Test Report for KJC Heliostat Wash

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1. Executive Summary

The Heliostat is a large mirror assembly, which can be rotated about both the vertical (azimuth) axis and the horizontal (elevation) axis. The Heliostat reflects, redirects and concentrates direct normal radiation from the sun onto the receiver surface. The orientation of each Heliostat is controlled by a computer such that the normal to the mirror surface bisects the angle between the sun and the Receiver. It is the primary component of the Collector System. The Collector System includes the following items:

- Solar One Heliostats with controllers 1818
- Refurbished "Lugo" tracker with controllers converted to Heliostats 108

The operational and maintenance objective for the Heliostat field is based upon a Heliostat Field availability of 98% and a Heliostat cleanliness of 95%, where cleanliness is defined as the average field reflectivity divided by the base line reflectivity for a clean Heliostat of 90% determined from measurements performed on the existing Solar One Heliostat field.

The Solar One Heliostat field has sat dormant since the shut down of Solar One in 1988. No maintenance or cleaning of the Heliostats has been performed during the period from shut down and refurbishment in preparation for startup of Solar Two. The mirrors reflectivity were questionable and the methods of cleaning were uncertain. Routine Heliostat washing will be required to maintain the Heliostat field's proper reflectiveness. The optimum cleaning frequency will be evaluated and determined during Solar Two Test and Evaluation period. Initially, some method had to be derived which would address the long term storage of the Heliostat field without maintenance and washing. This method also had the requirement of determining if high-pressure washing itself, would bring the reflectivity up to the 90% requirement.

A test program was setup with the help of equipment and personnel from KJC Operating Company. Their portable integrated high-pressure spray system consisting of a 1500 gallon deminerializer water tank, two diesel-powered high-pressure (3000 psi) water pumps, two spray wands and a set of nozzles (**0°**, **25°**, and **45°** nozzle patterns). This equipment was used for the test along with a μScan reflectometers. For the **25°**, and **45°** nozzles, a "Z" pattern was used for the washing technique. For the **0°** nozzle, a multi-pass "Z" pattern was used. This nozzle was also used to wash the top 6 facets for Heliostat 1846 which was in a vertical position. A sample of five Heliostats in a vertical wash position and one Heliostat in a horizontal stow position was used for the test. All Heliostats were washed but none were scrubbed. The overall test results are summarized below:

Reflectivity	μScan
As-Found	63.7 %
0° 1-Pass (Average Improvement)	7.2 %
25° 1-Pass (Average Improvement)	8.8 %
25° 2-Pass (Average Improvement)	12.0 %
45° 1-Pass (Average Improvement)	7.7 %
45° 2-Pass (Average Improvement)	11.6 %
Overall Average after Wash	73.2 %

The testing performed June 27, 1995 and subsequent analysis of the Reflectivity data, demonstrated that **neither** the 1-pass or the 2-pass method of high-pressure cleaning was sufficient to bring the Reflectivity up to 90%. This type of wash without a scrub was unable to remove the film coating on the mirror surface.

It was previously demonstrated with a scrub and high-pressure washing on June 7, 1995 by DLC, that proper reflectivity for the Solar One Heliostats can be achieved. Once the initial cleaning is performed **using both a scrub and wash**, it is believed that just high-pressure cleaning technique used on a regular schedule will maintain the Heliostats with the proper Reflectivity parameters. Based on the results of the Average Reflectivity Improvement, a 2-pass wash with a **25°** Nozzle provided the best results (12 % Improvement).

2. Test Objectives and Description

2.1 Purpose

This test was intended to evaluate the effectiveness of a high-pressure spray wash of the Solar Two Heliostats.

2.2 Scope

The test was designed to achieve the following objectives:

1) Compare the effectiveness of a 1-pass and a 2-pass spray washing
2) Evaluate the effectiveness of spray washing near facet edges
3) Determine if spray washing degrades the facet edge seals
4) Evaluate washing effectiveness as a function of distance and angle between nozzle and mirror

3. Background

The requirements for the Helicostats and the required reflectivity is defined in the Solar Two System Description for the Collector System (3YD-CS-001).

The Solar One Heliostat is a two-axis tracking assembly with 12 mirror modules (facets). Each Heliostat consists of 12 mirror modules, 4 bar joist trusses, a torque tube, an azimuth/elevation drive, a microprocessor controller, a wiring harness, a pedestal and a foundation.

The Heliostat mirror is a second-surface glass mirror, with the silver reflector applied to the back of the glass sheet. The mirrors are bonded to an aluminum honeycomb, which is 2 ½ inches thick, and the honeycomb is bonded to the inside of a shallow steel enclose pan. Each module has nominal dimensions of 3 ½ feet high by 10 feet wide. The total reflective area on each Heliostat varies between 39.47 and 39.12 m^2, and depends on the width of the edge seal on the enclosure pan. The mirrors are slightly curved in two directions, providing a focal length of approximately 1,000 feet. Some of the modules use glass with a high iron content and some use glass with a low iron content. The weighted average clean reflectivity of the Solar One Heliostat was 90.3 percent.

Some of the modules were replaced due to breakage which occurred during the period between Solar One shut down and site reactivation. These modules were obtained from Carrizo Solar (Carrizo Plains Solar site). These modules are larger than the Solar One modules. They use a later technology than the Solar One modules and were manufactured after the Solar One modules. These modules do not exhibit the film buildup which was found on the Solar One modules.

3.1 Test Requirements

Initial inspection of the mirror surfaces found that they were covered with dust and a thin film. It was anticipated that the reflectivity would be low based on this physical inspection.

This test was designed to 1) clean a representative sample of the Heliostats, 2) determine the existing as-found conditions of the mirrors and 3) determine and evaluate the effectiveness of high-pressure wash and its effect on the reflectivity of the mirrors.

3.2 Test Approach

Arrangements were made with KJC Operating Company to use their washing trailer, tractor and personnel to high-pressure wash a sample of Solar Two Heliostats with demineralized water. Their portable integrated high-pressure spray system consists of a 1500 gallon demineralizer water tank, gasoline-power high-pressure (3000 psi) water pumps, spray wand and a set of nozzles (**0°** , **25°** and **45°**) flat fan nozzle pattern. For the **25°**, and **45°** nozzles, a "Z" pattern was used for the washing technique. For the **0°** nozzle, a multi-pass "Z" pattern was used. This nozzle was also used to wash the top 6 facets for Heliostat 1846 which was in a vertical position. With this test configuration no manlift was required to reach the top facets. A sample of five Heliostats in a vertical wash position and one Heliostat in a horizontal stow position was used for the test. All Heliostats were washed but none were scrubbed. All the Heliostats facets were the Solar One design except for Heliostat 1846 Module 3, 7, 8, 12 and 1844 Module 2. These facets were replacement facets from Carrizo Solar.

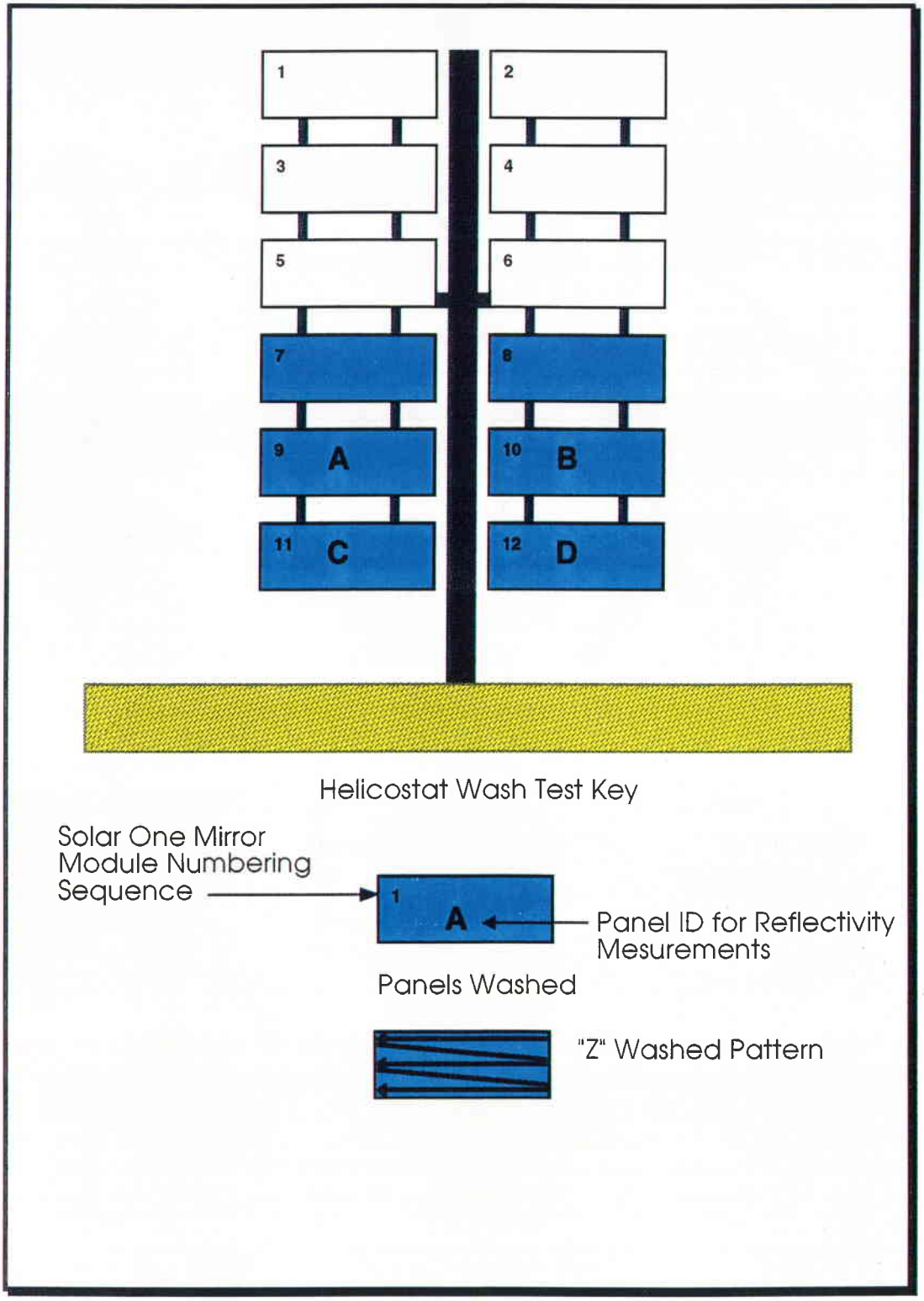


Figure 1 - Heliostat Configuration and Washing Pattern

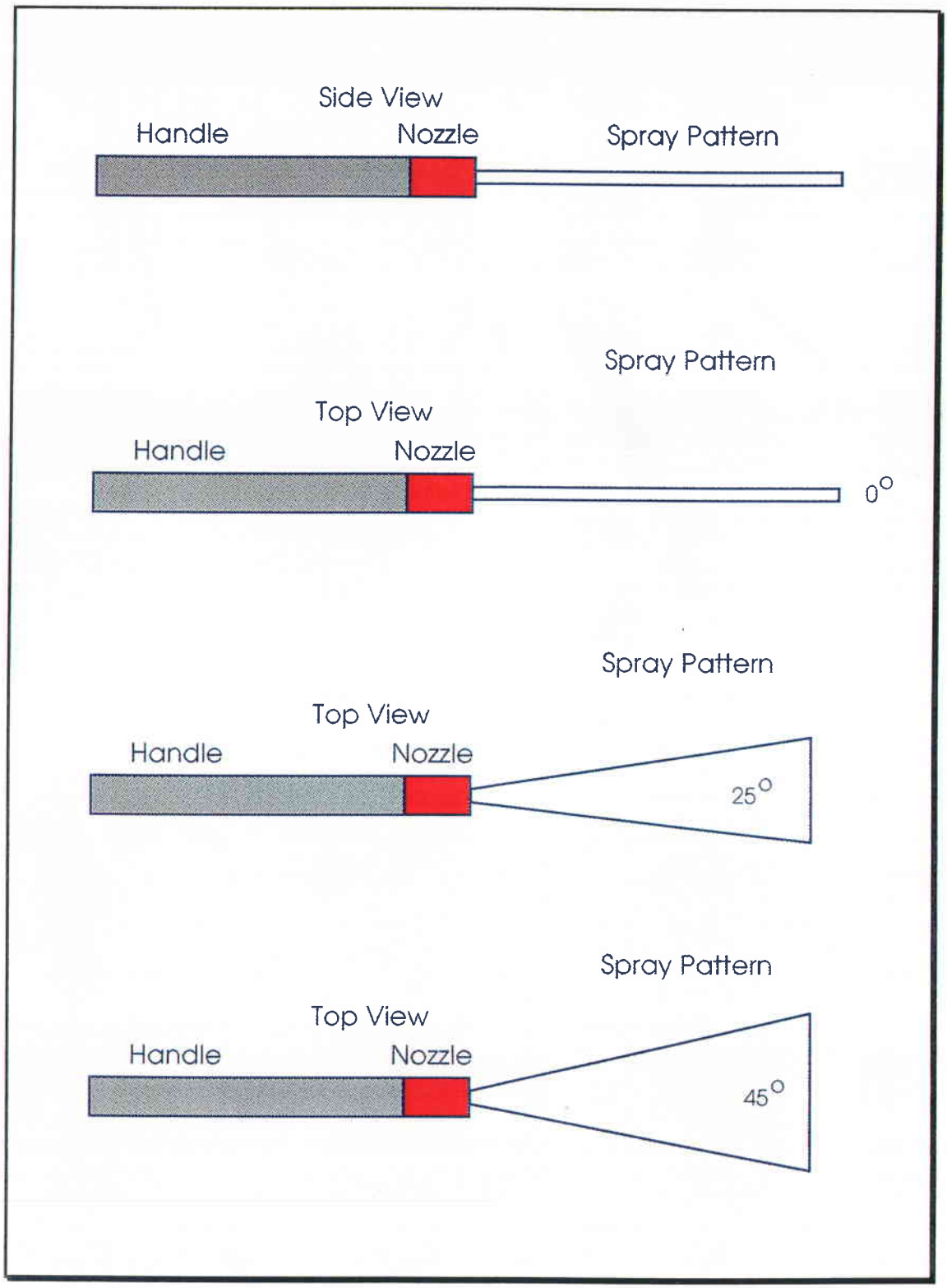


Figure 2 - Nozzle Spray Pattern

3.3 Test Procedure

1. Heliostats 1848, 1846, 1844, 1842, 1840 were placed in a vertical orientation.
2. Heliostat 1740 was left in a horizontal orientation with the mirror surface down.
3. Reflectivity measurements on each of the 4 lower facets of Heliostats 1848, 1846, 1844, 1842, 1840 were taken to obtain the as-found readings. Readings were taken in the center of the facet at the bottom, middle bottom, middle top and top.
4. **0°** 1 pass wash of the lower 6 facets (Module No. 7, 8, 9, 10, 11 & 12) was performed on Heliostats 1848
5. **0°** 1 pass wash of the upper 6 facets (Module No. 1, 2, 3, 4, 5, 6) was performed on Heliostats 1848
6. **25°** 1 pass wash of the lower 6 facets (Module No. 7, 8, 9, 10, 11 & 12) was performed on Heliostats 1846.
7. **25°** 2 pass wash of the lower 6 facets (Module No. 7, 8, 9, 10, 11 & 12) was performed on Heliostats 1844.
8. **45°** 1 pass wash of the lower 6 facets (Module No. 7, 8, 9, 10, 11 & 12) was performed on Heliostats
9. **45°** 2 pass wash of the lower 6 facets (Module No. 7, 8, 9, 10, 11 & 12) was performed on Heliostats 1840.
10. **25°** 1 pass wash of the right side 6 facets (Module No. 2, 4, 6, 8, 10, 12) was performed on Heliostats 1740.
11. Reflectivity measurements on each of the 4 lower facets of Heliostats 1848, 1846, 1844, 1842 and 1840 were taken after the wash. Readings were taken in the center of the facet at the bottom, middle bottom, middle top and top.

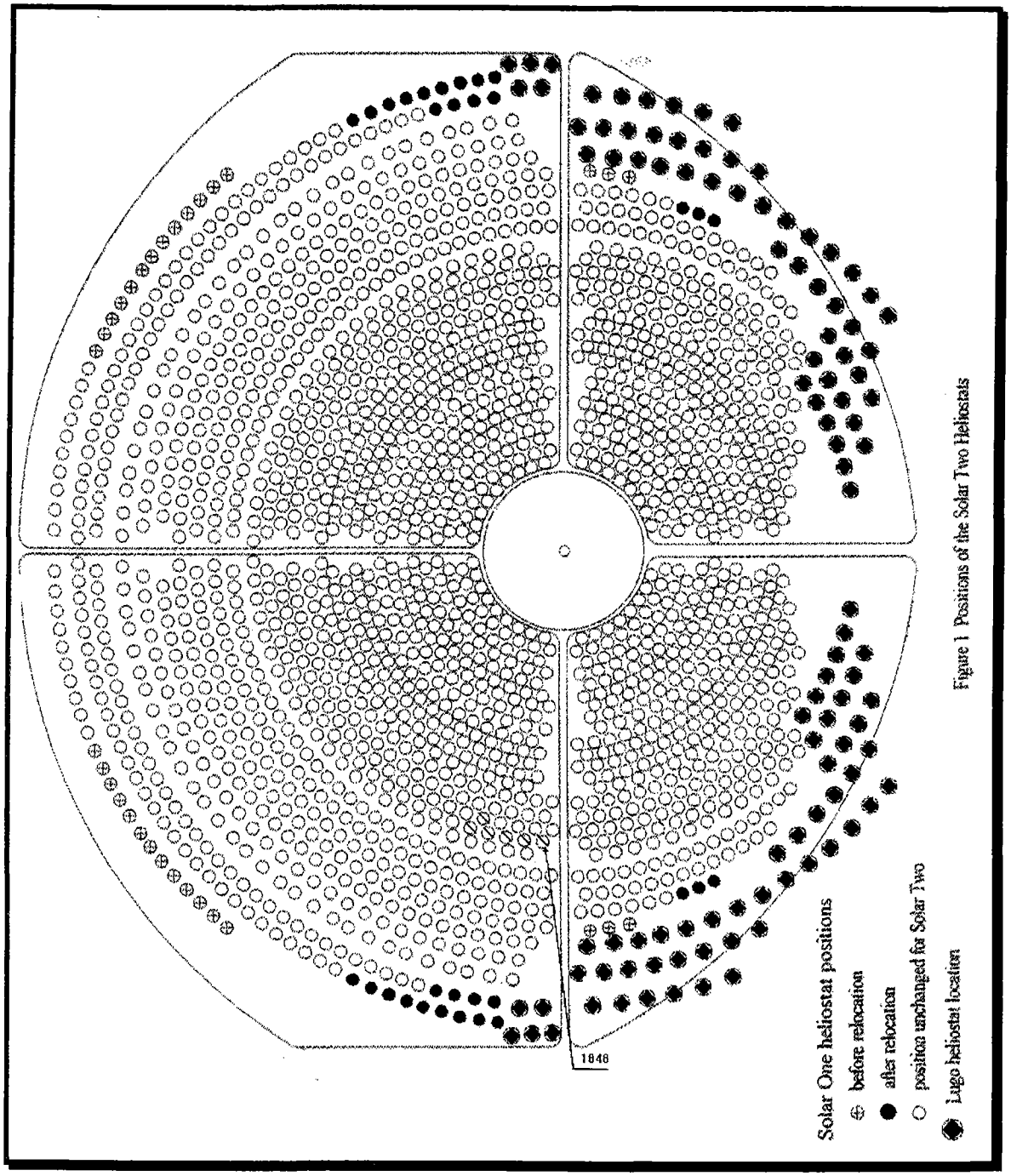


Figure 3 Heliostat Wash Test Site Location
(∅ = Heliostat washed during this test)

4. Test Results

4.1 Reflectivity

The overall reflectivity results are summarized below:

Heliostat	Before Wash Reflectivity (%)	After Wash Reflectivity (%)
μScan Reflectometer		
1840A	61.3	73.7
1840B	58.4	80.3
1840C	68.8	71.5
1840D	65.8	75.2
1842A	44.7	58.2
1842B	67.2	71.7
1842C	49.0	58.0
1842D	66.0	69.9
1844A	51.5	62.2
1844B	59.5	77.1
1844C	51.9	64.4
1844D	73.0	80.5
1846A	64.4	74.6
1846B	68.1	73.5
1846C	67.6	78.7
1846D ⊠	73.0	81.5
1848A	62.6	70.1
1848B	74.6	82.5
1848C	69.0	77.1
1848D	78.1	83.4
Average	**63.7**	**73.2**

Table 1 - Reflectivity Measurements with μScan
(⊠ = is a Carrizo Solar Facet)

4.2 Other

4.2.1 Test Equipment

4.2.1.1 μScan (TMA Technologies)

4.2.1.1.1 Handheld DAS

Model No.:	B1:03
S/N:	935102
P/N:	885-860-008

4.2.1.1.2 Sensor

Model No.:	H-670-01
S/N:	914905
P/N:	891-220-102

4.2.2 Accessibility within the Heliostat Field

Prior to and after the wash operation, the wash trailer and tractor was driven around the Heliostat field to determine if this configuration would have any problems with soft sand. No problems were encounter in the south and west section of the Heliostat field. One area (north-west - segment number 405), could pose a problem. When DLC wash Heliostats, they experience problems in this area. KJC's tank contained twice the amount of water and would be heavier than the DLC equipment. This maybe offset by the wider tires on the KJC trailer.

The dimensions of the tractor/trailer used, allowed free movement around the Heliostat field. No problems were found with clearance between the equipment and the Heliostats.

Wash of the Heliostats in a horizonal position was fast and very efficient. It also provided a constant washing distance between the nozzle and the mirror surfaces. This will provide an even wash of the surface for all facets.

4.2.3 Water Usage

The washing of the Heliostats for this test required approximately 160 gallons of water. This was equivalent to 1-pass wash for 4 ½ complete Heliostats or approximately 36 gals/heliostat for this test.

The KJC wash pumps are designed to deliver 25 gals/min. During operations of Solar Two, it is expected that washing of each Heliostat will take 5 minutes. This includes tractor/trailer positioning for the wash which would require two pass (one for each side) for complete the wash of one Heliostat. The wash will consume approximately 36 gals/Heliostat or 40 Heliostats before the tank has to be refilled. Based on these factors, 12 Heliostats can be washed per hour or 168 Heliostats in an 8 hour shift.

4.2.4 Washing Rate

After completion of the wash test by KJC, they estimated that approximately 12 Heliostats could be washed in one hour.

4.2.5 Crew Size

The crew size was representative of what is expected during operation of Solar Two. Once the initial Scrub is performed, only the 1-pass or 2-pass wash operation will be required. The crew required for this wash operation is only a Tractor Operator and two Wash Operators.

4.2.6 Facet Edges

4.2.6.1 Cleaning

It was observed that the use of the 1-pass or 2-pass wash did not remove the film completely and especially near the facet edges. Even with KJC's high operating pressure of 3000 psi, all the film was not removed. This confirms that for the initial cleaning of the Heliostat field, a scrub and wash is required.

4.2.6.2 Wash Effect on Facet Edge Seals

A visual inspection of the facet edges were made after the cleaning in an effort to determine if the high pressure spray wash degraded the facet edge seals. No conclusion could be drawn based on this sample size and the time period between the wash and inspections. Actually two inspections were made.

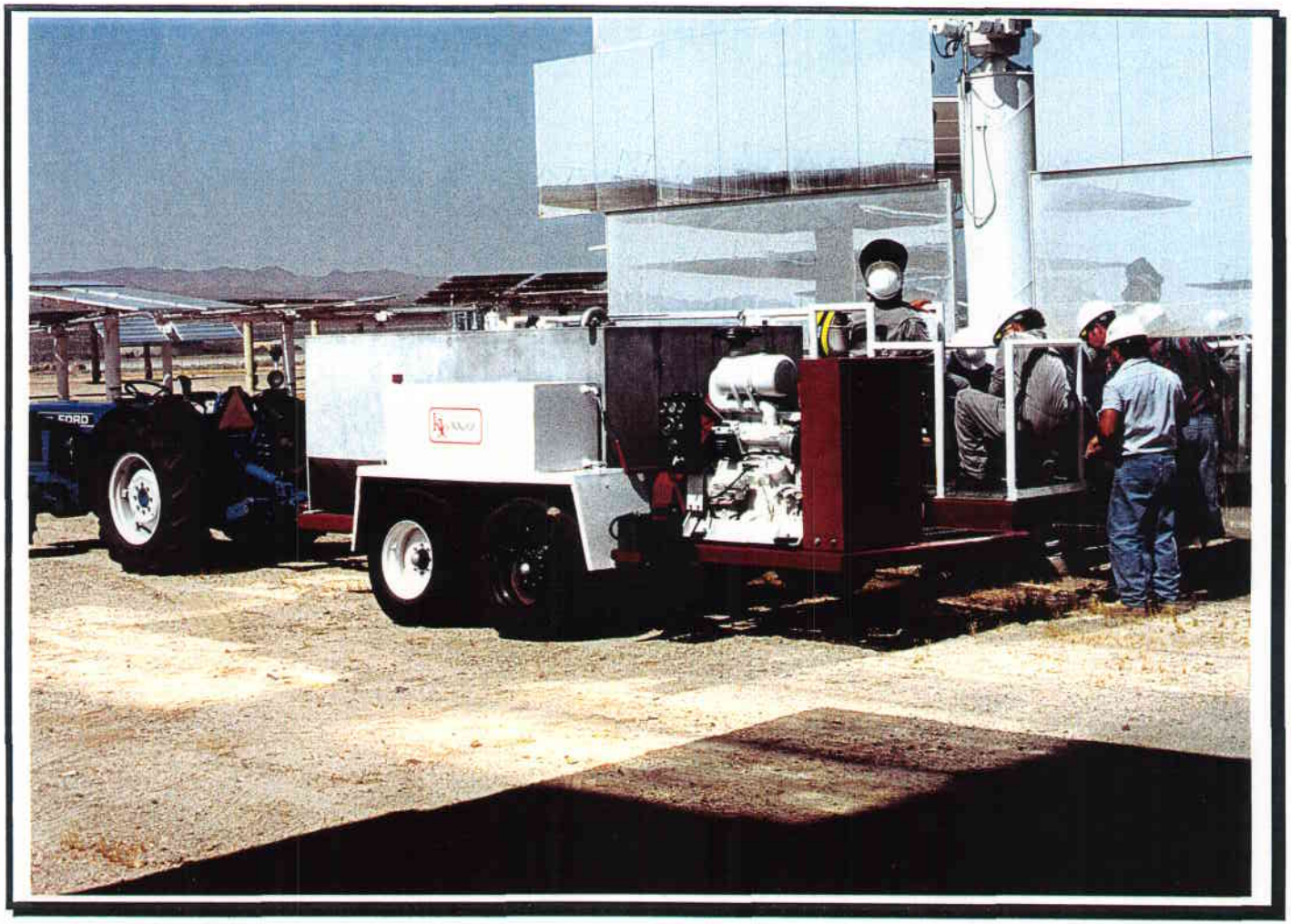
- 6/27 - After the washing
- 7/11 - Several weeks after the wash

No degradation of the sealing compound between the mirror housing and the mirror surface could be detected. It appears that the High Pressure (3000 psi) wash does not effect the facet edge seal.

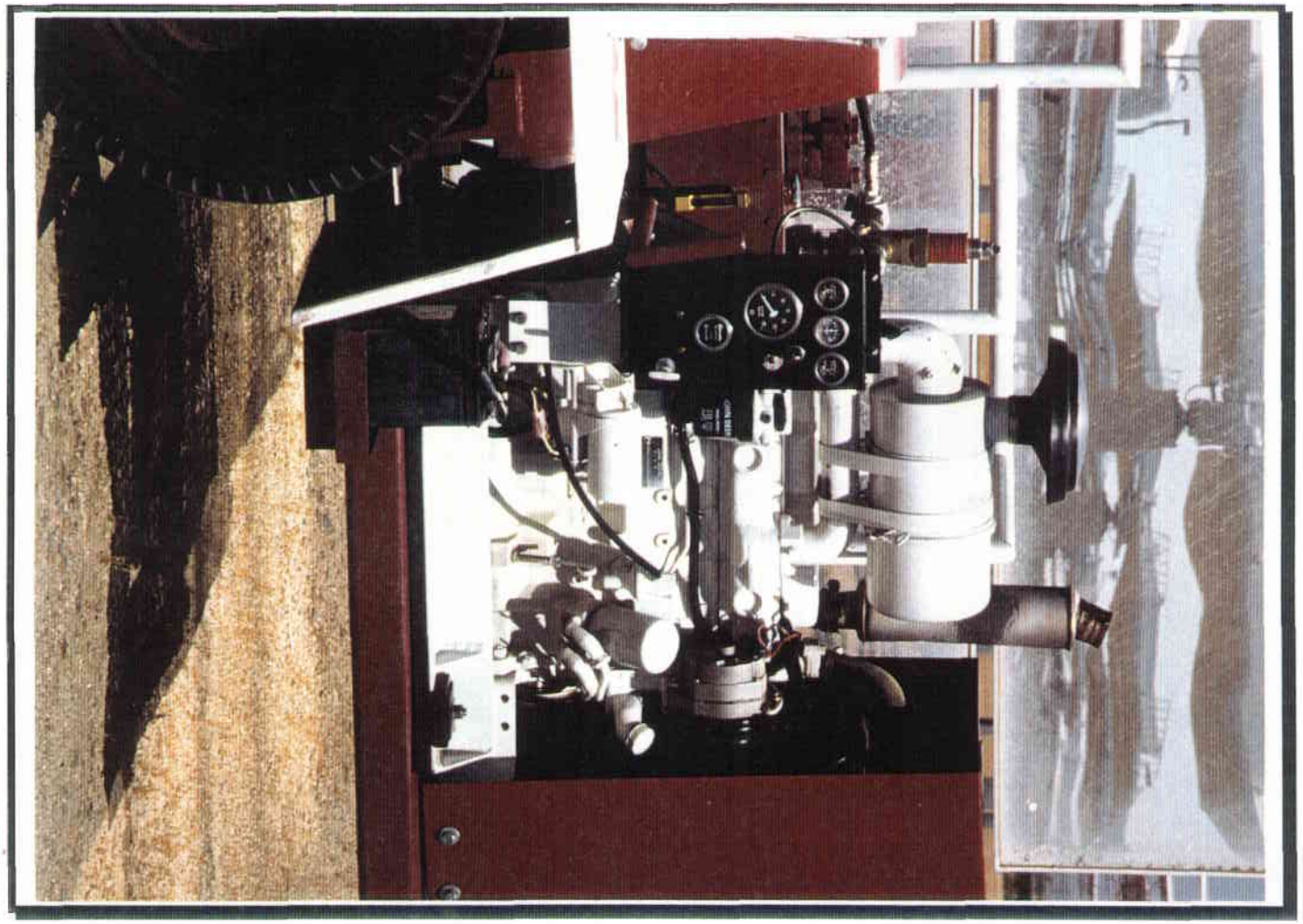
5. Appendix

5.1 Photographs

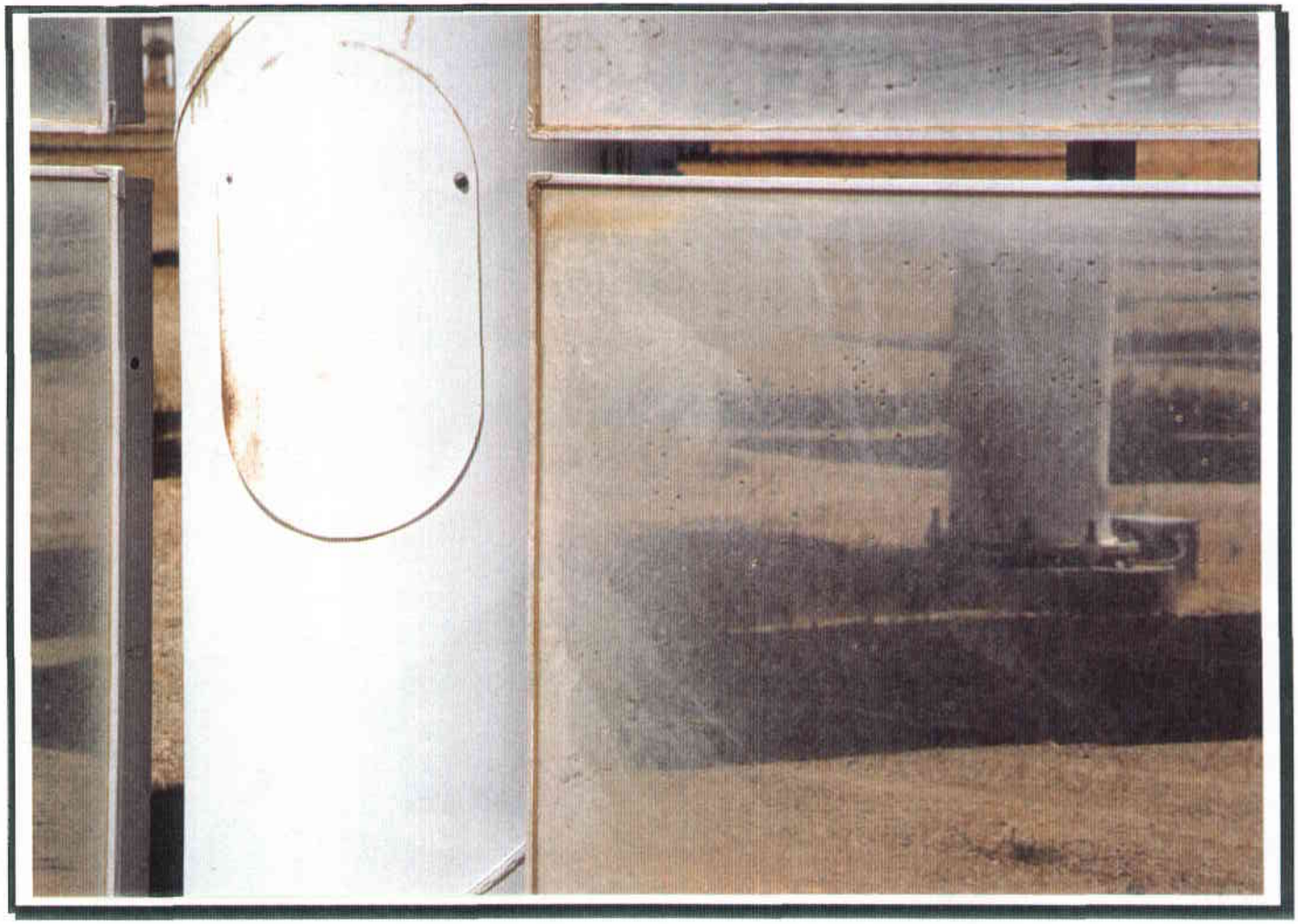
5.1.1 KJC Tractor & Wash Trailer (3000 psi with Two Wash Stations)



5.1.2 KJC High Pressure Wash Trailer (3000 psi)

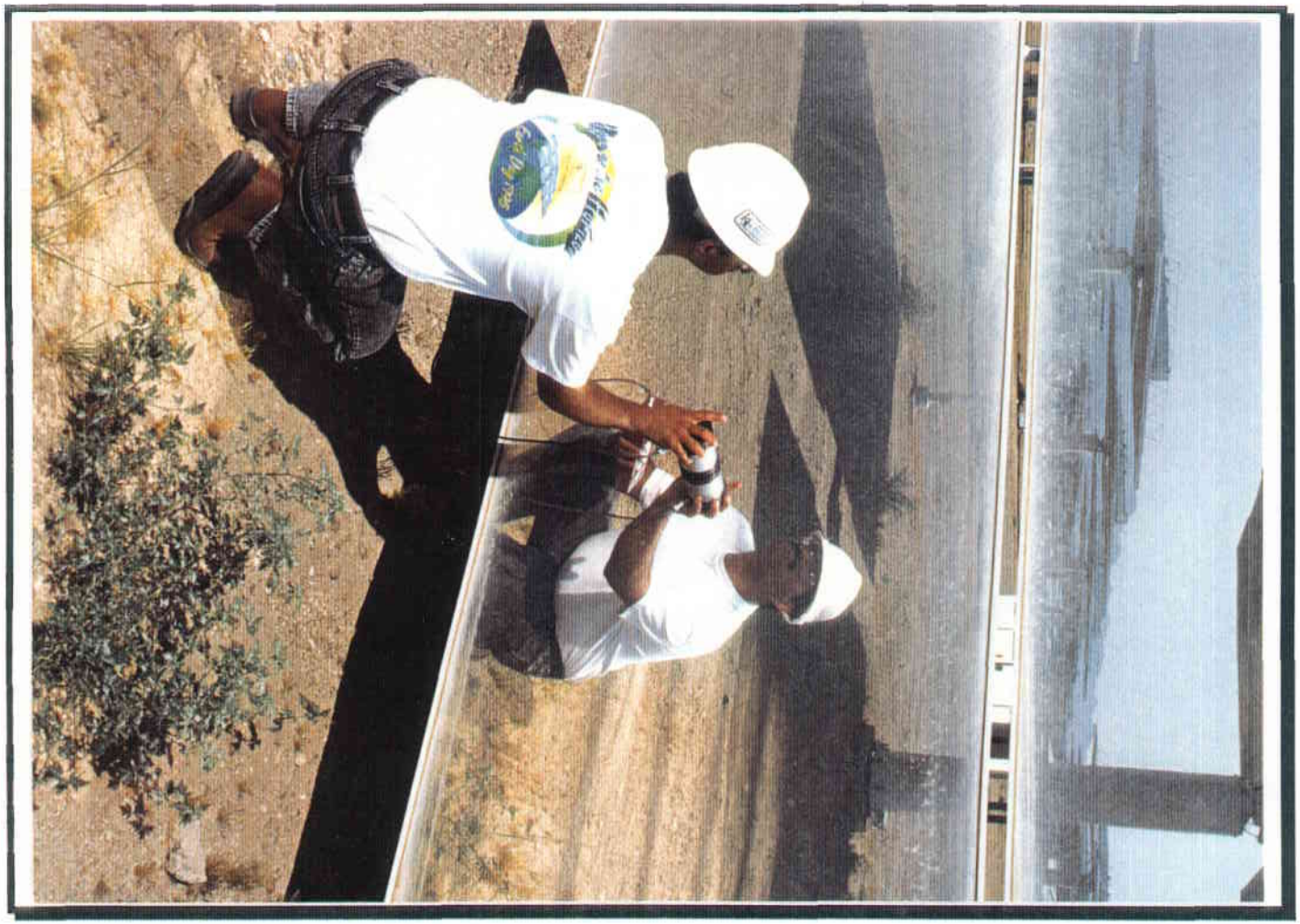


5.1.3 Heliostat 1848 Prior to Wash (Note Film)

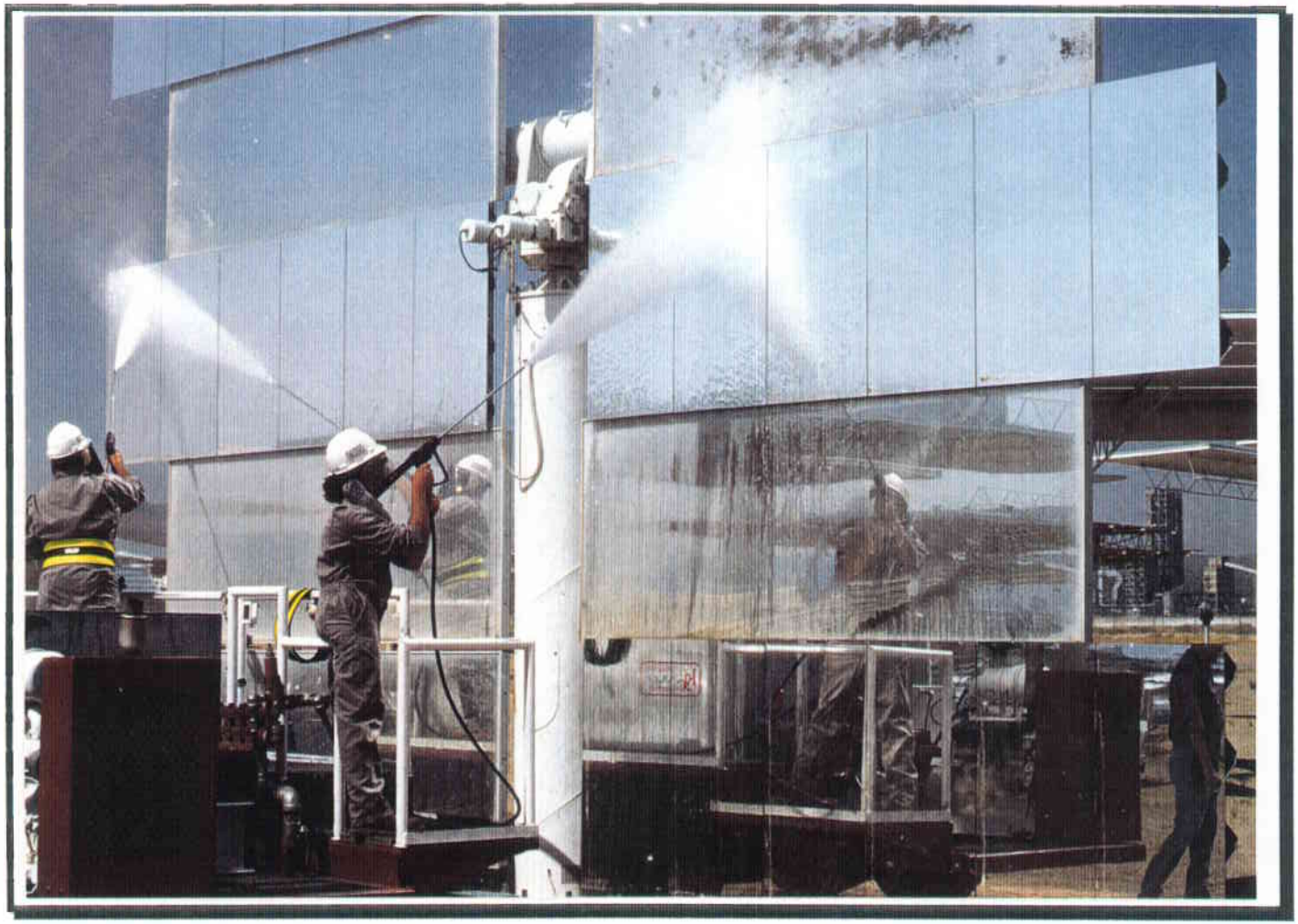


5.1.4 Heliostat 1848 Prior to Wash (Note Hand Clean Area)

5.1.5 Reflectivity Measurements of Heliostat 1848 (Prior to Wash)

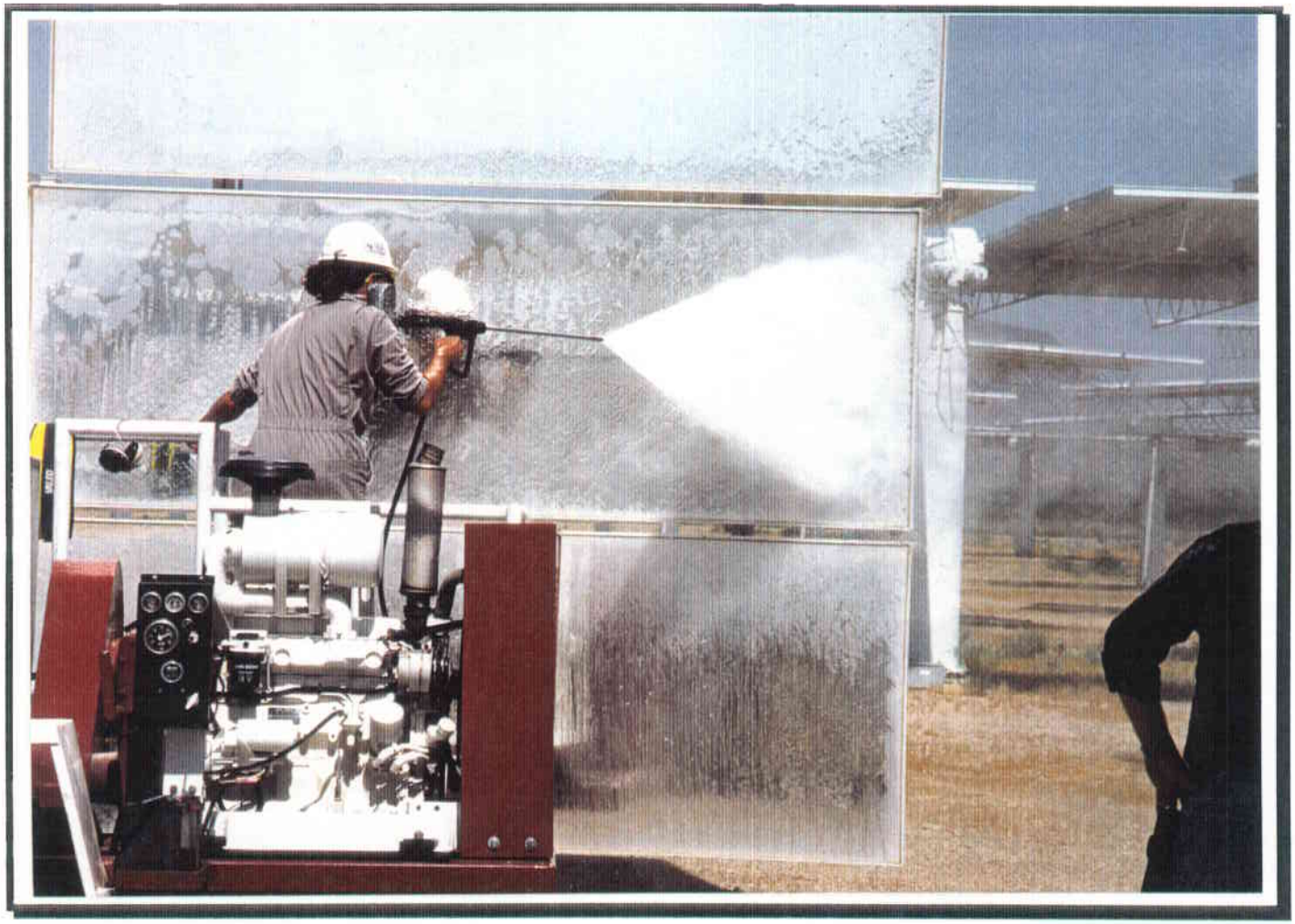


5.1.6 Wash of Heliostat 1846 (25° Nozzle)

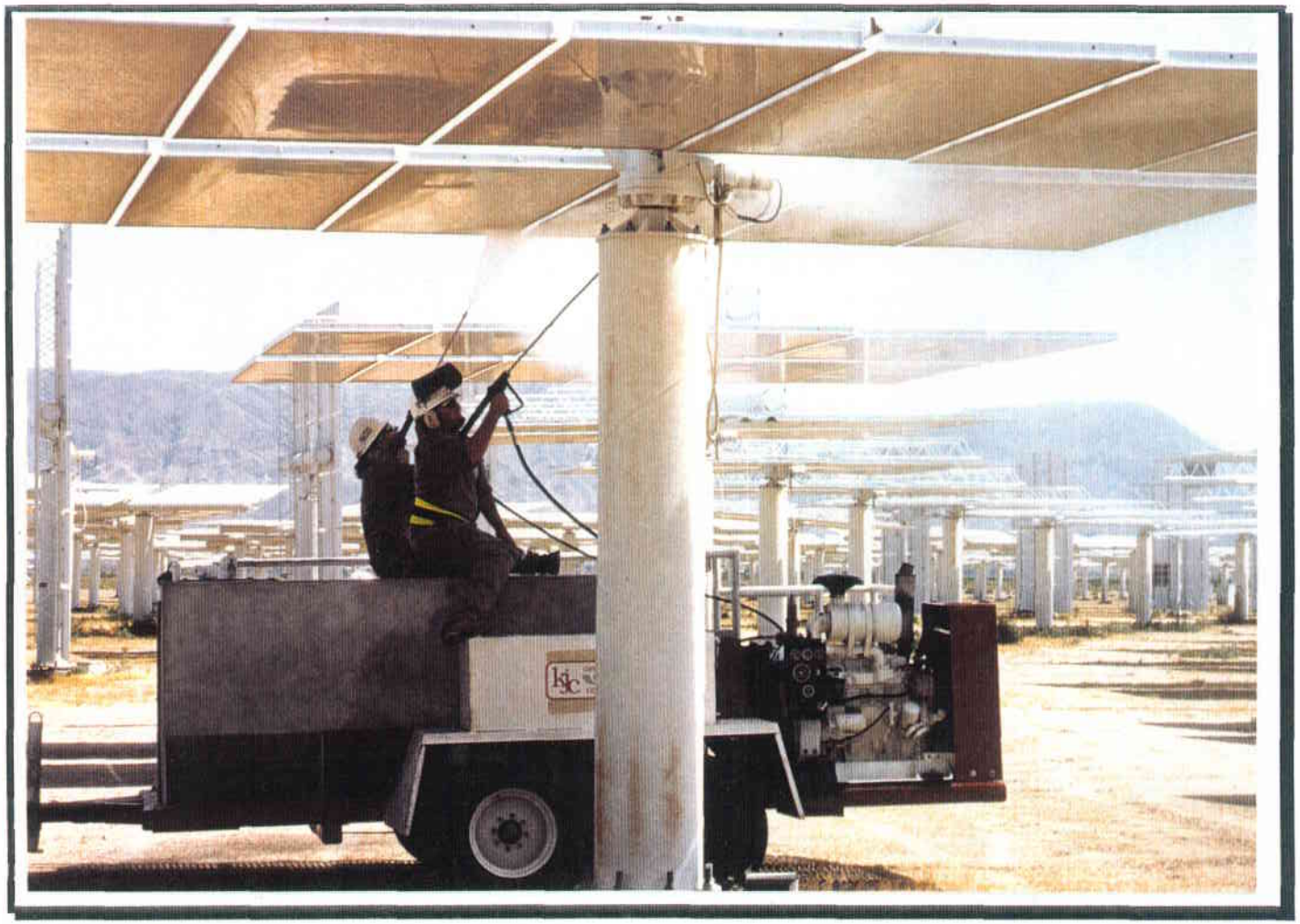


5.1.7 Wash of Heliostat 1844 (25° Nozzle)

5.1.8 Wash of Heliostat 1840 (45° Nozzle)



5.1.9 Wash of Heliostat 1740 (25° Nozzle)



5.2 Data Records

Reflectivity BEFORE Wash

Heliostat		Bottom RMS	Middle Bottom	Middle Top	Top	RMS AVG	% REF. AVG
1840	A	232.5	155.3	205.1	299.0	223.0	**61.3**
1840	B	259.0	160.6	186.1	334.3	235.0	**58.4**
1840	C	140.2	153.6	187.9	274.5	189.1	**68.8**
1840	D	127.3	160.0	230.8	290.0	202.0	**65.8**
1842	A	345.7	224.5	283.6	366.1	305.0	**44.7**
1842	B	161.1	139.7	193.4	293.7	197.0	**67.2**
1842	C	283.9	161.1	288.2	393.6	281.7	**49.0**
1842	D	154.9	129.2	191.8	328.7	201.2	**66.0**
1844	A	319.3	235.8	197.3	323.5	269.0	**51.5**
1844	B	323.5	249.4	173.5	174.7	230.3	**59.5**
1844	C	359.3	197.3	246.8	263.4	266.7	**51.9**
1844	D	187.9	175.3	167.4	150.9	170.4	**73.0**
1846	A	234.6	166.8	205.5	227.9	208.7	**64.4**
1846	B	164.4	148.3	193.5	265.1	192.8	**68.1**
1846	C	135.8	130.2	193.5	320.3	195.0	**67.6**
1846	D	133.0	128.8	165.4	256.5	170.9	**73.0**
1848	A	166.4	180.5	302.2	218.6	216.9	**62.6**
1848	B	142.2	135.3	159.3	215.3	163.0	**74.6**
1848	C	172.2	133.6	175.3	274.3	188.9	**69.0**
1848	D	130.9	131.1	140.1	183.2	146.3	**78.1**

BEFORE Wash Avg Reflectivity % **63.7**

Reflectivity AFTER Wash

Heliostat		Bottom RMS	Middle Bottom	Middle Top	Top	RMS AVG	% REF. AVG		Improve % REF.
1840	A	128.1	125.6	162.9	253.7	167.6	**73.7**	45 deg: 2 Pass	12.4
1840	B	122.6	120.8	114.0	184.0	135.4	**80.3**		21.8
1840	C	125.2	145.3	172.5	268.6	177.9	**71.5**		2.7
1840	D	101.2	111.7	157.2	273.5	160.9	**75.2**		9.4
1842	A	262.9	171.4	188.6	322.0	236.2	**58.2**	45 deg: 1 Pass	13.5
1842	B	140.0	111.2	165.2	288.9	176.3	**71.7**		4.5
1842	C	275.4	186.0	214.9	275.4	237.9	**58.0**		9.0
1842	D	135.0	97.2	186.9	318.6	184.4	**69.9**		3.9
1844	A	197.4	171.8	232.2	270.7	218.0	**62.2**	25 deg: 2 Pass	10.7
1844	B	138.0	164.9	118.3	183.5	151.2	**77.1**		17.6
1844	C	216.9	194.9	147.1	274.0	208.2	**64.4**		12.5
1844	D	144.9	158.0	116.9	118.3	134.5	**80.5**		7.4
1846	A	184.3	123.2	164.5	181.2	163.3	**74.6**	25 deg: 1 Pass	10.1
1846	B	132.8	95.2	164.1	283.8	169.0	**73.5**		5.4
1846	C	109.0	94.7	158.2	212.0	143.5	**78.7**		11.1
1846	D	101.8	89.2	124.8	198.6	128.6	**81.5**		8.5
1848	A	140.4	118.4	193.1	282.6	183.6	**70.1**	0 deg: 1 Pass	7.5
1848	B	120.2	92.6	122.0	154.2	122.3	**82.5**		7.9
1848	C	146.5	89.1	137.0	232.8	151.4	**77.1**		8.1
1848	D	105.3	103.2	117.7	139.1	116.3	**83.4**		5.3

AFTER Wash Avg Reflectivity % **73.2**

Average Improvement

	AVG	MAX	MIN
45 deg: 2 Pass	11.6	21.8	2.7
45 deg: 1 Pass	7.7	13.5	3.9
25 deg: 2 Pass	12.0	17.6	7.4
25 deg: 1 Pass	8.8	11.1	5.4
0 deg: 1 Pass	7.2	8.1	5.3