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10 MWe Solar Thermal Central Receiver Pilot Plant Repaint of a Single Receiver Panel Test Report

McDonnell Douglas Astronautics Company
5301 Bolsa Avenue
Huntington Beach, CA 92647

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10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT REPAINT OF A SINGLE RECEIVER PANEL TEST REPORT

Contract Report Prepared
Under SNLL Contract 98-1489

McDonnell Douglas Astronautics Company

ABSTRACT

This report describes the repainting of a receiver panel at the 10 MWe Solar Thermal Central Receiver Pilot Plant located near Barstow, Ca. The plant, called Solar One, is a cooperative activity between the Department of Energy and the Associates: Southern California Edison, the Los Angeles Dept. of Water and Power and the California Energy Commission. This report describes the painting preparation, painting process, and evaluation conducted following the actual painting. The receiver panel was repainted to restore the absorptivity. The panel absorptivity increased from .875 to .96 following the painting.

SOLAR THERMAL TECHNOLOGY
FOREWORD

The research and development described in this document was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.

Solar thermal technology concentrates solar radiation by means of tracking mirrors or lenses onto a receiver where the solar energy is absorbed as heat and converted into electricity or incorporated into products as process heat. The two primary solar thermal technologies, central receivers and distributed receivers, employ various point and line-focus optics to concentrate sunlight. Current central receiver systems use fields of heliostats (two-axis tracking mirrors) to focus the sun's radiant energy onto a single tower-mounted receiver. Parabolic dishes up to 17 meters in diameter track the sun in two axes and use mirrors or Fresnel lenses to focus radiant energy onto a receiver. Troughs and bowls are line-focus tracking reflectors that concentrate sunlight onto receiver tubes along their focal lines. Concentrating collector modules can be used alone or in a multi-module system. The concentrated radiant energy absorbed by the solar thermal receiver is transported to the conversion process by a circulating working fluid. Receiver temperatures range from 100°C in low-temperature troughs to over 1500°C in dish and central receiver systems.

The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems, and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories who work with private industry. Together they have established a comprehensive, goal directed program to improve performance and provide technically proven options for eventual incorporation into the nation's energy supply.

To be successful in contributing to an adequate national energy supply at reasonable cost, solar thermal energy must eventually be economically competitive with a variety of other energy sources. Components and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and making optimal component developments. These targets will be pursued vigorously to insure a successful program.

This report describes the repainting of a receiver panel at the 10 MWe Solar Thermal Central Receiver Pilot Plant (Solar One). This is part of the continuing evaluation of the pilot plant for the Solar Thermal Technology Program.

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SECTION 1

INTRODUCTION AND BACKGROUND

The Solar One receiver is an external, cylindrical, single-pass-to-superheat boiler which is 23 ft. in diameter and 45 ft. high mounted on top a 250 ft. high tower. It consists of 24 vertical panels with the 6 low-power south side panels (nos. 1-3 and 22-24) operating as preheaters and the remaining 18 panels (nos. 4-21) operating as independent steam boilers.

In order to maximize solar absorptance, the exposed receiver surfaces were originally painted with flat black Pyromark 2500 paint, a product of Big 3 Industries. The paint is a mixture of metal oxides and a silicate binder and is 20 percent solids by volume. The remaining 80 percent of the paint consists of volatile materials which serve to liquify the paint. It was applied by Lundeen Coating Corp. following panel fabrication, prior to their installation on the Solar One tower.

The first "hot" receiver operations carried out at Solar One in February 1982 involved a procedure to cure and vitrify the painted surface. The purpose of the cure process was to drive off the remaining volatile materials in a controlled manner. Manufacturer's instructions called for raising the painted surface temperature from 250^{o} to 460^{o}F in 1 hour and then holding the temperature at 460^{o} for 1 additional hour. This was accomplished by circulating water through the receiver and commanding groups of heliostats to track the receiver. Panel flows were then regulated to create 360^{o}F, 410^{o}F, and 460^{o}F hold points for each panel as determined by panel backface thermocouples located approximately 13 ft. below the tops of the panels. Each temperature condition was maintained for 20 minutes. An additional 1 hour hold period at the 460^{o}F temperature was also carried out to complete the paint cure operation.

Once the curing operation was completed, the remaining paint material was then vitrified (changed to a non-porous glass like surface) by gradually raising the surface temperature to 1000^{o}F. This was accomplished by regulating feedwater flow and stabilizing each boiler panel for 10 minutes at 600^{o}F, 720^{o}F, and 850^{o}F control points. No specific 1000^{o}F temperature condition was attempted since it was felt that the condition would occur as part of subsequent routine operation.

The quality of the paint cure and vitrification operation could only be assessed after subsequent periods of receiver operation. During the first three years of operation, no indication of any Pyromark blistering or flaking was observed during close-up surface inspections. In addition, paint stripping operations on selected tubes indicated that a good paint bond existed between the Pyromark and the grit blasted Incoloy 800 tube surface.

During that 3 year period, the absorptance characteristic of the paint, however, deteriorated from the new value of 0.95 to an average value of approximately 0.88 due to some type of weathering mechanism. A plot of this deterioration for panel 12 and on a receiver-average basis is shown in Figure 1-1. This loss in solar absorptance directly impacted the plant's solar-to-electric conversion efficiency with a corresponding penalty in power generation.

During the summer of 1984, receiver repainting discussions were initiated with the goal of restoring the receiver absorptance. Two approaches were considered. The first involved grit blasting the existing painted surfaces to remove the Pyromark paint and to establish a clean (bare metal) surface on to which fresh paint could be applied. This approach appeared to be costly and difficult to accomplish, particularly since the work must be performed approximately 300 ft. above the ground.

An alternate and less costly approach involved cleaning the existing painted surfaces and applying an overcoat layer of Pyromark paint. The key issues in this approach involved the adhesion and long term durability of the freshly applied coat of paint. In addition, since heat must be transferred through the paint layer to the absorbing tubes, total paint layer thickness was also of concern.

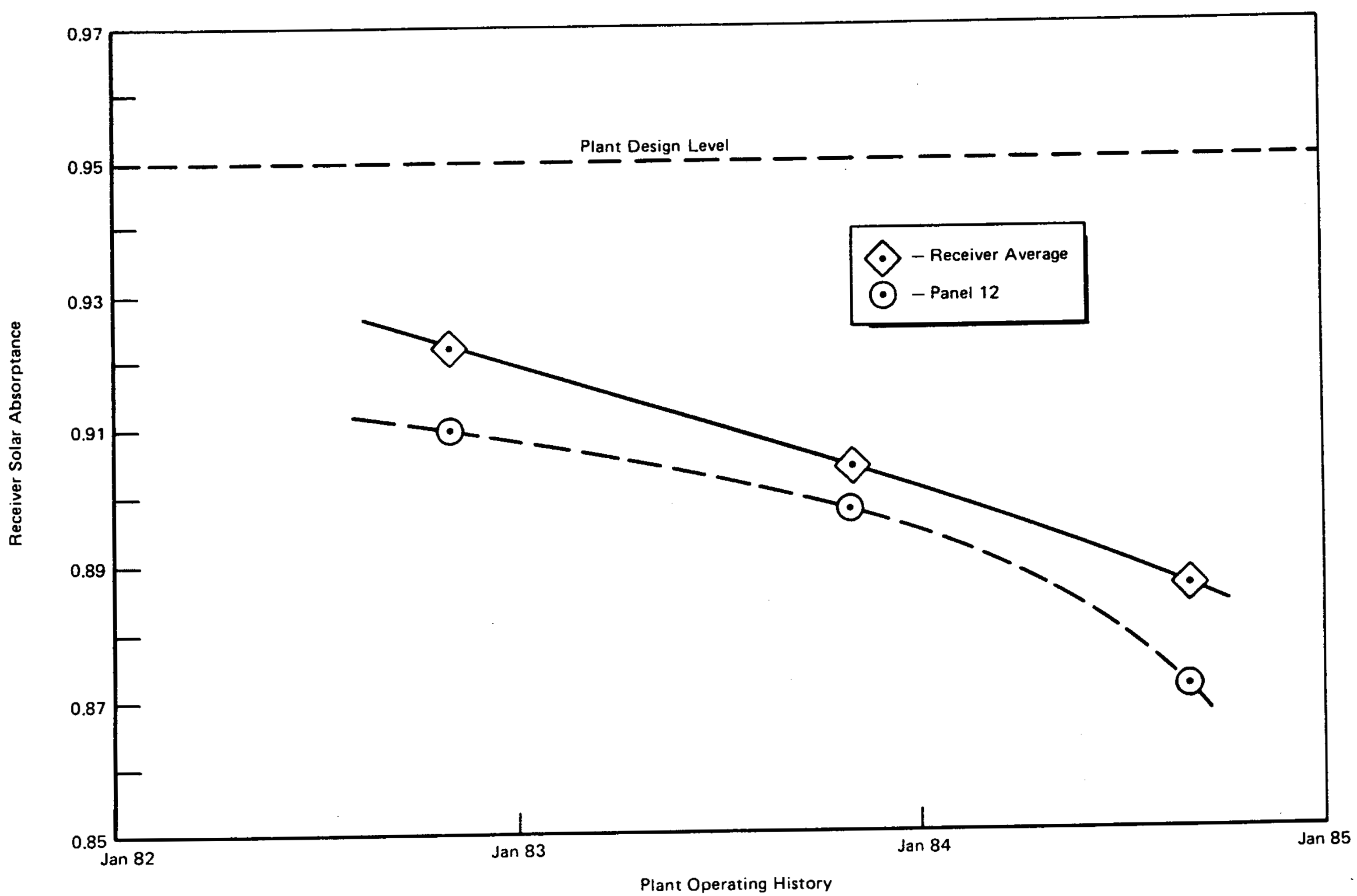


Figure 1-1. Receiver Solar Absorptance History

Prior to making a decision regarding the repainting of the entire receiver, a test program was set up to evaluate the overcoat painting approach. Receiver panel no. 12 (high power, well instrumented, north-facing panel) was selected for the test. The intention of the test was to develop and implement a repaint procedure and evaluate its results for a period of 6-12 months. This report documents the painting preparation, repainting of panel 12, and the subsequent evaluation that was carried out in support of this test program.

SECTION 2

PROCEDURE DEVELOPMENT

The procedure for repainting panel 12 was developed at the Painting and Coating Laboratory of the McDonnell Douglas Astronautics Co. in Huntington Beach, California. It represented a compilation of past solar receiver painting studies and current work aimed at the over-coating of panel 12.

2.1 Background Studies

The 1982-83 operating experience at Solar One indicated that excessive receiver tube temperatures were being experienced on certain panel edge tubes on a routine basis. This high temperature condition was a result of the larger surface area exposure associated with the edge tubes.

As a way to minimize the over temperature condition, consideration was given to reducing individual tube absorptance by removing the black Pyromark paint and replacing it with a reflective white high temperature Pyromark paint. Laboratory studies were conducted to determine the best method of applying the paint and the proper paint thickness to insure adequate coverage while minimizing the possibility of paint cracking or flaking. In addition, issues involving paint cure and vitrification were also verified.

The studies involved painting and evaluating a series of 302 stainless steel test coupons sized 2 1/4 in. x 2 1/2 in. x 0.040 in. Each of the test coupons was grit blasted on one surface with 320 mesh Al_2O_3 grit. The coupons were then cleaned with an MEK (methyl ethyl ketone) soaked rag to remove oil and particulate contamination. The thickness of each prepared coupon was then measured with a micrometer and recorded.

The white Pyromark paint was shaken on a Red Devil mechanical paint shaker for 10 minutes prior to use. The freshly shaken paint was then filtered through cheesecloth to remove any gross particulates present. The paint was then applied with a Binks Model 7 spray gun fitted with a 36SS needle and nozzle with a 36SD air cap. The application involved the use of a siphon cup only with air line pressure of 70 psi. The flow needle was adjusted to two turns open while the pattern width was set to produce a spray width of 6 in. at a distance of 8 in. No thinning of the paint was required. The paint was applied in two passes of 50% overlap to produce a more uniform thickness. The coated coupons were allowed to air dry for 2 hours prior to remeasuring the coated coupon thickness. The dry film thickness (DFT) of the coating was held to 0.4 to 0.6 mils per application.

Following an 18 hour air dry period of the first coat, selected coupons were subsequently painted with a second, third, and in some cases a fourth coat according to the following painting schedule:

Paint Coat	Air Dry Period
2	3 hours
3	2 hours
4	2 hours

This procedure resulted in test coupons containing anywhere from 1 to 4 coats with corresponding dry film thickness of 0.5 - 2.5 mils. This procedure was repeated for a total of 3 different batches of Pyromark paint.

With the completion of the painting operation, the test coupons were placed in a Perkin Elmer gas chromotograph oven. The oven was programmed to move from an initial ambient temperature of 73^{o}F to 250^{o}F at a rate of 3.6^{o}F/ minute. The coupons were then held at 250^{o}F for a 2-hour bake. The oven was then reprogrammed to move to 480^{o} at a rate of 7.2^{o}F/minute with a subsequent 2 hour hold at 480^{o}F.

With the completion of the curing operations, the test coupons were then cooled to room temperature and transferred to a furnace. The coupons were then heated to 1000^{o}F by incrementing the temperature controller at the rate of 50^{o}F every 2.5 minutes to accomplish the vitrification process. For this paint, the vitrification process involves a conversion of silicone resins to inorganic silicates. Once vitrified, the paint is advertised to withstand thermal shocks up to a maximum service temperature of 2500°F. This fact was not verified as part of this test program.

Paint life and durability tests were then conducted by maintaining the coupons at 1000°F for extended periods. After a temperature hold period of 116 hours the following observations were made:

Paint Batch	Uncured DFT*	Baked DFT*	Comment
#2932	1.1 mils	0.9 mils	No cracking observed.
#2361	1.7 mils	1.4 mils	Extensive cracking observed.
#0132	1.0 mils	0.7 mils	Minimal, isolated cracks.

* Dry film thickness.

Based on this test program, the following general conclusions were drawn regarding the white Pyromark paint:

1. The surface preparation and cleaning process as described earlier in this section is adequate to ensure good paint adhesion.

2. The paint preparation and spraying equipment/technique described earlier resulted in a uniform, well-controlled, and repeatable paint layer being applied to the test coupon surfaces.

3. Proper paint thickness to avoid cracking, spawling, and adhesion loss should be 1.1 mils max (uncured dry film thickness) or 0.9 mils max (baked dry film thickness). The paint can be applied successfully in two coats of 0.4 to 0.6 mils uncured dry film thickness each.

Although no tests were conducted at this time using the black Pyromark 2500 paint, discussions carried out with the paint manufacturer indicated the acceptability of these surface preparation and application techniques for use with black Pyromark paint. The manufacturer also indicated that total dry film thicknesses as large as 2.5 mils could be applied successfully through successive coats without subsequent problems involving surface cracking and flaking. This is a significantly thicker coating than was found to be acceptable for the white paint.

2.2 Panel 12 Preliminary Painting Studies

Once the decision was made to repaint panel 12 during the plant outage of February 9 - March 8, 1985, additional precursor studies were conducted to verify the feasibility of over-painting an existing painted surface and to finalize the preferred technique to be used in the field. Specific issues addressed were:

- the cleaning and surface preparation of a weathered Pyromark surface
- the paint application technique to be used on the actual receiver located 250 ft. above the ground
- The suitability of the solar absorptance of the repainted tubes.

The tubing specimens used to support this test were prepared by cutting up a portion of an existing (scrap) full scale 70 tube receiver panel into 12 test samples, 6 tubes wide by 3 in. long. This full scale panel, which had been painted with black Pyromark paint prior to its testing at the Central Receiver Test Facility in 1976 was used since it provided the best source of weathered Pyromark paint which had been exposed to concentrated sun light for extended periods. Aluminum witness plates were also prepared for use in determining paint application thickness and as an aid in evaluating alternate application techniques.

The initial paint tests involved a series of practice sessions using vertically mounted witness plates. Different spraying techniques were tested with the goal of creating a uniform wet paint layer of 3.5-4 mils thick. The professional painter found that the desired paint layer could easily be applied with a side-to-side motion using 50% overlapping coats and spray patterns of 4 1/2 - 5 in. wide (gun to plate distance of 6 in.). He also showed that the paint would start to run down the plate if wet film thicknesses in excess of 5 mils were applied during a single application.

Following the painting operation, the witness plates were allowed to air dry at room temperature for 18 hours. Dry (uncured) film thicknesses were then measured with a permascope. These measurements confirmed that the 3.5 - 4 mil wet thickness resulted in the desired 0.8 - 0.9 mil dry (uncured) film thickness.

The next test involved spraying the individual tube samples. In preparation, each specimen was thoroughly rinsed with water and scrubbed with a soft nylon brush to remove surface dirt. They were then sprayed with acetone and allowed to air dry in a vertical orientation (tubes running up and down). Tube samples 1-6 were then mounted vertically on a spray board with clean witness plates being positioned to the left and right side of the tube samples.

The tube samples and adjacent witness plates were then sprayed with black Pyromark 2500 paint in 50% overlapping coats. Details regarding the painting process are contained in Table 2-1. The painted tube samples and witness plates were allowed to air dry for 18 hours. A permascope was then used to measure the dry (uncured) paint layer on the witness plates. These measurements indicated paint layer thicknesses of 0.7 - 0.8 mils.

The next step was to remove tube specimens 1-3 from the spray board and repaint specimens 4-6 along with the adjacent witness plates. Following the repaint and an 18 hr. air dry, witness plate measurements indicated a total dry (uncured) paint thickness of 1.6 - 1.8 mils.

Tubing specimens 1-6 were then cured and vitrified per the following schedule:

- Ramp temperature from room temperature to 250°F in 10 minutes
- Hold at 250°F for 2 hours (flat position)

Table 2-1

Paint Application Process for Overcoat Tests

Gun type:	Binks Model 7
Nozzle:	36 SS (Fluid Tip)
Needle:	36 SS
Air Cap:	36 SD
Pressure Pot:	None required
Target to Gun Distance:	6 in.
Flow Needle Adjustment:	Open 1 3/4 - 2 turns
Spray Pattern:	4 1/2 - 5 in. (50% overlap)

- Ramp temperature from 250°F to 480°F in 15 minutes

- Hold at 480°F for 2 hours (flat position)

- Ramp temperature from 480°F to 1000°F in 20 minutes

- Hold at 1000°F for 24 hours (flat position)

At that point, the 6 tubing specimens were removed from the oven, allowed to cool, and visually inspected. The inspection revealed signs of paint cracking between the tubes (valley cracks) of specimens 4-6 which had been over painted twice (total uncured paint thickness of 1.6 - 1.8 mils). Specimens 1-3 (uncured paint thickness of 0.7 - 0.8 mils) showed no signs of paint cracking.

Solar absorptivity measurements of specimens 1-3 were then made using a Gier-Dunkle reflectometer. These measurements were then compared to absorptivity measurements made on the reference specimens 10-12 (weathered Pyromark surfaces which had been rinsed and cleaned but not repainted). The results of these measurements are summarized as follows:

Specimen	Solar Absorptivity
Freshly Painted	
#1	0.968 ± .004
#2	0.969 ± .004
#3	0.977 ± .003
Weather Surface (Cleaned)	
#10	0.932 ± .005
#11	0.940 ± .007
#12	0.941 ± .009

The results of this test program demonstrated the adequacy of the surface cleanup and single overcoat coverage in providing a crack free, highly absorptive coating. The single overcoat approach is also attractive in that it reduces the high altitude work on the Solar One receiver and minimizes plant downtime.

SECTION 3

RECEIVER PANEL REPAINT OPERATION

Based on previous test results and painting experience involving Pyromark paint, a painting specification was prepared to define the work scope for potential painting contractors. The specification addressed the following areas:

- Panel surface preparation
- Masking
- Painting of the panel surface
- Job cleanup

The actual job specification description prepared for this work is included as Appendix A of this report.

One notable difference between the job specification and previous painting tests involved the solvent used for panel cleaning prior to the paint application. The job specification called out 1, 1, 1 - Trichloroethane in place of MEK (methyl ethyl ketone) or acetone as the cleaning solvent. This selection was made based on environmental restrictions imposed by the Southern California Air Quality Management District which is the regulating agency that controls hydrocarbon vapor release at the Solar One site.

The painting contract was awarded to the McDonnell Douglas Astronautics Company primarily because of their involvement in developing the job specification and past experience with applying Pyromark 2500. The actual painting operation was carried out by John Hunter of the McDonnell Douglas paint shop.

The entire panel preparation, painting, and cleanup operation was accomplished on March 6-7, 1985 with high winds delaying the start of activities on March 6. The first day activities involved washing/scrubbing the panel surface to remove loose dirt and masking the appropriate areas. These areas included the adjacent panel tubes, the top and bottom heat shields and the exposed tips of the heat flux sensors. Aluminum witness plates were attached to the masking which covered the adjacent panels in order to provide a record of paint thickness application. The position and spacing of these plates was consistent with the information contained in the Job Specification (Appendix A). The washing was accomplished from top down using water taken from the Solar One service water system and a nylon brush. A photograph of the prepared panel is shown in Figure 3-1. The first day tasks were completed in approximately 3 hours.

The activities of March 7 commenced shortly after sunrise in an effort to avoid delays due to potential high winds. Initial activities involved the solvent spray to dissolve any oil residues. The solvent was sprayed on using a side-to-side motion starting at the top of the panel. The sky climber was gradually lowered to the bottom of the panel during the solvent spray operation. At the same time, the Pyromark 2500 paint was being shaken and strained in preparation for the painting operation.

The painting operation proceeded immediately by filling the spray gun with Pyromark 2500 and returning the sky climber to the top of the receiver. The painting procedure was consistent with the instructions prescribed in the Job Specification. The paint was applied with a side-to-side motion using 50% overlapping strokes. The spraying strokes were continued as appropriated into the masked area to cover the witness plates with representative coats of paint. The sky climber was gradually lowered until the entire panel had been painted. Figure 3-2 shows the paint spraying activity in progress. The combined solvent and paint spraying operation was completed in approximately 1 1/2 hours.

Following a brief air dry period, the witness plates and masking were removed. During that removal, care was exercised to prevent the sky climber from coming in contact with the freshly painted surface. This was accomplished by attaching standoff bumpers to the sky climber platform which

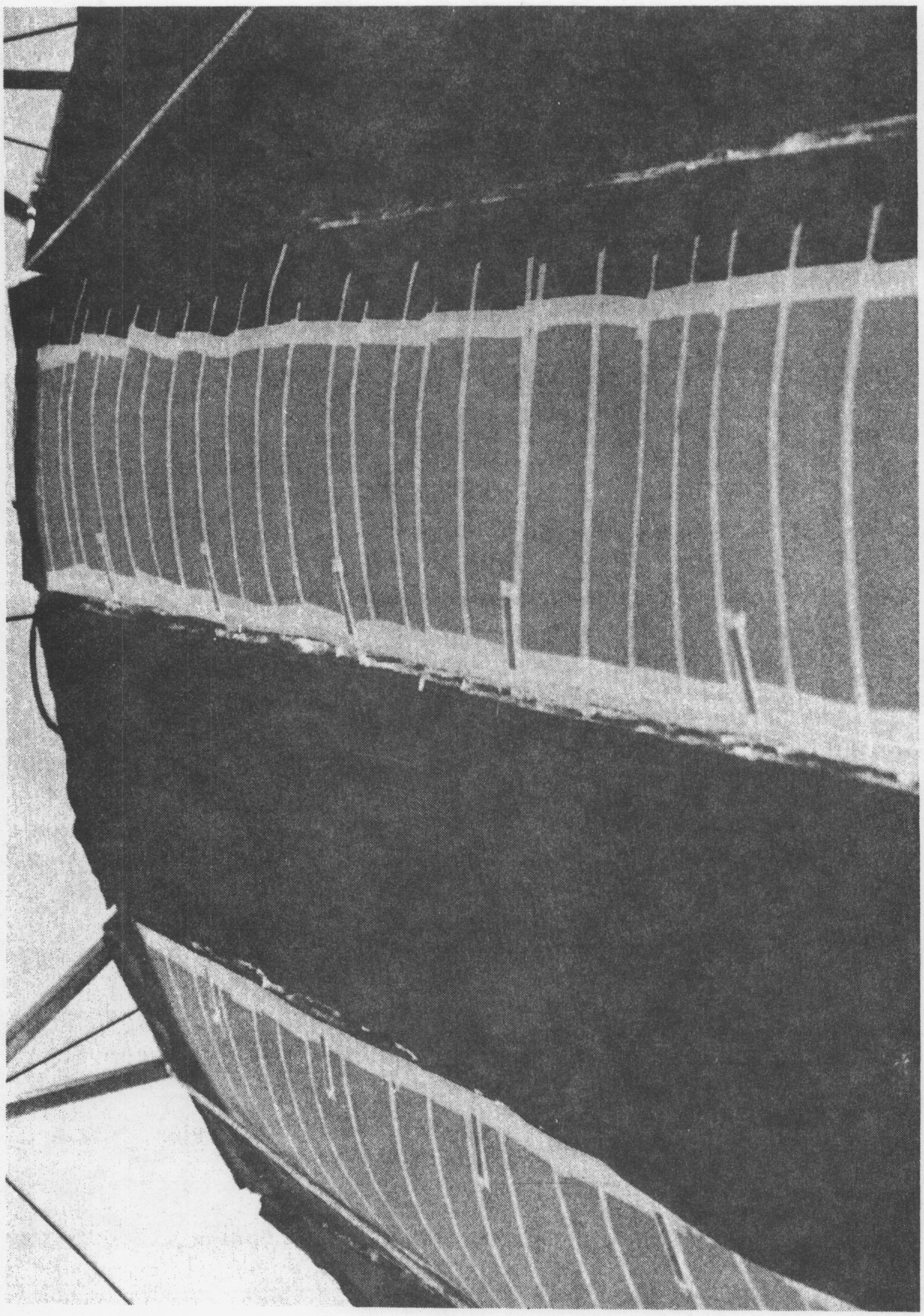


Figure 3-1. Panel 12 Prepared for Paint Application

Figure 3-2. Panel 12 Paint Spraying Activity

contacted adjacent panel surfaces. The issue of paint surface damage through mechanical contact (rubbing or scraping of the sky climber) was of concern until the paint cure and vitrification operations were complete.

The freshly painted witness plates were returned to the McDonnell Douglas paint shop for analysis. Paint thickness measurements were made with a permascope on March 8. The results of these thickness measurements for the dry, uncured plates are shown in Table 3-1. The left and right designations refer to locations on the same witness plate and are included to give a better indication of the uniformity of the paint layer. The location for each witness plate relative to the freshly painted panel is indicated in Figure 3-3. Visual inspections of both the freshly painted panel and the witness plates showed the painted surfaces to be smooth, uniform, and crack free.

Table 3-1

Pyromark Application Thickness

(Dry, Uncured Witness Plates)

Plate Identifier	Paint Thickness (mils)	
	Plate (Left Side)	Plate (Right Side)
1	0.80	0.85
2	0.60	0.65
3	0.70	0.65
4	0.85	0.80
5	0.75	0.70
6	0.70	0.80
7	0.90	0.95
8	0.95	0.90
9	0.75	0.75
10	0.70	0.80
11	0.70	0.70
12	0.70	0.70
13	0.70	0.70
14	0.80	0.80

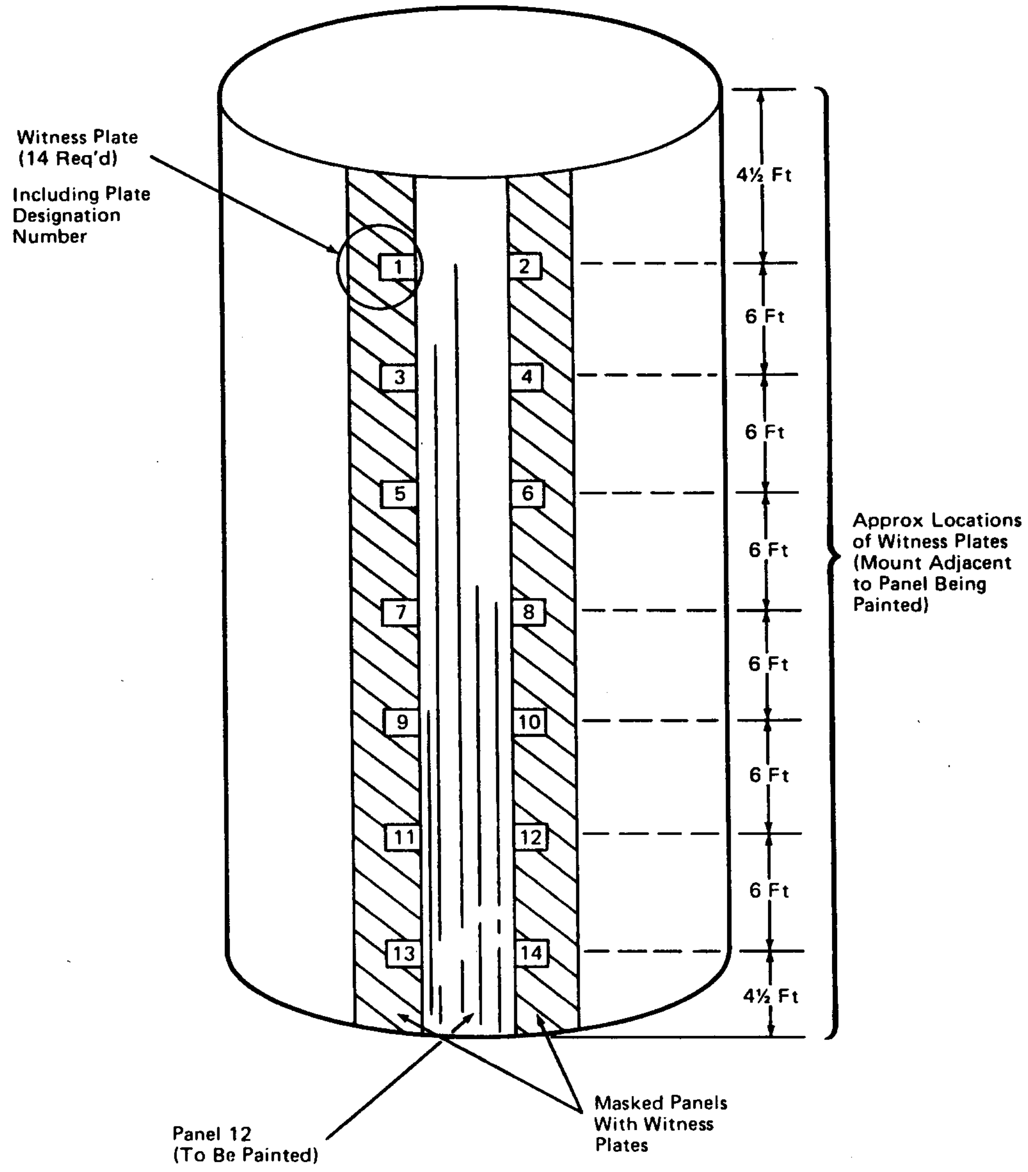


Figure 3-3. Witness Plate Locations and Numbering System

SECTION 4

PAINT CURE AND VITRIFICATION

The final operation before returning the receiver to service involved the cure and vitrification of the freshly painted surface. During that process, the remaining volitiles were driven off and the silicones contained in the paint were converted to silicates thereby creating a non porous surface which can withstand rapid temperature changes.

The actual cure and vitrification procedure used for panel 12 is contained in Appendix B. The procedure involves cure points at 250^{o}F and 450^{o}F as measured by the back wall control thermocouple TI 2503. The initial temperature condition (2 hour hold at 250^{o}F) was produced by circulating hot water through the panel. The water was heated in the preheat panels prior to flowing through panel 12. The 450^{o}F hold (for 2 hours) was accomplished by applying reflected sunlight directly on the freshly painted surface. A sufficient quantity of heliostats was used to create a two phase flow condition in the panel and the desired backwall temperature of 450^{o}F. The heliostats used to heat panel 12 were selected based on aim point considerations in order to produce a reasonably uniform flux distribution. Even with this distribution, lower portions of the panel would be naturally cooler than 450^{o}F due to the flow direction of the water through the panel.

The vitrification operation involved 10 minute holds at 600^{o}F, 720^{o}F, and 850^{o}F. These temperature conditions were produced through a combination of redirected collector field power and the adjustment of the temperature control set point. In all cases, the progression through the hold points was based on the back wall control thermocouple TI 2503. No attempt was made to increase the panel temperature to 1000^{o}F as part of this operation. This decision was based on potential panel damage that could result at elevated temperatures.

The time at elevated panel temperature required to cure and vitrify the freshly painted surface was accumulated over 4 operating days. Delays were caused by cloudy conditions, high winds, and equipment problems which led to a plant trip during the cure procedure. A fifth operating day was lost completely during that period due to cloud cover.

The initial attempt to cure the paint occurred on March 9. The attempt was made during a morning period of broken cloudiness which became completely overcast shortly after 1:00 PM. During this attempt, a total of 26 minutes of cure time (TI 2503 at 250^{o}F) was accumulated. Sky conditions remained cloudy through the balance of March 9 and during the entire day of March 10.

The next attempt to cure the panel occurred on March 11. The partly cloudy and windy conditions that prevailed on that day provided a highly transient environment which required continual operator action (adjustments to heat flux and panel flow) to maintain a reasonable temperature condition. A time history of representative panel temperatures is shown in Figure 4-1. The effects of the cloudy and windy conditions are apparent. This cure operation was halted at 1:20 PM due to cloud cover. Locations of thermocouples for these data and data subsequently presented are summarized in the following tabulation.

Thermocouple Tag ID	Distance Below Top Manifold Centerline	Tube
TEX 2556 C	2 ft. 2 in.	35
TEX 2556 K	7 ft. 4 in.	1
TEX 2556 N	7 ft. 4 in.	66
TEX 2559 E	19 ft. 4 in.	35
TEX 2559 K	28 ft. 4 in.	35
TEX 2559 X	40 ft. 4 in.	35
TI 2503 P	13 ft. 4 in.	35

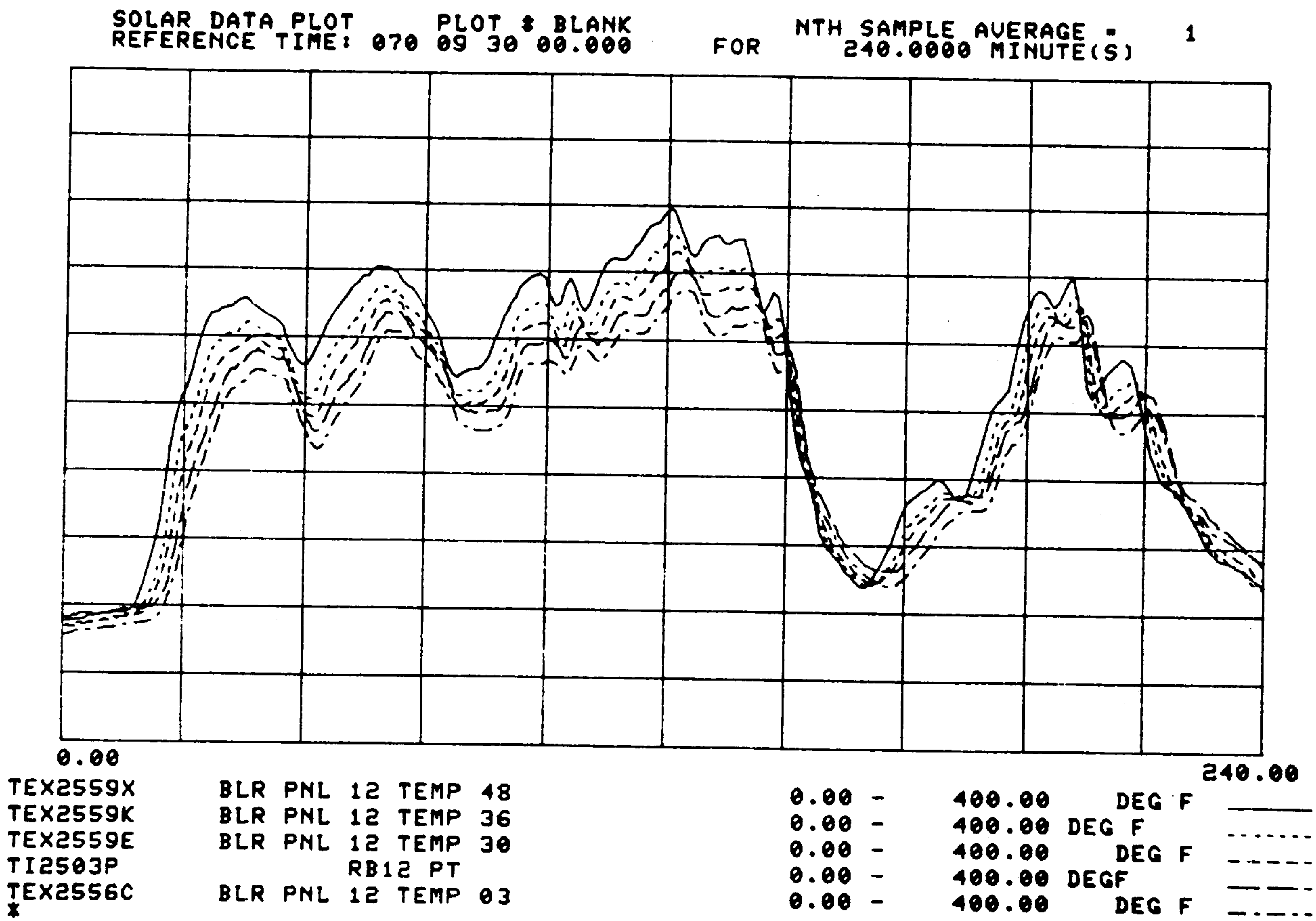


Figure 4-1. Representative Panel Temperatures During 250°F Cure Point

The third attempt to complete the paint cure and vitrification procedure occurred on March 12 which was a clear day with moderate winds. With these stable conditions, it was a relatively straight forward process of controlling heat flux and panel flow to complete the panel cure. Figure 4-2 shows representative temperatures as they existed during the completion of the 250^{O}F and the execution of the 450^{O}F hold. The spread in the temperatures that existed during the 450^{O}F hold are typical of what is to be expected when the hold condition is based on readings provided by a single thermocouple.

The first step of the vitrification operation (600^{O}F hold) was carried out on the afternoon of March 12 following a shutdown and reconfiguring of the receiver controls. A trace of representative temperature data during this period is shown in Figure 4-3. Again, the natural spread in temperatures between various locations on the panel is apparent. The erratic temperature traces are a result of hardware problems being experienced on another receiver panel (panel 21). This problem ultimately led to a receiver trip and subsequent panel cool down which is also shown in the Figure.

The final steps of the vitrification operation were accomplished on March 13 as part of a normal plant startup. The receiver temperature control set point was maintained at 720^{O}F and 850^{O}F to produce the necessary temperature hold points for panel 12. At that point, the receiver was returned to normal steam generation operation in support of thermal storage charging and power generation.

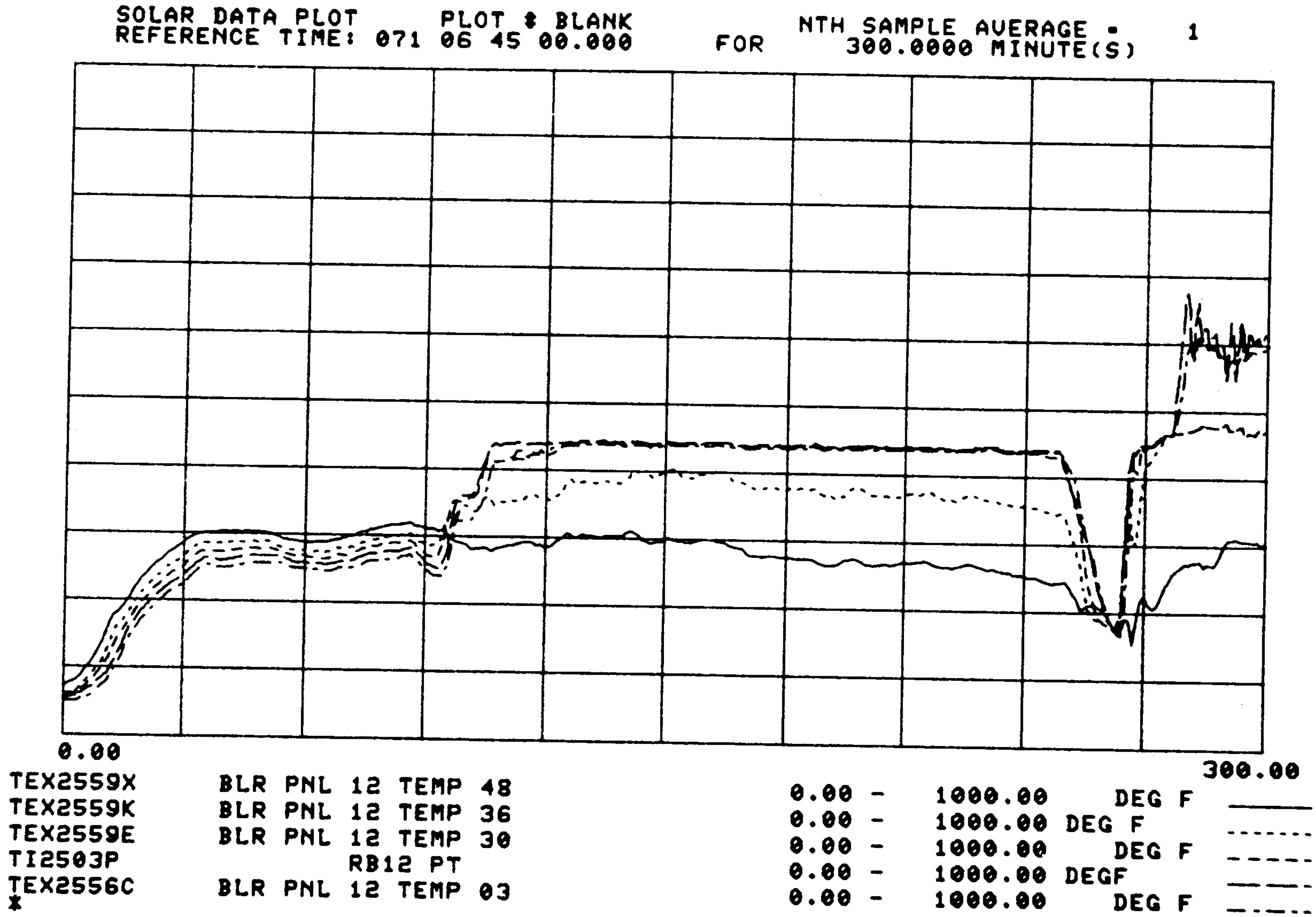


Figure 4-2. Representative Panel Temperatures During the 250°F and 450°F Cure Points

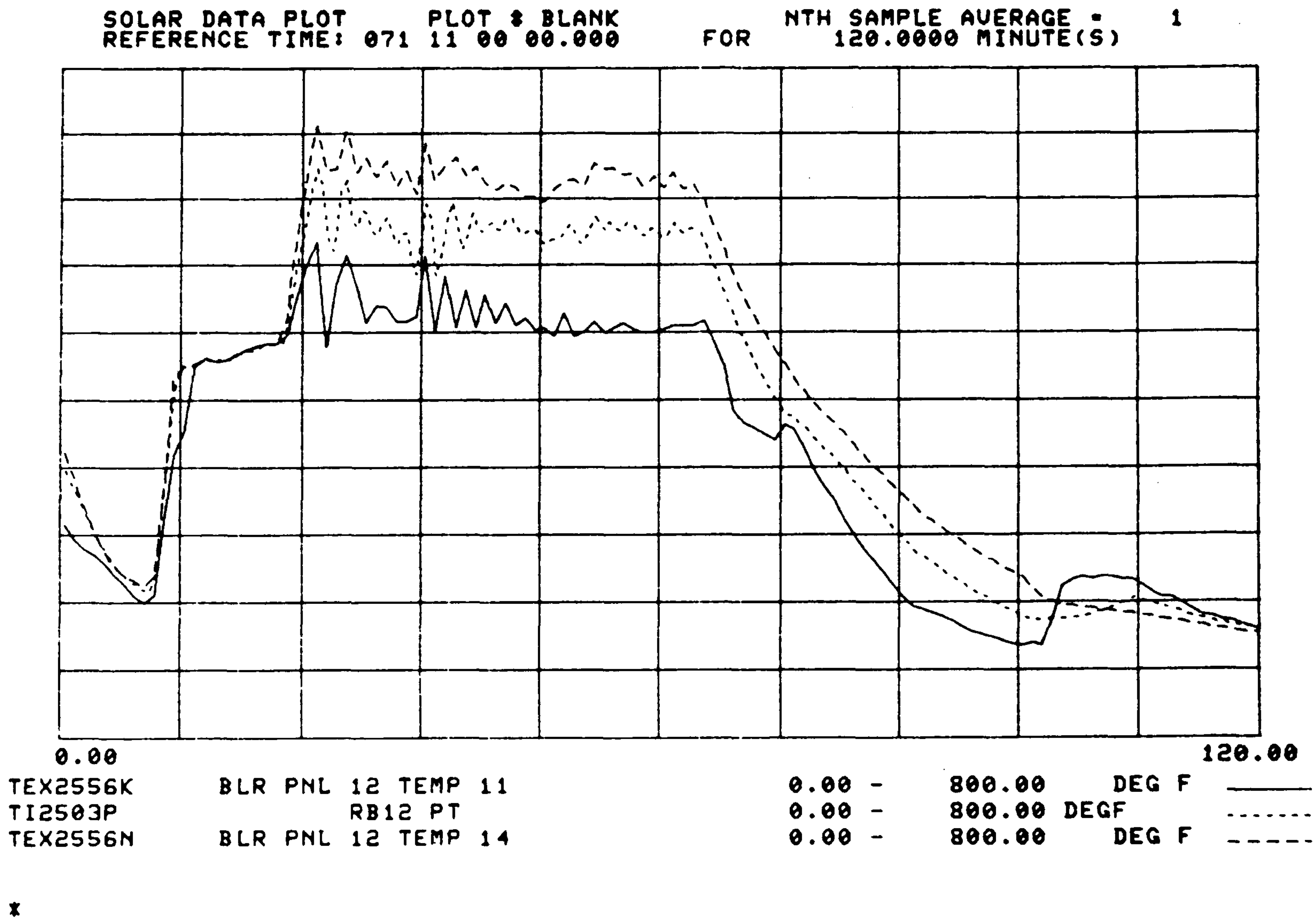


Figure 4-3. Representative Panel Temperatures During 600°F Vitrification Hold Point

SECTION 5

POST PAINTING EXPERIENCE

An early indication of the improved absorptance of the freshly painted panel was obvious during the curing and vitrification process. Figure 5-1 shows the north side of the receiver as it appeared when exposed to redirected sunlight. The improved absorptance is apparent as the panel appears much darker than neighboring panels. Also visible is the natural lateral streaking that occurred as a result of the recent painting process.

Of greater significance are the long term performance and paint durability effects associated with the repainted panel. These effects can be considered from the stand point of overall panel absorptance as a function of time and detailed studies of the repainted surfaces.

From the stand point of overall panel performance, absorptance measurements were made April 12 and August 23, 1985 to determine the initial performance deterioration characteristics. A total of 55 absorptance (reflectometer) measurements were made over 5 tubes. The resulting average absorptance values are shown in Figure 5-2 along with data points which represent the overall receiver average absorptance. The data show as expected that the absorptance associated with panel 12 is well above that exhibited for the rest of the receiver. It also shows a significantly steeper deterioration rate than that indicated for the rest of the receiver. Since comparable early receiver data are not available, it is unclear at the present time whether the panel 12 deterioration rate will continue its steep descent until it intersects the receiver average condition or whether it will deteriorate at a slower rate which is more representative of the receiver average deterioration rate following an initial "burn in" period.

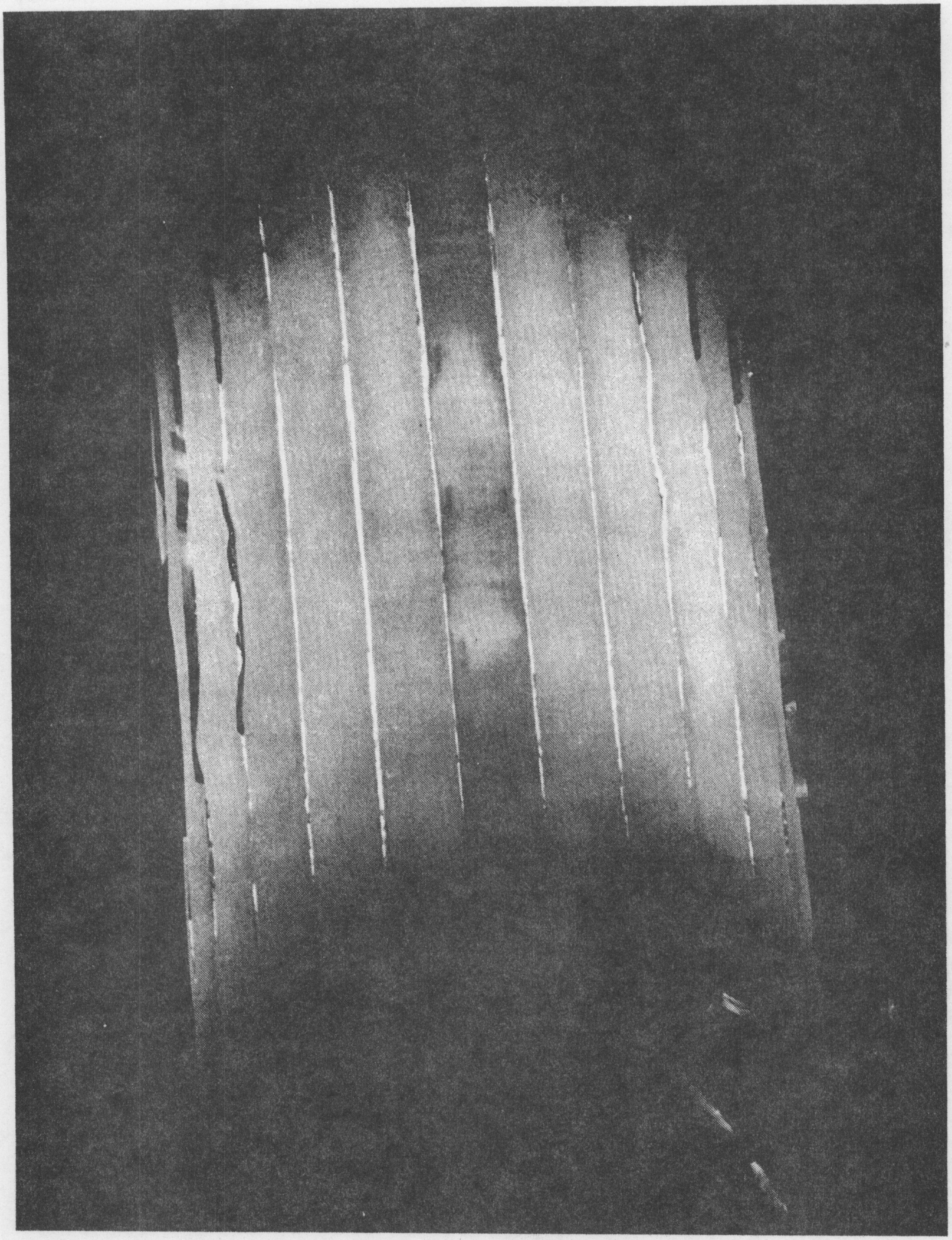


Figure 5-1. Appearance of Freshly Painted Panel During Curing and Vitrification Process

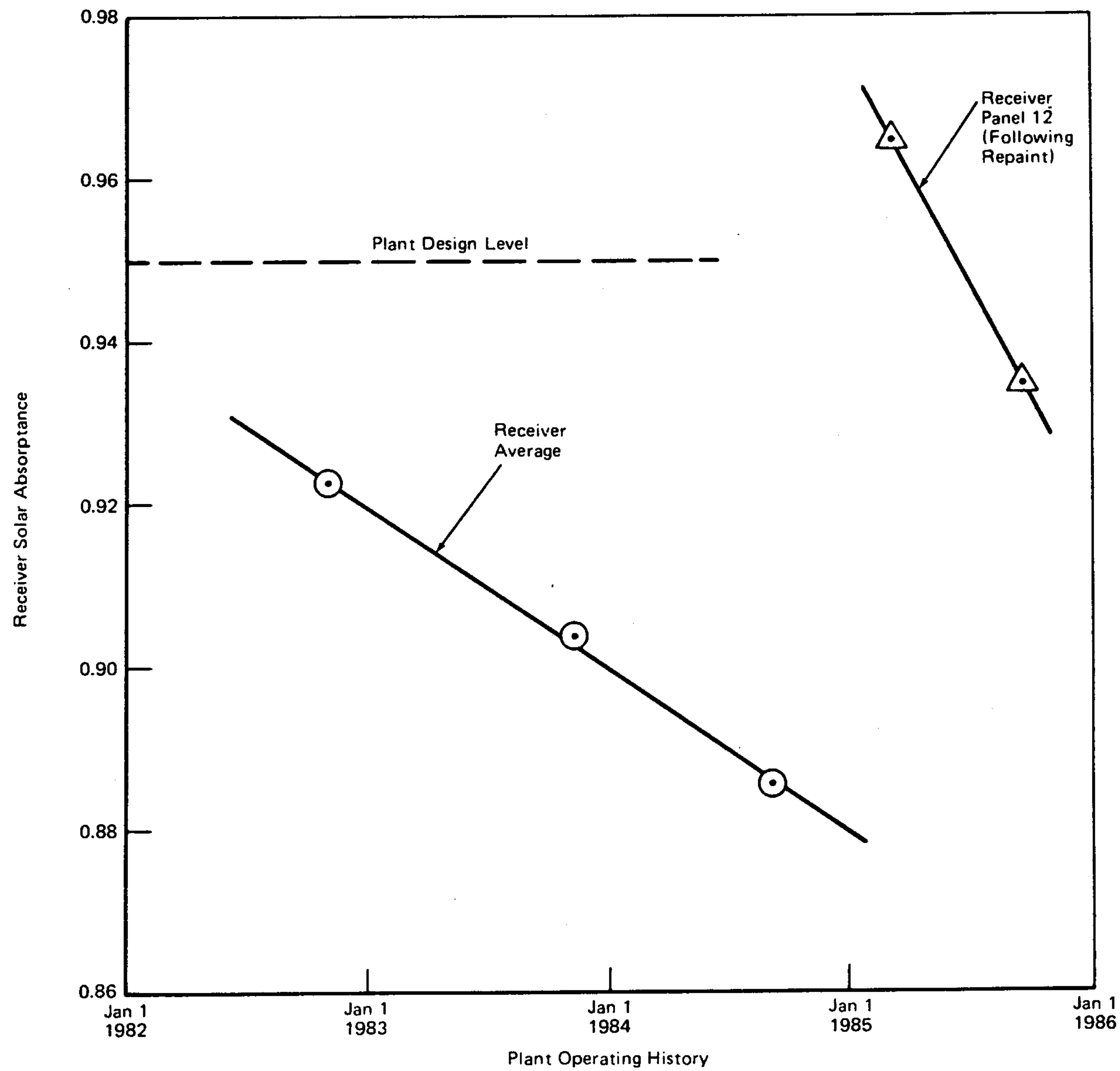


Figure 5-2. Receiver Absorptance History

On a more local basis, detailed observations and investigations were made of individual portions of the repainted surface. During the absorptance measurements made on April 12, the following specific observations were made:

- There were many areas on the panel surface where strips two to six inches wide ran across the panel where the paint had a glossy appearance. The rest of the panel had a flat appearance.

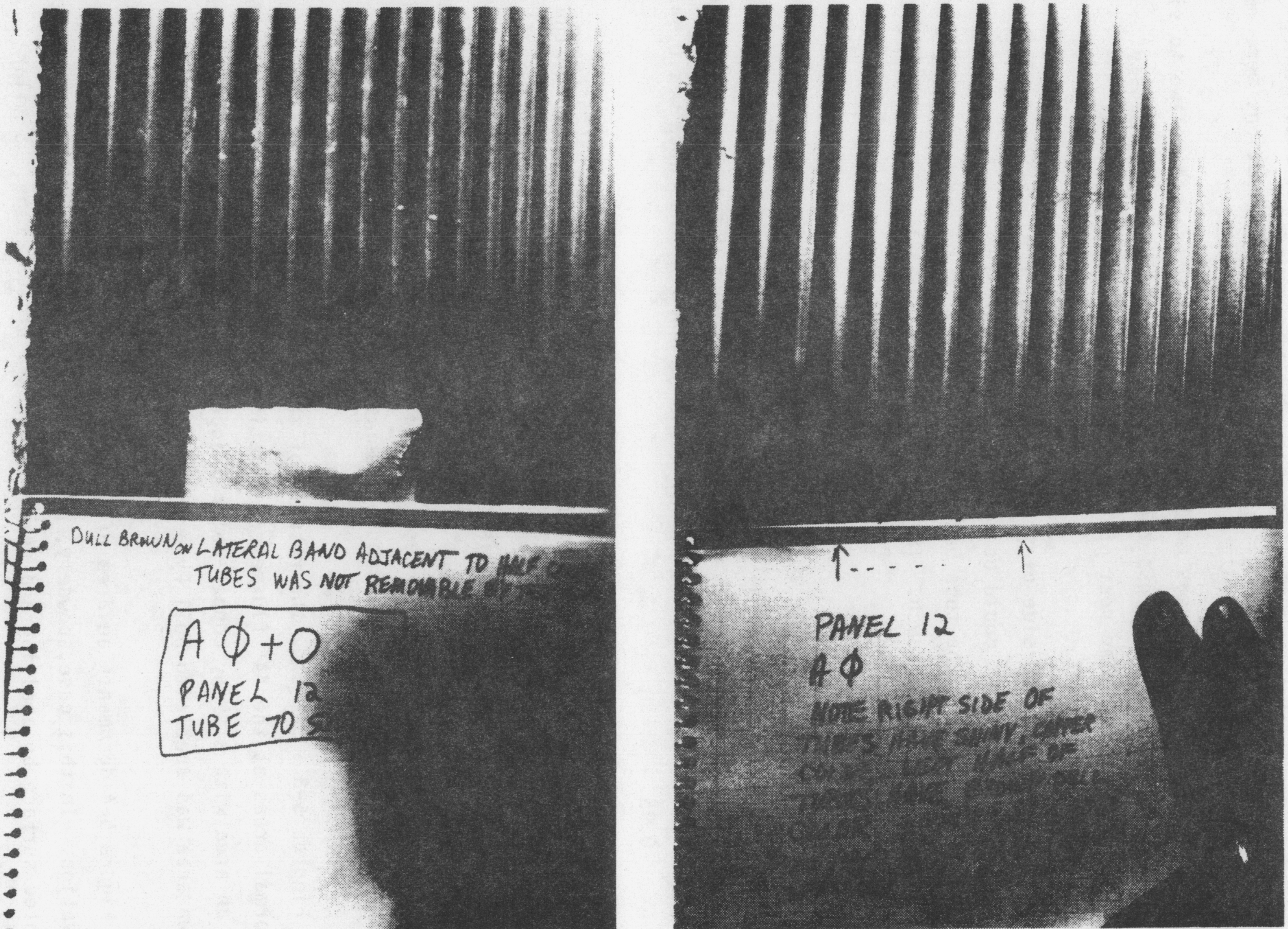
- On the tube 70 side of the panel (flux gage B elevation), the Pyromark paint could be partially wiped off the panel. The residue after wiping the tube had a black chalk-like appearance and was gritty to the touch. The absorptance of the tube after wiping was approximately 0.94.

- On the tube 70 side of the panel (flux gage A elevation), there was an area approximately 2 ft. X 2 ft. which had the same appearance and gritty texture as when the paint had been wiped off at the flux gage B elevation. The measured absorptance in this area was 0.94 - 0.95.

Following additional receiver operations, a detailed inspection of the panel 12 painted surface was conducted on June 25, 1985. At that time, it was noted that the extent of the chalking and discoloration was less than 1% of the painted surface. Photographs of the unusual areas of the painted surface were made and tape was used to test paint adhesion and to remove samples of the black chalky layer for subsequent laboratory analysis.

Figures 5-3 - 5-6 show the results of this work. Figure 5-3 documents two abnormal areas at the "A" fluxmeter elevation. They involve a dull brown band and an area with a shiny copper-colored appearance. Tape applied to the dull brown area was unable to pull Pyromark material from the painted surface.

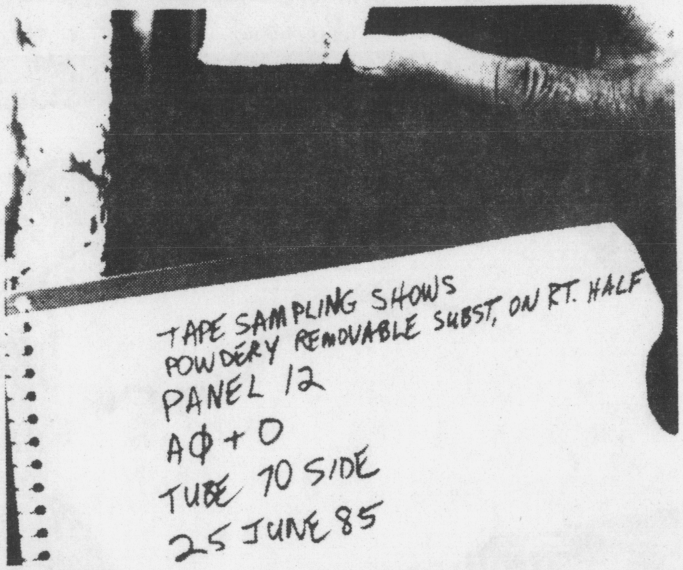
Figure 5-4 documents an area of paint degradation at the "A" fluxmeter elevation. In this case, powdery, gritty material was removed from the painted surface by applying and removing a strip of test tape. Similar degradation zones at the "B" and "C" fluxmeter elevations are shown in Figures 5-5 and 5-6.



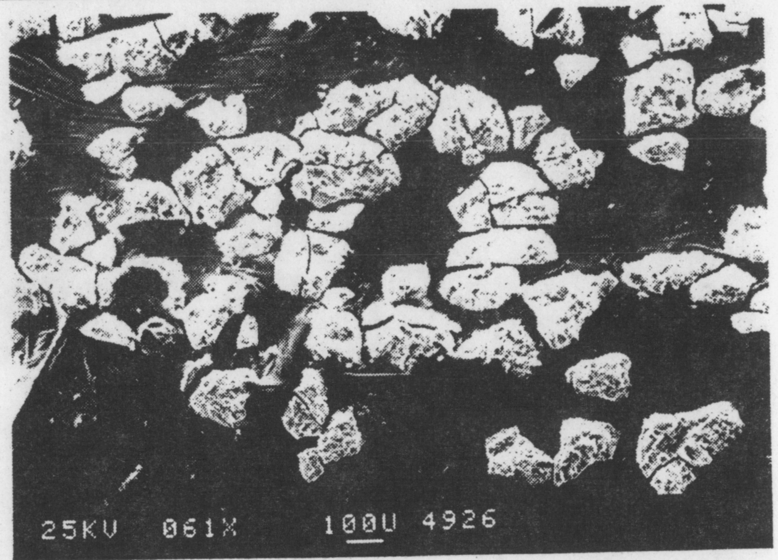
Discolored Area – Tape Test

Discolored Area – Below Tape Test

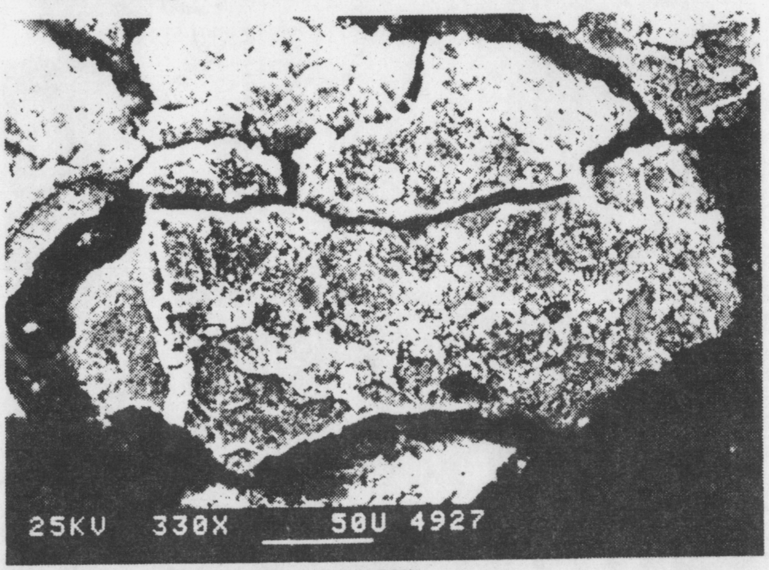
Figure 5-3. Panel 12 Overcoat Paint Discoloration – A Fluxmeter Elevation



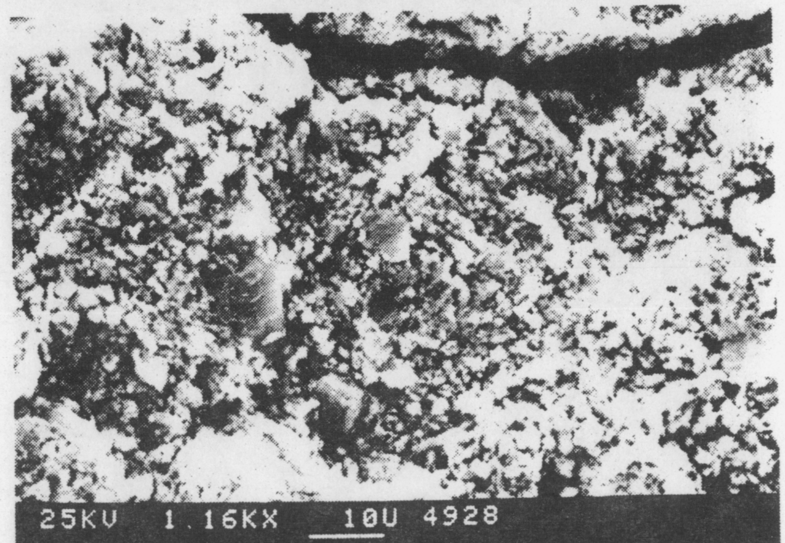
Paint "Flaking" – Tube 70 Side (Tape Test)



Paint Particles – 61 x Magnification (SEM)

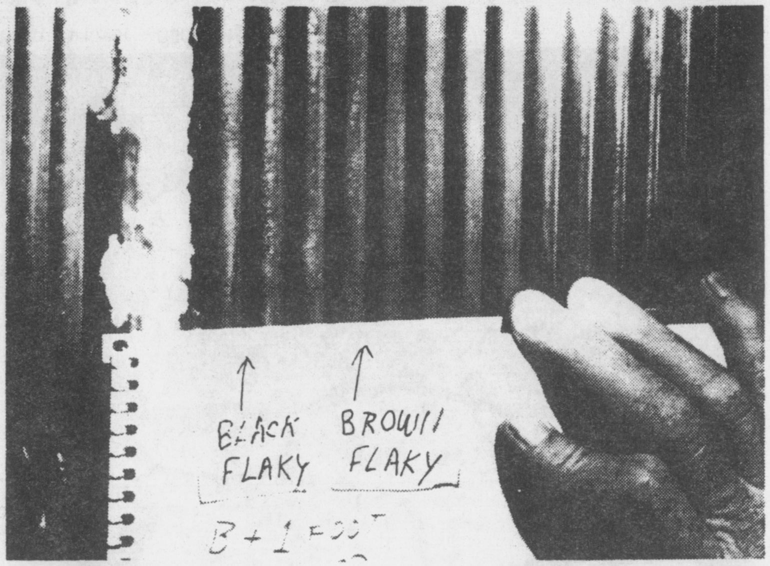


Paint Particles – 330 x Magnification (SEM)

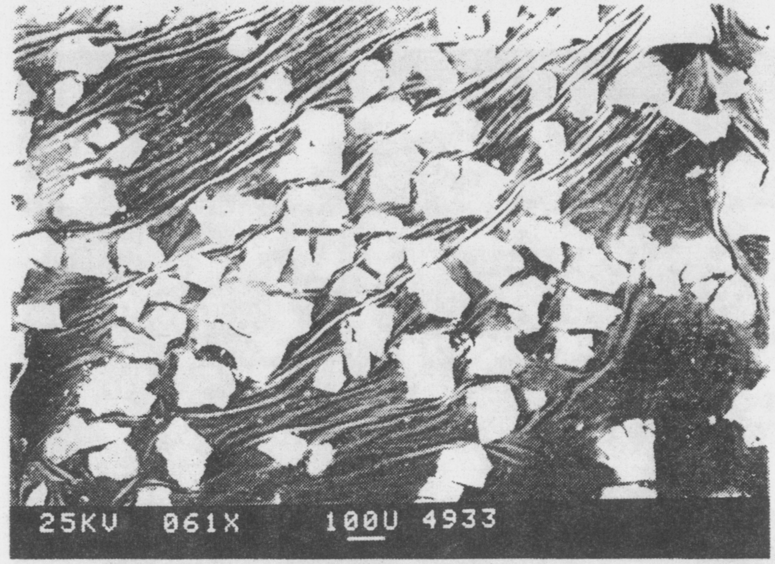


Paint Particles – 1160 x Magnification (SEM)

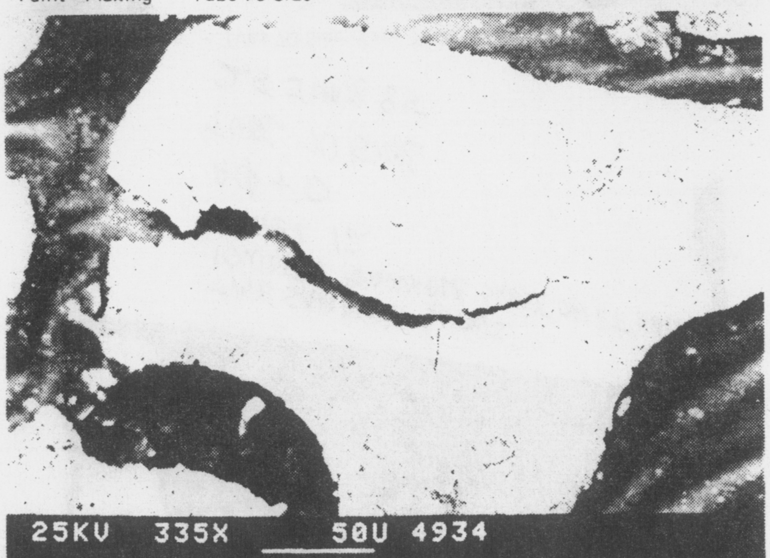
Figure 5-4. Panel 12 Overcoat Paint Degradation – A Fluxmeter Elevation



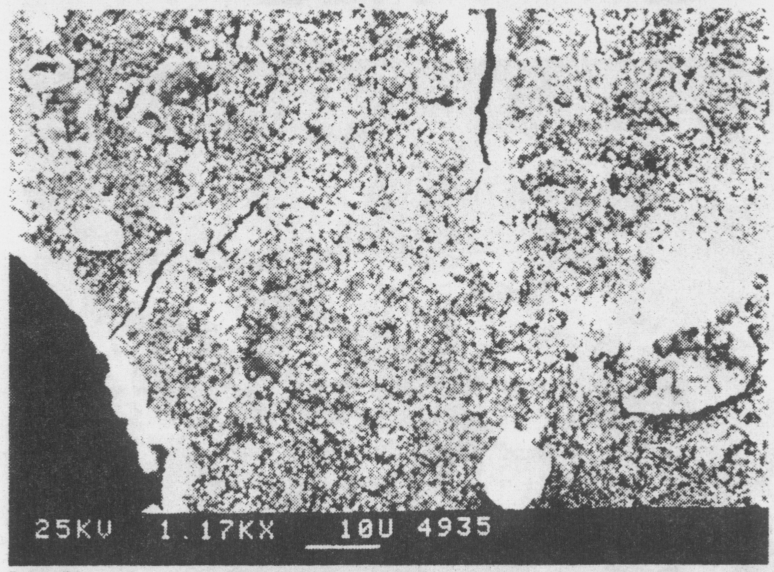
Paint "Flaking" – Tube 70 Side



Paint Particles – 61 x Magnification (SEM)

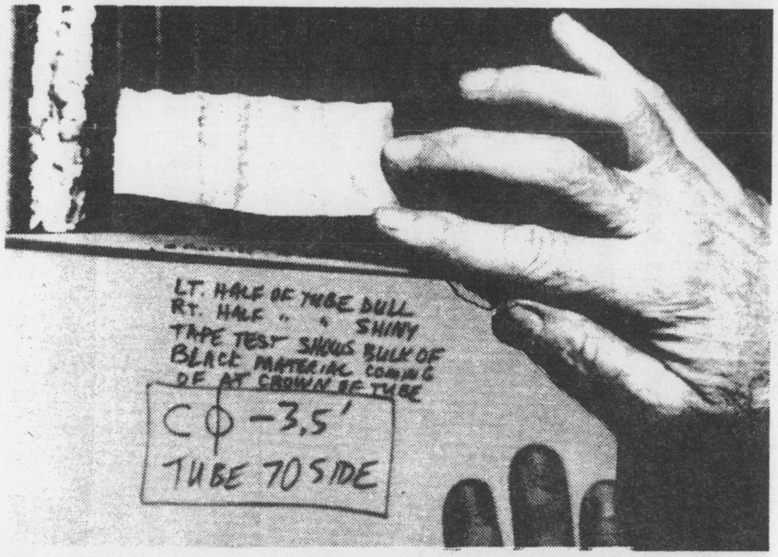


Paint Particles – 335 x Magnification (SEM)

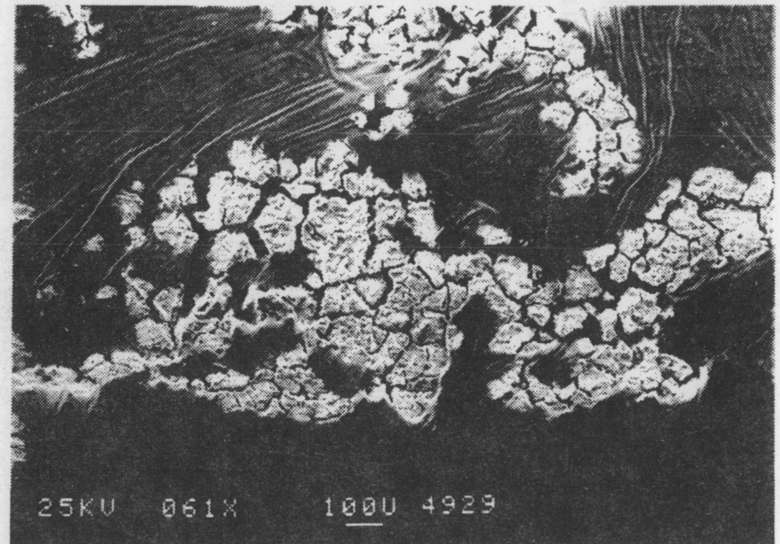


Paint Particles – 1170 x Magnification (SEM)

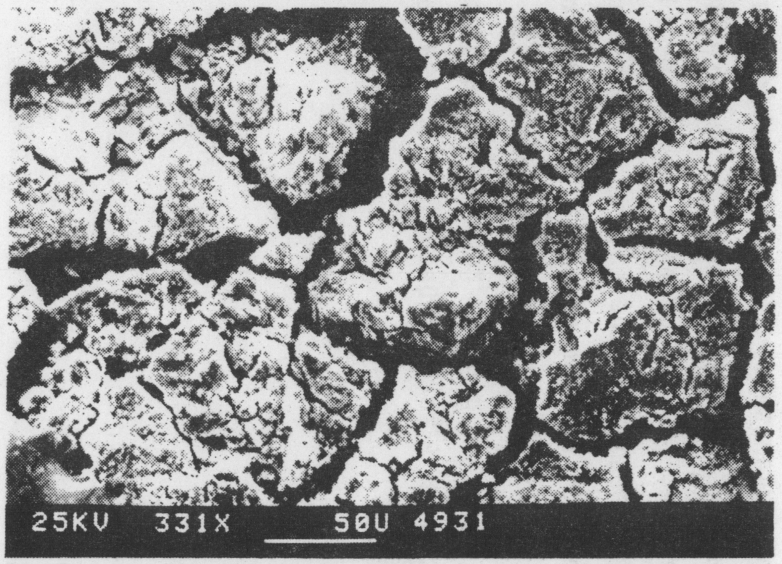
Figure 5-5. Panel 12 Overcoat Paint Degradation – B Fluxmeter Elevation



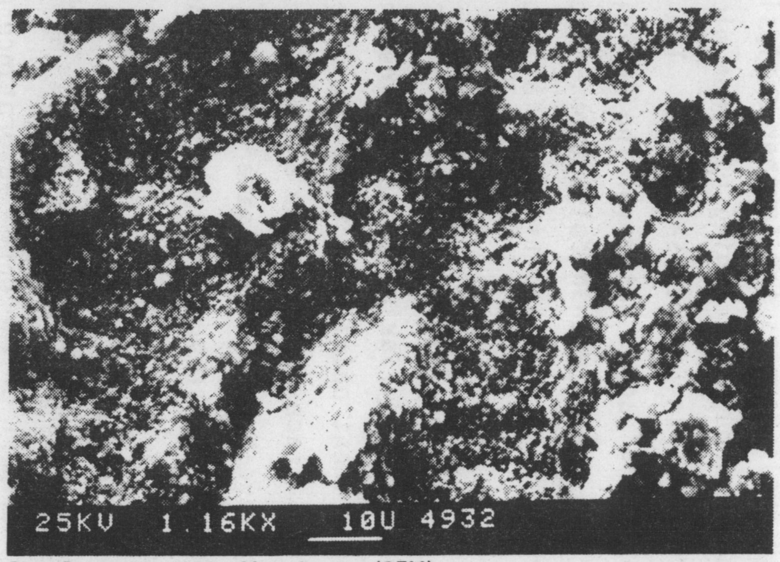
Paint "Flaking" - Tube 70 Side (Tape Test)



Paint Particles — 61 x Magnification (SEM)



Paint Particles — 331 x Magnification (SEM)



Paint Particles — 1160 x Magnification (SEM)

Figure 5-6. Panel 12 Overcoat Paint Degradation — C Fluxmeter Elevation

Residue samples taken from all three degradation zones were returned to McDonnell Douglas for further analysis. Photographs of the paint flakes as taken through a scanning electron microscope at various magnification levels are shown in Figures 5-4 - 5-6. The 61 X magnification photo in each case shows the jagged nature of the individual paint flakes which appeared to be broken due to mechanical action. Photographs taken at higher magnification levels also show additional details of individual paint flakes.

Additional laboratory analysis was conducted to gain insight as to the cause of the flaking process. The analysis of the flakes did not reveal any significant paint deterioration in terms of a chemical change. It did however reveal traces of aluminum and silicon. It was postulated that the aluminum may have been residual material from the original grit blasting operation carried out prior to original painting of the panel in 1980. The silicon could have also been attributed to residuals of the grit blasting operation or incomplete paint vitrification.

As part of the panel absorptance measurement activity of August 23, a detailed visual inspection of the painted surface was again made. This inspection showed that the flaking condition continued on a local basis but that the extent of the affected area was small compared to the entire painted surface. Based on this final inspection, the decision was made to proceed with repainting the entire receiver surface in the same manner that was demonstrated for panel 12. This operation would include a repaint of panel 12. This would allow subsequent data to be gathered for a twice over painted panel. The planned receiver repainting operation was accomplished from December 5 through December 15, 1985 during a planned outage period.

APPENDIX A

Job Specification - Painting

of Solar One Receiver Panel

JOB SPECIFICATION - PAINTING OF SOLAR ONE RECEIVER PANEL

1.0 General Description: Prepare surface, mask adjacent areas, and apply single coat of flat black Pyromark 2500 paint to 1 of 24 Solar One receiver panels. The receiver is located at the Southern California Edison Solar One generating station at Daggett, CA (12 miles east of Barstow). The receiver is situated on top of a steel tower with an elevation (to the top of the receiver) of approximately 290 ft (see Figure 1). The receiver forms an external cylinder which is made up of 24 vertical panels. The cylinder is 23 ft in diameter and 45 ft high. The single panel to be painted is 3 ft across and 45 ft high. It is composed of 70 vertical 1/2 in tubes which have been previously painted with Pyromark 2500. The work is to be accomplished from a 2 man skywalker platform (provided by Southern California Edison) which is suspended from the top of the receiver and is capable of moving up and down over the full length of the receiver. A large working deck exists as part of the permanent structure at an elevation of 211 ft. This deck is available for placement of support equipment. Personnel and equipment access to the working deck is available by elevator and jib crane. All painting required for this job is to be accomplished with the existing 2 gal Pyromark inventory. Solar One site work is to be accomplished during a benign dust free weather period. For safety reasons, skywalker work is prohibited during high wind periods. Cleaning and painting shall not be attempted during dusty periods.

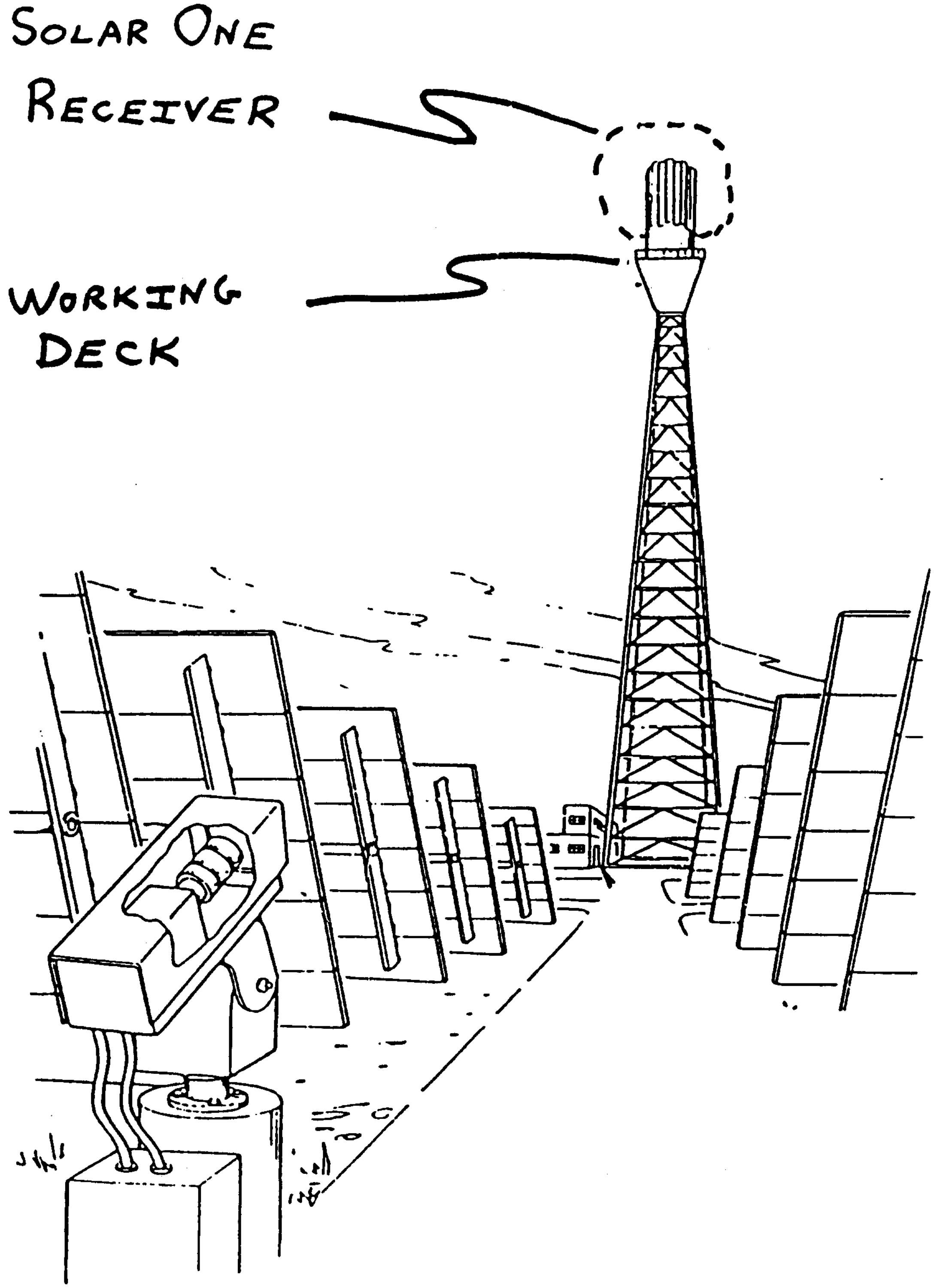


FIGURE 1 LOCATION OF RECEIVER AND WORKING DECK

2.0 Panel Surface Preparation: A two step cleaning process shall be accomplished immediately prior to painting.

2.1 Dirt/Dust Removal - The panel shall be washed with water and scrubbed with a soft nylon brush to remove all dirt and dust. The water shall be available from a hose provided by Southern California Edison which is connected to an existing plant water supply system. The nylon brush shall be of a soft bristle type and be used in a manner which does not damage the existing paint surface. The surface shall be cleaned from top to bottom and allowed to drip dry. Soft bristle brush to be supplied by contractor.

2.2 Solvent Cleaning - Following the water wash, the panel shall be allowed to dry completely. The panel shall then be rinsed (no scrubbing) with solvent 1, 1, 1 - Trichloroethane and allowed to air dry. Solvent to be supplied by contractor.

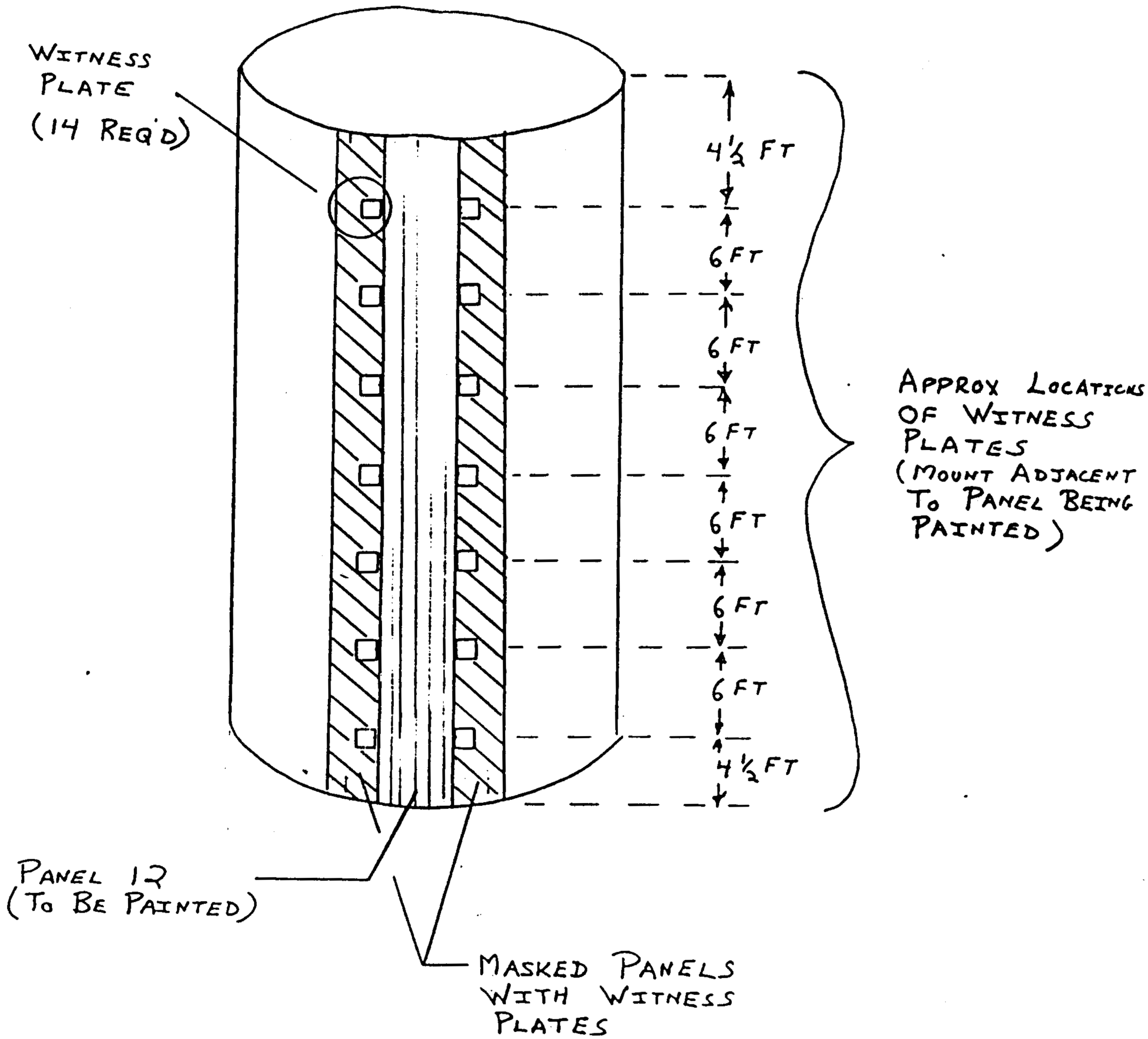
3.0 Masking of Adjacent Areas: The vertical panel is positioned between two adjacent 45 ft long panels. Stainless steel heat shields are located at the top and bottom ends of the 45 ft long panel. Masking supplies to be supplied by the contractor.

3.1 Protection of Adjacent Panels - The adjacent panels shall be masked to protect them from overspray. The masking shall be nominally 2 ft in width and run the entire length of the 2 adjacent panels. The masking shall be of a heavy paper type which is taped to the existing panel surface. A tape shall be used which does not damage the existing painted surface either through chemical action or adhesion which pulls the paint off upon removal.

Witness plates (nominally 3 x 3 inch aluminum plates) shall be attached to the masking paper immediately adjacent to the panel being painted and spaced approximately as shown in Figure 2. Prior to installation, permanent marking (number or letter) shall be applied to the back of each plate. A micrometer reading of each witness plate (unpainted) thickness shall be made by the contractor prior to installation. The contractor shall keep a log of witness plate identifier (number or letter), plate thickness, and location on the receiver as they are installed.

3.2 Protection of Heat Shields - The stainless steel shields shall be protected in a manner described in Section 3.1. The stainless steel is an exposed metal surface so cautions regarding taping to existing painted surfaces as described in Section 3.1 do not apply.

4.0 <u>Painting of Panel Surface:</u> Dry film thickness (DFT) is the most critical factor of the painting operation. A nominal DFT of 0.7 to 0.8 mils shall be applied over the existing aged paint. This corresponds to a wet film thickness of 3.5 to 4.0 mils (Pyromark 2500 is 20 percent solids by volume). At no time shall the DFT of the fresh coat exceed 1.0 mil or be less than 0.5 mils. Paint supplied by McDonnell Douglas.



WITNESS PLATES APPROX 3 X 3 IN

FIGURE 2 PLACEMENT OF WITNESS PLATES ON RECEIVER

4.1 Spraying Process

Gun type:	Binks Model 7, Model 18, or equivalent
Nozzle:	36 SS (fluid tip)
Air Cap:	36 SD
Needle:	36 SS
Pressure Pot:	None required
Atomization Air:	70 psi (supplied by SCE)
Target to Gun Distance:	6-8 in
Flow Needle Adjustment:	Open 1-3/4 - 2 turns (typical)
Pattern Width:	4-1/2 - 5 in (at specified target-to-gun distance)
Application:	1 application; side to side movement across tubes; 50% overlap on each stroke. Paint application shall cover the entire tube surface and the witness plates mounted adjacent to the panel.
Thickness Verification:	Measurement of paint thickness during application process shall be made by measuring WFT on the witness plates.

4.2 Paint Preparation - The paint shall be mixed by placing it in a mechanical shaker for 10 to 15 minutes. Subsequent to mixing, it shall be strained with a standard paint strainer to remove any solid or foreign material which could adversely affect spray gun operation. No paint thinning is required.

4.3 Paint Test Samples - Prior to attempting the painting of the receiver panel, test samples (approximately 3 by 3 inches) shall be painted by the selected painter. The purpose of this operation is to determine proper spray equipment settings and to develop the painter's final technique. The painted samples shall be reviewed and approved prior to starting the painting of the actual panel. Dry paint thickness shall be verified with the aid of witness plates. Panel test samples shall be provided to the painting contractor at his facility by McDonnell Douglas. Paint consumption should be held to a minimum since it will be taken from the 2 gal total inventory.

5.0 <u>Job Cleanup:</u> The contractor shall be responsible for the cleanup and restoration of the receiver and adjacent working area to a condition which existed prior to the start of the painting operation. Witness plates shall be removed from the masking when dry and provided to McDonnell Douglas personnel along with the installation log so that final DFT measurements can be made and a final painting record can be made.

Note: Pyromark 2500 is a silicone paint. The spray gun is best cleaned with toluene after painting.

APPENDIX B

Cure and Vitrification of

Pyromark 2500 Paint

CURE AND VITRIFICATION OF PYROMARK 2500 PAINT

1.0 General Information

Solar One receiver panel 12 has been repainted with a single coat of Pyromark 2500 flat black paint. The paint is a mixture of metal oxides and a silicate binder and is 20 percent solids by volume. The remaining 80 percent of the paint consists of volatile materials which serve to liquify the paint.

Prior to placing the receiver back into routine service, a paint cure and vitrification procedure must be carried out. The purpose of the cure process is to drive off the remaining volatile materials in a controlled manner which have not already evaporated into the air. This operation is carried out at temperatures of approximately 250°F and 450°F. Once the cure cycle is complete, the remaining paint material is then vitrified (changed to a non-porous glass like surface) by gradually raising the panel temperature to its maximum operating value (~850°F). The indication of panel 12 temperature used during the cure and vitrification procedures shall be the control system metal temperature sensor TI2503. Failure to accomplish the cure and vitrification procedures can lead to cracking, blistering, and flaking of the freshly painted surface.

2.0 Curing Procedure

The curing procedure shall be accomplished in two steps; 250°F cure and a 450°F cure.

2.1 Cure at 250°F

The cure at 250°F shall be accomplished by using hot water which is generated in the receiver preheat panels. No solar energy is intended to be applied directly on panel 12. This is because a 250°F panel 12 temperature could easily be achieved with only a few heliostats shining on panel 12. This would create a very non-uniform panel 12 temperature distribution and not produce the desired curing action. The use of hot water on the otherhand creates a much more uniform temperature.

The receiver feedpump and receiver flows shall be set up in accordance with normal startup procedures. The pump should be in a pressure control mode with a set point of approximately 500 psi. Flow should be established through all receiver panels in a normal manner with the individual panel controllers in manual (control values at preset fixed positions). Preheater panel power shall be gradually applied to the receiver using wedges 1 and 12 of the collector field. The preheaters should be allowed to stabilize and should be operating at a mix discharge temperature of 270° to 280°F (indicated by TI2005). Panel 12 temperature (TI2503) should then be monitored. The goal is for this temperature to reach approximately 250°F and to remain at that condition for 2 hours. If the panel temperature does not reach 250°F, flow through other non-heated panels should be cut back by closing down on the appropriate control valves. This will divert more hot water through panel 12 and reduce total receiver flow which will tend to raise the preheater discharge temperature. Boiler panels adjacent to the preheaters (panels 4, 5, 20, and 21) should also be monitored and flow adjustments should be made to prevent these panels from moving into temperature control and experiencing high temperature conditions. This step of the curing procedures is complete when panel 12 has been maintained at approximately 250°F (indicated by TI2503) for 2 hours.

2.2 Cure at 450°F

This step of the cure operation is to be accomplished by forcing panel 12 into its two phase conditions which routinely occurs during all receiver startups. This is to be accomplished by gradually adding heliostat power to panel 12 while preheat panel power is maintained at the level used in the previous cure step. Prior to applying power to panel 12, panel valve controllers should be restored to their normal startup conditions if they had been closed down during the previous cure step.

Power to panel 12 should be applied by using "increase" commands on wedge 6 of the collector field. By doing so, heliostat images should be applied on a more or less uniform basis over the length of the panel. The power level should be gradually increased until the panel 12 temperature indicates that it is firmly in the two phase zone (TI2503 ~445°F). This temperature condition should be maintained for a 2 hour hold period. Flows to other heated panels should be adjusted if required during this period to also maintain those panels in a two phase condition. High temperature excursions and overshoots on those panels should be avoided by increasing flow.

3.0 Vitrification Procedure

This procedure can be simply accomplished as part of a routine receiver startup. It involves holding the panel 12 temperature (TI2503) at approximate values of 600°F, 720°F, and 850°F for time intervals of at least 10 minutes.

During a normal receiver startup, panels switch to temperature control at 600°F. Thus the first hold point for panel 12 occurs naturally at that point. Once the hold time has elapsed, the panel 12 temperature set point should be raised to 720°F and 850°F for respective 10 minute hold periods. The preferred method of implementing this operation is to simply raise the master temperature set point of the receiver (TSP2929) to the desired values. In this way, the preprogrammed set point ramp rate will be executed which minimizes temperature overshoots. If the operator chooses to control panel 12 individually (temperature controller in auto-console), he should gradually increase the temperature set point for panel 12 to the desired hold values since this action will bypass the preprogrammed set point ramp rate and could cause significant temperature overshoots.

Upon completion of the vitrification procedure, the receiver is ready for routine operation. In fact, vitrification will continue to occur over the next 24 hours of high temperature receiver operation.

General Note: If the above cure and vitrification procedure is interrupted by clouds or equipment problems, it should be resumed at the point where work left off. Do not go back to the beginning and restart the entire procedure.

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