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DUST BUILDUP TESTS OF HELIOSTATS AND MIRROR SPECIMENS

By
J. B. Blackmon

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DUST BUILDUP TESTS OF HELIOSTATS AND MIRROR SPECIMENS

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PREFACE

This report was prepared under DOE Contract EY-76-C-03-1108. The assistance provided in test setup and test support by J. Pryor, Naval Weapons Center, China Lake, California, Professor Lorin Vant-Hull, University of Houston, and R. Champion and Dr. R. Pettit of Sandia Laboratories, Albuquerque, New Mexico is gratefully acknowledged. The assistance of M. Curcija in all phases of this program and the assistance of T. Ahern in data acquisition and data reduction is also gratefully acknowledged.

HELIOSTAT REFLECTIVITY VARIATIONS DUE TO DUST BUILDUP UNDER DESERT CONDITIONS

ABSTRACT

A series of tests were conducted of heliostat and mirror specimen reflectance variations in a desert environment. Factors investigated included weather, site location, mirror type, and stowage position. Reflectivity variation data are presented for full-scale heliostats and sixty mirror specimens. Reflectance monitoring was conducted on heliostats and mirror specimens located at the Naval Weapons Center, China Lake, California, and on mirror specimens located at Sandia Laboratories, Albuquerque, New Mexico. Heliostats were monitored with two types of reflective surface: second surface silvered laminated glass and first surface silvered glass with an experimental acrylic protective coating. Specimens of different mirror types were mounted on racks providing five stowage positions: continuous face-up, continuous face-down, face-up in daytime and face-down at night, face-up in daytime and near-vertical at night, and face-up in daytime to face-down at night or during heavy cloud cover (controlled by a sun sensor). A method of obtaining reflectivity data on heliostats and specimens under field conditions is presented. Reflectivity degradation rates are determined for different stowage positions and compared with weather conditions. Time-averaged reflectivity values are determined. Natural cleaning effectiveness of rain, snow, and frost is discussed. Heliostat operational procedures which appear to decrease reflectivity losses due to dust buildup are described. Measurements were conducted intermittently from mid-1976 to mid-1978.

CONTENTS

Section 1

INTRODUCTION

Major operations and maintenance considerations for solar energy collector systems are the reflectivity and transmissivity losses due to dust buildup, the associated cleaning frequency, and effects of various weather conditions on the dust buildup rates. For the central receiver solar thermal power system with its field of heliostats, these problems are of additional concern because of the cost implications of design criteria on the heliostat stowage position as well as the operational aspects for stowage at night or during inclement weather. Design requirements on heliostat stowage position depend in part on the possible decrease of reflectivity degradation rates by having a nightly inverted stow (reflector face-down) position or a near-vertical stow position, compared to the face-up position. Considerations of concern to future plant operators are the preferred stowage positions as a function of the weather conditions, the effectiveness of natural cleaning (rain, condensation, snow, frost, and ice), and the maintenance cleaning frequency.

The objectives of this test program were to: (1) obtain preliminary data on reflectivity variations at two desert locations with such variables as weather, mirror type, and stowage position, (2) evaluate the effectiveness of natural cleaning, and (3) develop a practical field technique for obtaining site specific data on reflectivity variations. One aspect of particular interest was the possible existence of a maximum or "equilibrium" dust buildup reflectivity loss.

The approach taken was to install one exposure fixture at the Sandia Laboratories, Albuquerque, New Mexico and one at the Naval Weapons Center, China Lake, California. Each exposure fixture had five racks with different stowage positions and different types of reflectors. Data on reflectivity were taken as frequently as practical, considering the scope of the program and weather conditions. The specimens at the NWC site were near an array of six heliostats so that direct comparisons could be made with actual, full size heliostats.

Results obtained to date support the conclusions that: (1) heliostat dust buildup rates are strongly dependent on exposure and stowage position, (2) variations in these rates are high due to weather conditions, (3) natural cleaning can be highly effective, (4) losses of the order of 20 to 40 percent are seen if there is no cleaning, and (5) specimen buildup rates are comparable to full-scale heliostat buildup rates.

Data obtained suggest a number of ways of minimizing the dust buildup rates and hence washing frequency. It should be noted that the detailed surface chemistry, dust composition, and attachment mechanisms are not considered in this discussion, and that the overall soiling effect of particles, films, salts, etc., deposited on the surface is loosely referred to as a "dust buildup." Information on the dust attachment and surface interaction mechanisms is contained in References 1 through 3.

Section 2

TECHNICAL APPROACH

2.1 DESERT SITE SELECTION

Site selection was dictated primarily by two factors: frequency of occurrence of certain meteorological conditions, and test support capability. Meteorological conditions expected to have bearing on the dust buildup rate were compared to select two sites representative of the extremes of interest. Table 1 summarizes these data for locations having the requisite test support capability. The Naval Weapons Center, China Lake, California has the least amount of thunderstorms, rain/drizzle, snow/sleet/freezing rain, and fog, and has low blowing dust/sand. Albuquerque has the highest frequency of occurrence of these conditions, and the same degree of blowing dust/sand. In view of the practical aspects of test site security, surveillance, monthly weather data and test support obtainable at both NWC and Sandia, it was fortuitous that these sites exhibited the extremes in averaged meteorological phenomena. The NWC site was used for heliostat array tests, and therefore, the location of one of the racks at this site allowed direct comparisons between specimens and heliostats to be made. Similar comparisons could be made with the Sandia Solar Thermal Test Facility heliostats and collectors, but this was not a part of this program.

The heliostat array at NWC is shown in Figure 1. Four octagonal noninverting heliostats and one inverting heliostat are positioned in a manner that simulates a portion of an actual central receiver field north of its tower mounted receiver. Three of the octagonal heliostats have acrylic first surface mirrors and are the noninverting, eight-petal design, normally stowed horizontally, face-up. A fourth noninverting emplaced heliostat has a laminate glass second surface mirror. The fifth is the inverted stow laminate glass heliostat. These heliostats are designated H1, H2,

Table 1

METEOROLOGICAL SUMMARY

Station	Location	Elevation	Mean Percentage of Days Per Montn For Occurrence of Various Meteorological Phenomena, From Daily Observations: Thunder-Storms	Rain/Drizzle	Snow/Sleet/Freezing Rain	Fog	Dust/Sand	Years of Observation
Naval Weapons Center	Indian Wells Valley, CA	760M	0.9	9.6	0.5	0.7	1.2	20
Edwards Air Force base	Western Mojave Desert Near Mojave	770M	1.2	9.6	0.9	1.9	1.6	19
George Air Force Base	Western Mojave Desert Near Victorville	960M	1.7	10.1	1.4	2.3	1.0	18
Kirtland Air Force base	Albuquerque, NM	1780M	10.2	22.9	6.9	2.7	1.2	26

NOTE:

Data compiled from Aerospace tapes.

Blowing dust/sand reported only when visibility is less than 1 km.

Heliostat Array Test Site located at Randsburg Wash, elevation 650M

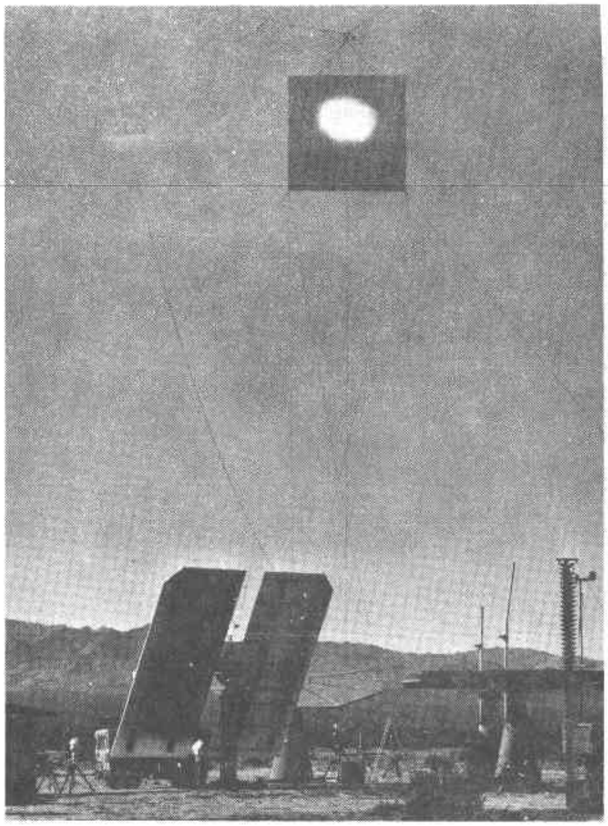


Figure 1. Heliostat Array Test Site — Randsburg Wash, Naval Weapons Center, China Lake, California

H3, H4, and IH-1, respectively. A fifth noninverting laminate heliostat, mounted on a trailer 1,100 feet northeast of the target was exposed, but not washed for six months to determine maximum reflectance loss. The reflective area of each heliostat is approximately 400 ft^2.

2.2 TEST EQUIPMENT

Figures 2 through 6 illustrate the dust buildup fixtures and sites. The test apparatus consists of the fixture containing five racks for mounting samples. The racks are supported about 12 feet above the ground by a truss structure.

Five exposure orientations are provided by racks: (1) continuous face-up, (2) continuous face-down, (3) face-up in daytime to face-down at night on an astronomical timer, (4) face-up in daytime to near-vertical at night on an astronomical timer, and (5) face-up in daytime to face-down at night on a sun presence photocell. Up to twelve samples of mirrors under each stowage condition are tested at each location.

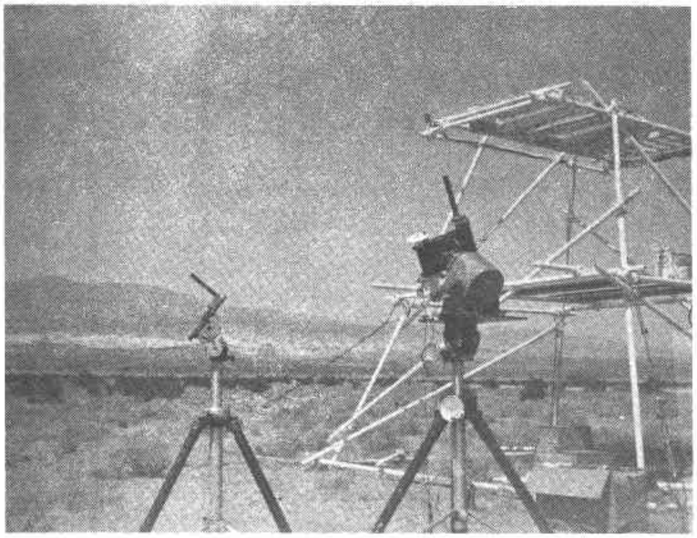


Figure 6. Pyrheliometer Setup — NWC

Primary samples include Sheldahl first surface silver, acrylic protective coating mirrors, ASG laminated glass mirrors, and second surface standard and low iron content glass mirrors. Two 5" by 5" samples of each mirror type in each orientation are provided, where feasible, to simultaneously gather data on effects of cleaning frequency and equilibrium dust buildup.

The three movable racks are controlled by DC motors and limit switches. The two racks operating off of the astronomical timer are connected by a chain and sprocket such that one rack is either face-up for exposure or face-down for nighttime stowage, while the other is face-up for exposure or near-vertical (mirror facing up at $\sim 20°$) for nighttime stowage. The third movable rack is controlled by a sun sensor, adjusted such that the rack turns face-up approximately 30 minutes after dawn and face-down approximately 30 minutes before sundown on a clear day, and turns or remains face-down under overcast conditions which accompany heavy rains. Additional discussion of the test hardware is given in Appendix A.

2.3 REFLECTIVITY MEASUREMENT TECHNIQUE

Since there is currently no suitable portable reflectivity instrument, a relatively practical technique for obtaining data in the field was devised using Eppley pyrheliometers. Eppley normal incidence pyrheliometers (NIP) have a 5.8° (100 mr) included cone angle aperture. Since light reflected from a heliostat at a cone angle greater than approximately 1° would miss the receiver, most of the data were taken with the Eppleys modified by an extender tube which provided a 1° aperture. Two techniques were used to obtain field reflectivity data. The first technique used one modified Eppley NIP which was aligned to view the sun, a reading taken, then quickly turned to view the reflected image of the sun in the mirror or heliostat, and the second reading taken. The ratio gave the net reflectivity. Measurements were repeated to improve accuracy. The second method used two modified Eppleys and one 5.8° NIP. One modified Eppley tracking the sun would be used for continuous readings while the other two would be used for readings of the reflected image. In both cases, the movement of the reflected beam is sufficiently slow that multiple measurements can be taken with a standard data logger or by hand. Variations of this technique were used, such as placing the mirror specimen on a tracking heliostat, and measuring the tracking heliostat directly. Heliostat tracking was maintained to within 0.25 to 0.5 milliradian, and therefore reflected beam angle variations due to tracking commands did not degrade the data. Calibration coefficients were verified by pointing all three at the sun simultaneously, recording the readings and comparing. Normally, these calibration readings agreed to within 0.3 percent on bright, clear days. Variations in reflectivity for a single reading observed by either of these techniques can be due to the variable degree of dust buildup on the surface or the surface waviness. Therefore, measurements were made to evaluate these effects.

Typically, multiple measurements were made at a convenient spot on the heliostats, care being taken to avoid bird droppings and other nontypical, heavily soiled areas such as the edges. Measurements were also made at several additional spots (approximately 1-3 feet apart) to determine the variation in reflectivity over the surface. In one case, measurements made at six different locations on the bottom segment of each of the three acrylic surface heliostats (H1, H2, H3) showed a standard deviation of reflectivity of $\pm$ 2.5 percent; the glass mirror (H4) measured at the same time had approximately $\pm$ 1-2 percent standard deviation. However, much greater variations in glass and acrylic surface dust-induced reflectance losses have been observed. In general, the degree of nonuniformity of reflectivity due to dust buildup was a stronger function of heliostat position and environment than surface type. Measurements could not be made with the available equipment on the upper portions of the heliostat, and therefore, greater reflectivity variations may be present, but not measured. For example, heliostat H2 (acrylic surface) has three visibly noticeable swaths of what appears to be a permanent "staining" that is darker than the lower part of the heliostat, where measurements were made with the pyrheliometers. This "staining" effect was noticeable following cleaning as well as exposure.

Reflectivity measurements of different areas of some of the exposed specimens were taken on occassion to determine the degree of reflectivity variation which can be encountered, especially with adverse environmental conditions. For example, several specimens from the Sandia rack showed a high degree of reflectivity variation and a visibly obvious variation in the amount of dust deposited, indicative of a prevailing wind blowing a dirty water film on the specimens (due to a light rain) towards one corner, where the dust settled as the water evaporated. Selected data are shown in Table 2. With the field measurement set up, it was difficult to determine precisely where on the surface the reflectivity measurements was being made, and it was important not to move the measurement area too close to the edge, since this would block off a portion of the sun image and decrease the reading. To decrease measurement error due to this variation in dust thickness, it was usually necessary to encompass as much of the specimen area as practical. However, by taking multiple measurements in roughly 1 in^2 regions, a difference of approximately 20 percent between the minimum and maximum readings was observed, and higher variations could be possible. As would be expected, the highest concentrations usually appear at the edge of the reflectors, especially if overlapping strips are used, since water on the surface can entrain and suspend the dust, flow by wind action or gravity to the edges, collect, and adhere as the water evaporates. Dust

Table 2

REFLECTIVITY VARIATIONS OVER THE SPECIMEN SURFACE

MAY 17, 1978

SANDIA, ALBUQUERQUE RACK

Specimen ID	Reflectivity Value (%)	Mean ± Standard Deviation (%)
63-5	55.3	67.2 ± 11
(Acrylic over coating)	69.4	
	76.9	
65-6	74.1	84.3 ± 9.5
	85.9	
	92.9	
63-8	51.2	54.2 ± 2.7
	54.8	
	56.5	

NOTE:

All face-up rack specimens showed significant variation with dust collection predominating in the northeast corner, probably due to wind action on a wetted surface. The above specimen data are indicative of the variations for many of the exposed specimens for May 17, 1978.

deposited near the edges is difficult to measure in the field. There was no first order difference observed in the degree of surface dust thickness nonuniformity as a function of specimen type. Both acrylic overcoated mirrors, and glass second surface mirrors showed nonuniform dust patterns on occassion. However, unlike the heliostats, it was possible to position each specimen so that at least 25-50 percent of its area was measured and, therefore, for most of the specimens and for the majority of measurements, errors in reflectance loss due to nonuniformity could be kept below 3-5 percent.

Dust concentration on the edges of heliostat panels was observed following light rains, as shown in Figure 7. It should be noted that the dust deposit is relatively high near the edges downwind of the prevailing wind during that period and that dust has concentrated on edges with and without the protective edge strips. (However, protective edge strips which overlap appear to accumulate greater amounts of dust and pose cleaning difficulties.)

Other types of nonuniform reflectance degradation have been observed. For example, dust patterns are normally seen outlining the support structure for glass reflectors bonded to, or supported by, metal beams, as shown in Figure 8. This effect appears to be due to thermal conditions affecting the deposition rate and amount of dew and frost, and is discussed further in this report.

Another surface degradation effect observed involved the deposition of edge sealant material on the surface of foam core panels due to rain. The material could not be removed by washing and it was necessary to change the edge sealant composition to eliminate this problem.

These variations suggest that total power received relative to the reflectivity value at one point may differ by several percent under relatively good conditions, and by much higher percentages under adverse conditions, for both the glass and acrylic heliostats. Therefore, a means of measuring the total power from a soiled heliostat is necessary for highly accurate assessments of dust buildup and cleaning effectiveness. However, the visually observed uniformity of dust for the majority of the heliostat area for most conditions, coupled with the relatively low deviation in the reflectivity as a function of position, shows that isolated measurements of the heliostats are adequate to meet the objectives

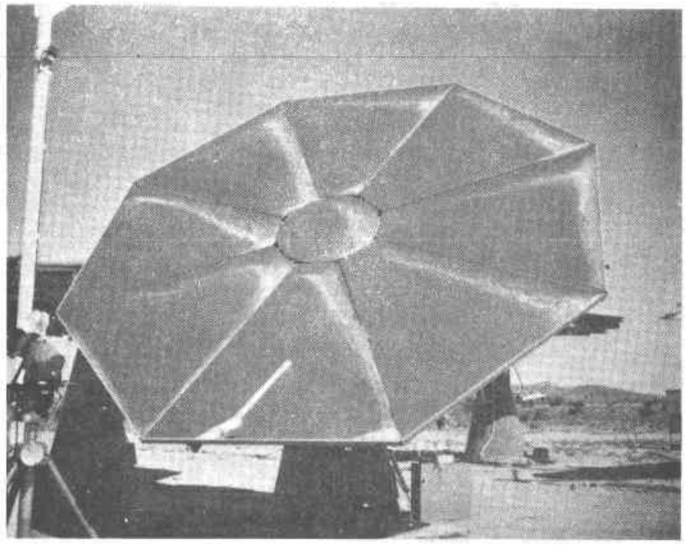


Figure 7. Dust Pattern Formed on Laminate Glass Heliostat H4 From Light Rains of 5/25/77 and 5/24/77. Winds From South and West. (Photo taken 5/26/77)

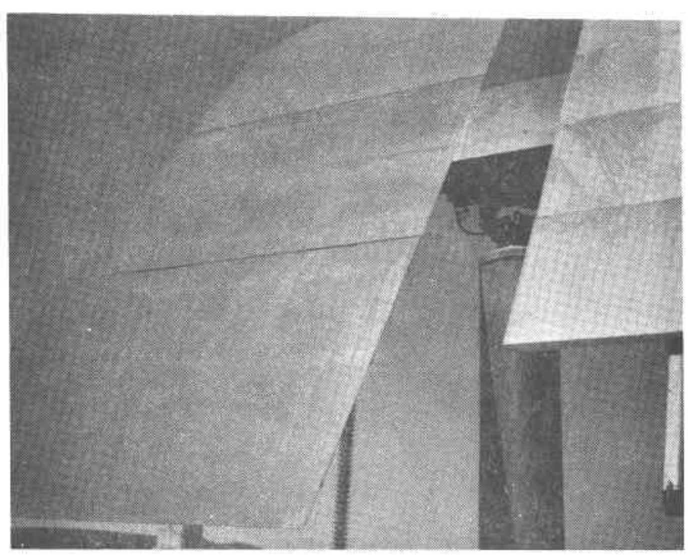


Figure 8. Accumulated Dust Pattern Variation Effected by Support Beams of Laminate Glass Panels

of this program, if care is taken in selecting the area to be measured and multiple measurements made.

Nonuniformity of the reflected beam from certain types of reflectors has produced high variations in the apparent reflectivity. The surface waviness effects observed include striations, as sometimes occurs with float glass, concave/convex surface deformations, deformations due to glass bonding to various substrates, and nonuniform protective film layers. In some cases, these nonuniformities were so severe that the specimens could not be used to obtain consistent reflectivity measurements. In one case, full size heliostat panels reflected the light in such a nonuniform pattern that the reflectivity varied from 67 to 116 percent for the Eppley 1-3 feet from the panel, with measurement locations on one of the panels only a few inches apart. This effect is shown in Figure 9 for an early panel design. In other cases, the specimens gave unrealistically high values for reflectivity, as with a few of the ASG laminate glass specimens, due to a slight focussing effect, but were sufficiently constant when clean and measured under the same conditions to be used to obtain relative degradation rates.

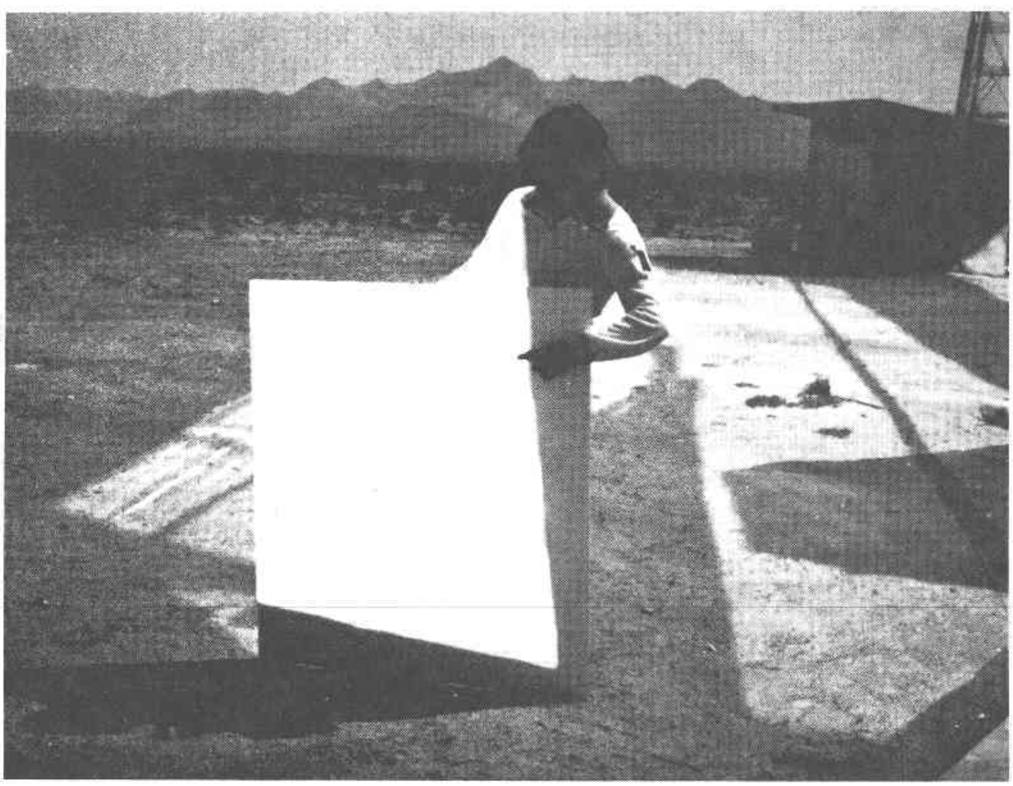


Figure 9. Nonuniform Reflected Image of Early Panel Design

With specimens exhibiting a moderate focussing or defocussing effect (± 5-10 percent) it was practical to measure these in the same manner each time. Confidence in this technique was gained by comparing measurements for the clean specimens, which showed variations of two percent maximum in nearly all cases; since the ability to clean was usually of the order of two percent for most techniques used to simulate actual field washing, and since this variation is smaller than the usually observed dust-induced degradation of approximately 10 percent, the nonuniformity due to specimen curvature was accepted. In some cases, certain specimens (ASG laminate and acrylic) exhibited too great a degree of surface nonuniformity and were discarded or the data ignored. For large panels of glass, the degree of nonuniformity has been observed to be severe in some cases, and therefore, a technique was verified which allows these curvature induced reflectivity variations to be accommodated. Figure 10 shows a pattern from an unbonded 42" x 84" low iron float glass mirror at a distance of approximately 30 feet. The alternating light/dark patterns illustrate that single reflectivity measurements made with an Eppley are subject to significant error. However, by making a series of measurements over a given region, it is possible to obtain a mean value for the reflectivity which compares well with laboratory

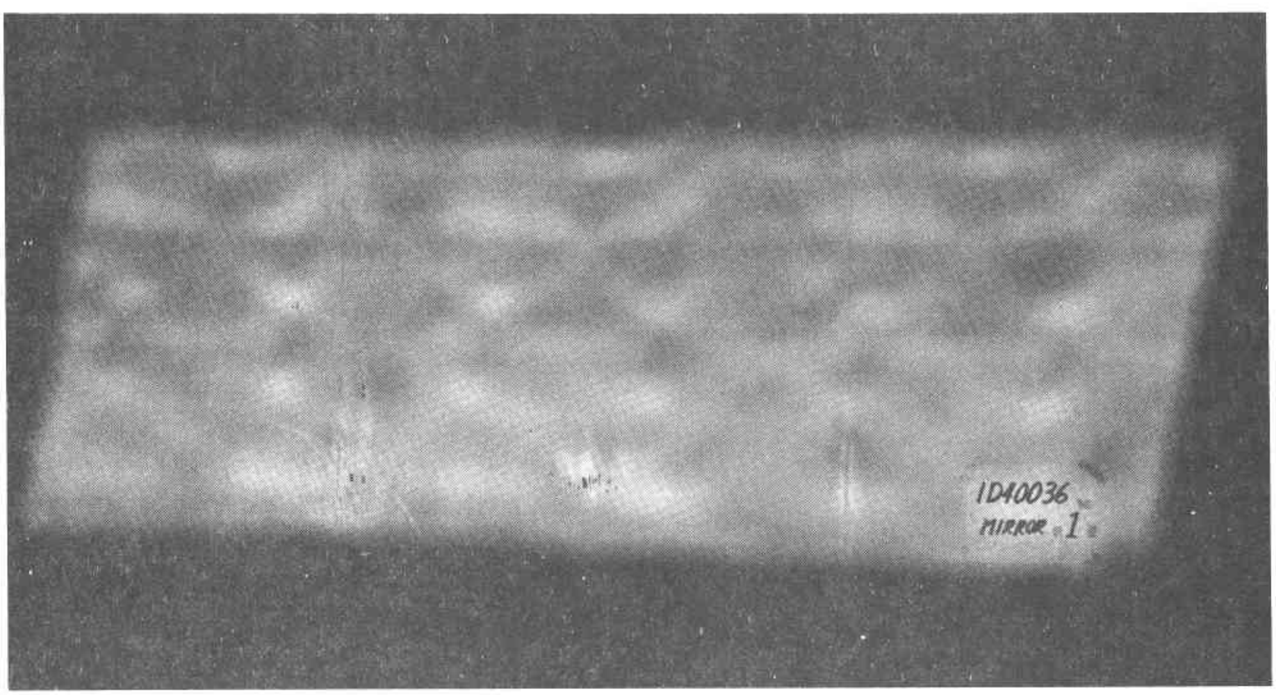


Figure 10. Reflected Image From GFE Low Iron Float Glass Panel

measurements. Table 3 shows a comparison of a series of measurements made on glass panels. An area of approximately 1' by 2' is measured with 10 measurements made vertically for 10 columns, or 100 measurements altogether, for a given distance from the mirror. The distance is then varied, and another set of 100 measurements taken. The mean and standard deviation of the reflectivities are then compared. From Table 3 it is seen that mean reflectivities are in agreement with laboratory measurements to within 1.5 percent, and that the standard deviation illustrates the degree of nonuniformity of the reflectance These measurements can be made at a rate of better than one per 3-5 seconds by two technicians.

To assess the difference between dust induced and surface waviness induced reflectance variations with a heliostat, multiple measurements of the dust buildup on heliostat H4 (laminate glass) were made on June 28, 1978, following one year of exposure in the face-up stowage position. H4 had been cleaned and stowed at the end of the Subsystem Research Experiment (SRE) Program (Reference 4) in June 1977. The mean reflectivity was 52.5%, for a drop of over 30% from the clean reflectivity. The 1° pyrheliometer was used to make 23 measurements at a distance from the mirror of approximately five feet, over an area of roughly 2' x 2', to determine the reflectivity variation due to dust thickness and composition variations and mirror waviness.

The mean and standard deviation obtained was 52.5 ± 3.0%, with a minimum of 46.8% and a maximum of 57.0%. H4 was then cleaned and the measurements repeated, obtaining a reflectivity of 83.6 ± 2.5% for 15 measurements at a distance of approximately 5 feet, with a minimum reflectivity of 79.3%, and a maximum of 87.8%. There was visible streaking on the surface, which accounted for some of the reflectivity variation. The measurements were again repeated with the pyrheliometer as close as practical to the mirror. Eleven measurements were made, giving essentially the same mean reflectivity of 83.5 with a somewhat lower standard deviation of ± 2.1%. The minimum and maximum reflectivities were 80.5% and 86.6%, respectively. At this close distance, the focus/defocus effect is minor and therefore the 2-3% standard deviation appears to be due to residual wash solution and soiling, with perhaps ± 1% standard deviation due to measurement error. Since this wash test gave fairly typical results, it appears that the spray and rinse

Table 3

REFLECTOR PANEL PERFORMANCE DATA

Specimen	Laboratory Reflectivity Measurements: Solar Spectrum, π R, Beckman %	Laboratory Reflectivity Measurements: Solar Spectrum, Specular Spectro-photometer, %			Field Reflectivity Measurements (%) with 17.5 mr Eppley Pyrheliometer (Mean ± Standard Deviation of 100 Measurements		
		4 mr	8 mr	16 mr	9 feet	18 feet	27 feet
Low Iron Float S/N 30					87.8 ± 3.1	87.54 ± 6.7	86.7 ± 8.5
Low Iron Float S/N 31	92	82	88.7	89.7	88.1 ± 3.5	87.7 ± 4.7	86.9 ± 6
Laminate #1 (PPG Low Iron)					88.0 ± 2.5	90.7 ± 3.0	87.7 ± 2.9

Reflectivity = 87.9 ± 1.15 for all measurements technique can clean effectively to within 2-3% of the optimum reflectivity, with the major problem being streaking. Streaking appeared to be due primarily to the presence of overlapping metal edge strips on the mirror outer edges, which collected dirt, were difficult to clean thoroughly, and were the source of dirty water during the final stages of draining. The absence of these edge strips would have most probably improved the cleaning effectiveness.

In order to obtain a representative reflectivity value for a soiled reflector, an area of the order of 1-6 inches in diameter must be measured, as a minimum, or multiple measurements made with small beams. This requirement results from the degree of nonuniformity observed visually for typical soiled surfaces. Often, the variations are due to droplet condensation, rivulets of water running off of the surface, etc., which make a "spotty" or streaked appearance of the order of 0.25-0.5 inch diameter or width or cause alternating heavily and lightly soiled regions of the order of .5 to 1 inch variation. Therefore, we normally positioned the Eppley approximately four feet from the heliostats and 2-3 feet from the specimens.

These techniques were developed in order to minimize as much as possible the errors due to reflector out-of-flatness and reflectance variations due, predominantly, to dust buildup thickness variation and rinse solution streaking. To some extent, these problems are present with laboratory measurements of the specimens as well as field measurements, since dust collected in one area of the specimen can be transported by water and wind to another area, or removed from the surface, and specimen out-of-flatness can cause errors. Ultimately, therefore, accurate data on heliostat reflectance losses in the field will require a means of measuring total heliostat power. However, the data obtained to date by the relatively straightforward use of the pyrheliometer has for the most part shown much less variation in reflective loss rates due to limitations in the equipment, than in the environmental variations which cause the dust buildup, and therefore the trends and conclusions reached with respect to orientation and surface type appear to be valid.

2.4 WASHING TECHNIQUE

The procedure for cleaning the heliostat by washing and rinsing the reflective surface was as follows:

1. A set of reflectance measurements of the reflective surface was taken immediately prior to washing.
2. Each reflector was positioned near vertical, approximately 70°, in a manner which avoided excessive irradiation of the surroundings, as a safety precaution.
3. The reflector was rotated so that it faced the direction of Northeast for early morning washing, North for mid-day washing, and Northeast for afternoon washing. This orientation minimized spotting of the surface due to rigid drying of the wash solution and minimized glare.
4. The entire reflective surface was sprayed with a washing solution (See Figure 11)
5. At the end of the specified soak time for the washing solution (approximately one minute) the reflective surface was rinsed thoroughly with deionized water (See Figure 12).
6. A reflective measurement of the reflective surface was taken when the surface dried.

Heliostat H3, H4 and IH-1 were washed on 9 December 1976, with reflectivity increased by 9.1, 13.8, and 3.4 percent, respectively. McGean Chemical Company A69M was used for H3 and CB 120 for H4 and IH-1. Heliostats H1 and H2 (acrylics) were washed on 18 December 1976 with reflectivity increased by 13.5 percent and 5.3 percent, respectively. These heliostats arrived at the site in a soiled condition, and both had been used for tests at Huntington Beach. Both heliostats were washed with McGean Chemical A69M, a chemical cleaning agent shown to be compatible with acrylics.

For the initial wash, relatively large amounts of wash and rinse solutions were used to obtain as high an initial reflectivity as considered practically achievable. Results are presented in Table 4. However, these results are not directly applicable to commercial plants, since the amounts used, wash time, etc., are probably not compatible with plant economics.

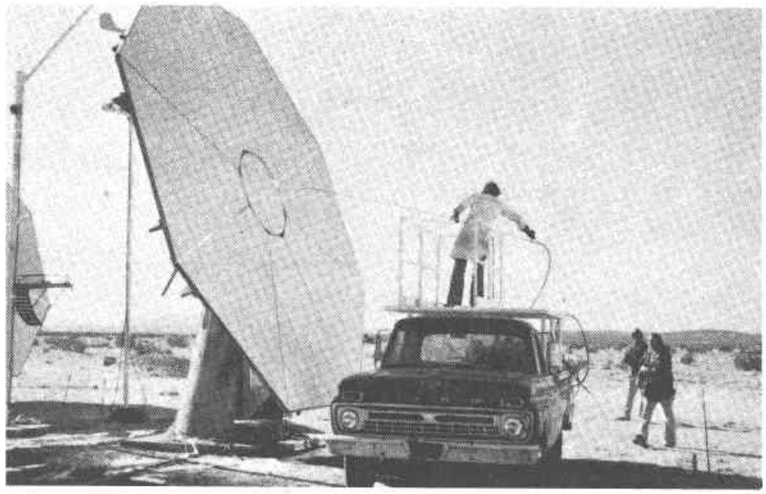


Figure 11. Spray Application of Wash Solution

Figure 12. Spray Application of Rinse Solution

Table 4

WASHING EFFECTIVITY RESULTS, 12/9/76 AND 12/17/76

Helio-stat No.	Prewash Reflect-ance	Postwash Reflect-ance	Reflect-ance Increase	Application Time		Solution Quantity		Solution Type		Nozzle Type		Waiting Period
	R1	R2	ΔR	Wash	Rinse	Wash	Rinse	Wash	Rinse	Wash	Rinse	--
	%	%	%	Min	Min	Gal	Gal	--	Water	GPM	GPM	Min
H1	67.78	81.29	13.51	4.07	3.80	5.25	12.50	A69M	D. I.	1	5	1.0
H2	64.89	70.20	5.31	5.98	5.75	6.40	15.00	A69M	D. I.	1	5	6.0
H3	77.25	86.34	9.09	5.50	3.43	9.25	10.50	A69M	D. I.	1	5	15.0
H4	72.07	85.89	13.82	3.92	2.45	6.63	10.25	CB120	D. I.	1	5	5.0
IH1	78.25	81.64	3.39	5.47	3.27	5.25	10.50	CB120	D. I.	1	5	2.0

H3, H4, IH1 washed on 9 December 1976.
H1, H2 washed on 17 December 1976.
A69-M dilution 1:10. Available from McGean Chemical
CB 120 dilution 1:20. Available from McGean Chemical

The five heliostats were washed on 15 March 1977 and reflectivity measurements made before and after. Results are summarized in Table 5. An effort was made to use minimum amounts of wash/rinse solution and to apply the solutions rapidly, to simulate commercial plant requirements. For H4, wash solution was applied in one minute, followed by a one-minute dwell time to loosen the accumulated dust, and then deionized water rinse was applied for two minutes. This procedure worked as well as the longer rinse time and quantity tests performed on the other heliostats.

Based on our experience to date, it is likely that with automated equipment, wash solution can be applied in less than one minute (i.e., 30-45 seconds), followed by a 30-second to one-minute dwell time, and a 30-second to two-minute rinse. It also appears that one gallon of wash solution and five to six gallons of deionized water are minimal quantities. Both washing solutions (A69M and CB 120) are effective, with CB 120 more so. However, the CB 120 contains slight amounts of hydrofluoric acid which may eventually degrade the glass surface. Therefore, CB 120 has been reformulated without the hydrofluoric acid. Additional investigations to obtain suitable cleaning agents and techniques will be conducted as a part of a future study on collector cleaning techniques, funded by Sandia, Albuquerque.

Heliostat H4 was measured, cleaned, and remeasured on June 29 and 30, 1978, using CB 120 as the cleaning agent and the usual spray-on wash and rinse technique.

Heliostat H4 was cleaned with the surface facing the sun, at 10:30 AM (PDT) to assess the effect of the insolation on drying time and cleaning effectiveness. The heliostat was washed as usual, with a spray application of the wash solution, followed by a one minute dwell time, and a 1-2 minute rinse. It was noted that the wash solution dried at the top of the heliostat and wash solution was quickly reapplied in that region to prevent spotting. Drying was probably due to the surface being relatively warm initially. As shown in the photograph of Figure 13, approximately 15 minutes were required for the heliostat to dry, and streaking and spotting problems were not caused by the surface facing the sun, but by the protective edge strips. From a practical standpoint, these data indicate that regions which can entrap dirt and con-

Table 5

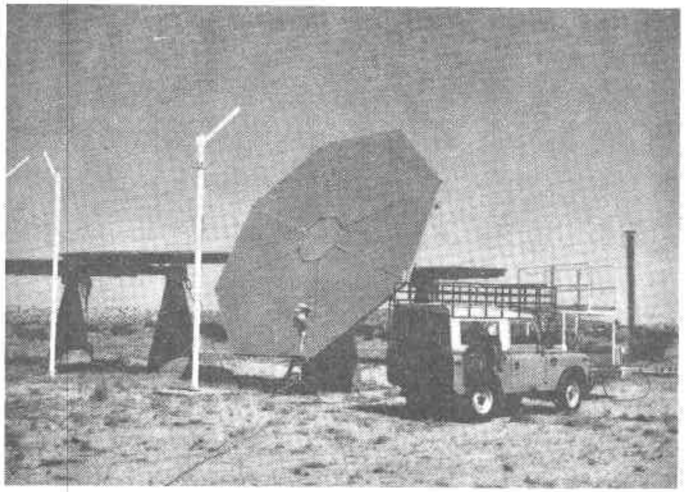
WASHING EFFECTIVITY RESULTS, 3/15/77

Heliostat No.	Prewash Reflectance	Postwash Reflectance	Reflectance Increase	Application Time		Solution Quantity		Solution Type		Nozzle Type	
	R1	R1	ΔR	Wash	Rinse	Wash	Rinse	Wash	Rinse	Wash	Rinse
	%	%	%	Min	Min	Gal	Gal	--	Water	GPM	GPM
H1	65.88	78.24	12.36	1.0	5.0	1.50	14.00	A69M	D. I.	1	5
H2	56.08	76.50	20.42	1.0	3.7	1.25	8.75	A69M	D. I.	1	5
H3	69.23	87.46	18.23	1.0	3.0	0.75	8.0	A69M	D. I.	1	5
H4	73.31	87.65	10.69	1.0	2.0	1.25	5.75	CB120	D. I.	1	5
IH1	76.80	86.5	8.30	1.4	2.8	1.60	7.75	CB120	D. I.	1	5
IH1'	72.16*	86.60	14.44								

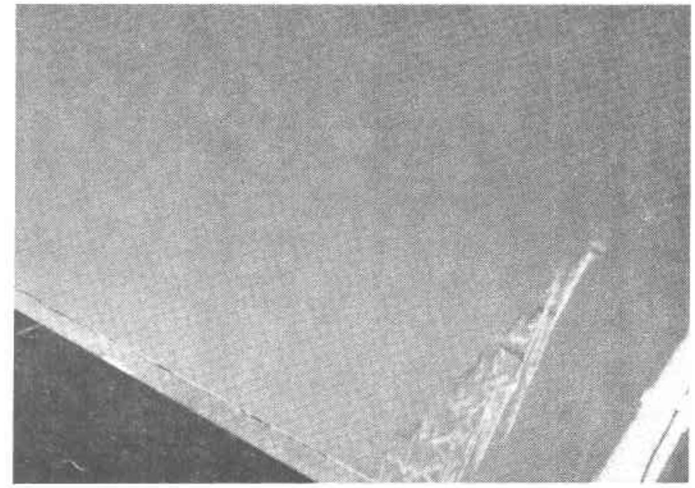
Waiting period between wash and rinse = 1 minute

IH1' = 3/32 in. float glass (foam core)
IH1 = 1/4 in. float glass (laminated)
H4 = Laminated glass

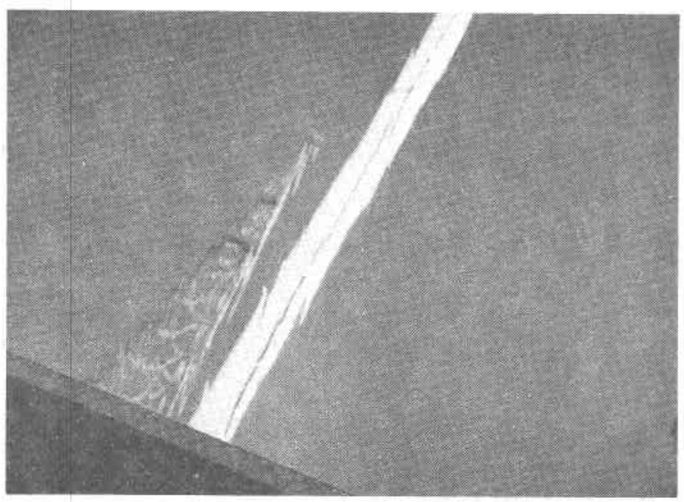
H1, H2, H3 = Acrylic coating
*Reflectivity of IH1' as received from plant following fabrication



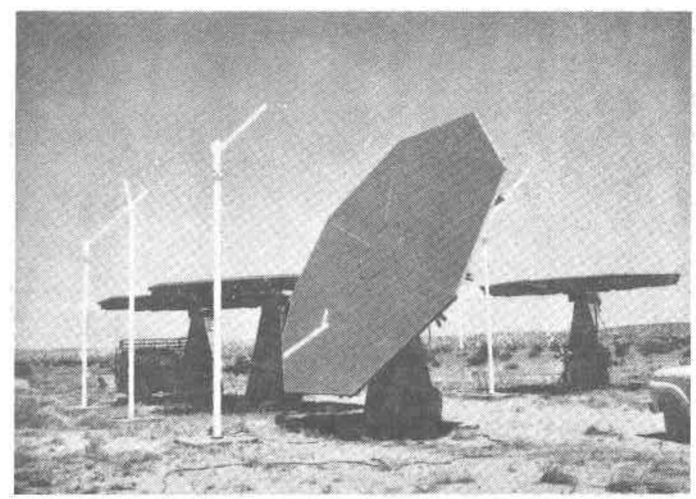
HELIOSTAT H4 PRIOR TO WASHING



RINSE WATER RUNOFF AT 10:33 AM, JUNE 30, 1978
APPROXIMATELY 3 MINUTES AFTER CESSATION OF RINSE



RINSE WATER RUNOFF AT 10:39 AM



HELIOSTAT AT 10:40 AM

Figure 13. Heliostat H4 Washing. (Heliostat Essentially Dry at 10:45 AM Air Temp ~75°F)

taminate the rinse water, such as the overlapping protective strips, should be avoided in the heliostat design to minimize streaking.

No attempt was made to simulate practical washing techniques with the specimens. In general, they were washed with a cleaning agent using a soft rag, rinsed with deionized water, and allowed to air dry. Various solutions were used, including CB120, A69M (McGean Chemical), Cutscum (Fisher Scientific), and Ball Brothers commercial glass cleaner. All solutions provided adequate cleaning.

2.5 RESULTS OF REFLECTIVITY VARIATION MONITORING

Preliminary results are presented below for the effects observed over the last one and one-half years on both heliostats and specimens.

2.5.1 Long Term Exposure

Specimens and heliostats have been exposed for periods ranging from several weeks or months to over a year without washing to observe the long-term reflectivity degradation. During this period, the surfaces have been exposed to a variety of weather conditions including rain, snow, frost, and high winds, sand/dust storms, as well as the common relatively benign conditions typical of the Southwest desert. For example, heliostat H5 was exposed face up at NWC from December 1976 to June 1977. On June 22, H5 was found to have a reflectivity of 62.2 percent, for a drop of approximately 25 percent.

Specimens exposed at Albuquerque without washing from July 1976 to November 1977 were measured. Results are shown in Table 6. Each rack has two ASG laminate glass mirrors, two second-surface mirrors, and two Sheldahl acrylic mirrors. The reflectance loss values were determined for each specimen and the mean and standard deviation values determined for each rack for the combined specimens. The acrylic tends to show a slightly greater degree of soiling that the glass, but the differences are not significant for this set of data. It can be noted that the permanent face-up position has a loss approximately five times that of the permanent face-down position and the face-up/face-down and near vertical stow reflectivity losses are one-half that of the face-up.

Table 6

AVERAGED REFLECTANCE LOSS DATA FOR SPECIMENS EXPOSED FROM JULY 1976 TO NOVEMBER 1977 AT ALBUQUERQUE, NM

Specimen Rack	Mean ± Standard Deviation Loss for Six Specimens per Rack
Permanent Face-up	27.0 ± 12.8
Astronomical Timer Face-up/Face-down	14.5 ± 3.7
Astronomical Timer Near Vertical Stow	13.6 ± 2.3
Sensor Face-up/ Face-down	13.2 ± 3.2
Permanent Face-down	5.3 ± 4.8

Specimens were exposed at NWC for long periods to assess long-term effects. Table 7 shows the results for each specimen on the permanent face-up and permanent face-down racks for the period January 26, 1978 until June 28, 1978 for a duration of 153 days. The face-up specimens show a reflectance degradation of roughly 20% to 40%, with the acrylic surface losses higher than for the glass surfaces. The losses for the glass specimens are similar to that for the heliostat, H4; the average loss for 65-15 and 65-19 (ASG laminate) was approximately 30%, and the loss for H4 during the same period was 31%. Generally, it was found that the NWC face-up specimens and NWC heliostats showed similar loss rates. It should also be noted that the permanent face-down specimen incurred a relatively small loss, of the order of 5% maximum. Heliostats H1 and H4 were monitored from June 1977 until December 1977 without washing, and found to have dropped to 45 percent and 62.5 percent respectively, for losses of approximately 35 percent and 25 percent, respectively, compared to their clean values. During this period, there were three trace rains with a severe rain (1.7 inches on August 16, 17 and 18). These data indicate that

Table 7

DEGRADATION DATA COMPARED TO PREVIOUS MEASUREMENTS
(JANUARY 26, 1978 TO JUNE 28, 1978)
NWC SPECIMENS

	ASG LAMINATE				SECOND SURFACE				SHELDAHL ACRYLIC			
	ID	INITIAL	FINAL	DEGRAD. RATE % DAY	ID	INITIAL	FINAL	DEGRAD. RATE % DAY	ID	INITIAL	FINAL	DEGRAD. RATE % DAY
FACE UP	65-19	80.5	52.5	.183	64-8	67.8	48.8	.124	63-12	87.4	52.5	.228
	65-15	89.1	57.5	.207	64-9	67.8	50.6	.112	63-13	87.4	47.5	.261
									63-28	86.2	41.6	.292
FACE DOWN	65-20	81.6	80.5	.007	64-10	70.0	64.9	.033	63-25	85.1	87.0	-.013
	65-21	82.2	79.2	.020					63-26	85.1	80.5	.030
									63-11	85.1	79.2	.039

DURATION: 153 DAYS

NOTE: Rains occurred in iterim which affect degradation rate.

equilibrium values of reflectivity, if they exist, are too low to be considered as a means of eliminating all mirror washing for the desert conditions observed. It is possible that certain sites have rain, snow, frost, and ice in sufficient amounts and with sufficient frequency to essentially eliminate the need for mirror washing, but this has not been observed in our tests.

2.5.2 Weather Effects on Reflectivity

Key weather conditions which exacerbate dust build-up and induce a form of natural cleaning are described below. In some cases, rain and frost cleaned the mirrors, while in others they tended to cause reflectance loss. However, by properly positioning the heliostats, these effects can often be used to advantage. Specific beneficial and adverse cases are described below.

2.5.2.1 Frost Effects

During the week of 10 January to 17 January 1977, a heavy frost was deposited on the mirrors. Frost is an additional reflectance degradation effect since airborne dust is deposited and collected during the condensation and icing phase, but it can be a very effective method of cleaning the mirrors. We have noted that the heliostat radiates to the night sky, and reaches a temperature of the order of 2.5°F less than the ambient temperature, as seen in Figure 14.

Since the heliostat thermocouple is located underneath the steel channel, the glass surface should have a temperature somewhat lower than that measured. Therefore, the top surface of the glass may be approximately 3°F less than the ambient temperature. Determination of the number of heavy frosts to be encountered for a particular site should account for this type of temperature difference, rather than using ambient temperature data alone. The hygro-thermograph of Figure 15 corresponds to the heavy frost observed in mid-January, and is included in case future effort is directed toward forecasting natural cleaning condition frequency.

The frost formed on the mirrors is shown in Figures 16 and 17. Approximately 30 minutes after bringing the heliostats onto track, the laminated glass mirrors (both the inverted and baseline designs) were cleared of frost. As the frost melted, the water and ice mixture flowed off the mirror, carrying off

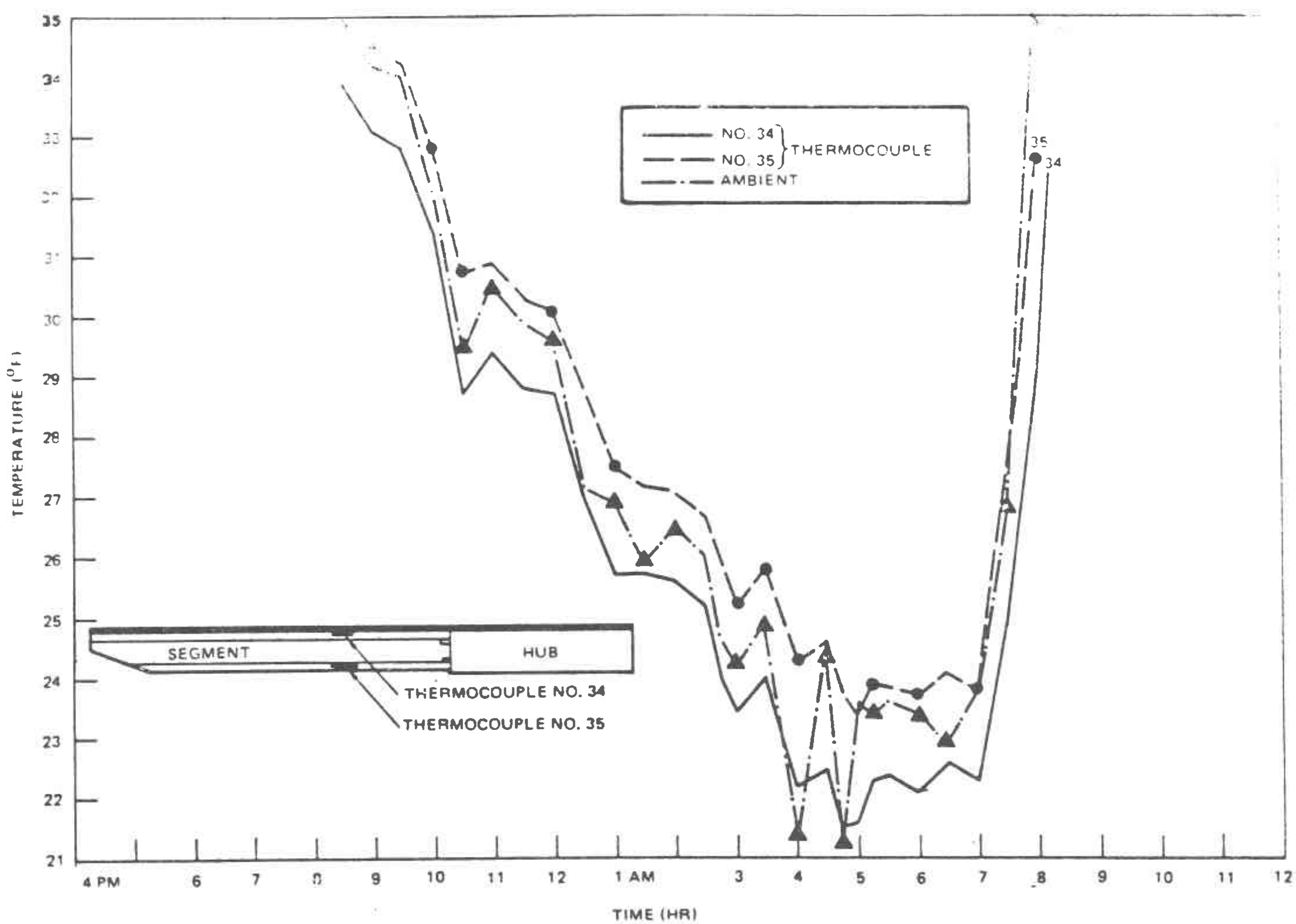


Figure 14. Nocturnal Temperature Variation

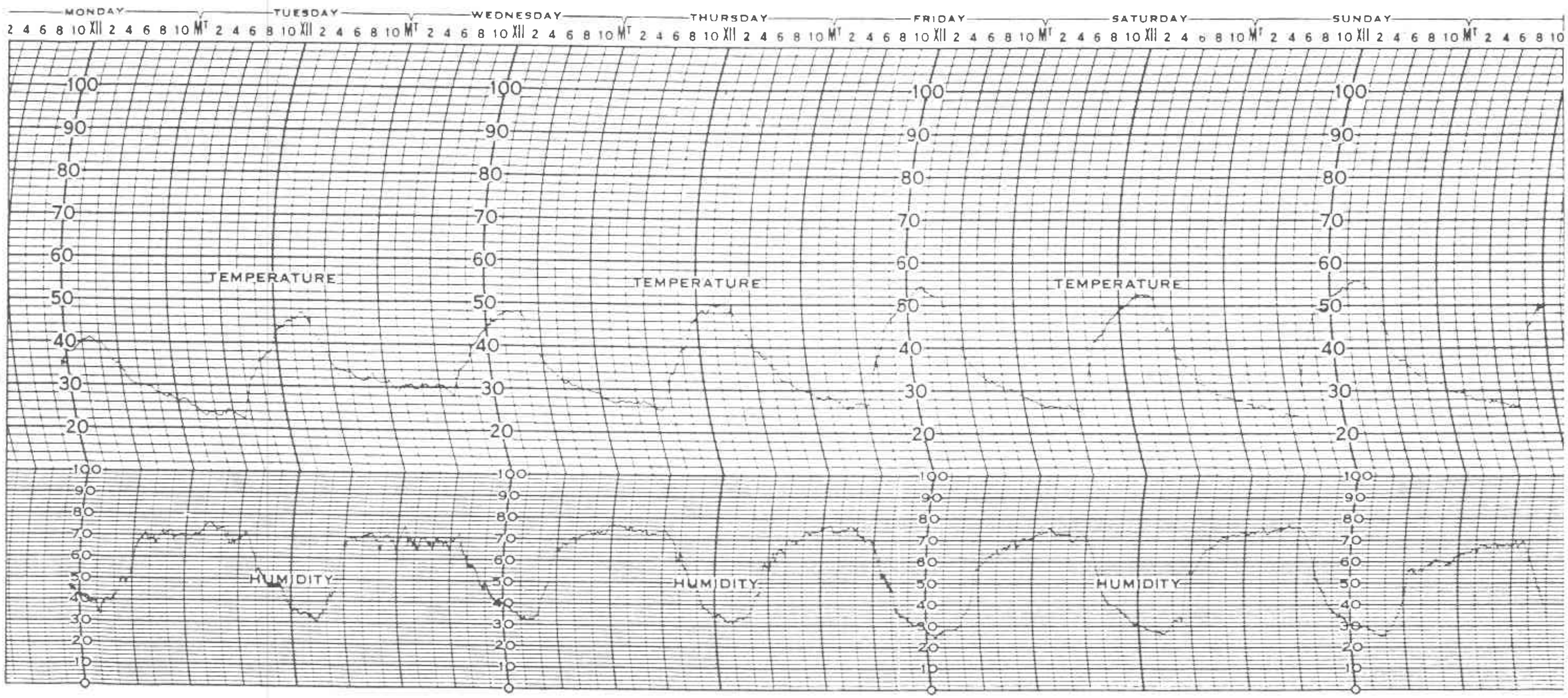


Figure 15. Temperature/Humidity Data 1/10/77 to 1/17/77

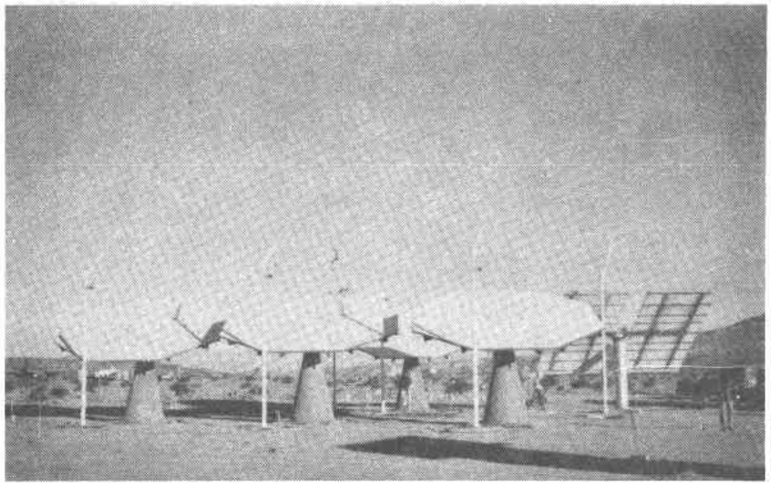


Figure 16. Frost at 8:15 AM

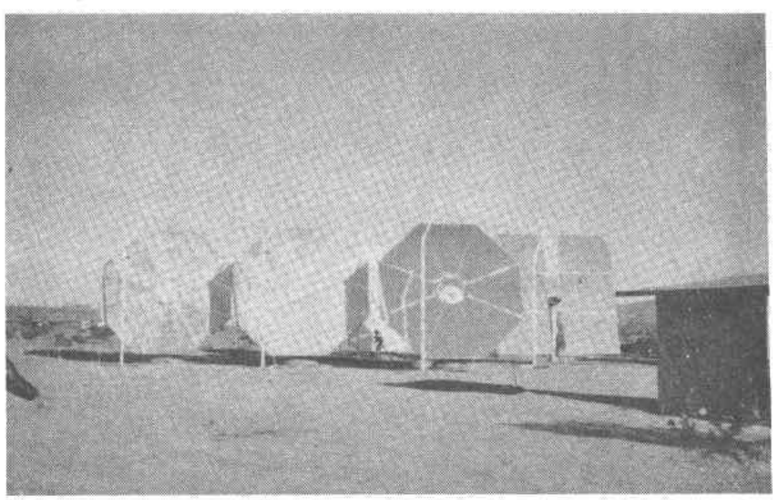


Figure 17. Frost on H4 and IH-1 (Glass) Essentially Clear After 30 Minutes. Substantial Frost Remains on Acrylic Heliostats IH1, H2, and H3

dirt and dust and cleaning the mirrors more effectively than the initial wash for heliostats H2, H4, and IH-1; H3 was cleaned as effectively as the initial wash, and H1 was cleaned somewhat less effectively. The glass mirrors, mirrors, H4 and IH-1, were cleaned more effectively than the acrylics because the water/ice mixture could flow easily on the surface.

On the acrylic mirrors, the time required to cause substantial melting was approximately one hour. The water tended to bead-up and remain in place, which decreased the washing effect. The difference in time required to melt the frost is primarily due to the nonwetting effect of water on the acrylic, but the additional absorption of radiation in the glass of the second surface laminate may be more than a negligible effect. Noticeable scattering of the reflected light from the acrylic heliostats due to the water beads was evident after 2.5 hours (10:30 AM).

These times correspond to the North field heliostats on track. For heliostats in the eastern and southern portion of the field, the mirrors would be approximately horizontal and the frost melting rate and cleaning effectiveness would be reduced. If frost is shown to occur frequently for a site, the loss in energy may have to be considered and adjustments made in the operating procedure for startup.

It has also been noted on almost all occasions in which frost and dew form on the mirror surfaces that the region directly above the structural supports does not tend to accumulate frost or dew as readily as the mirror surface outside of this region (See Figure 18). The effect is evident whether the structure is bonded to the glass or directly beneath it. Also, the areas immediately outside the structural member area accumulate a noticeably thicker dust film, apparently due to the condensation depositing airborne dust particles and capturing windblown dust more effectively than with a dry surface.

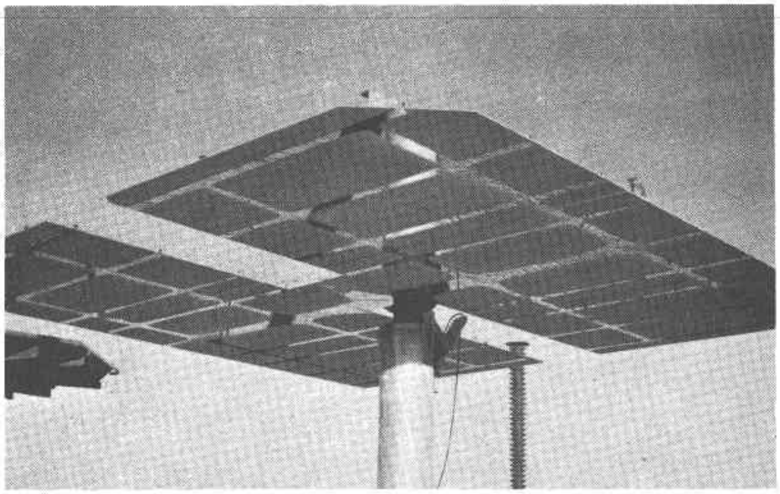


Figure 18. Frost on Inverted Stow 7:45 AM January 10, 1977

2.5.2.2 Rain/Snow

Rain has been observed to both improve and exacerbate the dust buildup problem. There was a relatively heavy rain on 5 and 6 January 1977. The total quantity measured was 1.26 inch. Since the octagonal heliostats were stowed horizontally, the dirt/dust could not be washed off as effectively as in a near-vertical storage position. It was our visual observation that the rain had not cleaned the mirrors, and had left them with a "spotty" appearance. The improvement in reflectivity noted several days after the rain is in fact due more to the following frost, which occurred for several days after the rain and effectively cleaned the mirrors as the heliostats were moved to a tracking position in the morning. The inverted heliostat had been stowed face-down during this period. It was observed that accumulated dirt from the mirror support structure was washed onto the mirror surface, causing substantial smearing over the surface within one to two feet of the outer edge of the mirror panels. It is apparent that both the octagonal and inverted stow heliostats should be tilted from horizontal or perhaps stowed near-vertically during substantial rain storms to obtain maximum rinsing of the reflective surface.

Heliostats H1 and H4 were measured on January 26, 1978 following seven months of exposure. Approximately 1.5 inches of rain fell on December 27, 1977 and 0.5 inch on January 3. On January 10, 11, 15, and 16, the rainfall was 0.05, 0.08, 0.62 and 0.46 inch. On January 25, reflectivity measurements were taken of H1 and H4, giving 62 percent and 83.5 percent, respectively. H4, the laminated glass heliostat was within roughly three to four percent of its nominally clean value, indicating that it had been effectively washed and demonstrating that heavy rains can clean glass surfaces even for horizontal stowage. Data from H1, an acrylic heliostat, are not as encouraging, since H1 has a clean reflectivity of approximately 83 percent. The relatively ineffectual washing of H1 is primarily due to the stowage position coupled with: (1) water not being able to wet the acrylic surface as well as glass, (2) a greater degree of dust adherence to the acrylic.

However, rain does not necessarily clean the soiled surfaces. Specimens were cleaned on May 17, 1978, and exposed at Sandia until June 17, 1978. Reflectance loss data are shown in Table 8. Rainfall on June 13, 1978 does not appear to have cleaned the specimens, with the exception of five specimens which appear to have been cleaned slightly. This data set is another example of the high degree of variability of environmental effects on dust buildup.

Approximately two inches of snow fell on March 25, 1977. The baseline heliostats were placed in a near-vertical position to determine if the snow would clean the surface. It was observed that snow slid off of the glass surface of H4, resulting in a very clean surface; although measurements could not be made, it was visually obvious that snow was a highly effective cleaning agent for glass. The snow did not readily slide off of the acrylic surface, and in fact caused part of heliostat H3 to delaminate, probably as a result of the combined differential coefficient of expansion stresses and the gravity induced stress on the acrylic film.

2.5.2.3 Sand/Dust Storm

A rather severe sand/dust storm with wind gusts to 48 knots was encountered on March 9, 1977, the only one of its kind during the test period. Reflectance

Table 8
SANDIA SPECIMEN REFLECTIVITY AND DEGRADATION RATE SUMMARY
MAY 17 - JUNE 15, 1978

	ASG LAMINATE				SECOND SURFACE				SHELDAHL			
	ID	INITIAL	FINAL	DEGRADATION RATE (%/DAY)	ID	INITIAL	FINAL	DEGRADATION RATE (%/DAY)	ID	INITIAL	FINAL	DEGRADATION RATE (%/DAY)
Sensor Face Up/ Face Down	65-1	88.5%	64.8%	.79	56-2	86.2%	63.6%	.753	63-1	89.7%	63.6%	.870
	65-2	73.9%	58.0%	.53	62-1	64.8%	68.2%	-.113	63-2	88.6%	61.4%	.907
Astronomical Time/Near Vertical Stow	65-4	78.4%	80.4%	-.066	57-2	88.6%	81.6%	.233	63-3	84.1%	69.3%	.493
	65-5	86.4%	80.4%	.200	58-2	73.9%	60.2%	.457	63-4	86.4%	69.0%	.580
Astronomical Timer Face Up/ Face Down	65-6	105.7%	89.7%	.533	59-2	79.5%	68.4%	.370	63-5	89.8%	73.6%	.540
	65-7	98.9%	87.4%	.383	60-2	68.6%	62.1%	.217	63-6	86-2%	74.7%	38
Permanent Face Up	65-8	92.5%	70.1%	.747	54-4	74.0%	60.9%	.437				
	65-9	80.5%	66.7%	.466	62-2	67.8%	58.6%	.307	63-8	88.5%	64.4%	.803
Permanent Face Down	65-10	89.5%	97.7%	-.273(3)	55-2	85.0%	86.2%	.040	63-9	85.0%	85.6%	-.050
	65-11	96.5%	92.8%	.12								

NOTES: (1) Rain fell on June 13, 1978

(2) Some ASG laminate specimens (especially 65-6,7,10, & 11) showed a strong focus effect which makes consistent reflectance data difficult to obtain. Visually, most of the specimens, even the permanent face-down specimens, appeared soiled, relative to the clean condition of May 17, 1978, but the rainfall caused a high degree of surface film non-uniformity.

(3) Invalid data point due to specimen curvature.

data was obtained on March 2 and on March 14; therefore, the loss due to the sand/dust storm can only be approximated. It was visually observed that a fine dust was deposited on the surface by the storm, but measurements could not be taken until five days later.

The reflectance loss for H2 and H3 after the dust storm was observed to be 10.95% and 7.17%, respectively. These measurements were taken in a relatively small area (6 inches x 6 inches) of the bottom panel of each heliostat.

The reflectivity of the laminate glass baseline heliostat (H4) remained essentially unchanged (0.5 percent loss, which is within standard deviation for reflectivity loss), which indicated that the glass tended to stay substantially cleaner than the acrylic for dust storm conditions, perhaps because dust did not adhere to the glass as strongly as to the acrylic.

2.5.3 Effects of Soiling on Reflectivity

Two major effects of dust layers on reflectivity have been investigated: (1) effects of dust on the scattering of the reflected light, and (2) the effects of dust induced reflectance loss as a function of the incident light angle.

2.5.3.1 Dust-Induced Reflected Beam Scattering

Preliminary results on the effect of dust scattering are shown in Table 9. Data were taken with the 5.8° and 1° NIP's and reflectivity in both cases are defined as the ratio of the reflected beam flux density (watts/m^2) measured by the NIP's to the incident solar insolation measured with a 1° NIP. Thus, the difference in reflectivity between the higher value associated with the 5.8° NIP and the lower value for the 1° NIP is the amount of light scattered outside of the 1° cone and within the 5.8° cone. The variation observed is surprisingly large, and unexplained, but the impact on the reflectivity is significant in most cases. A possible explanation for the variation in results may be that since measurement with the 1° and 5.8° aperture could not be taken of the same area with the equipment used, the nonuniformity in the dust layer thickness are affecting the results. There also may be intrinsic variations in the non-specular properties of

Table 9

DUST BUILDUP EFFECTS ON ANGULAR DISPERSION

Specimen	Rack	1° Reflect. (%)	5.8° Reflect. (%)	1° Clean (%)	1° Loss (%)	5.8° Loss (%)	Δ Loss (%)
63-14 (SI)	Photocell face-up/	71.94	73.90	82.60	10.66	8.70	1.96
63-15 (SI)	face-down	68.42	70.0	88.32	19.90	18.32	1.58
63-22 (SI)		72.57	75.85	88.86	16.29	13.01	3.28
63-24 (SI)		71.16	77.00	88.27	17.11	11.27	5.84
64-2 (SS)		53.48	59.3	70.48	17.00	11.18	5.82
64-3 (SS)		59.06	62.60	70.66	11.60	8.06	3.54
65-17 (ASGL)							
65-18 (ASGL)							
63-16 (SI)	Astronomical	57.80	73.30	86.36	28.56	13.06	15.50
63-17 (SI)	Timer Near	60.33	72.49	85.44	25.11	12.95	12.16
63-18 (SI)	Vertical Stow	65.83	71.64	88.22	22.39	16.58	5.81
64-4 (SS)		54.94	59.52	69.03	14.09	9.51	4.58
64-5 (SS)		55.59	60.90	69.46	13.87	8.56	5.31
65-12 (ASGL)		75.92	79.22	90.33	14.41	11.11	3.30
65-13 (ASGL)		75.87	81.03	91.02	15.15	9.99	5.16
63-19 (SI)	Astronomical	69.73	75.91	87.18	17.45	11.27	6.18
63-20 (SI)	Timer Face-up/	73.16	77.34	87.67	14.51	10.33	4.18
63-21 (SI)	Face-down	73.13	75.40	89.78	16.65	14.38	2.27
64-6 (SS)		61.94	63.10	67.99	6.05	4.89	1.16
64-7 (SS)		59.60	61.97	69.44	9.84	7.47	2.37
65-14 (ASGL)		74.16	77.90	89.35	15.19	11.45	3.74
65-16 (ASGL)		80.67	86.05	93.01	12.34	6.96	5.38
63-12 (SI)	Permanent Face-up	60.80	69.60	85.84	25.04	16.24	8.80
63-13 (SI)		60.20	63.80	88.17	27.97	24.37	3.60
63-28 (SI)		59.52	63.10	88.17	28.65	25.07	3.58
64-8 (SS)		48.2	55.0	69.98	21.78	14.98	6.80
64-9 (SS)		47.2	49.9	69.63	22.43	19.73	2.70
65-15 (ASGL)		61.12	72.5	89.80	28.68	17.30	11.38
65-19 (ASGL)		61.30	66.2	81.34	20.04	15.14	4.90

SUMMARY

Position	Glass Reflectivity Difference (%)	Acrylic Reflectivity Difference (%)
Photocell Face-up/Face-down	4.68 ± 1.6	3.16 ± 1.9
Astronomical Timer Near Vertical Stow	4.6 ± .9	11.2 ± 4.9
Astronomical Timer Face-up/Face-down	3.16 ± 1.8	4.21 ± 1.9
Permanent Face-up	6.4 ± 3.7	5.33 ± 3.0
Total	4.7 ± 1.3	5.97 ± 3.6

the dust deposits. Similar comparisons of the reflectivity for 1° and 5.8° included cone angles were made with the heliostats. On December 1, 1977, heliostat H1 (acrylic coating) was measured. Data are given in Table 10. The reflectivity values obtained by dividing the reflected solar insolation by the incident solar insolation (measured in millivolts output) are seen to be very consistent ($\pm$ 1.14% for the 1° pyrheliometer, and $\pm$ .83% for the 5.8° pyrheliometer, even with the incident solar insolation varying $\pm$ 4% and 1.1%, respectively, due to atmospheric variations. The 7% increase in reflectivity for the 5.8° pyrheliometer is consistent with the mean difference due to scattering of 5.97 $\pm$ 3.6% observed for the acrylic specimen.

These data indicate that for certain types of solar collectors (flat plate, trough, etc.), the dust buildup effect is less significant than with heliostats required to reflect light within a 1° cone angle.

2.5.3.2 Reflectivity Dependence on Incident Angle

One test was performed in the field on heliostat H4 to determine the effect of incident angle on the reflectivity loss due to dust. The near-normal reflectivity loss was approximately five percent. The Eppley NIP was set up to view reflected light from a heliostat oriented to give known angles; with the sun angles known, the incident and reflected light angles with respect to the heliostat were determined. Results are shown in Figure 19.

These data indicate that there may be an additional reflectance loss due to greater scattering at small incidence angles, but it is not large. In practice, most heliostats are not oriented to give small incidence angles, and therefore, the additional loss of $\sim$ 5 percent at small angles is probably a negligible effect for plant operation. Further, these results show that errors due to off-normal incidence angles of as much as 30-45 degrees would have a negligible effect on the reflectance data obtained during the monitoring of these tests, at least for the usual 5-10 percent losses normally observed.

Table 10

HELIOSTAT REFLECTIVITY

NWC, CHINA LAKE

Date: 12/1/77

Helio-stat ID	1° Pyrheliometer Reflected Intensity MV	1° Pyrheliometer Solar Intensity MV	Reflectivity (Ref. Int./Sol. Int.) %
H1	2.847	6.620	43.0
	3.040	6.625	45.88
	3.067	6.805	45.07
	3.040	6.768	44.92
	3.275	7.330	44.68
	3.248	7.015	46.3
		6.8605 ± 0.272 (± 3.96%)	44.98 ± 1.14

Helio-stat ID	5.8° Pyrheliometer Reflected Intensity (MV)	5.8° Pyrheliometer Solar Intensity (MV)	
H1	3.418	6.445	53.03
	3.380	6.460	52.3
	3.233	6.330	51.07
	3.280	6.340	51.74
		6.39375 ± .068 (1.07%)	52.03 ± .83

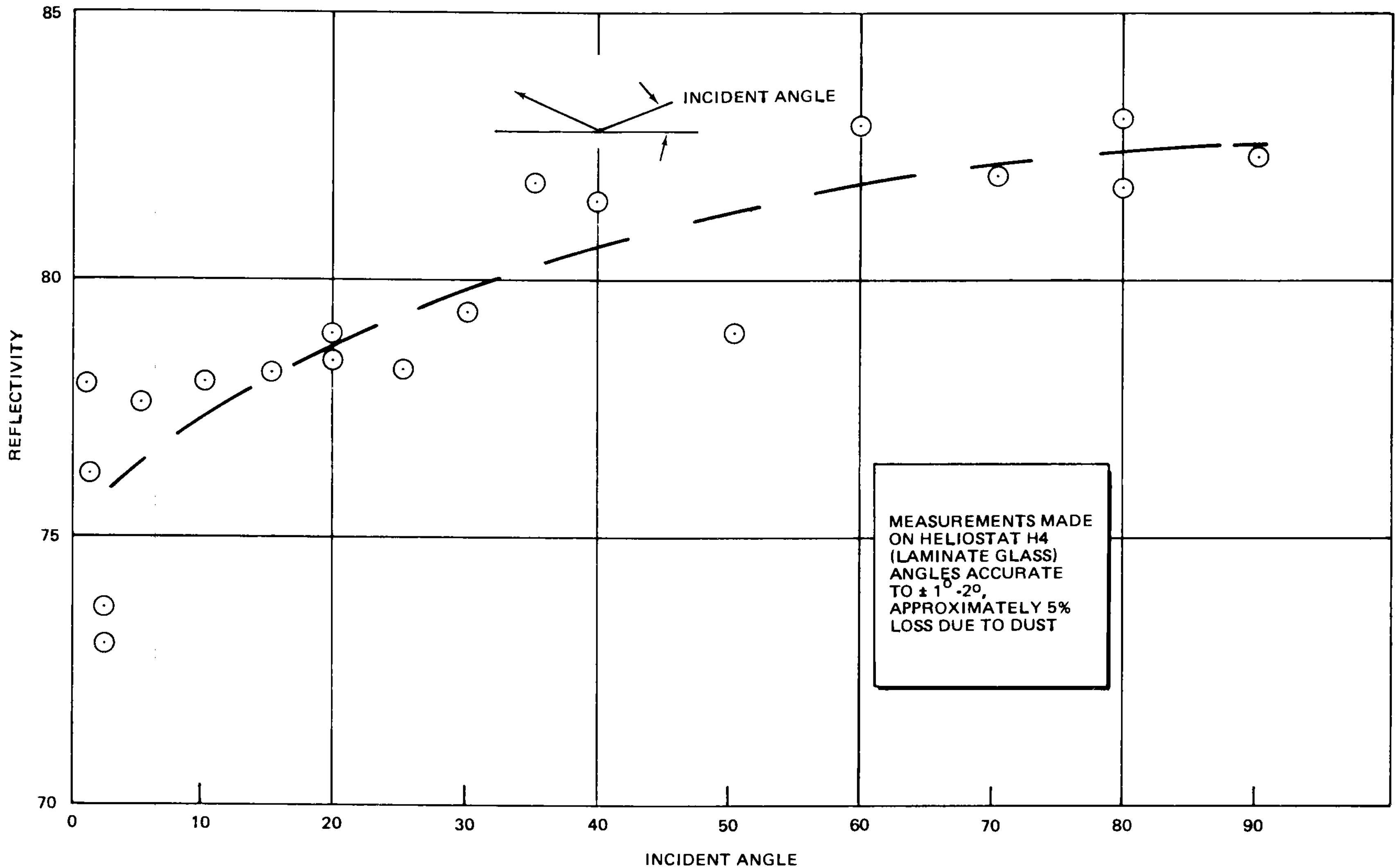


Figure 19. Reflectivity Dependence on Incident Angle

2.6 REFLECTIVITY DEGRADATION

Intermittent reflectivity degradation data have been obtained and time-correlated with the weather conditions for an overall period of one and one-half years. Representative data for degradation rates and observed values have been selected and are presented in the following for both the heliostats and the specimens. In general, dust buildup induced degradation rates are calculated by subtracting initial and final reflectivities, and dividing by the period between measurements, to obtain a value in percent reflectivity loss per day. However, if during this period significant rain, snow, etc., falls, the rate is not calculated, since the natural cleaning usually causes an abrupt increase in reflectivity and would therefore give a lower value for the degradation rate. All data on degradation rates are, therefore, obtained for periods not including these natural cleaning phenomena.

In addition, the time averaged reflectivity for the heliostats over a period of approximately seven months has been calculated, including the effects of natural cleaning or manual washing occurring at a frequency of approximately once per month.

The rate of decrease in heliostat reflectivity under actual desert field conditions has been monitored fairly regularly from December 1976 to May 1977, and intermittently until June 1978. Results are summarized in Table 11 and Appendix B. Results for December and January indicate that reflectivity of both the acrylic and glass mirrors can be degraded by six to eight percent in two to three weeks and can remain essentially constant for approximately the same period. A surprising difference in degradation occurred during this period between heliostats H2 and H3, which are side by side and would be expected to show more closely similar reflectivity curves. H2 decreased from 70% to 64% between December 17, 1976 and January 3, 1977, whereas H3 decreased slightly, from 83.6% to 82.8%.

It is also interesting to note that IH-1 and H4 show a similar rate of reflectivity degradation, even though IH-1 was kept in the face-down stowage position for approximately two-thirds of this time, both day and night, to establish what was expected to be a baseline minimum degradation rate for near-continuous inverted stow relative to continuous face-up stow. Normally, however, continuous face-down stowage does result in very low reflectance degradation rates.

From January 3, to January 14, 1977, H2 showed a ten percent increase (due to rain and frost) whereas H3, being initially cleaner, showed a 2.5 percent increase.

Comparing the March 14, 1977 prewash reflectivity measurements of Table 11 with the March 2, 1977, data shows that H1 lost 1.5 percent and H4 was essentially unchanged, whereas H2 lost 11 percent and H3 lost 7.2 percent. These variations in degradation rate for neighboring heliostats has not been explained. Better agreement is found on comparing data from February 15, and March 1977. In this period, heliostat IH-1 can be included; IH-1 had been disassembled on March 1 and reassembled on March 4 and was, therefore, not available for reflectivity measurements on March 2. For the period February 15 to March 14, heliostats H1, H2, H3, H4, and IH-1, had degradation rates of 9, 14, 9, 8, and 9 percent, respectively, for an average degradation of approximately 10 percent (.37 percent per day). February and March had higher wind conditions than December and January, and there was a dust storm on March 9; such conditions would be expected to cause an increase in the reflectivity degradation rate.

Snow fell on March 25 and heliostats H1, H2, H3, and H4, were positioned near vertical to observe the cleaning effect. Visually, H4 was cleaned as well as any washing case. However, weather conditions prevented measuring the reflectivity. Therefore, it is assumed that the reflectivity of H4 following the snowfall was near its maximum value of 88 percent. Between March 25, and April 1, H4 thus lost approximately five percent reflectivity in seven days, but during the next week the reflectivity remained essentially constant.

The data available from December to April were time-averaged to estimate the effective heliostat reflectivity. Results summarized in Table 12 show that the three noninverting acrylics (H1, H2, and H3) lost approximately 7 to 8 percent and the noninverting laminate lost 6.5 percent. The average period between either washing or natural cleaning by frost, rain, and snow was roughly one month for the test period.

Calculating the degradation rates from Table 11 and determining the mean and standard deviation, it is seen in Table 12 that the degradation rates for the four face-up heliostats are of the order of 0.36 to .45 percent per day. Comparable results were obtained for the specimens, with some instances of higher degradation rates, as discussed below.

The heliostats were washed on June 2, 1977, and the test site deactivated. The inverted stow and mobile heliostats were removed and the remaining four heliostats left in a face-up stow position. Measurements were resumed in November 1977, on heliostats H1 and H4, and results are shown in Table 11. During this five month period, the acrylic reflectivity degradation for H1 was greater than for the glass reflectivity of H4. Subsequent to the November 16 measurement, the reflectivity degradation rate (during a two week period with no rain) was .19 percent/day for the glass. There is insufficient data to explain degradation rate differences such as this, but it does not appear from the data available that acrylic surfaces for specimen or heliostats have a degradation rate that differs consistently and significantly from that of glass, but it does appear to be more difficult for natural cleaning phenomena to remove deposits from the acrylic. This effect has been noticed on several occasions, and is also seen by noting that on January 25, 1978, H4 (glass) was cleaned by rain essentially as well as with manual washing, whereas H1 (acrylic) had a reflectivity 20% below its clean value. It would be necessary to measure acrylic and glass specimens on a much more frequent basis than was possible within the scope of this program to accurately determine the relative dust-induced degradation rates for acrylic and glass, but the bulk of these data indicate that acrylic may accumulate dust somewhat more rapidly than glass, but that it is significantly more difficult to remove the deposited dust.

Tables 13 and 14, show reflectance degradation rates for the different rack positions and types of mirrors for two periods at NWC. A comparison of the permanent face-up specimen degradation rates shows these rates to be comparable

Table 11

SUMMARY OF HELIOSTAT REFLECTIVITY VARIATIONS

Heliostat No.	Reflectivity (%) (Degradation Rate, % Per Day)							
	12/9/76	12/9/76	12/17/76	12/17/76	1/3/77	1/14/77	1/28/77	2/4/77
H1	N/A	N/A	67.78	81.29	N/A	77.49±0.3	N/A	76.61±0.5 (0.42)
H2	N/A	N/A	64.89 (.35)	70.20	64.28+21 (.55)	74.13±1.5	66.45+0.8 (≈ 0)	65.15±0.7 (.17)
H3	77.25	86.34	83.63 (.34)	N/A	82.80±2.3 (.21)	85.53±0.19	81.85±2.2 (.26)	79.71+0.5 (.3)
H4	72.07	85.89	78.18 (.96)	N/A	83.62±1.6 (.13)	87.65±0.76	83.51±0.2 (.29)	80.37±0.6 (.45)
IH1	78.25	81.64	83.92	N/A	81.92±1.1 ∿	86.49±0.19	85.05±0.2 (0.1)	85.78±0.1 (≈ 0)
Comment	Dirty	Washed	Dirty	Washed	Rain	Frost during week of 1/10 cleaned surfaces		

Heliostat No.	Reflectivity (%) (Degradation Rate, % Per Day)							
	2/15/77	3/2/77	3/14/77	3/15/77	3/25/77	4/1/77	4/7/77	4/8/77
H1	75.37±1.0 (11)	67.33±0.5 (.45)	65.88±0.1 (.12)	78.24±0.5	82.0	77.95±0.9 (.58)	71.28±0.5 (1.1)	83.22
H2	70.15±0.5 (≈ 0)	67.03±1.0 (.17)	56.08±0.7 (.9)	76.50±0.4	75.0	71.90±0.5 (.59)	66.89 (0.835)	68.18
H3	78.11±1.0 (.14)	76.40±0.4 (.1)	69.23±0.2 (.6)	87.46±1.5		N/A	N/A	N/A
H4	81.79±1.1 (≈ 0)	73.79±0.4 (.44)	73.31±1.6 (.04)	84.00±1.3	87.0	81.56±1.8 (.77)	80.4 (.19)	85.43
IH1	85.58±0.2 (≈ 0)	N/A	76.80±0.8 (.29)	85.10±0.01		81.25±1.5 (.24)	82.09 (≈ 0)	80.04
Comment			Dust storm	Washed		Snow on 3/25/77 cleaned surfaces		

Heliostat No.	Reflectivity (%) (Degradation Rate, % Per Day)						
	6/2/77	9/27/77	11/16/77	12/1/77	1/25/78	6/29/78	6/30/78
H1 (Acrylic)	82.0	47.6	47.8	45.0±1.14	62±3.2	-	-
H4 (Laminate Glass)	83.5	65.8	66.8±1.64	62.5±1.6 (.29)	83.5±1.6	52.5±3	83.5±2.1
Comment	Washed		Rain .05" on 10/5/77	No rain	Rain (3.35" between 12/15 and 1/16)		Washed

Table 12

AVERAGE REFLECTANCE VARIATIONS

Heliostat No.	Exposure Time (Days)	Time Averaged Reflectivity (%)	Time Averaged Degradation (%)	Degradation Rate (% Per Day) Mean ± Standard Deviation	
H1 (Acrylic)	113	$\bar{\rho}$ = 75.46	7.76	0.4±0.4	0.37±0.09 for four heliostats stowed face-up
H2 (Acrylic	113	$\bar{\rho}$ = 68.37	8.13	0.45±0.32	
H3 (Acrylic)	97	$\bar{\rho}$ = 80.47	6.99	0.28±0.18	
H4 (Laminate Glass)	121	$\bar{\rho}$ = 81.10	6.55	0.36±0.32	
IH1 (Laminate Glass	121	$\bar{\rho}$ = 83.30	3.19*	0.1±0.13	

*NOTE: IH-1 was stowed in the face-down position for most of the test period (≈ 2/3 of exposure time). Data above are for periods without rain or other significant matural cleaning conditions.

Table 13

NWC SPECIMEN REFLECTIVITY AND DEGRADATION RATE SUMMARY

JUNE 22 TO AUGUST 8, 1977

	ASG Laminate				Second Surface				Sheldahl			
	ID	Clean	Dirty	Degradation Rate (% Per Day)	ID	Clean	Dirty	Degradation Rate (% Per Day)	ID	Clean	Dirty	Degradation Rate (% Per Day)
Sensor Face up/ Face down	-	Data not available			64-2	69.61	53.48	.34	63-14	84.2	71.94	.26
					64-3	70.13	59.06	.24	63-15	87.8	68.42	.41
									63-22	90.35	72.57	.38
									63-24	90.98	71.16	.42
Astronomical Timer/Near Vertical Stow	65-12	90.67	75.92	.31	64-4	70.76	54.94	.34	63-16	87.48	57.8	.63
	65-13	96.39*	75.87	.44	64-5	68.97	55.59	.28	63-17	86.16	60.33	.55
									63-18	91.38	65-83	.54
Astronomical Timer Face up/ Face down	65-14	89.02	74.16	.32	64-6	67.66	61.94	.12	63-19	82.21	69.73	.24
	65-16	93.88	80.67	.28	64-7	69.86	59.61	.22	63-20	89.21	73.16	.34
									63-21	88.12	73.13	.32
Permanent Face up	65-14	91.44	61.12	.64	64-8	69.39	48.2	.45	63-13	91.33	60.2	.66
	65-19	82.73	61.3	.46	64-9	70.03	47.2	.48	63-28	89.81	59.52	.64
Permanent Face down	65-20	82.26	78.1	.09	64-10	69.11	65-8	.07	63-11	84;94	83.5	.03
	65-21	81.70	81.3	.01					63-25	89.22	87.9	.03
									63-26	87.83	86.4	.03

Table 14

NWC SPECIMEN REFLECTIVITY AND DEGRADATION RATE SUMMARY

NOVEMBER 11 TO DECEMBER 1, 1977

	ASG Laminate				Second Surface				Sheldahl			
	ID	Initial	Final	Degradation Rate (% Per Day)	ID	Initial	Final	Degradation Rate (% Per Day)	ID	Initial	Final	Degradation Rate (% Per Day)
Sensor Face up/ Face down	65-17*	78.43	78.18*	.01	64-2	60.1	59.65	0.02[2]	63-14*	88.0	87.5	0.02
	65-18	71.0	73.47	~[2]	64-3*	70.6	68.42	0.11	63-15	75.9	71.67	0.21
									63-22	79.6	78.68	0.05
									63-24	78.6	76.27	0.12
Astronomical Timer/Near Vertical Stow	65-12	89.4[1]	75.36	0.41	64-4	72.3	63.97	0.42	63-16	80.0	76.92	0.15
	65-13*	91.0	87.69	0.16	64-5	69.4	66.15	0.16	63-17	75.3	76.92	~ 0
									63-18*	88.2	86.76	0.07
Astronomical Timer Face up/ Face down	65-14*	89.2	89.23	~ 0	64-6*	68.9	65.22	.184	63-19	80.8	79.1	0.085
	65-16	92.6	83.58	0.45	64-7	61.4	61.43	~ 0[2]	63-21*	89.8	81.82	0.40
Permanent Face up	65-15	70.4	57.57	0.64	64-8	56.4	55.38	0.05[2]	63-12*	85.8	80.77	.25
					64-9*	69.6	61.29	0.41	63-13	72.6	69.70	.14
									63-28	69.5	63.63	.29
Permanent Face down	No data available due to weather											

*NOTE: Certain specimens washed on November 11, 1977

(1) Previous measurement for 65-12 made on 9/28, for 34 days duration

(2) Illustrates tendency for degradation rate to decrease as specimens are soiled

to those of the heliostats. The rate variability is also comparable, exhibiting the same puzzling effects of essentially no loss in some cases, and relatively high losses in others. For both periods, the relative degree of degradation rate is highest for the permanent face-down and roughly the same for the sensor and astronomical timer, and somewhat higher for the near vertical stow.

Specimen reflectivity and degradation rate data for the Albuquerque site are shown for one 30-day period in Table 8. Unfortunately, rain fell two days before the measurements were taken, which points out one of the obvious difficulties of monitoring remote sites with a limited scope program. However, the data on degradation rates are presented because they show that rainfall does not necessarily clean the specimens. In most cases, the degradation rate data show a higher rate of degradation for the Albuquerque site than for the NWC site, but there is insufficient data to assess site differences. It should be noted that degradation rates as high as 0.9 percent per day have been observed at the Albuquerque site. As shown in Table 8, the highest degradation rates occurred for the sensor controlled face-down stow.

The mean degradation rate for all of the specimens showing reflectance loss on the three moving racks is 0.51 percent per day, with a standard deviation of $\pm$ 0.22 percent per day. The permanent face-up mean degradation rate is 0.55 $\pm$ .2, indicating that for this 30-day period, with the rain occurring several days prior to reflectance measurements, there was no significant difference in degradation rate as a function of stowage position. Normally, however, vertical or face down stowage decreases the dust buildup rate.

Table 15 compares the degradation rates for glass and acrylic specimens at NWC for each stow position. The degradation rates as a function of specimen type lie within the uncertainty. Therefore, these data do not show a distinction due to acrylic or glass surface differences. The reflectivity degradation rate for the face-down data has been used to normalize the NWC data for the other stow positions in Table 16. It is found that the face-up position has a degradation rate fourteen times higher, and the face-up/down and near vertical positions have rates of the order of six to ten times higher than the permanent

Table 15

SUMMARY OF DEGRADATION RATE
DATA FOR SUMMER AND WINTER
(NWC SITE)

Ranking (In Order of Increasing Rate)	Degradation Rate (% Per Day)	
	Glass (ASG Laminate and 2nd Surface	Sheldahl Acrylic
1. Permanent face-down	0.06 ± 0.04	0.03
2. Sensor face-up/face-down	0.12 ± 0.14	0.23 ± 0.16
3. Astronomical timer face-up/face-down	0.20 ± 0.16	0.283 ± 0.12
4. Astronomical timer/near vertical stow	0.315 ± 0.11	0.32 ± 0.28
5. Permanent face-up	0.45 ± 0.20	0.40 ± 0.24

NOTE: Data for NWC specimens, November-December 1977, and June-August, 1977.

Table 16

COMBINED RANKING OF
DEGRADATION RATES VS. STOW POSITION
(NWC SITE)

Combined Ranking for Both Glass and Acrylic	Rate (% Per Day)	Normalized Rate W.R.T. 0.03% Per Day	Average Rate
1. Permanent face-down	0.03 to 0.06	1-2	1.5
2. Sensor face-up/face-down	0.12 to 0.23	4-7.7	5.8
3. Astronomical timer face-up/face-down	0.20 to 0.283	6.67-9.4	8.0
4. Astronomical timer/near vertical stow	0.315 to 0.32	10.5-10.67	10.6
5. Permanent face-up	0.40 to 0.45	13.3-15	14.15

NOTE: Data for NWC specimens, November-December 1977, and June-August, 1977.

face-down mean degradation rate. These data, therefore, show again that a face-up nightly stow will increase the dust buildup rate, and therefore, benefits are to be gained by stowing heliostats near-vertical or face-down. Data from the 30-day period at Albuquerque are not ranked in terms of stow position because the rain that occurred prior to the measurements makes conclusions as to stow position subject to question.

One uncertainty in applying the small specimen near vertical stow data to actual heliostats is that if heliostats were stowed near vertical, a significant fraction of their area would lie within the first 3-6 feet above the ground. This region is expected to have higher dust levels than the region 12 feet above the ground where the specimens were located. Furthermore, actual heliostats cannot be stowed near vertical in high winds, and thus in operating plants, a near vertical stow cannot be used every night.

CONCLUSIONS

A number of preliminary conclusions have resulted from this study, including:

- Specimen racks can simulate heliostat dust buildup
- Washing of heliostats by spray application is feasible
- Rain, snow and frost can be used to effectively clean heliostats by proper positioning
- Nightly stowage positions have a significant impact on the degradation rate with near vertical or inverted stow resulting in significantly lower degradation rates than face-up stowage.
- Acrylic surfaces are harder to clean than glass by natural cleaning techniques and dust buildup rates may be somewhat more rapid.
- The degradation rates are very strongly dependent on weather conditions, and exhibit large, puzzling variations occasionally. These variations, coupled with natural cleaning, make it difficult to defend scheduled cleaning of heliostats. Unscheduled cleaning, based on reflector degradation and weather forecasts is probably

more cost effective. In this case, plant operators can plan to stow heliostats in near vertical positions for expected rain, frost, snow, etc., when available, and manually clean only when necessary.

- Dry climates will cause significant losses to occur, and therefore maintenance cleaning will be required. Losses can exceed 25%.

- These data indicate that equilibrium values of reflectivity, if they exist, are too low to be considered as a means of eliminating all mirror washing for the desert conditions observed.

- Overlapping protective edge strips which can entrap dirt will increase streaking and degrade cleaning effectiveness.

Additional exposure data and analyses are required to obtain a final resolution of the issues of dust buildup rates vs. site and weather. There is a clear need for a convenient, portable reflectometer. However, care must be taken to obtain statistically valid data whenever isolated, spot measurements are taken. For actual plant operation, techniques for obtaining total reflected power losses from the heliostats would probably be of more benefit to plant operation for determining washing requirements.

Plant operator algorithms to position heliostats at night and during inclement weather are suggested by these results which deserve further tests with full-scale heliostats. For example, heliostats could be positioned approximately 20° to 45° from vertical during rain, snow, and frost conditions to maximize the cleaning effect. Vertical or near-vertical stow could be used during periods of low wind. Inverted stow would be used during periods of high wind. Lack of an inverted stow capability during periods of high wind would require a face-up stow position, which may result in a loss of significant reflectivity due to soiling. However, if a significant cost savings can be achieved by eliminating the inverted stow capability, proper use of natural cleaning conditions may minimize the additional reflectance degradation and allow a net savings in overall heliostat capital investment and maintenance costs.

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APPENDIX A

TEST EQUIPMENT AND EXPOSURE RACK DESIGN AND OPERATION

The dust build-up apparatus is composed of specimen racks, a motor-driven gear drive train and controller, and the supporting structure. Sand/dust cone collectors were also installed in an attempt to determine dust concentration versus height, but this was not successful since dust could not be retained in the cones.

Support Structure

The support structure is assembled in the field from commercial scaffolding, and can be completely assembled without the need of a crane, if necessary, by two men. The structure drawing is shown in Figure A-1. The frame is 12 feet high to simulate dust buildup conditions for full size heliostats.

Specimen Racks

The specimen racks are made of drilled angle iron, bolted together, as shown in Figure A-2. The specimens are 5" x 5" glass plates, bonded to two parallel 1" x 6" x 3/16" aluminum strips. The specimens slide into place on aluminum extrusion runners (Figure A-3).

Controller/Drive Train

The three movable racks function as follows:

Sun Sensor Drive: Face-up during day, face-down at night or during heavy overcast.

Timer Drive - Near Vertical: Face-up during day, approximately 15° from vertical at night (slightly face-up).

Timer Drive - Face-up/Down: Face-up during day, face-down at night.

An astronomical timer is used to account for variations in sunrise and sunset, and controls the DC motors through a set of relays. Kollmorgen U9FG printed circuit DC motors are used with a 50:1 gearhead output to a 30:1 worm gear to drive the rotating panels. The sun sensor controller performs in a similar manner. The circuit diagram is shown in Figures A-4 and A-5.

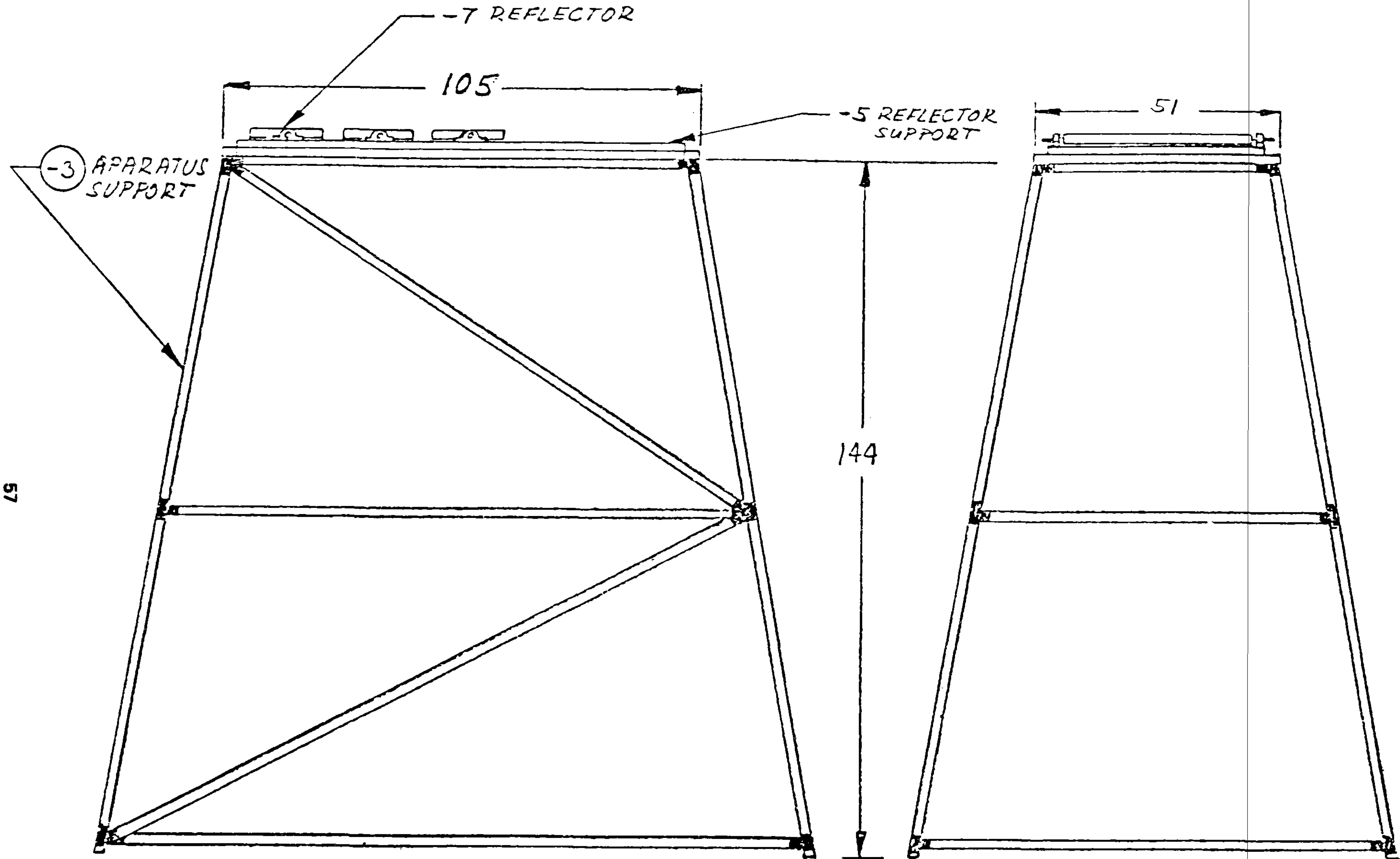


Figure A-1. Dust-Build Up Apparatus Stand

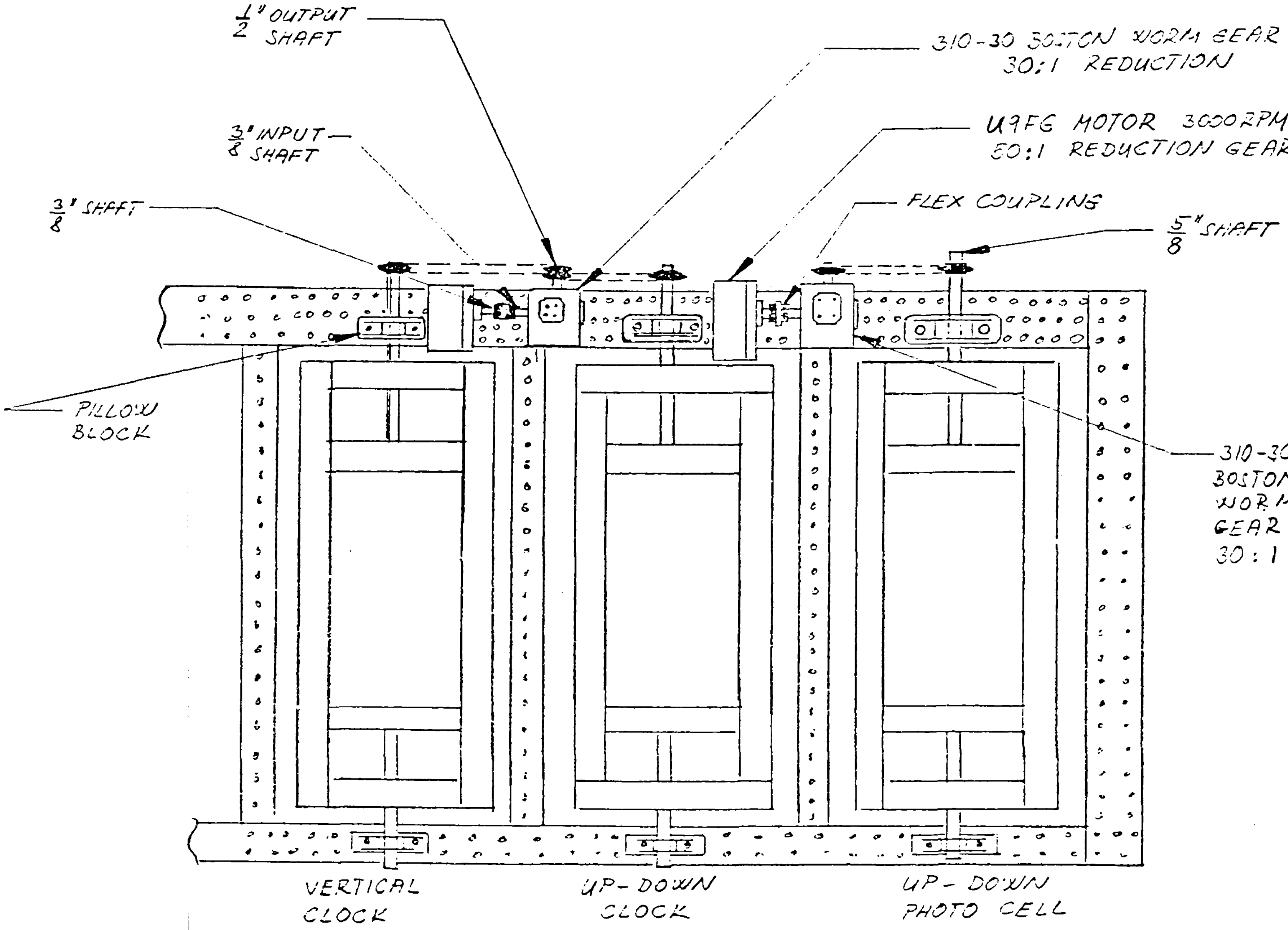


Figure A-2. Dust-Build Up Apparatus Rack

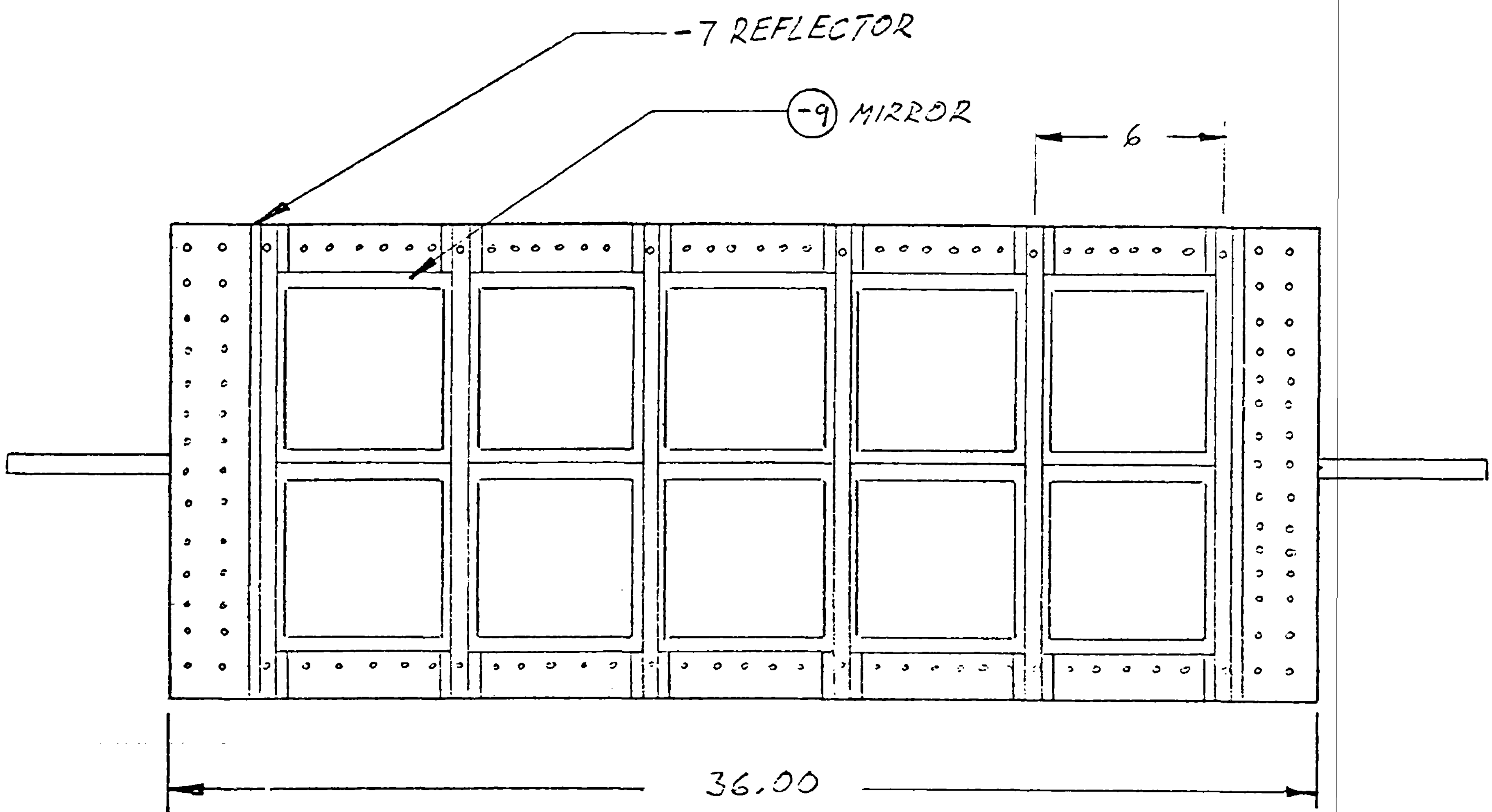


Figure A-3. Dust-Build Up Apparatus Panel

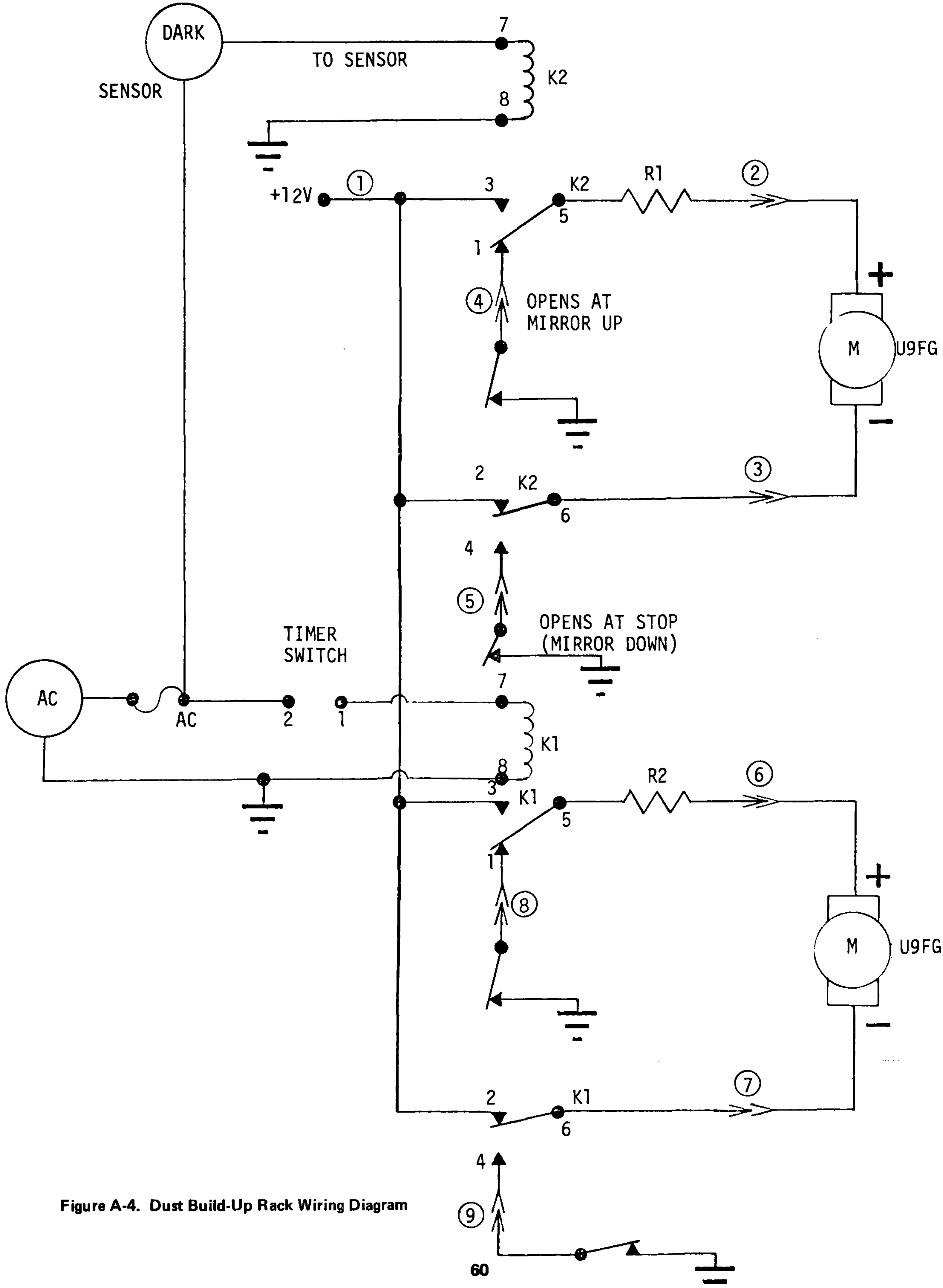
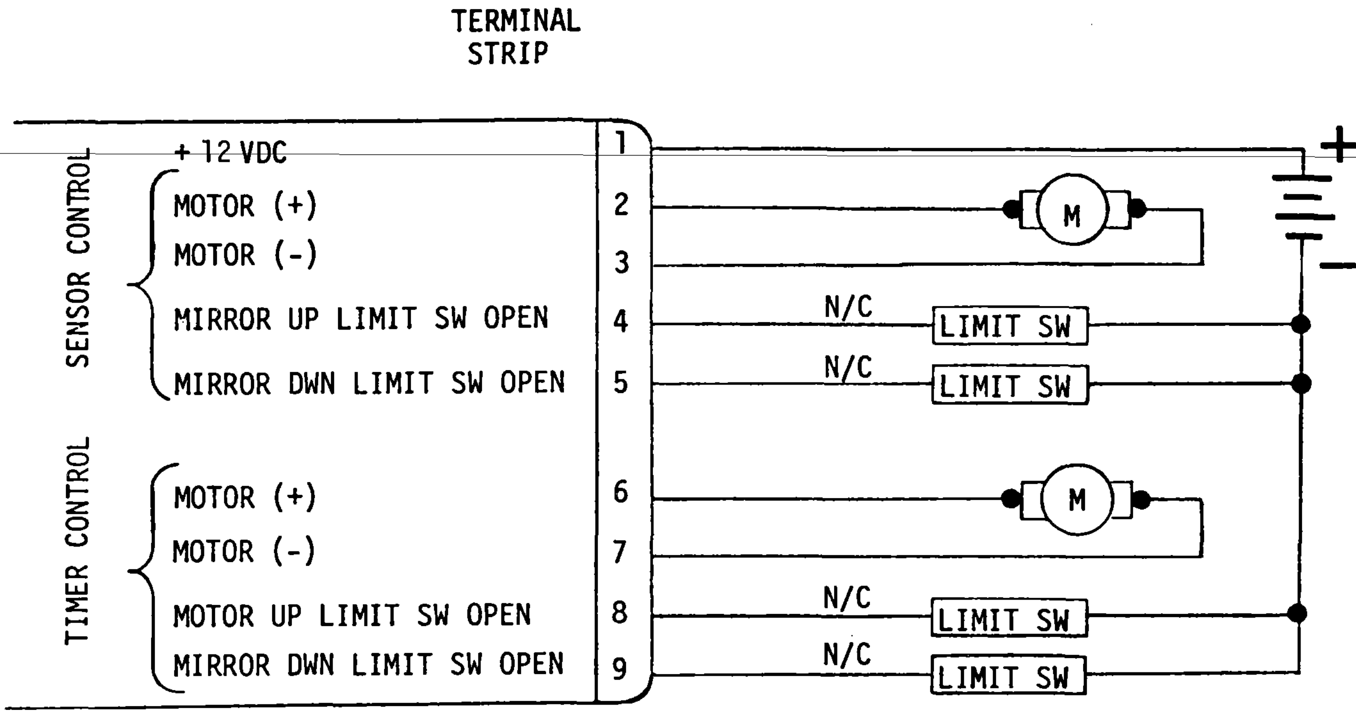


Figure A-4. Dust Build-Up Rack Wiring Diagram



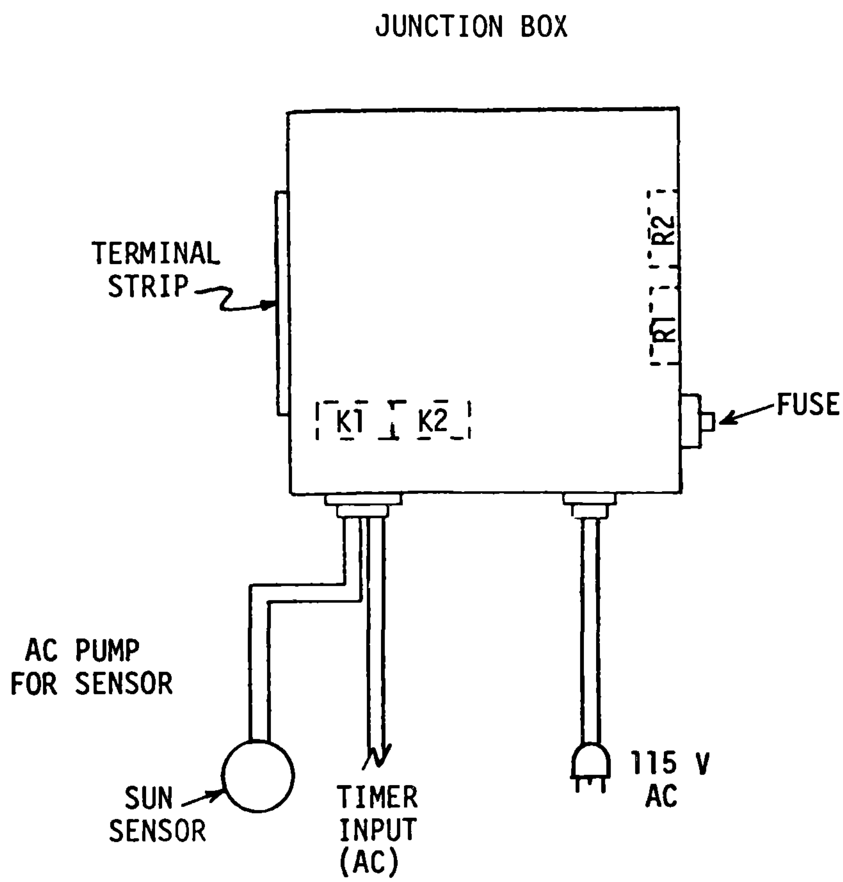


Figure A-5. Wiring Diagram Descriptors

Sand/Dust Cone Collector

Sand/dust cone collectors, shown in Figure A-1 and Figure A-6 were installed at the sites to collect sand and dust and assist in determining the height dependence. However, it was found that dry dust could not be collected by the cones. Blowing sand and dust was generally swirled out of the cones, and partially collected only when the cones contained water. As the water evaporated, the dust and sand would harden. However, above approximately 1-2 feet, the quantities collected were so small that no attempt was made to compare the relative amounts of dust versus height.

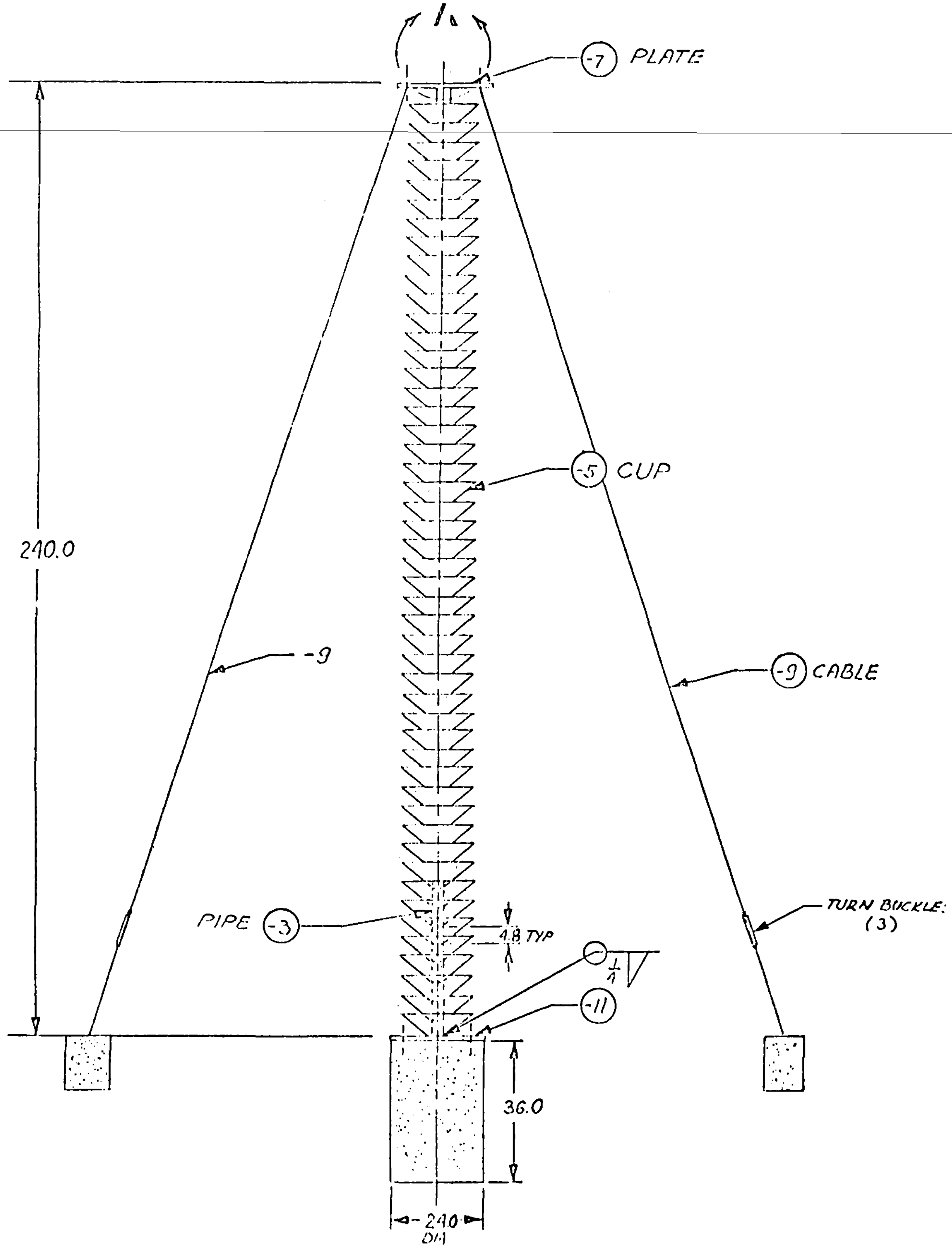


Figure A-6. Sand-Dust Cone Collector

MDAC DUST BUILD-UP APPARATUS

Operation (assuming bright, daylight conditions)

1. Visually inspect apparatus. Check for stiffness, structural integrity.
2. Unplug 120 VAC at junction box. Observe clock drive horizontal and vertical racks moving to stow position (face down and near vertical, respectively). Sensor rack should remain in face up position.
3. Plug 120 VAC cable into junction. Observe clock drive horizontal and near vertical racks returning to face up position. After approximately one minute, sensor rack will automatically invert (face down) remain in that position for approximately one minute, and then return to face up position. Cover sensor after approximately one minute, sensor rack will invert. Uncover sensor. After approximately one minute, sensor should move to face up position. If the above operations are observed, the control electronics and mechanisms are performing properly, and normal inspection may proceed. If these operations appear faulty, disconnect 120 VAC power and initiate fault finding.
4. With 120 VAC power disconnected, inspect timer, battery charger, and battery. Note that these operations cause the astronomical timer to lose time, which must be corrected at the end of the inspection.
5. Record numbers on rack rotation counters, distinguishing between counter numbers before and after initial inspection operations.
6. Carefully remove and measure or crate specimens as detailed in the table to be supplied by the Principal Investigator for the particular site involved. Generally, one specimen of each class of reflective or transparent material will be removed from each rack, and one specimen of each class will remain semi-permanently to determine asymptotic reflectivity/transmissivity losses. Replace specimens following measurements.
7. Inspect bolted connections, rack/specimen integrity, mechanisms.

8. Record any noteworthy observations, including general appearance of rack, surrounding region, bird droppings, and dust build-up on specimens, collected water, rust, degradation of specimen, etc.

9. Turn 120 VAC power On, observe step 3. Block sensor window and verify that sensor rack inverts after approximately 1 minute delay. With the sensor window clear, verify that rack returns to face up position after approximately one minute.

10. IMPORTANT - Prior to leaving site, reset timer to correct standard time (one hour less than daylight savings time).

11. Re-verify battery charger is operational. Check battery level. Fill if required.

12. Verify cable hold downs.

13. Remove all tools, etc., from site.

14. IMPORTANT - Transport specimen box to laboratory in vertical position, such that specimens are always horizontal, face up, to minimize loss of dust.

NOTE

Periodically observe automatic operations during late evening and early morning to verify clock control and sensor operation for sunlight conditions. Record observed times. Site should be inspected, whenever practical, during or after severe storm conditions.

- CAUTION -

Do not remove/install specimens with 120 VAC connected since cloud cover, incorrect clock setting, etc., may initiate rack rotation.

- EQUIPMENT TOOLS REQUIRED -

Diagnostic tools and instruments (as required)
Battery tester
Multimeter (as required)

NOTE

For convenience and as an additional precaution, samples may be removed/installed from racks in face-up position. First, disconnect 12 VDC power, then disconnect 120 VAC power. Racks will remain stationary. Following specimen removal, connect 12 VDC, then 120 VAC. Verify correct polarity. Note that sensor controlled rack will invert and return to face up position upon reconnecting 120 VAC (See Step 3).

APPENDIX B

REFLECTIVITY VARIATIONS AND WEATHER CONDITIONS

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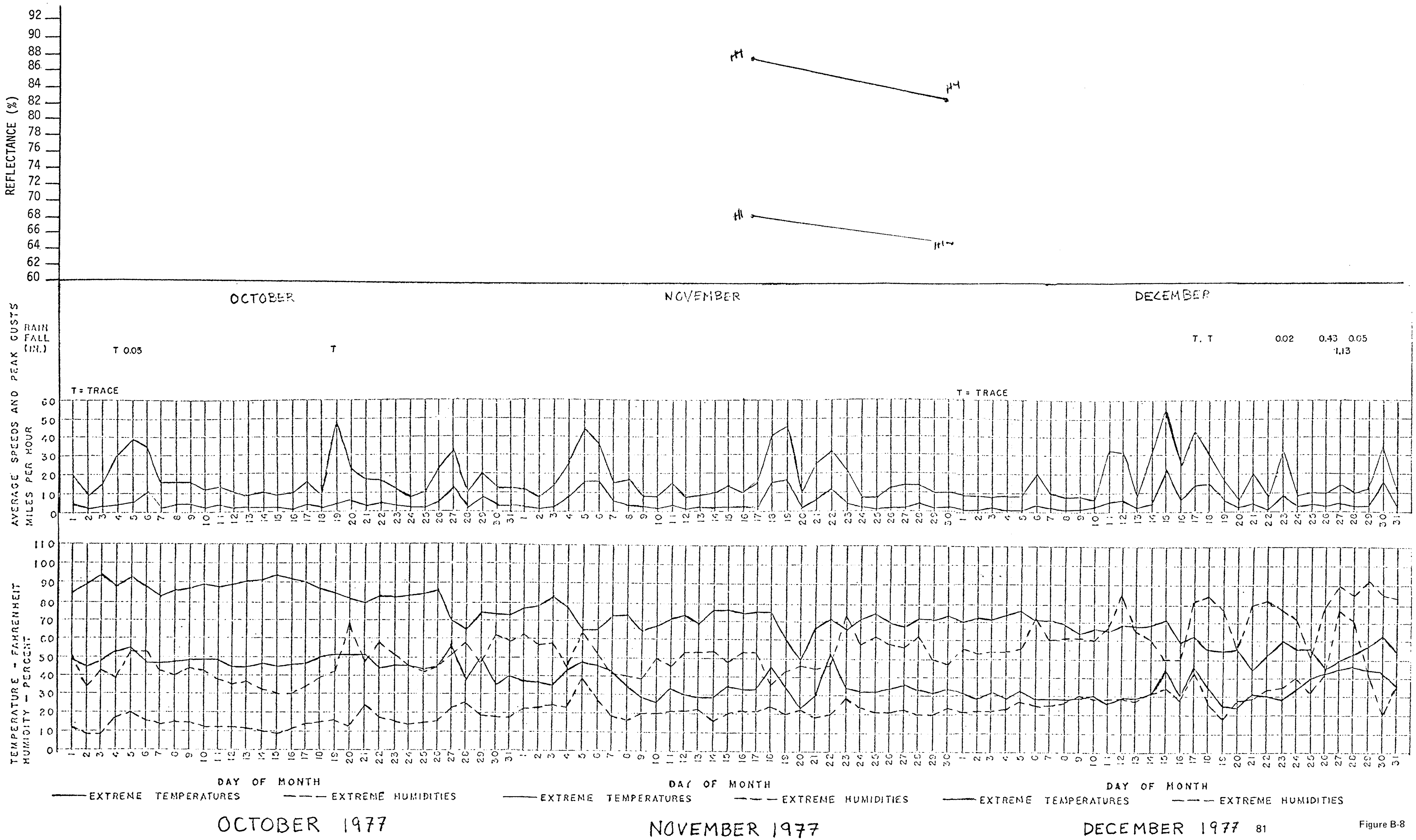
REFLECTANCE (%)
92
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
OCTOBER
NOVEMBER
DECEMBER
AVERAGE SPEEDS AND PEAK GUSTS MILES PER HOUR
RAIN FALL (IN.)
T 0.05
T
T. T
0.02
0.43 0.05
1.13
T = TRACE
T = TRACE
TEMPERATURE - FAHRENHEIT HUMIDITY - PERCENT
DAY OF MONTH
DAY OF MONTH
DAY OF MONTH
EXTREME TEMPERATURES
EXTREME HUMIDITIES
EXTREME TEMPERATURES
EXTREME HUMIDITIES
EXTREME TEMPERATURES
EXTREME HUMIDITIES
OCTOBER 1977
NOVEMBER 1977
DECEMBER 1977

Figure B-8

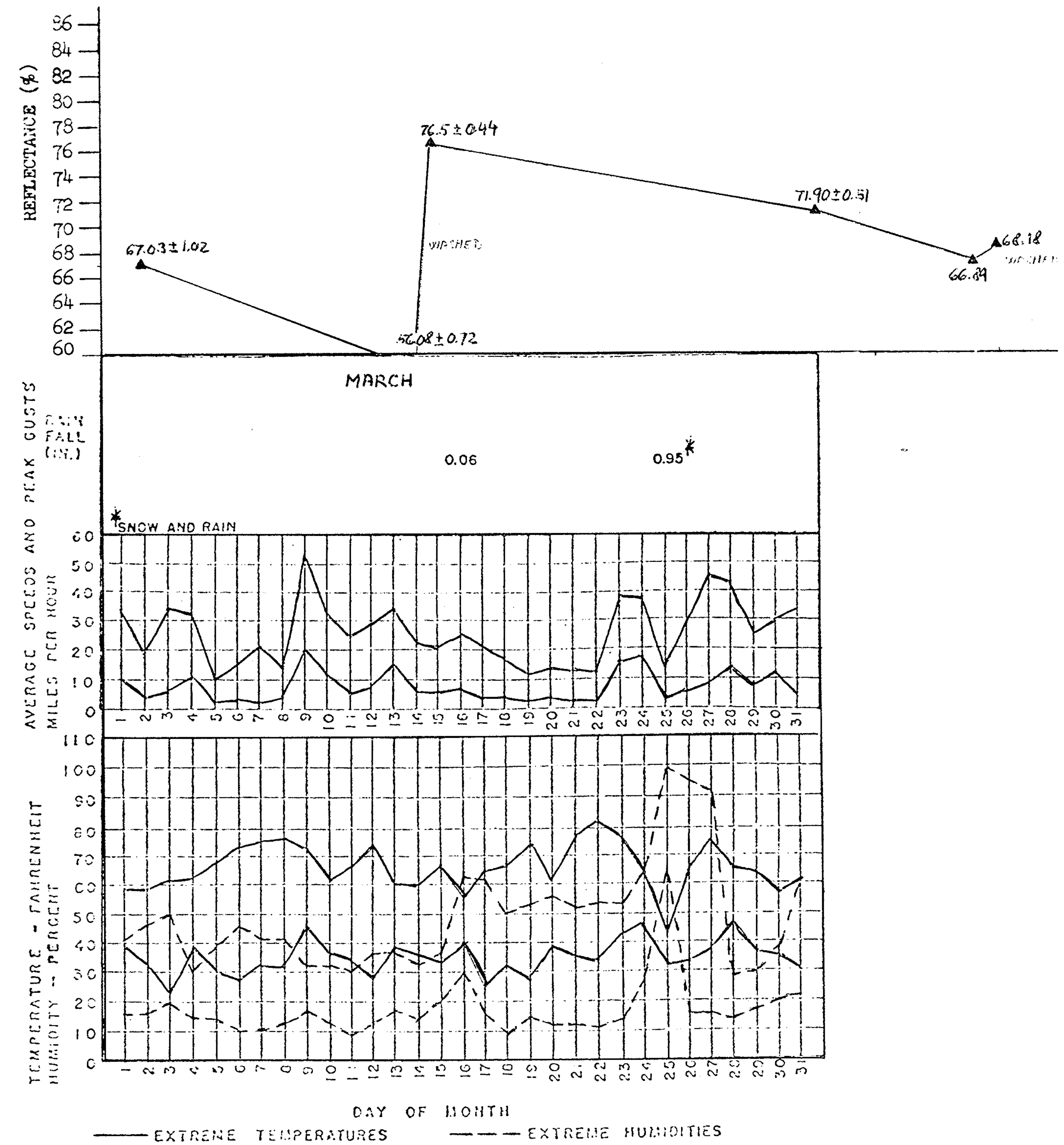

Figure B-2. Heliostat H2 Reflectivity/Weather (Page 2 of 2)

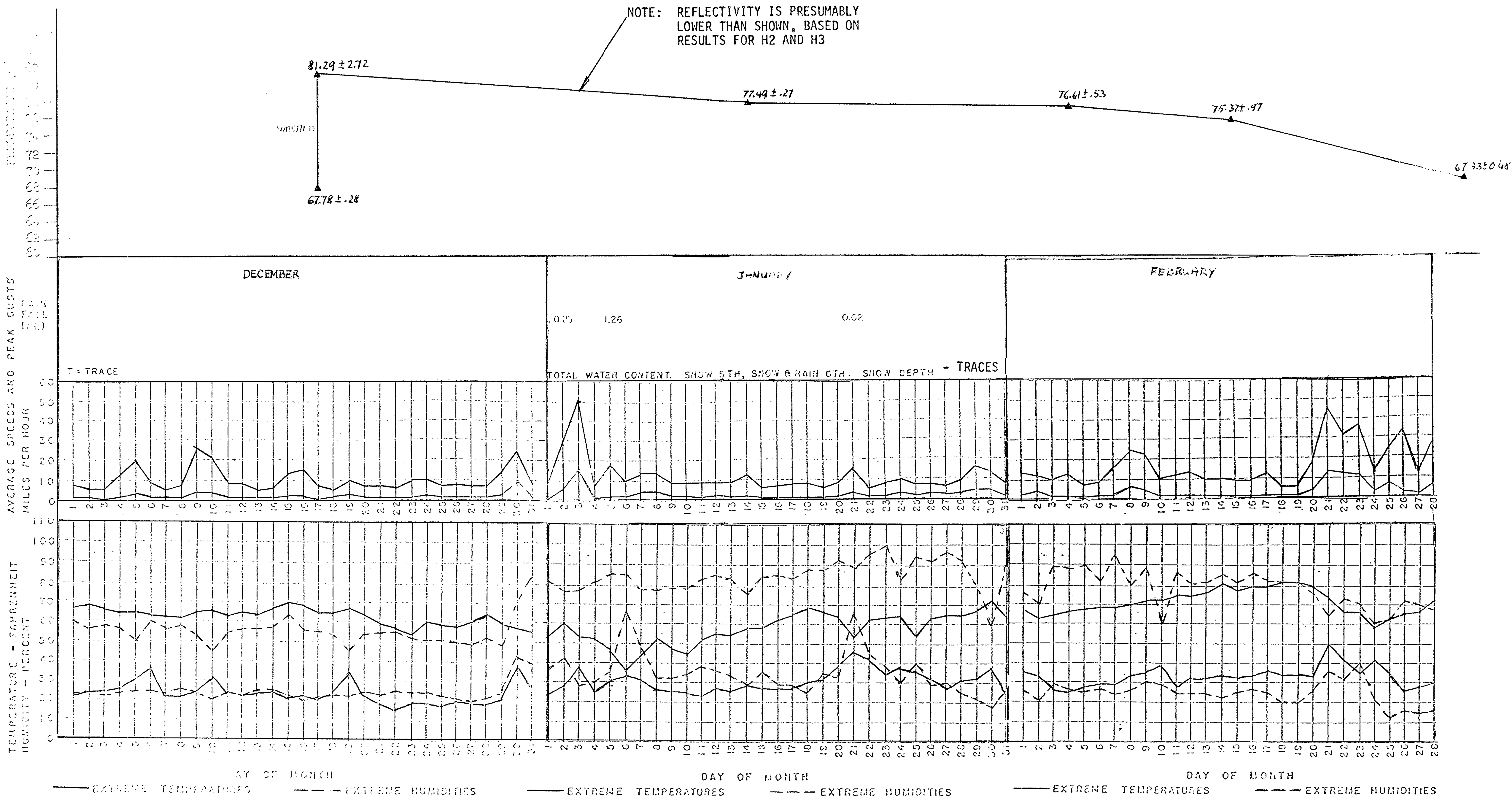

Figure B-1. Heliostat H1 Reflectivity/Weather H1 (Page 1 of 2)

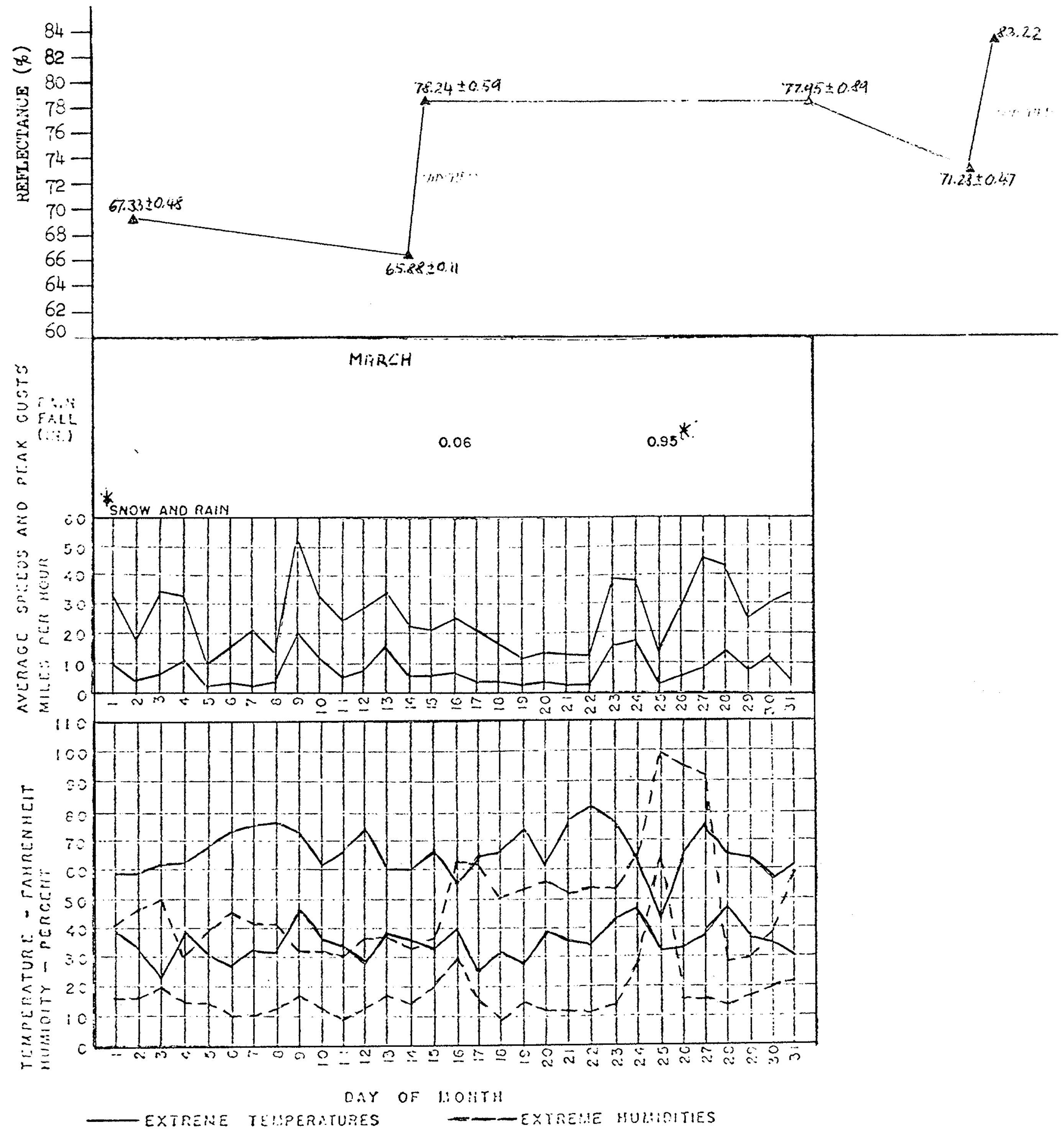

Figure B-1. Heliostat H1 Reflectivity/Weather H1 (Page 2 of 2)

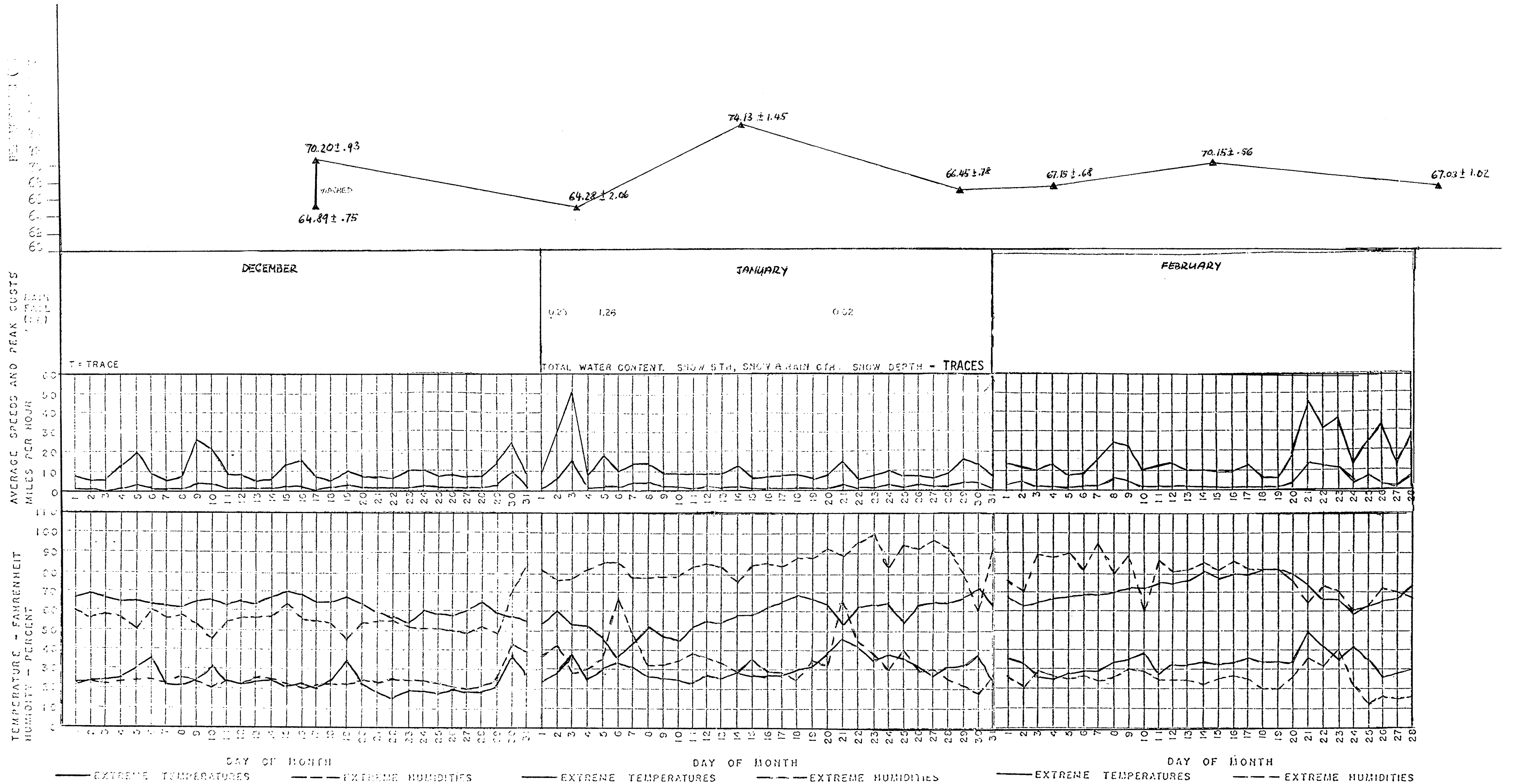

Figure B-2. Heliostat H2 Reflectivity/Weather (Page 1 of 2)

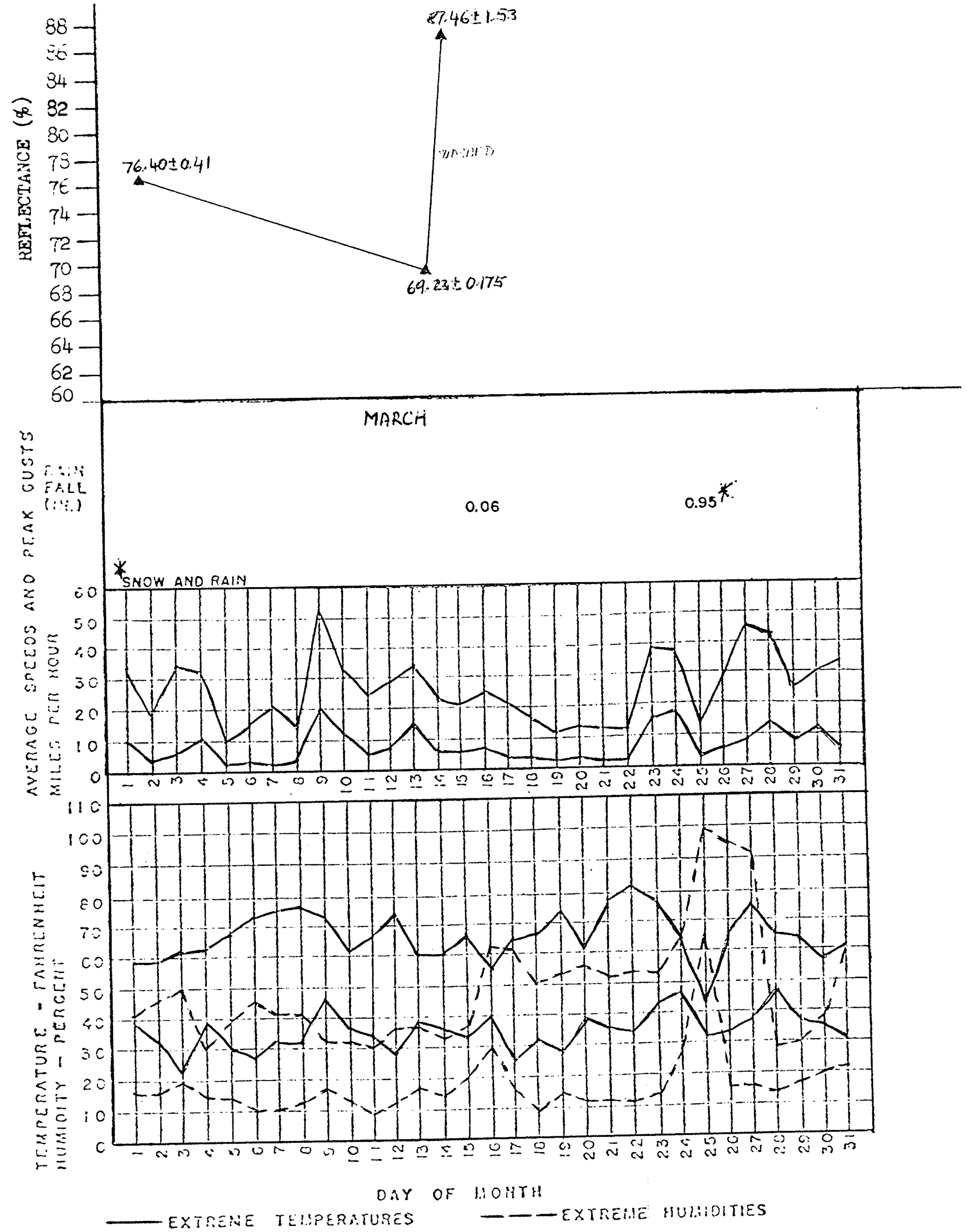

Figure B-3. Heliostat H3 Reflectivity/Weather (Page 2 of 2)

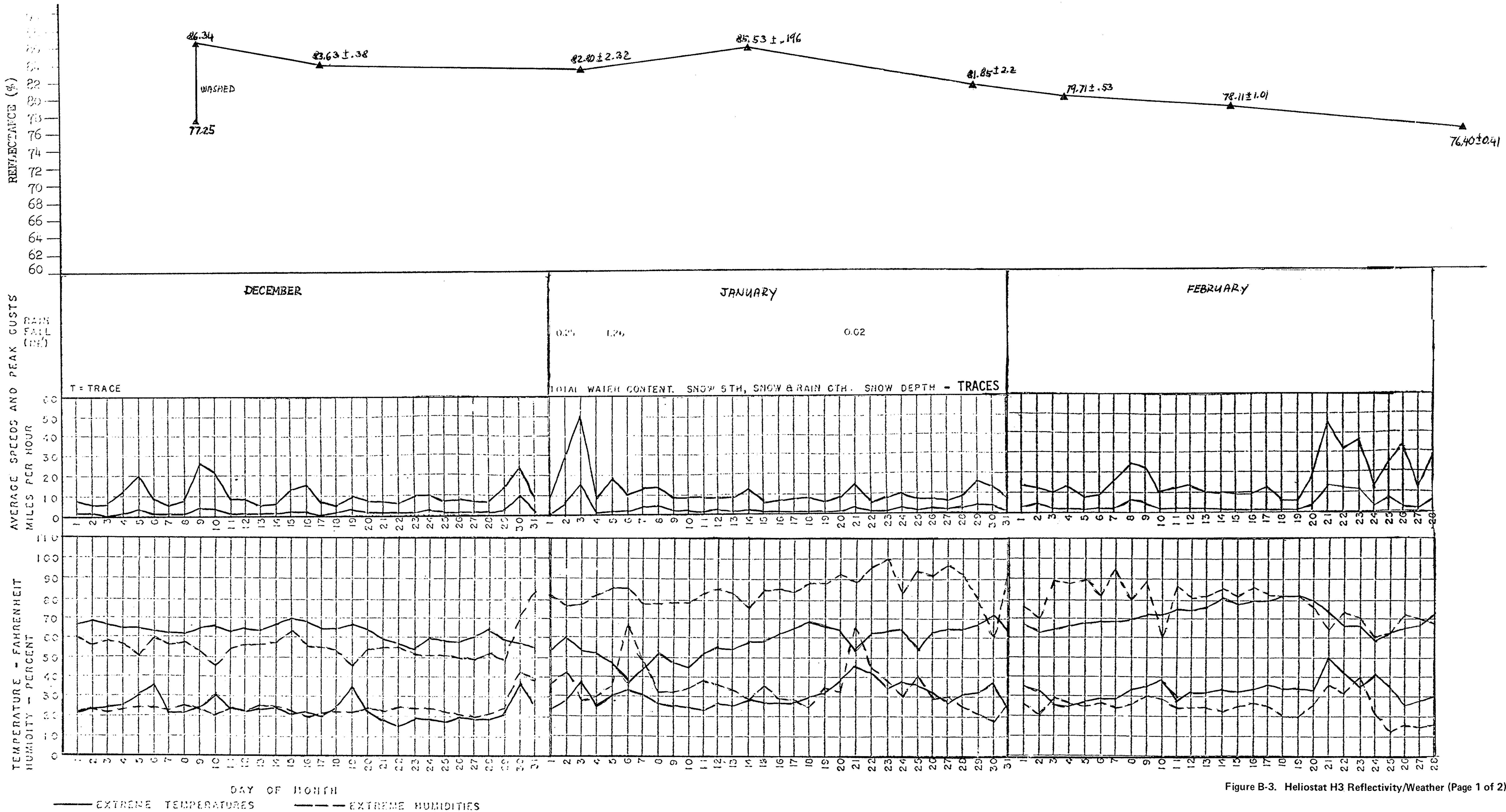

Figure B-3. Heliostat H3 Reflectivity/Weather (Page 1 of 2)

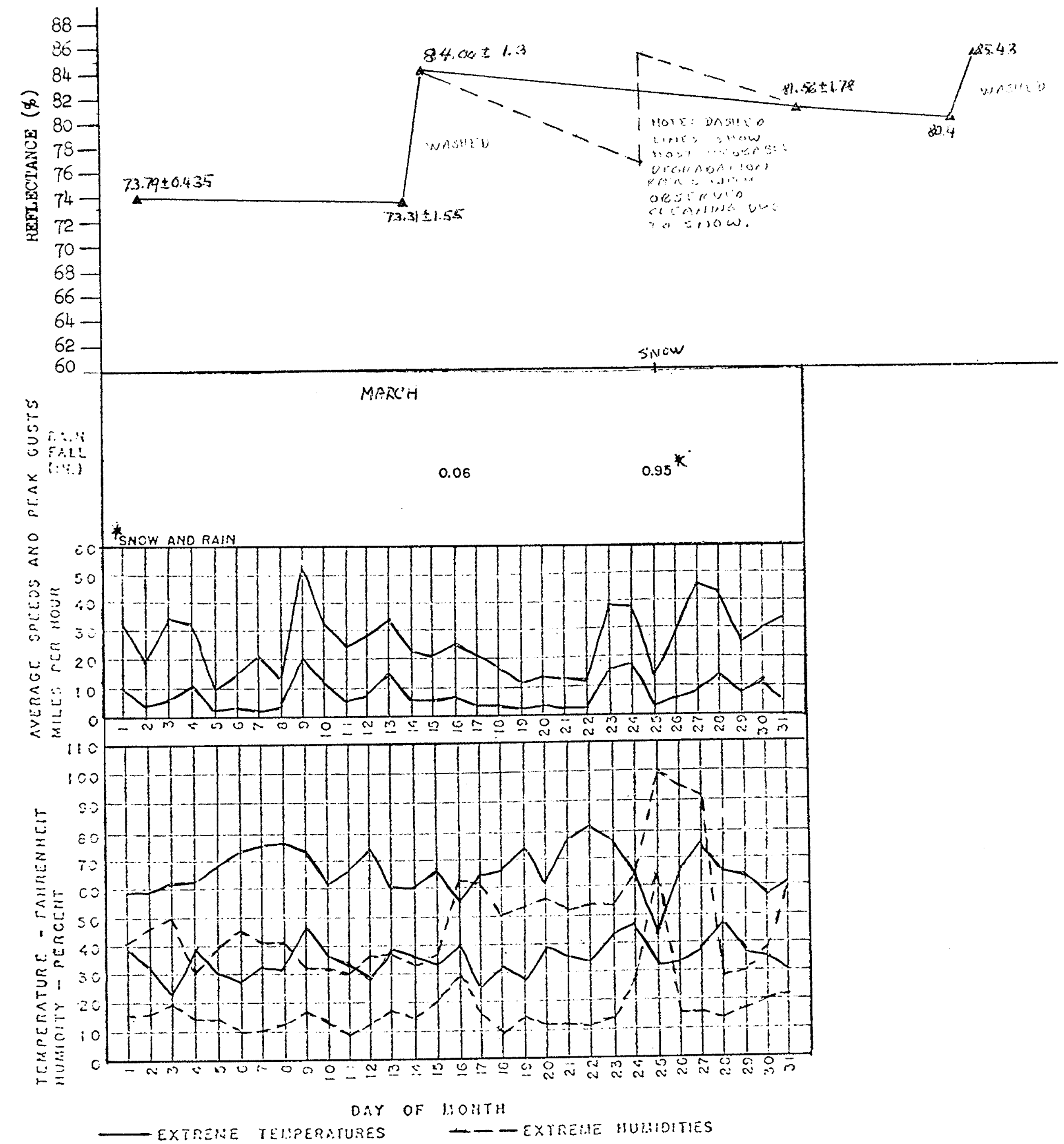

Figure B-4. Heliostat H4 Reflectivity/Weather (Page 2 of 2)

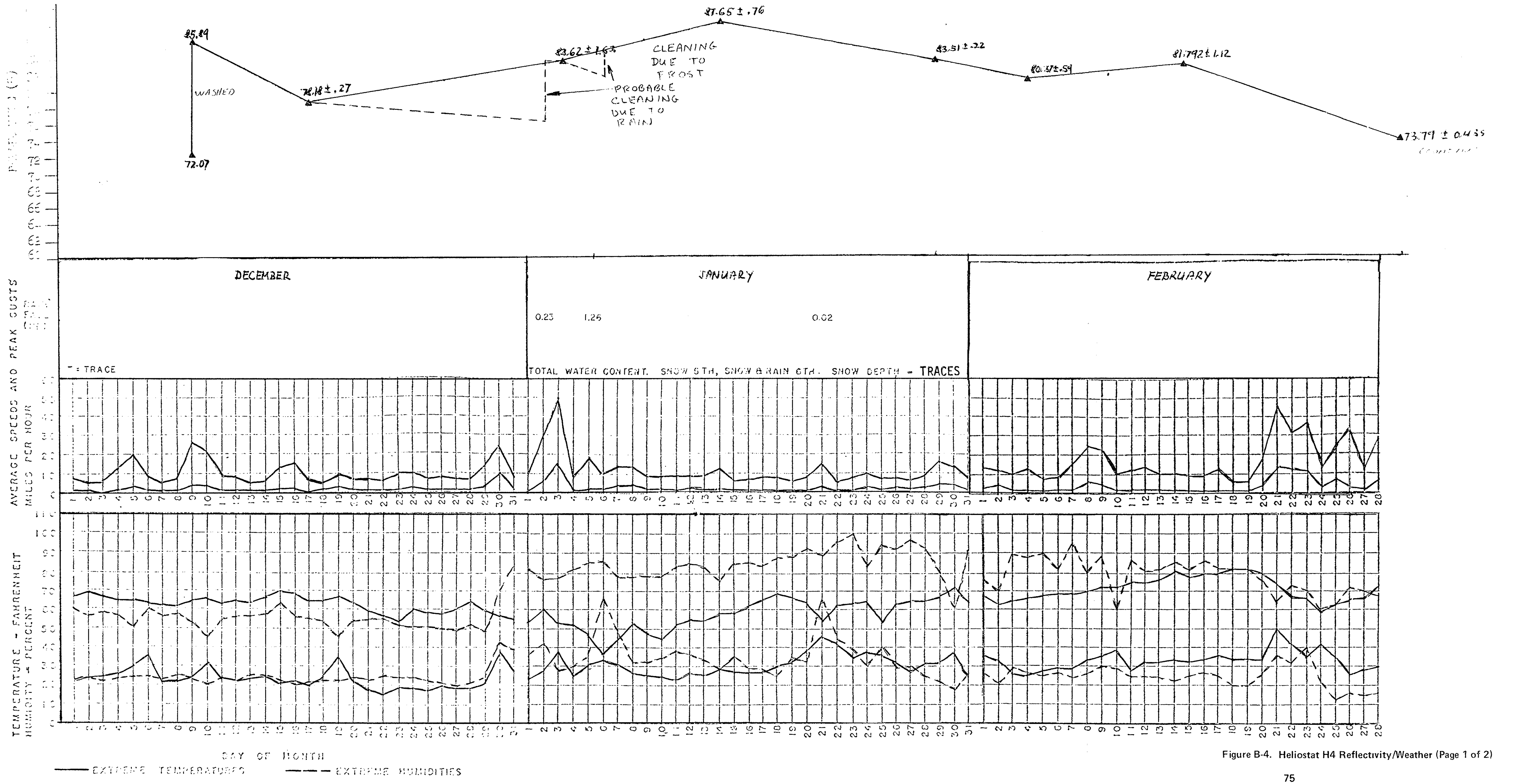

Figure B-4. Heliostat H4 Reflectivity/Weather (Page 1 of 2)

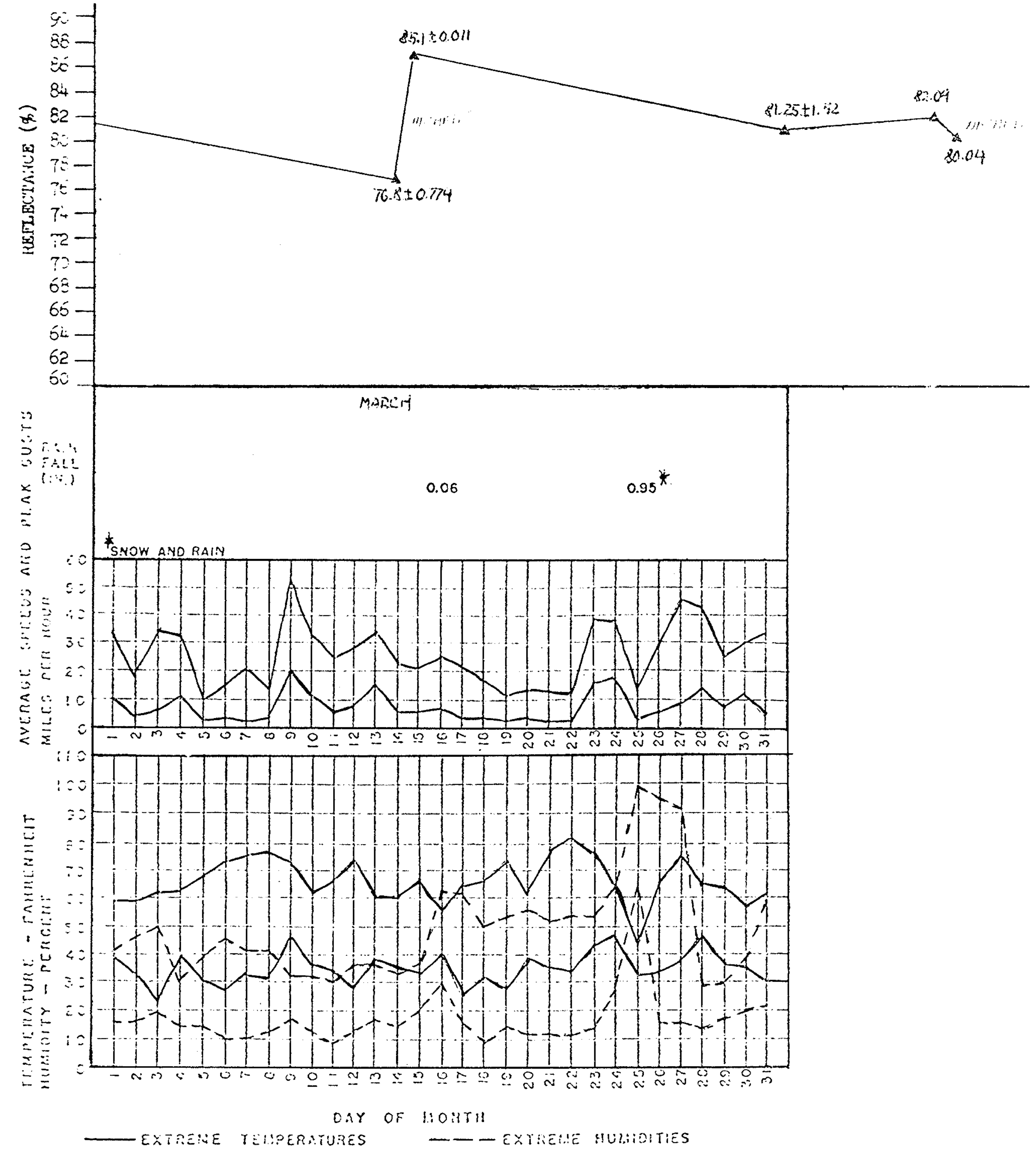

Figure B-5. Heliostat IH-1 Reflectivity/Weather (Page 2 of 2)

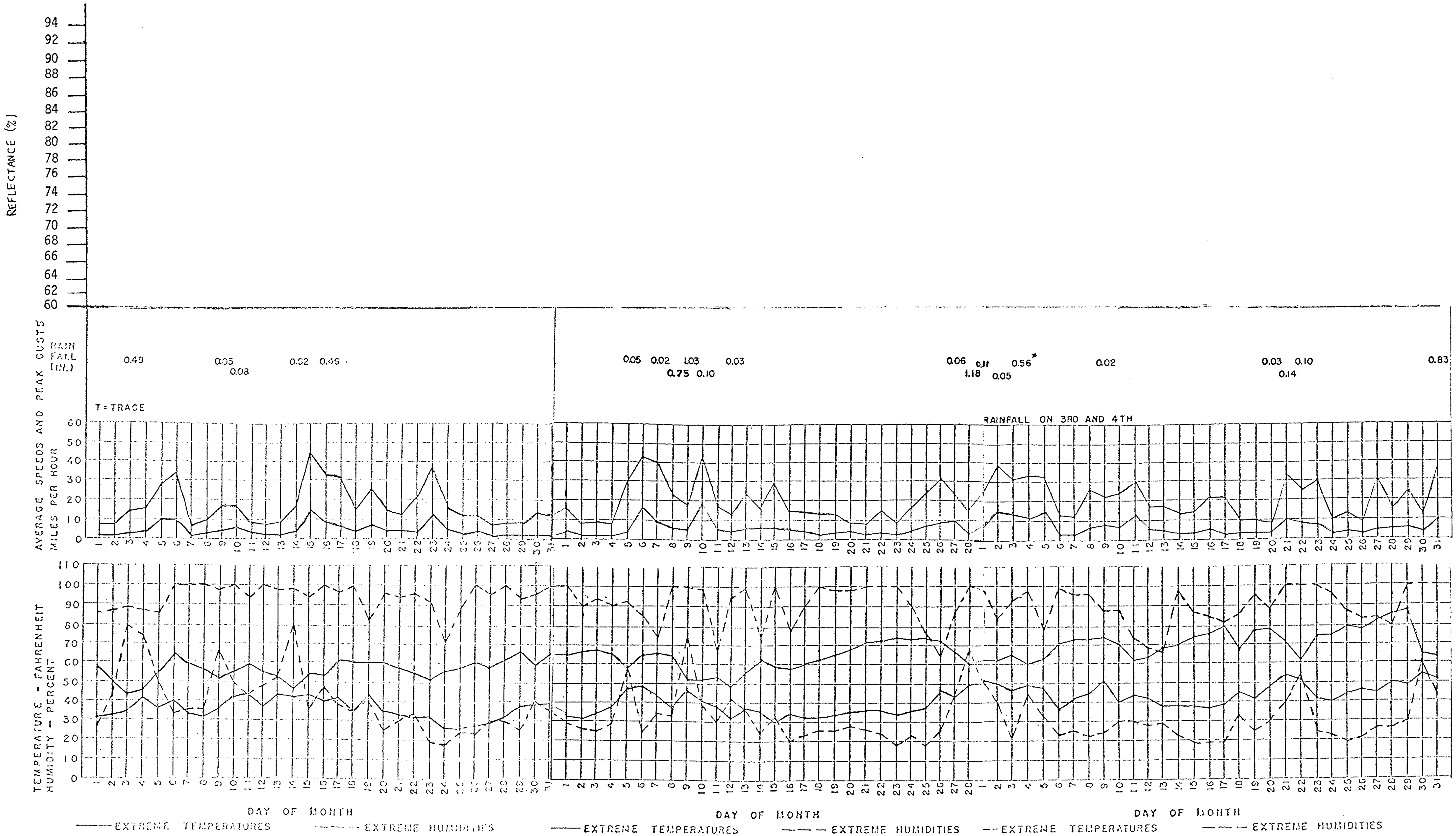

Figure B-9.

WEATHER JANUARY 1978 WEATHER — FEBRUARY 1978 WEATHER — MARCH 1978

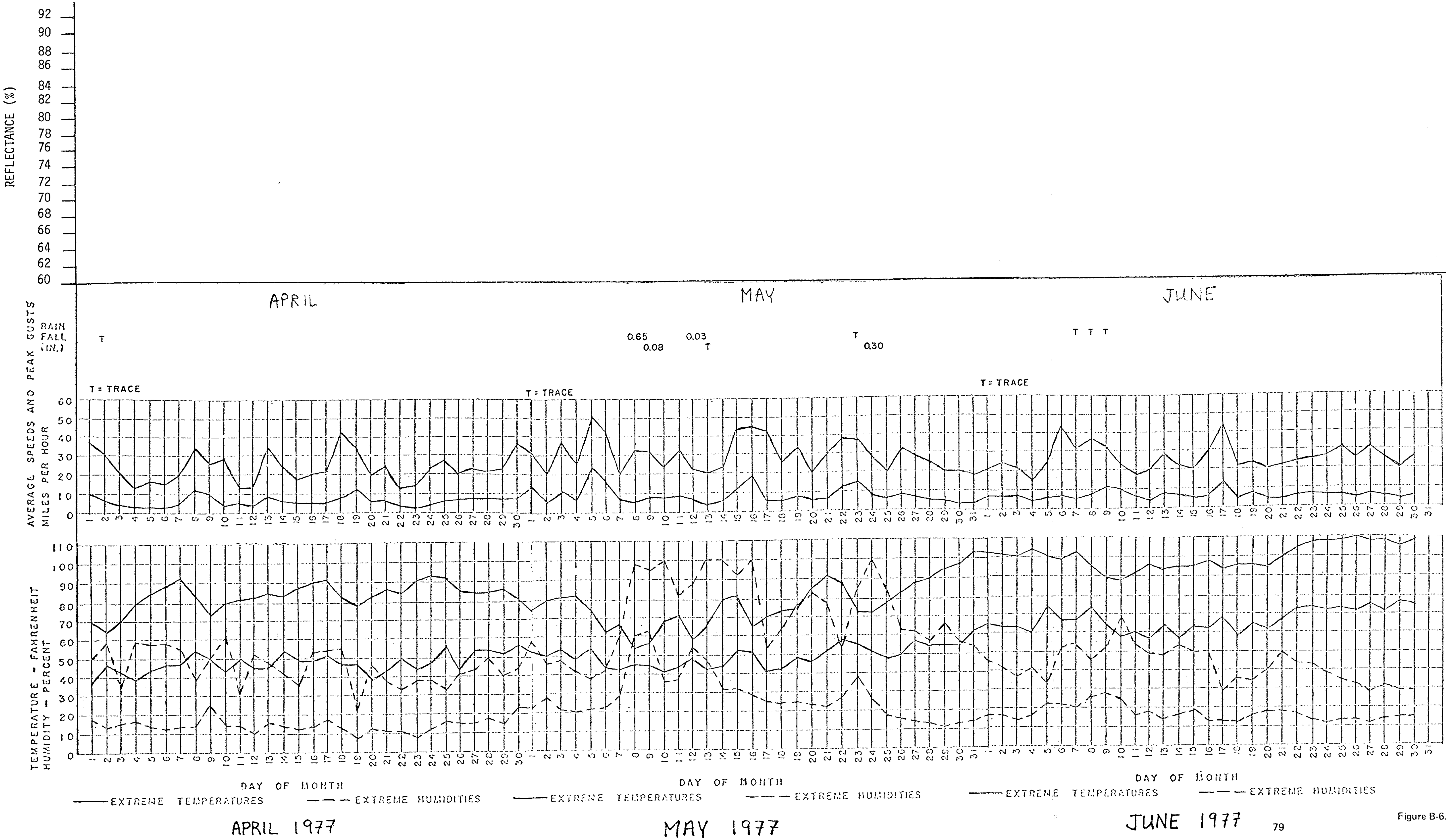
REFLECTANCE (%)
92
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
APRIL
MAY
JUNE
RAIN FALL (IN.)
T
0.65
0.08
0.03
T
T
0.30
T T T
T = TRACE
T = TRACE
T = TRACE
AVERAGE SPEEDS AND PEAK GUSTS MILES PER HOUR
60
50
40
30
20
10
0
TEMPERATURE - FAHRENHEIT HUMIDITY - PERCENT
110
100
90
80
70
60
50
40
30
20
10
0
DAY OF MONTH
DAY OF MONTH
DAY OF MONTH
EXTREME TEMPERATURES
EXTREME HUMIDITIES
EXTREME TEMPERATURES
EXTREME HUMIDITIES
EXTREME TEMPERATURES
EXTREME HUMIDITIES
APRIL 1977
MAY 1977
JUNE 1977

Figure B-6.

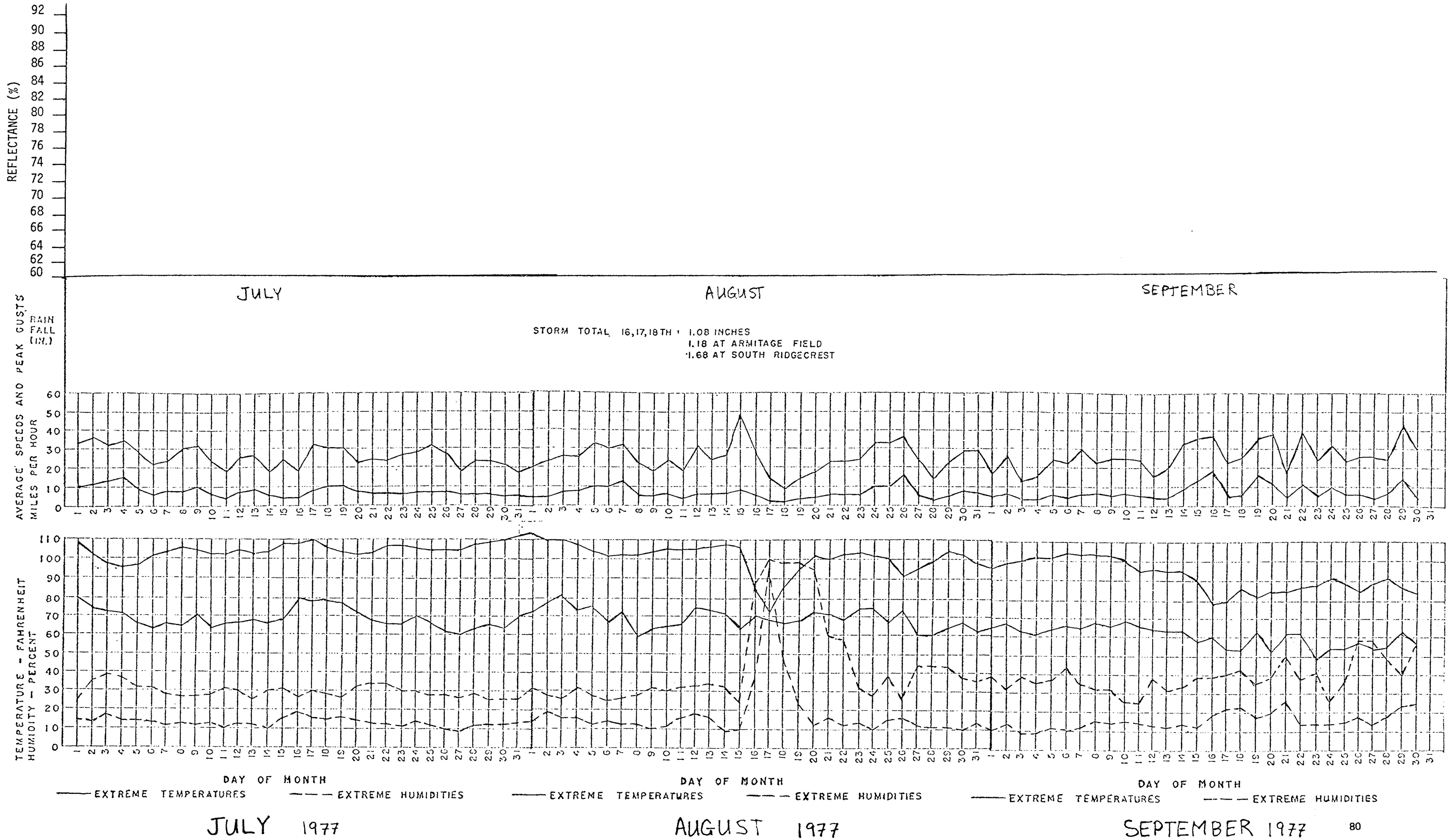
REFLECTANCE (%)
JULY
AUGUST
SEPTEMBER
RAIN FALL (IN.)
STORM TOTAL 16,17,18TH : 1.08 INCHES
1.18 AT ARMITAGE FIELD
1.68 AT SOUTH RIDGECREST
AVERAGE SPEEDS AND PEAK GUSTS MILES PER HOUR
TEMPERATURE - FAHRENHEIT HUMIDITY - PERCENT
DAY OF MONTH
EXTREME TEMPERATURES
EXTREME HUMIDITIES
JULY 1977
AUGUST 1977
SEPTEMBER 1977

Figure B-7.

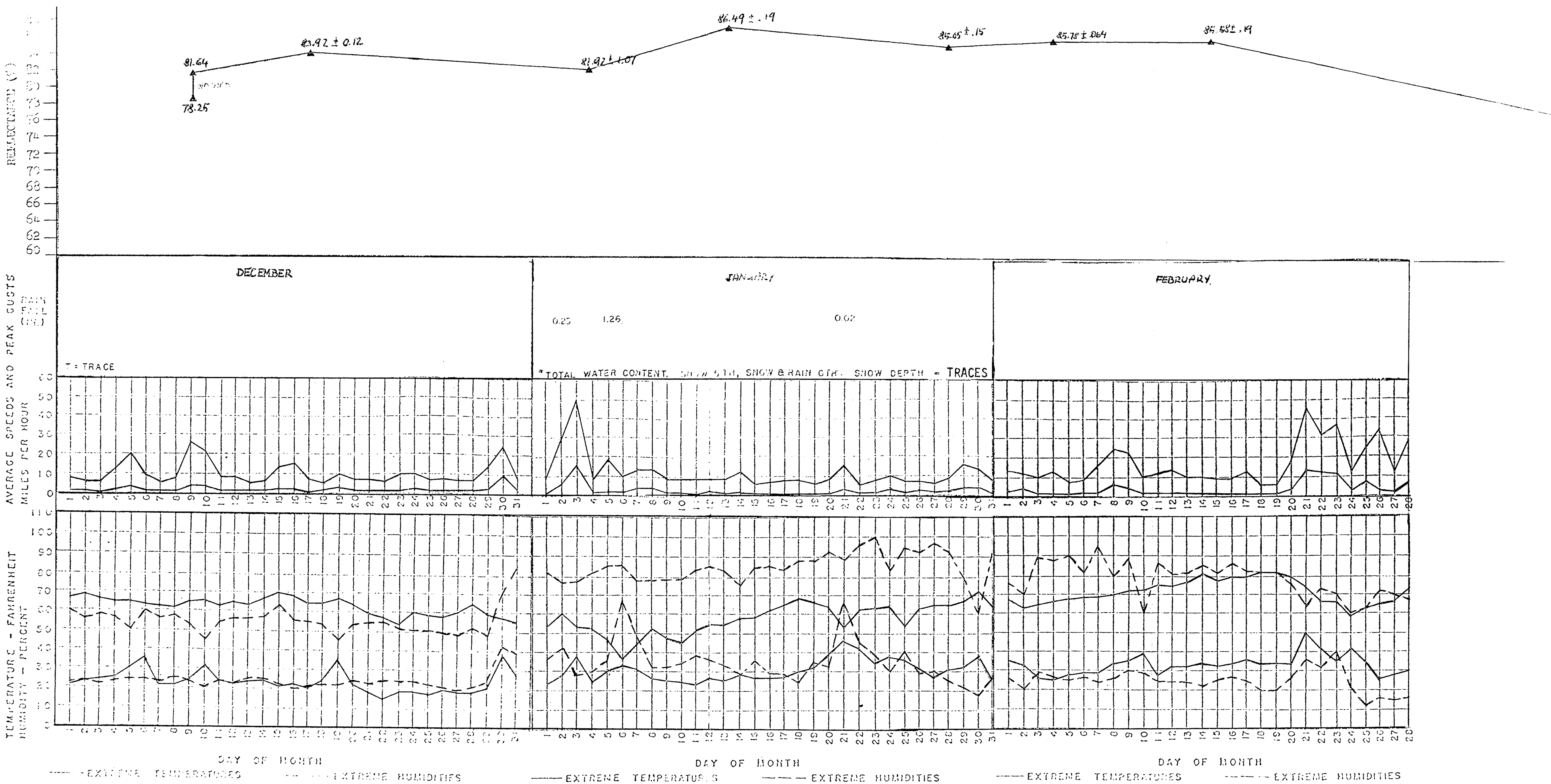

Figure B-5. Heliostat IH-1 Reflectivity/Weather (Page 1 of 2)

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