey can greatly increase the accuracy of estimation because all heliostats are surveyed. However, an accurate survey of the 98 heliostats can accomplish a quality survey in less time.

Figure 3 shows the distribution of the 98 randomly preselected heliostats. Table VI lists the 98 heliostats by quadrant. The northeast quadrant contains one-third of the total heliostats (33) and also two-thirds the total corrosion of the field. Therefore, the northeast quadrant is an important segment for this survey.

1986 Data Collection Procedure

In 1986 the corrosion survey of ninety-eight heliostats was performed in a different manner than in previous years. Each module was visually divided into eighteen sections (Figure 4) and each section was estimated separately. This estimation method proved to be more accurate.

Estimation Method:

1. Place heliostats in the vertical stow position, making estimation of all modules easier.

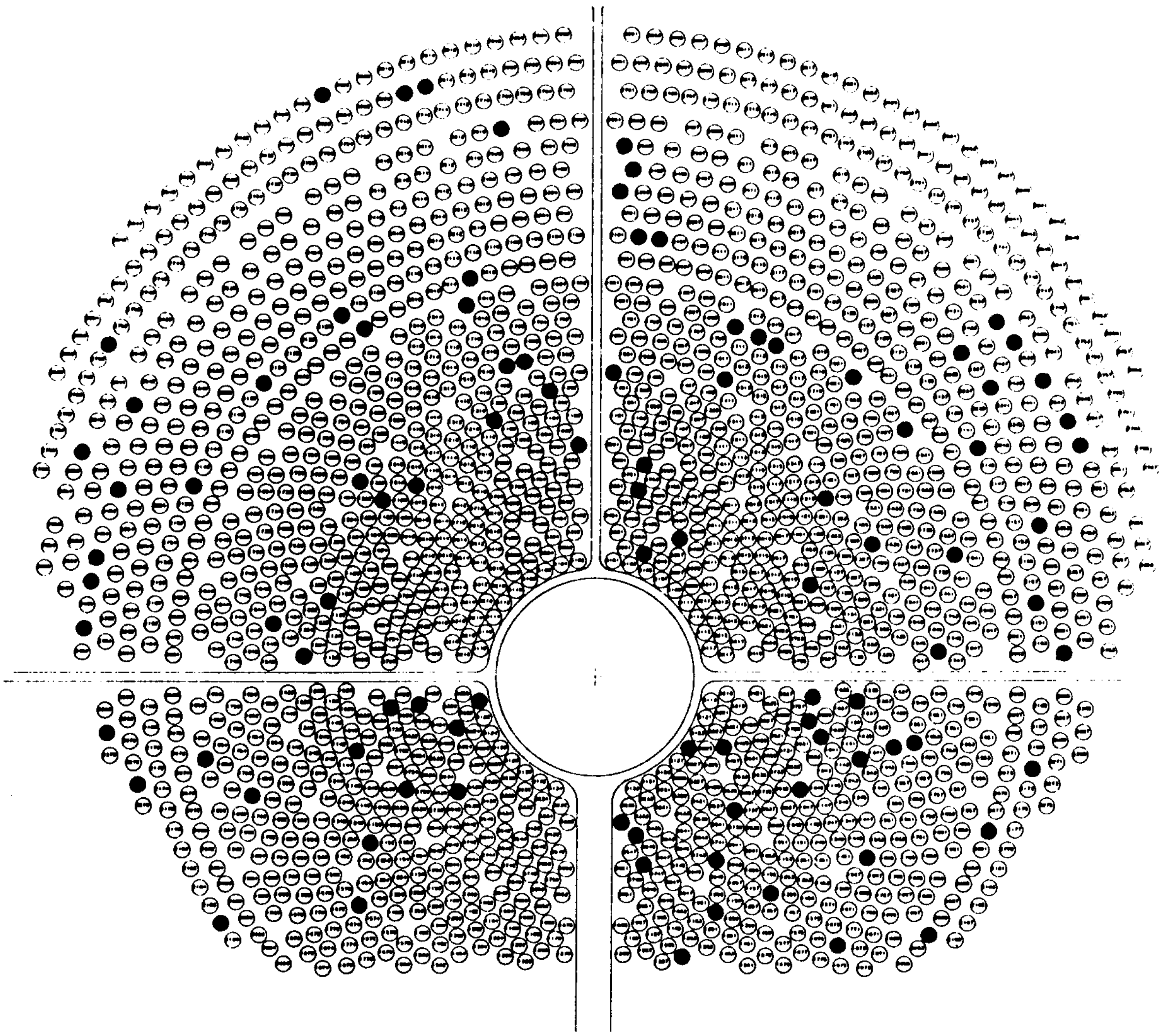
2. Map corrosion (as in previous years) onto a mirror corrosion survey sheet as shown in Figure 4.

3. Visually divide each module into eighteen equal sections as shown on the survey sheet in Figure 4.

4. Next, estimate the corrosion within each section and write this figure into the box of the survey sheet that corresponds to that corrosion location as shown in Figure 5.

5. Sum up the figures in each of the eighteen sections to attain a corrosion value for each module.

6. Finally, add up the corrosion of all 12 modules to get corrosion total for entire heliostat.



SOLAR ONE

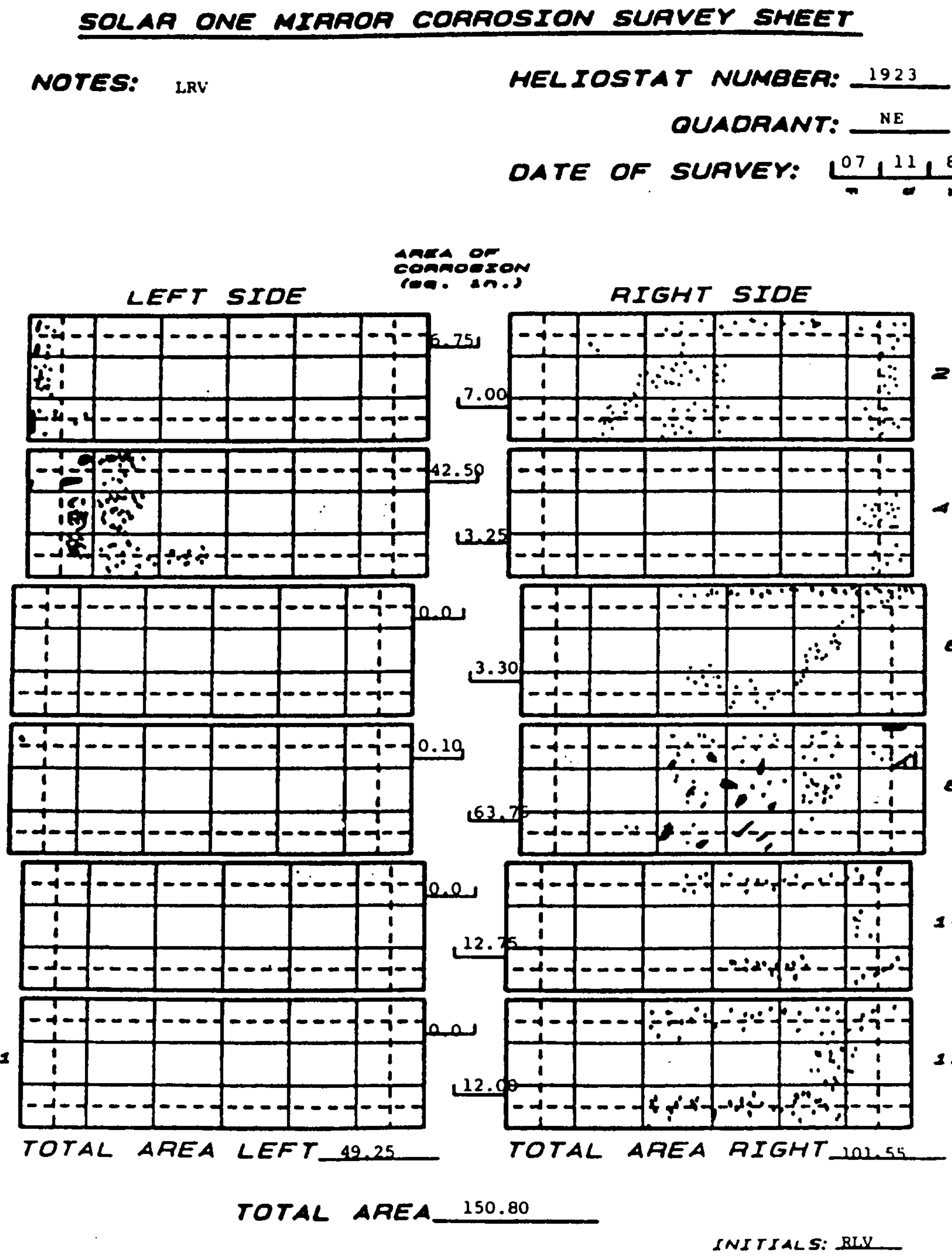
● = PRESELECTED HELIOSTAT USED IN THE CORROSION SURVEY

NUMBER OF HELIOSTATS IN EACH QUADRANT
NORTHEAST=33
NORTHWEST=28
SOUTHEAST=23
SOUTHWEST=14

Figure 3. Field Distribution of 98 Survey Heliostats

Table VI-- List of The 98 Survey Heliostats by Quadrant

NE	NW	SE	SW
203	902	125	120
407	1118	323	322
603	1208	335	526
803	1220	437	636
921	1230	639	728
1321	1304	827	936
1401	1336	829	1042
1427	1422	843	1250
1511	1506	849	1572
1647	1508	931	1758
1811	1544	935	1954
1813	1912	1137	2188
1815	2012	1161	2274
1839	2024	1241	2368
1923	2126	1255	
1929	2138	1365	n=14
2103	2148	1441	
2105	2450	1553	
2125	2456	1565	
2143	2458	1773	
2159	2462	2071	
2203	2544	2079	
2251	2608	2091	
2263	2650		
2333	2734	n=23	
2339	2816		
2401	2818		
2501	2924		
2535			
2537	n=28		
2541			
2545			
2547			
n=33			


SOLAR ONE MIRROR CORROSION SURVEY SHEET

NOTES: LRV

HELIOSTAT NUMBER: 1923

QUADRANT: NE

DATE OF SURVEY: 07 11 86

TOTAL AREA LEFT 49.25 TOTAL AREA RIGHT 101.55

TOTAL AREA 150.80

INITIALS: RLV

Figure 4. Sample Mirror Corrosion Map Sheet

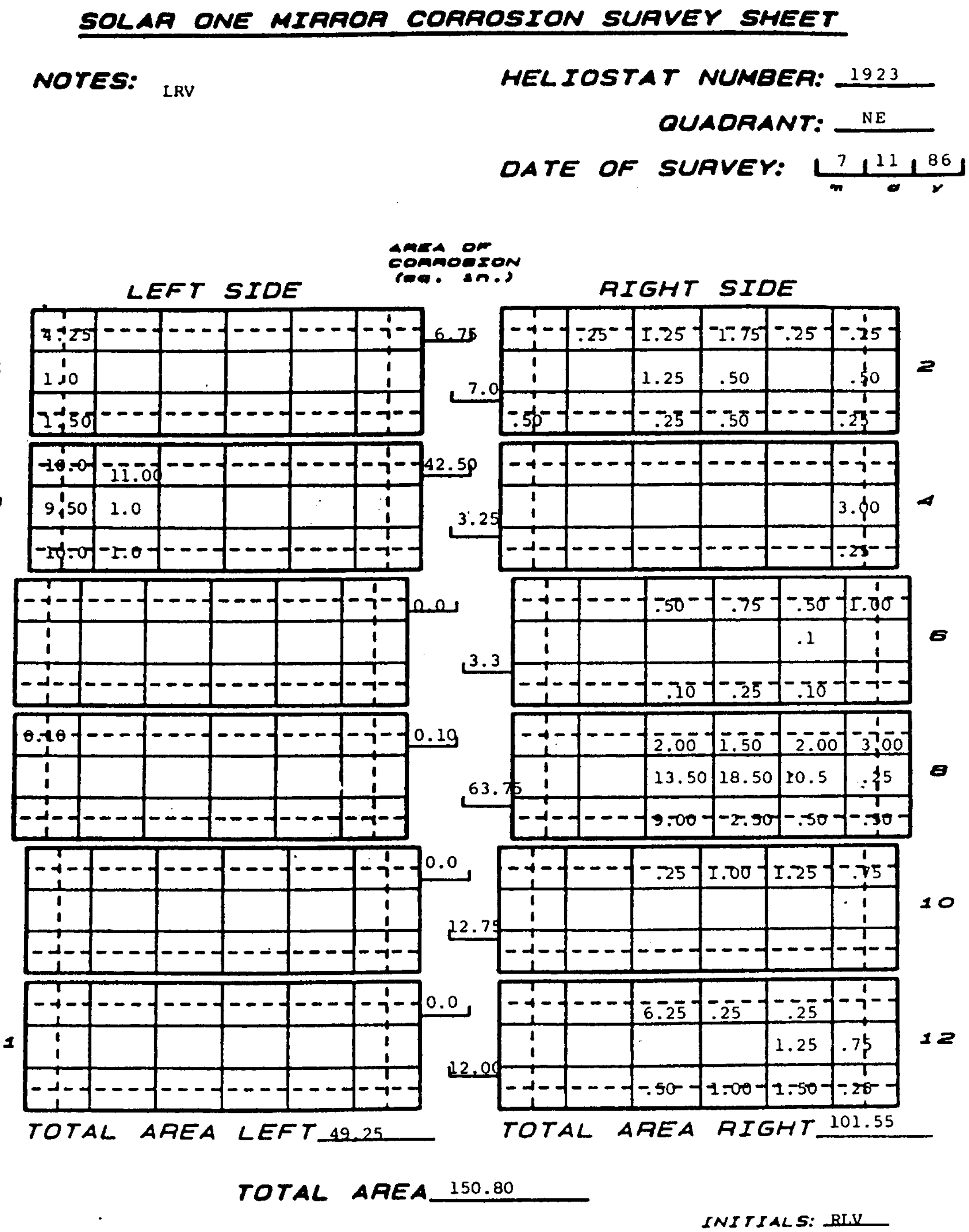


Figure 5. Sample Mirror Corrosion Estimation Sheet

This concept is well-grounded because of its higher probability of accuracy. Eighteen small estimates for each module contain eighteen small percentage errors compared to the previous method which consists of one to four large estimates for each module, causing the margin of error to be quite large. When a greater number of estimates are involved, some errors are negative and others are positive, therefore, greatly reducing the total error for each module. The same concept applies to each heliostat because it has twelve modules. On July 10, 1986, a comparison of 1985 and 1986 estimation methods was performed and recorded, as shown in Table VII. The 1985 and 1986 visually "estimated" values are of different methodology, but the "measured" values for both years are identical and were obtained by tracing the corrosion onto transparent grid paper and then calculating the actual corrosion. Additional samples are listed for future comparisons.

Table VII-- Estimation Method Comparison for 1985 and 1986

Heliostat Number	Module Number	1985 Estimate sq. in.	1985 Measd. sq. in.	1985 Error %	1986 Estimate sq. in.	1986 Measd. sq. in.	1986 Error %
2411	11	5.00	6.00	-16.7	8.00	5.94	+34.7
1144	09	1.50	2.50	-40.0	8.00	7.69	+ 4.0
2505	12	1.50	3.10	-66.7	7.00	6.88	+ 1.7
2203	11	3.75	2.04	+83.8	5.60	3.75	+49.0
1669	11	3.00	6.58	-54.4	7.60	8.00	- 5.0
2604	12	0.75	0.44	+70.4	4.25	5.38	-21.0
1361	11	2.00	2.88	-30.6	2.50	2.31	+ 8.0
1773	11	2.00	2.80	-28.6	2.75	3.13	-12.1
1459	09	3.00	5.00	-40.0	7.00	5.37	+24.3
	TOTALS:	22.50	31.34	-28.2	52.70	48.45	+8.8
Additional Samples:							
2042	12				.1	.125	-20.0
2172	12				.1	.063	+59.0
2168	12				.5	.40	+25.0
	GRAND TOTALS:				53.4	49.0	+8.9

Only nine modules are compared because 2 heliostats were replaced with the improved glass on glass type mirror modules. This may have influenced the large error of -28% reported for 1985, but the error would still have been above 20%. The 1986 error was +9%. In an actual field survey of heliostats the error may vary from -9% to a +9% for each heliostat and of the entire field.

The smallest estimation figure used on a module in 1986 was ".1"; (.31 X .31) square inches. Many times that was all the corrosion that was on a module: a very small spot. This ".1" was used in order to demonstrate that corrosion has begun in that module this year, and it should be monitored for its corrosion growth in the future.

The one disadvantage to this method is the time involved to estimate the corrosion on a heliostat. It is much more time consuming than the previous methods, as it will take five-days to survey the entire 98 heliostat field correctly. Approximately five to twenty minutes is spent on each heliostat depending upon the degree of corrosion. As the survey continued, the surveyor obtained a confident calibration of corrosion, enabling the estimation process to accelerate.

This method of estimating eighteen sections of each module is a quality survey due to the accuracy involved. The methodology is recommended for future surveys of the 98 heliostats.

1986 Corrosion Survey

In past surveys the logarithmic vertical scale was used for graphing of percent reflective area corroded versus the year as shown in Figure 2. Figure 6 is a graph of percent reflective area corroded in the ordinate versus the year in the abscissa, with both scales uniformly distributed. This uniformity of scales is not as deceiving as the logarithmic scale may be if it is not understood.

In the total corrosion trend graph of Figure 6, line C-UF is the Unvented Field theorem-Line; it predicts the path of corrosion as if vents were never installed. This line is constructed using points B through E because they were not affected by ventilation. Based upon the Unvented Field Theorem-Line, the % reflective area corroded in 1986 would have been approximately .081 (point UF) rather than the actual .061 (point GG) estimated from the 98 heliostat field survey. The prediction for 1986 shown in Figure 2 is .090 rather than .081 which indicates that mirror venting was more effective than predicted.

In the same Figure 6, the Average Corrosion Reference Line was constructed from all the data points plotted. This average line shows that the corrosion growth is constant from summer 1982 to summer 1986. The % reflective area corroded has been .015 per year from point B to point GG. This small percentage area growth per year is due to vents being installed. Points F and FF are above the Average Corrosion Reference Line, and would have been higher, closer to the unvented field line, but summer 1985 was the first year affected by venting, causing it to be lower. Point GG is on the average reference line either for two reasons: first, the corrosion growth is continuing the average growth pattern or second, the growth pattern will continue this year's path toward HH, which seems to be apparent. A survey to be conducted in the summer 1987 should establish some answers on the permanent corrosion trend.

If results from the summer 1987 survey show that the % reflective area corroded is just above .072 (point LL), then the corrosion is following the average corrosion reference line. But, if results show that the % reflective area corroded is below (point HH), then it can be said that the corrosion growth rate is decreasing.

Table VIII was constructed based upon future expectations; if corrosion does in fact continue the path of the average corrosion reference line shown in Figure 6. Table VIII shows the total number of heliostats expected to be corroded by the posted year along with the % reflective area corroded.

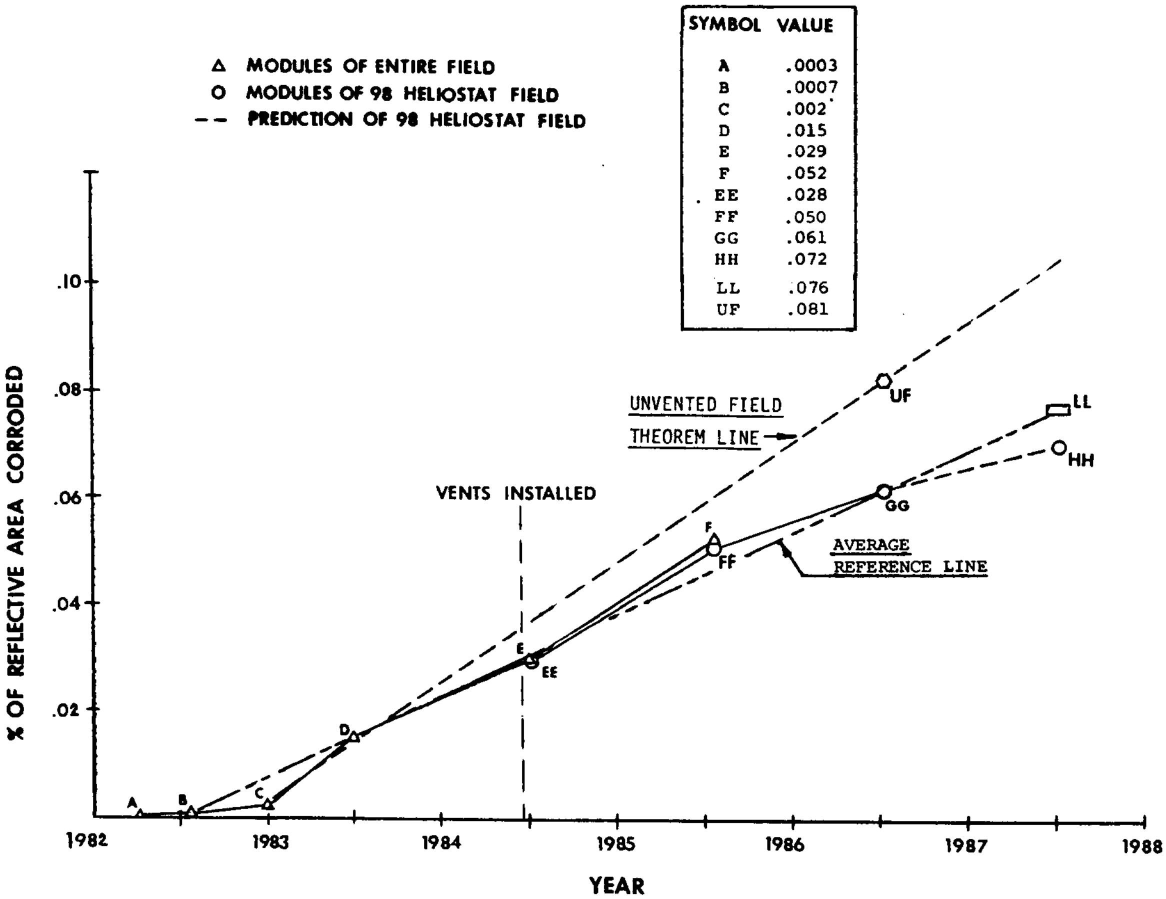


Figure 6. Total Corrosion Trend

Table VIII-- Future Expected Corrosion

Year	Equivalent No. of Corroded Heliostats	% Reflective Area Corroded
1986	1.13	.061 (Reference Year)
1987	1.38	.076
1988	1.65	.091
1991	2.50	.136
1996	3.84	.211
2001	5.20	.286
2006	6.56	.365
2011	7.93	.436 (25 Years From Reference Year)

Based upon Table VIII, in the year 2011 the equivalent of 8 heliostats will be lost due to corrosion, a very low percentage when compared to the entire field. The power output loss would be approximately 52 MWh for that year, which translates into $4,500 for the entire field when using a 12,000 MWh per year as the reference. At the current corrosion trend, a loss of $60,000 can be estimated over the 25-year period. This expectation of corrosion growth will not have a serious impact on plant performance over the next 25-years.

Comparison of Vented and Unvented Modules

Table IX lists the four types of modules that are compared: the unvented modules above 17,000 serial number, unvented modules below 17,000 serial number, all unvented modules and all vented modules. For each category, the total corroded area is separated by quadrants.

Ninety one percent of all modules in the northeast quadrant are vented; it also has the largest % reflective area corroded; with vented modules at .123% and all type modules at .112%. The total corrosion increase for this entire quadrant was .015%: the same value as the entire field average per year. For future reports, it is recommended that the % reflective area corroded in the northeast quadrant in past years be graphed and that its trend be compared to the total field corrosion trend.

The most effective way to prove that venting has indeed inhibited the total corrosion growth is by making a simple comparison of vented versus unvented modules all below the 17,000 serial number. Supporting data are listed below:

1. Both type modules were manufactured identically.
2. Neither is influenced by improved module production methods (above 17,000 serial number).

Table IX-- Vented and Unvented Module Comparison-
98 Heliostat Field Totals

	Unvented Above 17,000	Unvented Below 17,000	All Unvented	All Vented	TOTALS
Area (sq in)	192	816	1008	2640	3648
% Reflective Area Corroded	.013	.064	.035	.085	.061
* 1985-86 % Increase **		64	9	14	24
		BY QUADRANT			
NORTHEAST (91% VENTED)					
Area (sq in)	10	NOT	10	2242	2252
% Reflective Area Corroded	.006	APPLICABLE	.006	.123	.112
NORTHWEST (20% VENTED)					
Area (sq in)	89	246	335	50	385
% Reflective Area Corroded	.009	.074	.025	.015	.023
SOUTHEAST					
Area (sq in)	NOT	384	384	142	526
% Reflective Area Corroded	APPLICABLE	.055	.055	.020	.038
SOUTHWEST					
Area (sq in)	92	186	278	207	485
% Reflective Area Corroded	.026	.077	.046	.085	.057

* Increase is approximate; 1985 entire field and 1986 - 98 field are compared, therefore, small discrepancies may exist.

** 1985 value was unattainable.

The reader should bear in mind that a greater number of modules below the 17,000 serial number have vents. This vented module category contained more corrosion than the unvented modules. This is the reason why the vented line lies higher than the unvented line in Figure 7. The important observation is that the vented slope is less than the unvented slope. The corrosion of unvented modules increases (.025%) at more than double the vented module (.010%) corrosion rate. This proves that venting has been effective in decreasing the corrosion growth of the field. If the % reflective area corrosion of .015% per year continues, then it would not be necessary to vent more modules. But in turn, if corrosion tremendously exceeds the .015% increase per year, then it would be advisable to install vents in unvented modules.

The unvented modules above the 17,000 serial number were not included in the above comparison because of its improved production method of water tight sealing that experienced a .003% increase from last year.

Comparison of Left and Right Side Modules

In Table X the two negative values listed in the left side modules of the northwest (-9%) and the southeast (-17%) quadrants are due to a combination of reasons. First, the summer 1984 estimate in the southeast quadrant was extremely high which is confirmed by the negatives listed for this quadrant in the next two consecutive summers of 1985 and 1986.

These observations may be supportive evidence of the difference between the two estimation methods of the previous years and 1986; which were discussed in the 1986 Data Collection Procedure. Discrepancies between the previous and present results are due to the following.

1. High estimates in the previous methods.

2. The 1986 new corrosion method may result in slightly lower estimates when compared to the previous method.

It can be observed in Figure 8 that the difference in % reflective area corroded of left and right side modules was maintained for the summers of 1983 and 1984. This parallel growth was deviated after the 10,036 mirror modules were vented in April 1984. The vented left side modules comprised 75% of all modules with vents. The effects were apparent in summer of 1985 where the left and right side corrosions were almost identical. In the summer of 1985 it was predicted that the corrosion of right side modules would surpass the left side module corrosion; this indeed did happen in 1986 and is verified in Figure 8.

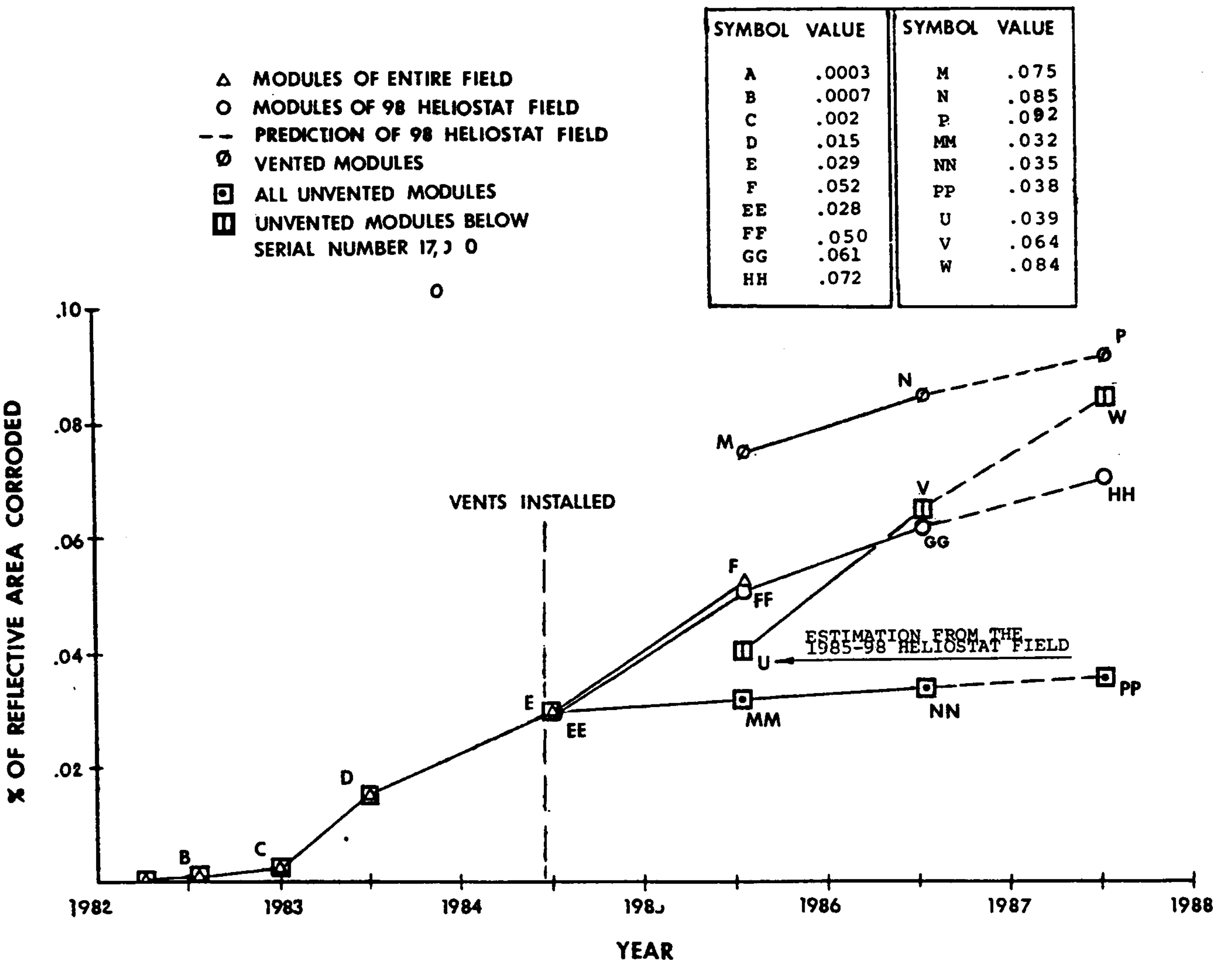


Figure 7. Vented vs Unvented Corrosion Comparisons

Table X-- 98 Heliostat Corrosion Update

* All Numbers Are Square Inches Of Corrosion

Corrosion	84-85 % Increase	85-86 % Increase	July 85	July 86	1986 % of Total
TOTAL	28	1	1513	3648	100
Left-Side	182	48	1434	1533	42
Right-Side	74	24	2947	2115	58

BY QUADRANT

	84-85 % Increase	85-86 % Increase	July 85	July 86	1986 % of Total
NORTHEAST					
TOTAL	75	16	1948	2252	62
Left-Side	30	6	965	1022	28
Right-Side	165	25	983	1230	34
NORTHWEST					
TOTAL	152	53	251	385	11
Left-Side	55	-9	117	106	3
Right-Side	458	108	134	279	8
SOUTHEAST					
TOTAL	36	39	379	526	14
Left-Side	-10	-17	172	142	4
Right-Side	136	86	207	384	10
SOUTHWEST					
TOTAL	83	31	369	485	13
Left-Side	48	2	259	263	7
Right-Side	322	101	110	222	6

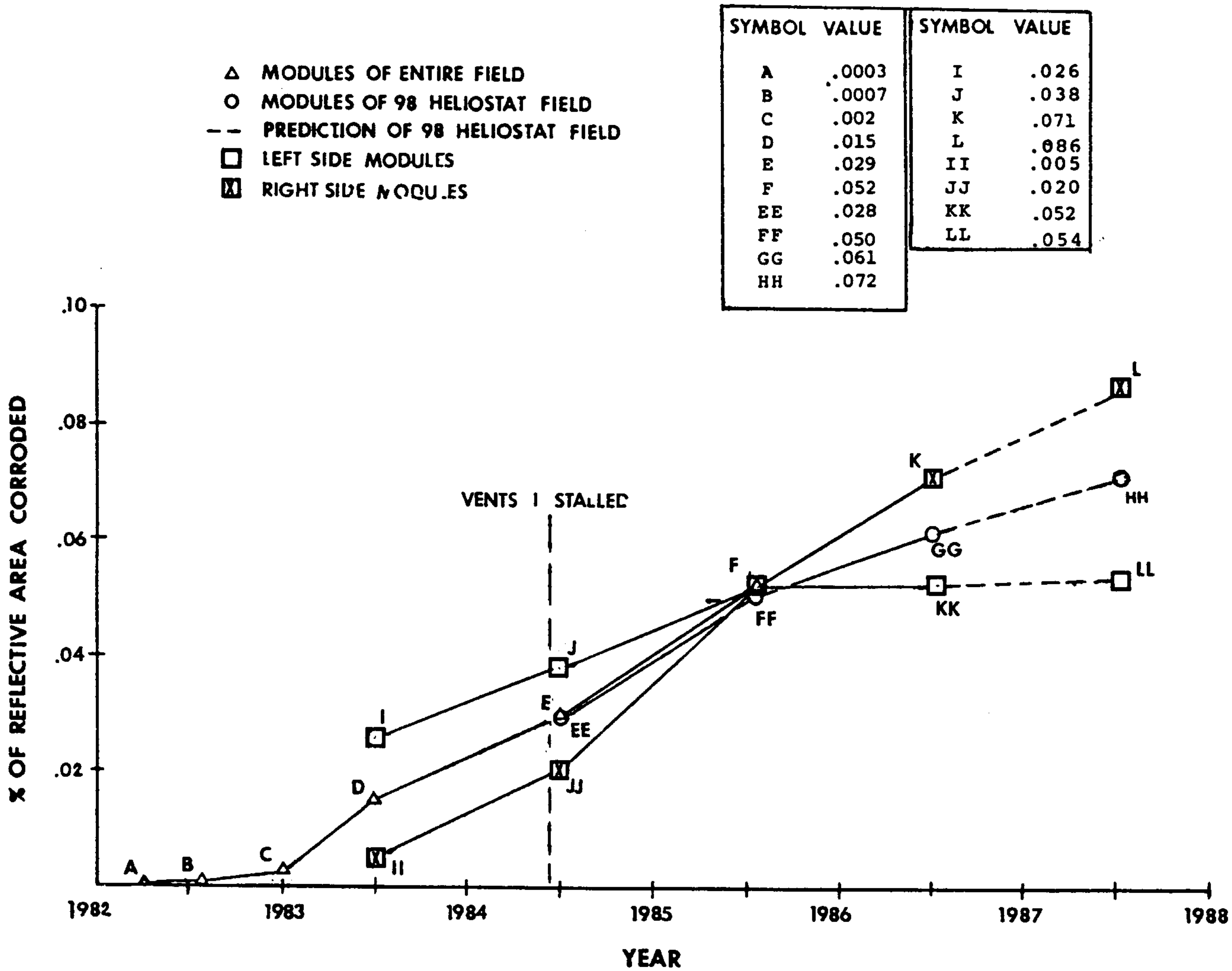


Figure 8. Left vs Right Corrosion Comparisons

The left side modules had a 1% increase in corrosion growth from 1985, due to the vent installation. The left side modules have an annual .002% corrosion rate increase compared to a .020% rate for right side modules. This vast difference is mainly due to vents having been installed in left side modules.

<u>1986 Entire Field Prediction Figures From the 98 Heliostat Survey Field</u>

Table XI presents the predicted 1986 entire field corrosion figures. The calculation method used was first experimented on the 1985 field survey of 98 heliostats to derive the predicted 1985 entire field corrosion; this resulted in a +8% error from the actual total corrosion surveyed of the entire field. Therefore, Table XI should only be used for rough estimates of corrosion for left and right side modules, and for the totals of each quadrant. It was more accurate to use the total corrosion percentage increase of 24% from the 98 field and apply it directly to last year's total corrosion of 57,279 to obtain this year's figure of 71,026.

<u>Discussion on the Decrease of Corrosion on Left-Side Modules in the Southeast Quadrant:</u>

Left-side modules in the southeast quadrant showed a decrease in corrosion from 1984 to 1985. This anomaly may have stemmed from two differences in the corrosion estimation procedures used. First, the 1984 surveyor "estimated all corrosion to the nearest inch even though some corrosion was obviously less than 1 square inch" (verbal communication of August 29, 1985). In contrast, in 1985 all corrosion that was less than 1 square inch was estimated to the nearest 1/4 inch. Second, "1984 estimates of corrosion were made while heliostats tracked the sun" (verbal communication of August 29, 1985). At some heliostat tracking angles, corrosion is difficult to see and a good estimation of areas is harder to make. During the 1985 survey, each heliostat was positioned at -90 degrees, 0 degrees (vertical facing east) when making estimates. This position yielded the best contrast of corrosion against the clear mirror background. This enabled estimates of corrosion to be more precise.

To determine the difference between these techniques and to try to explain the decreases, all estimates less than 1 square inch were re-counted and rounded to 1 square inch. This yielded 404 additional square inches of corrosion. However, the decrease in corrosion still existed, but it changed from -14% to -1%. These changes suggest that a slight over-estimation of corrosion was present in 1984 values, while a slight under-estimation occurred in 1985 values.

In another attempt to account for this decrease, 10 heliostats in the southeast quadrant were randomly selected and the 1984 and 1985 estimates of corrosion were compared in Table XII. Results show that 1984 estimates for left side corrosion were an average of 3.81 square inches larger than 1985 estimates. This suggests that many small errors were made in estimating the corrosion in the southeast quadrant instead of a few large errors. This is supported by the fact that every heliostat in the southeast quadrant contained the same type of corrosion, thus, accounting for small errors in corrosion many times.

Table XI-- 1986 - Entire Field Corrosion Update
(Predicted From the 98 Heliostat Field)

* All Numbers Are Square Inches Of Corrosion

Corrosion	84-85 % Increase	Estimate 85-86 % Increase	July 85	Estimate July 86	1986 % Of Total
TOTAL	78	28	57,279	73,599	100
Left-Side	32	0.05	28,456	28,574	39
Right-Side	167	56	28,822	45,025	61
		24*			
BY QUADRANT					
NORTHEAST					
TOTAL	61	16	16,500	38,409	52
Left-Side	24	6	16,735	17,490	24
Right-Side	129	25	33,236	20,919	28
NORTHWEST					
TOTAL	194	53	11,399	17,330	24
Left-Side	138	-9	5,453	4,962	7
Right-Side	273	108	5,946	12,368	17
SOUTHEAST					
TOTAL	50	39	6,711	9,712	13
Left-Side	-14	-17	2,690	2,233	3
Right-Side	203	86	4,021	7,479	10
SOUTHWEST					
TOTAL	84	31	5,933	8,148	11
Left-Side	43	2	3,813	3,889	5
Right-Side	276	101	2,119	4,259	6

* The entire field figures of the 24% increase from 1985 and the 71,026 total corrosion better represent figures for the totals because they are derived directly from the 98 heliostat field figures.

Table XII-- Comparison of 1984 and 1985 Estimates of Corrosion in the Southeast Quadrant

Heliostat Number		1984 Estimates	1985 Estimates	Comments
235	Total	30	54	
	Left	17	12.75	
	Right	13	41.25	
527	Total	28	51.25	
	Left	25	18.25	
	Right	3	33	
647	Total	6	20.25	
	Left	5	9	
	Right	1	11.25	
1235	Total	3	2	
	Left	1	.25	
	Right	2	1.75	
1267	Total	3	3.5	
	Left	1	.25	
	Right	2	3.5	
1573	Total	8	3.5	1984 estimate recorded 2 square inches on Facet 1; there was none in 1985
	Left	7	1.25	
1655	Total	37	45	
	Left	27	20	
	Right	10	25	
1855	Total	20	20.25	
	Left	19	15	
	Right	1	5.25	
2065	Total	31	41	
	Left	21	16	
	Right	10	25	
2185	Total	24	31	1984 estimate recorded 1 square in. on Facet 1; There were none in 1985.
	Left	10	6	
	Right	24	25	

It is recommended that heliostats be stowed in a position that allows accurate and consistent estimation of corrosion when performing the survey. Moreover, the area of corrosion should be estimated to the nearest value that will provide consistent measurements among past and future surveys.

15 Most Corroded Heliostats in the Entire Field--1985

Table XIII lists the 15 most corroded heliostats in the collector field in 1985. It describes the amount of corrosion, quadrant, and venting of each heliostat. The last column on the Table gives the particular facets responsible for most of the corrosion on the heliostat. This is done to show that corrosion is not evenly distributed over some heliostats. In most cases, only one or two mirror modules account for most of the corrosion. For example, a single mirror module on Heliostat #1811 comprises 54% of the total corroded area, while two modules contain 75% of the corrosion on Heliostat #2912. Photographs illustrating the corrosion on these two heliostats are shown in Figure 9.

10 Most Corroded Heliostats in the Entire Field--1986

Table XIV lists the 10 most corroded heliostats in the entire collector field in 1986. It compares corrosion in 1985 with corrosion in 1986 and shows the percentage increase. Notice that 8 of the 10 heliostats are in the northeast quadrant; this goes hand in hand with the 1985 data which shows that most of the corrosion in the entire field is in that quadrant. The overall corrosion, for this 10-heliostat sample, has increased 20%, compared to 24% for the 98 heliostat field. For modules with no vents, the corrosion has increased 34% (64% for the sample survey) and 8% (14 % for sample survey) for modules with venting. These ten heliostats and the 98 heliostat field survey results have similar corrosion trends.

1985 Torque Tube Damage Survey Results

Each heliostat torque tube was inspected from the ground, while the heliostats were tracking, and any dents or rust in the area near the drive were noted along with an estimation of the size of the dent. The July 1984 survey listed 35 dented torque tubes. Observation of those damaged torque tubes showed that 14 reimpacted their gear boxes in the last year. In addition, nine newly dented torque tubes were found. A list of these 23 damaged heliostats along with a short description of the damage is shown in Table XV.

Only one of the damaged torque tubes impacted with the gear box on the side where the motors are mounted. The size of the dents ranged from only 1/8" to 1/2", all with rust except one.

Data that shows 14 of the 35 torque tubes (that were painted red last year) were redented suggests the collector field is experiencing a continuing control system problem. The single dented torque tube found in this year's survey without rust is more evidence against the hypothesis suggesting that denting occurred during collector field start-up.

Table XIII-- 15 Most Corroded Heliostats, 1985

Heliostat No.	Quadrant	Area,(Sq. in.)	Venting By	Corrosion Distribution Facet
2912	NW	382	L	2 Facets for 75% (#1, #9)
2902	NW	347	L	1 Facet for 46% (#5)
1823	NE	325	L,R	Evenly Distributed
2906	NW	303	L	2 Facets for 60% (#7, #9)
1811	NE	299	L,R	1 Facet for 54% (#10)
1711	NE	265	NONE	1 Facet for 50% (#2)
2910	NW	265	L	2 Facets for 69% (#1, #5)
1412	NW	255	NONE	1 Facet for 100% (#4)
2417	NE	240	L,R	Evenly Distributed
1719	NE	236	NONE	1 Facet for 59% (#2)
2908	NW	233	L	Evenly Distributed
2411	NE	232	L,R	Evenly Distributed
1709	NE	222	NONE	Evenly Distributed
2005	NE	220	L,R	Evenly Distributed
1873	SE	212	L	1 Facet for 49% (#6)

L is left side mirrors and R is right side mirrors

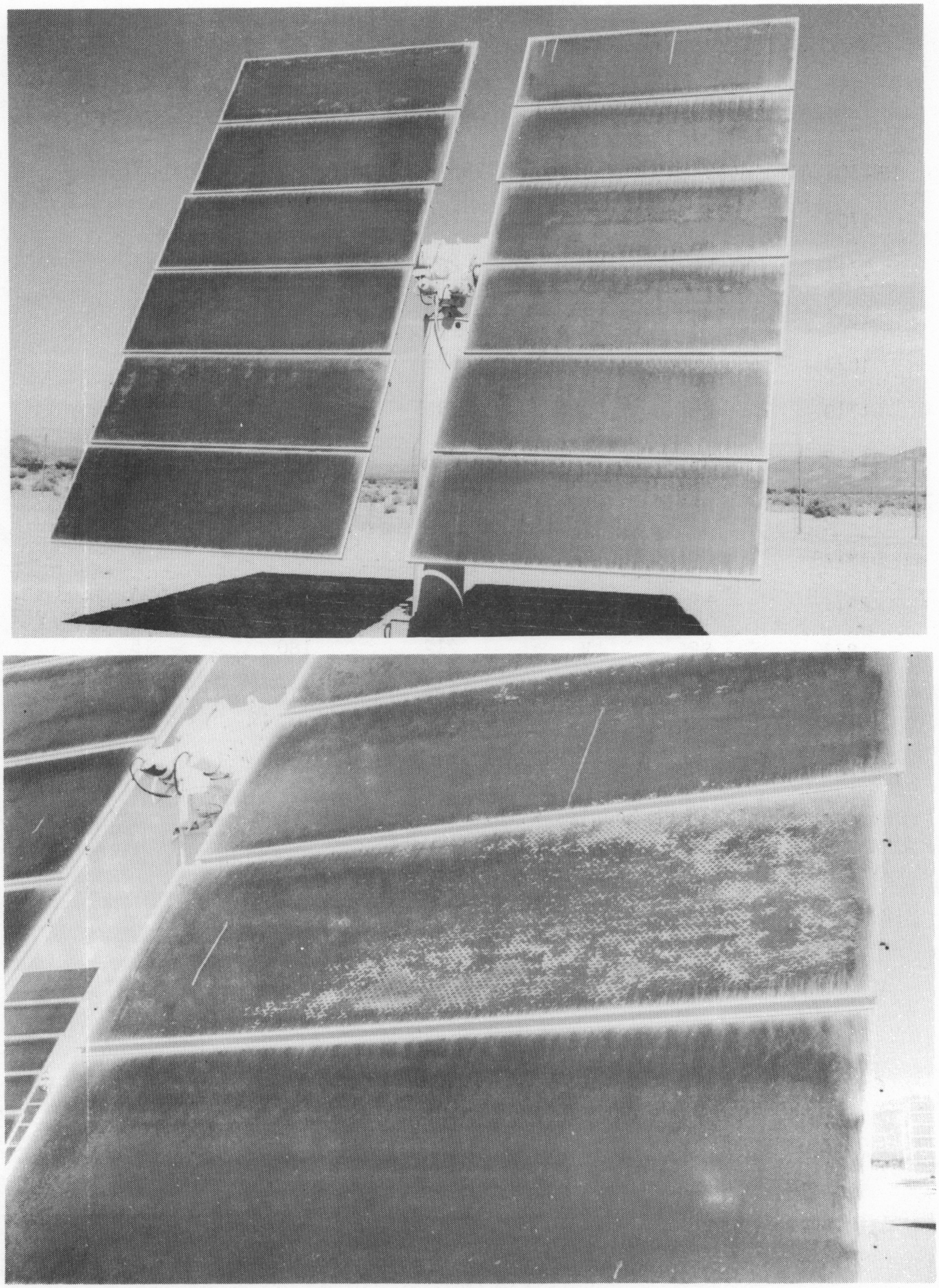


Figure 9. Photograph of Corroded Mirror Modules

Table XIV-- 10 Most Corroded Heliostats, 1986

HELIOSTAT	QUADRANT	VENTING	1985 AREA	1986 AREA	% INCREASE
1709	NE	NONE	222	410	85
1711	NE	NONE	265	390	47
1811	NE	LRV	299	360	20
1823	NE	LRV	325	320	- 2
1719	NE	NONE	236	310	31
1412	NW	NONE	255	298	17
2005	NE	LRV	220	260	18
2417	NE	LRV	240	255	6
2411	NE	LRV	232	232	0
1873	SE	LV	212	180	- 15
			2506	3015	20

NOTES:

From the Table above Modules with;

1. No venting; corrosion has increased 34%.
2. Venting; corrosion has increased 8%.

ALL MODULES LISTED HAVE SERIAL NUMBERS BELOW 17,000

Table XV-- Survey of Torque Tube Damage, 1985

Heliostat Number	Quadrant	Depth of Dent With Rust
	Redented Torque Tubes	
121	SW	1/2"
1857	SE	1/2"
1859	SE	3/4"
1875	SE	1/2"
601	NE	1/2"
1909	NE	1/2"
1917	NE	6/7"
2263	NE	1/2"
2555	NE	1/2"
1516	NW	1/2"
1518	NW	1/2"
2336	NW	1/2"
2434	NW	1/2"
2622	NW	1/2"
	Newly Dented Torque Tubes	
1534	NW	1/2"
2008	NW	1/4"
2112	NW	1/8"
2116	NW	1/8"
315	NE	1/2"
2427	NE	1/4"
2511	NE	1/2" dent, w/rust, motor side
2607	NE	1/4" dent, no rust
2643	NE	1/8" dent, w/rust

Although the size of dents in the torque tubes is relatively small and the type of damage to the tubes is not precise, if the gears are damaged, they can fail at a later date and allow the mirror assembly to rotate freely. Thus, the cause of overtravel problems should be further investigated. To do this, another color paint should be sprayed on the newly found dents and observed carefully every month for signs of reimpacting. The paint should be a dark color such as blue or green so that scratched areas can be readily identified.

1986 Torque Tube Damage Survey Results

The entire field was in the vertical stow position while inspecting the motor side and back side of every heliostat torque tube. Thirty-nine torque tubes were newly dented of which four were redented from 1984. A list of these 39 heliostats, along with a short description of the damage, is shown in Table XVI. The 1985 torque tube survey did not paint the reported dents, and, therefore, redenting from 1985 could not be determined for comparison. In 1986, an additional seventeen torque tubes had minor scratches. Ten damaged torque tubes are on the motor side; all others are on the opposite side of the motors.

In 1986 all new dents and scratched torque tubes were painted green to determine any future re-occurring denting. All redented torque tubes were painted red again. Those torque tubes that were reported in 1985, but not painted, were painted in 1986.

Conclusions and Recommendations

Corrosion:

Mirror corrosion has increased to the equivalent of 1.13 heliostats and should continue to increase at a constant rate of .015% of reflective area corroded per year, based upon results obtained from the corrosion trend of Figure 6. It is predicted that over the next 25-years, the equivalent of 8 heliostats will have corroded causing a 52 MW_eh per year loss of energy in the year 2011. Therefore, the corrosion rate is not severe and will not have a serious impact on the plant's future performance.

It is recommended that:

1. Further surveys of the same 98 randomly selected heliostats should be continued in the next few years to monitor the growth rate.

2. Complete field surveys should be conducted every two or three years to confirm the relationship of the 98 heliostat field results and the entire field results.

Table XVI-- Survey of Torque Tube Damage, 1986

DENTED TORQUE TUBES

HELIOSTAT NUMBER	QUADRANT	DESCRIPTION OF DAMAGE (LENGTH IS IN INCHES)
124	SW	1.0
1066	SW	2.5
1876	SW	1.0
121	SE	2.0 RIGHT MOTOR SIDE
579	SE	1.0
1137	SE	1.5
* 1445	SE	MOTOR SIDE *** SCRATCH, SCRATCH & 3.5
* 1455	SE	MOTOR SIDE *** SCRATCH, SCRATCH & 3.5
* 1457	SE	MOTOR SIDE *** 0.0, SCRATCH, 3.0
1459	SE	2.5
* 1851	SE	MOTOR SIDE *** 2.0, 3.0 & 5.0
1967	SE	1.5
1031	NE	MOTOR SIDE *** SCRATCH, 3.0 & 3.0
1417	NE	3.5
2029	NE	MOTOR SIDE *** SCRATCH, 1.0, 5.0
2333	NE	3.5
2425	NE	1.5
* 2427	NE	2.0
2559	NE	1.0
2937	NE	MOTOR SIDE *** SCRATCH, SCRATCH & 4.0 NO RUST
412	NW	3.5
918	NW	1.0
1018	NW	1.5
1122	NW	1.5
1228	NW	2.0

Table XVI--Survey of Torque Tube Damage, 1986 (Cont)

DENTED TORQUE TUBES

HELIOSTAT NUMBER	QUADRANT	DESCRIPTION OF DAMAGE (LENGTH IS IN INCHES)
1724	NW	MOTOR SIDE *** SCRATCH 3.0 & 5.0 NO RUST
1632	NW	1.0
1804	NW	2.0 ABOVE LEFT MOTOR
* 2112	NW	1.0
2140	NW	2.0
2302	NW	1.0
2704	NW	MOTOR SIDE *** 2.0, 3.0, 4.0 ALSO ON OPPOSITE SIDE OF MOTORS 4.0
2802	NW	1.0
2826	NW	2.0
2920	NW	1.0 NO RUST

REDENTED TORQUE TUBES
REPORTED & PAINTED RED IN SUMMER 1984)

HELIOSTAT NUMBER	QUADRANT	DESCRIPTION OF DAMAGE (LENGTH IS IN INCHES)
* 121	SE	SCRATCH
1875	SE	1.5
601	NE	1.0
1909	NE	SCRATCH
1917	NE	3.5
2434	NW	SCRATCH
2622	NW	2.25

Table XVI--Survey of Torque Tube Damage, 1986 (Cont)

SCRATCHED TORQUE TUBE (NO DENT)

HELIOSTAT NUMBER	QUADRANT:L	HELIOSTAT NUMBER	QUADRANT
531	SE	* 2643	NE
629	SE	2852	NE
1439	SE	824	NW
1573	SE	* 1534	NW
217	NE MOTOR SIDE	* 2008	NW
** 315	NE	2744	NW
* 2607	NE	* 2116	NW

NOTE: 1. All dents contain rust unless otherwise specified.

2. All dents are located opposite the motor side where the torque tube would impact with the gear box flange unless otherwise specified.

* Are listed as damaged torque tubes in the 1984 Sandia Report. (Were not painted red in 1984.)

** Are listed as damaged torque tubes in the 1985 Sandia Report.

*** Motor side listed dent lengths are in the following order, 1st - above left motor, 2nd - above right motor, 3rd - above right motor but further away from pedestal center line.

Vent Tubes:

Unvented modules experienced more than twice the corrosion growth rate of the vented modules. The vent tubes have been effective in the decrease of the corrosion growth. However, the cost of additional vents may exceed the cost of the power output loss in the next several years.

It is recommended that:

1. If the constant .015% of reflective area corroded rate per year is continued, additional vents should not be installed.

2. If the constant .015% of reflective area corroded rate per year is exceeded, then additional vent installation should be considered.

Torque Tube Damage:

Thirty nine newly dented and 17 scratched torque tubes found during the 1986 field survey were painted green. In addition, 7 torque tubes were redented from the 1984 survey. These findings suggest that a continuing control system problem exists. The damage has been attributed to overtrack of the heliostat drive gear box due to the failure of the elevation limit switch, after the heliostat controller fails to stop the elevation drive motor. The limit switch failure is believed to be caused by a short circuit in the diode that is in parallel with the switch. This was identified as the cause of a failure of Heliostat 2937 in September 1986. This diode allows the motor to be reversed when the limit switch is open.

It is recommended that:

1. Future new dents be colored a different color other than red or green to identify the year in which the dent was first reported.

2. An inspection be done periodically to all painted torque tubes to verify if the problem is re-occurring, and, if so, it should be corrected immediately. The diode in parallel with the limit switch should be removed, and the reason the controller drove the gear box into the limit switch should be determined and corrected.

3. If the problem becomes serious (broken gears) consideration should be given to removing the diodes on all heliostats.

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1. J.E. Noring, C.L. Mavis, E.V. Decker, and P.E. Skvarna, "10 MW_e Solar Thermal Central Receiver Pilot Plant Mirror Module Corrosion Survey, July 1983", Sandia National Laboratories, SAND 84-8214, March 1984.

2. J.E. Noring, C.L. Mavis, E.V. Decker, and C.W. Lopez, "10 MW_e Solar Thermal Central Receiver Pilot Plant Mirror Module Corrosion, Torque Tube Damage, and Mirror Reflectance Survey, July 1984", Sandia National Laboratories, SAND 85-8225, July 1985.

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