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SURVEYOR III PARTS AND MATERIALS/EVALUATION OF LUNAR EFFECTS

RETURNED FROM THE MOON BY APOLLO XII

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ACKNOWLEDGMENTS

Studies and evaluation of the returned parts of the Surveyor III spacecraft involved several technical areas of Hughes Aircraft Company, with most of the work conducted within the Hughes Materials Technology Department.

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Acknowledgment is due S. Jacobs and L. J. Leger of NASA-MSC and W. F. Carroll of JPL for their contributions to the program. Recognition should also be made of the support of B. Milwitzky of NASA Headquarters and J. G. Zarcaro of NASA-MSC, without whose personal interest this program would not have been possible.

Special tribute is extended by the designers and builders of Surveyor spacecraft to the Apollo Program Office and to the Apollo XII astronauts who made the return of this valuable hardware from the surface of the moon.

ABSTRACT

Results of engineering tests of parts of the Surveyor III spacecraft brought back from the moon by the Apollo XII astronauts are presented. These parts include the scoop from the soil mechanics/surface sampler; a section of television camera cabling; and sections of support aluminum tubing – polished, as well as painted with white inorganic paint. These parts resided on the moon 2-1/2 years prior to their recovery. Tests were conducted to determine the effects of this exposure to the lunar environment.

It was determined that all of the parts withstood the environment exceedingly well. The major effect was the discoloration of surfaces, which was determined to be attributable to the combined effect of radiation damage and coating with lunar dust. No major changes in physical properties occurred, and no effects of cold welding were noted. The performance of the scoop motor was nominal.

The data presented in this report are supplemented by results of tests of the Surveyor III television camera retrieved by the Apollo XII astronauts, which are contained in a companion report, Hughes Aircraft Company SSD 00545R.

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1. INTRODUCTION, OBJECTIVES, AND SCOPE

1.1 INTRODUCTION

This report presents the results of the test and evaluation program conducted by Hughes Aircraft Company during the period 7 January 1970 to 22 January 1971 on the following Surveyor III parts returned from the moon by the Apollo XII astronauts:

- Soil mechanics/surface sampler (SM/SS) scoop
- Section of television camera cable
- 7-3/4 inch section of polished aluminum tubing
- 4 inch section of aluminum tube coated with inorganic white paint

This program was conducted under a contract with NASA Manned Spacecraft Center (MSC), Houston, Texas. A separate report, Test and Evaluation of Surveyor III Television Camera Returned from the Moon, Hughes Aircraft Company SSD 00545R (Reference 1) contains the results of tests conducted during this period under a companion contract with the Jet Propulsion Laboratory (JPL) on the television camera also retrieved by the Apollo XII astronauts.

Surveyor III, one of seven Surveyors designed and built by Hughes, was the second of five spacecraft to land successfully on the surface of the moon. Its soft landing took place 20 April 1967 in a small crater in the Ocean of Storms, subsequently named the Surveyor Crater. All subsystems operated successfully throughout the first lunar day except for some minor anomalies.

The Surveyor III television camera took more than 6000 photographs of the lunar terrain. Attempts to revive the spacecraft on the second lunar day were unsuccessful; however, survival of Surveyors throughout lunar nights was not a design requirement. A brief summary of mission performance of the Surveyors is presented in Table 1-1.

TABLE 1-1. SUMMARY OF MISSION PERFORMANCE OF SURVEYOR SPACECRAFT

Surveyor Spacecraft				Operation on Following Lunar Days		
Design Class	Number	Major Payload	First Lunar Day Operation	Response to Commands	Photographs	Remarks
First-generation	I	TV camera	Nominal	2, 5, 6, and 8	2	Activation not attempted on third, fourth, and seventh days
	2	TV camera	(Unsuccessful)			Tumbled after midcourse maneuver
	III	TV camera SM/SS	Nominal	None	None	Abnormal landing (several hops)
	4	TV camera SM/SS	(Unsuccessful)			Loss of communication during retro burning
Second-generation	V	TV camera Alpha scattering experiment	Nominal	2 and 4	2	Activation not attempted on third day
Improved design	VI	TV camera Alpha scattering experiment	Nominal	2	None	
	VII	TV camera SM/SS Alpha scattering experiment	Nominal	2	2	Activation not attempted after second day

Two and a half years later, corresponding to 32 lunar day-night cycles, the Apollo XII Lunar Module landed nearby. In accordance with the mission plan based on recommendations by Hughes (Reference 2), JPL, and others, the Apollo astronauts retrieved the parts noted above after examining and taking a number of photographs of the spacecraft.

The decision to retrieve the Surveyor III parts followed a comprehensive study of benefits to be accrued and of the relative merits and difficulties of retrieving various parts of the Surveyor spacecraft. In addition to listing the scientific benefits, the study (Reference 2) employed the unique opportunity to obtain information on the effects of thermal cycling, radiation, and meteoroid exposure; occurrence of cold welding; and consequences of prolonged exposure of various optics, materials, components, and subsystems which would be applicable to future space programs.

The retrieved parts were delivered to the MSC Lunar Receiving Laboratory (LRL) in Houston, where they remained in quarantine until 7 January 1970. From 7 to 16 January, a microscopic visual examination and extensive photography were conducted in the LRL by Hughes, NASA, and JPL personnel.

On 16 January the parts were shipped on a Hughes airplane to the specially prepared Hughes facility in Culver City, California, and the formal test and evaluation program was initiated. The program entailed strict parts control and security measures and carefully planned and sequenced testing tailored to maximize the amount of information obtained for use in potential future applications. These operations were conducted in full cognizance of the uniqueness of the equipment and of the irreversibility of many of the steps.*

1.2 OBJECTIVES

The primary objectives of this study were to determine the various effects of the prolonged exposure to the lunar environment on the retrieved parts. The test plan was structured to obtain maximum information on those conditions and changes which could be attributed to the effects of this environment while exposing a minimum amount of material to destructive testing.

The study of the returned hardware offered a unique engineering opportunity. It was believed that the assessment of the conditions of the

*Management of the program is described in detail in Appendix A of the companion report on the Surveyor III television camera (Reference 1).

various materials and components would yield valuable engineering design data for future applications and could point out fruitful areas for additional research and development.

The returned hardware also presented a unique scientific opportunity. A parallel scientific investigation of the returned Surveyor parts instituted under NASA-JPL coordination was vigorously supported by Hughes as a secondary objective of this program. Results of the science test and evaluation program will presumably be reported separately.

It was specifically understood at the inception of this program and throughout the study that testing and analysis solely for the purpose of obtaining diagnostic data on the design integrity and performance of the Surveyor spacecraft was not a program objective.

1.3 SCOPE

A separate task was defined for each of the returned parts studied. A combined evaluation task was conducted to compare and integrate the information obtained. Results of these efforts are presented in the following sections of this report. Tests included a detailed visual and microscopic examination of all parts and surfaces; extensive measurements of physical, chemical, metallurgical, and electrical properties of materials and components to determine any changes that might have been induced by the lunar exposure; and tests of the SM/SS scoop motor and its components to assess the functional performance and determine the degree of wear. In addition, a special surface discoloration and contamination study was undertaken in conjunction with the companion Surveyor III television camera test program. Results of this special study are reported in this report and in the Surveyor III television camera report (Reference 1). *

The purpose of this joint surface discoloration and contamination study was to determine the nature of the discoloration and contamination of the external surfaces. The study, which was coordinated with the pertinent science investigations by the JPL technical coordinator of the companion television camera contract, included an attempt to identify the relative contributions of the various possible causes of the discoloration: solar radiation, deposition of organic materials or products of outgassing from other portions of the Surveyor spacecraft, impingement of lunar dust during the original Surveyor landing and during the Apollo XII Lunar Module descent, and even possible prelaunch contamination (e.g., during solar-thermal-vacuum testing).

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*Section 11 and Appendix J (with a separate list of references). The nomenclature is that used in the context of the television camera report. These sections were extracted verbatim for inclusion here to simplify the process of publication of both reports.

The various parallel science investigations were actively supported in the course of the program by special visual, microscopic, and photographic examinations; optical measurements; removal of selected sections, samples, etc., for evaluation; preparation and transmittal of control samples and background information; and other.

Also included in this report are comments relative to certain other parts of Surveyor III which were not recovered (Reference 3), i.e., the thermal compartment mirrors and solar panel. These comments are based on a preliminary engineering assessment of the photographs returned by the Apollo XII astronauts, coupled with a study of their comments when viewing the spacecraft on the moon. This assessment is by no means complete, and future studies may be useful.

Particular attention was directed to avoid duplication between tests conducted on this program and those conducted on the companion study of the television camera. The two programs were coordinated to maximize the total amount of information obtained. For example, studies of the external cable section conducted here complemented the studies of internal cables and wires conducted on the companion contract.

A concerted effort was made throughout the program to ensure that adequate planning preceded the performance of all tests, thereby ensuring minimum disturbance of parts and materials that might be used for future studies. A basic ground rule was established early in the program that at least 50 percent of all retrieved materials be retained in the original condition. This ground rule was strictly observed with one necessary exception, that is, the dismantling and testing of the scoop motor. All test procedures and program milestones based upon them were fully coordinated with the customer, and all decisions to conduct irreversible tests were approved by the customer.

All results of tests were recorded in program log books, and a careful monitoring and inventory system was established for surveillance and accounting of all parts. A list of the program log books is given in Appendix B; all are available in program files.

Of major significance to the successful performance of the tests and to the evaluation of results was the availability of 1) past Surveyor records and 2) Hughes personnel intimately familiar with the design of the Surveyor spacecraft. Past records available included design data and, in many cases, previous test data.

1.4 REPORT ORGANIZATION

The technical material is discussed in the following sequence. Section 2 presents a general assessment of results and major conclusions and recommendations. Section 3 contains a description of the returned parts, including their location on the Surveyor III spacecraft, and the results of the visual examination conducted to assess their appearance after 2-1/2 years exposure to the lunar environment. Section 4, which constitutes the major segment of this report, gives the results of tests and analysis conducted on various parts. The material is generally grouped by technical areas of investigation. Thus, for example, results of metallurgical tests on all the various materials are presented in one subsection.

The final portion of the report deals with the discoloration and contamination of the surfaces of the returned parts. As noted earlier, this work was conducted as a joint effort with the companion contract on the retrieved Surveyor III television camera and is presented in a separate section (Section 11) and appendix (Appendix J), extracted verbatim from Reference 1. This material is supplemented by an additional analysis of the contamination of the polished tube in Section 4.7, including a discussion of the sectioning of the tube in Appendix A.

2. GENERAL ASSESSMENT OF RESULTS

2.1 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Extensive studies were conducted on the Surveyor III parts returned from the moon by the Apollo XII astronauts. These studies are believed to have produced a significant amount of useful information directly applicable to future programs. Significant effects of lunar exposure have been noted, including some that had not been previously anticipated (Reference 2). Of equal significance were some effects previously conjectured, for which no apparent evidence was observed.

It is believed that the test program, albeit limited in scope, was reasonably comprehensive. A fairly complete sequence of tests was conducted on the various components and materials, including chemical, physical, mechanical, electrical, and metallurgical examinations. Nevertheless, these tests can by no means be termed exhaustive, and additional work may be warranted. Publication of results of the parallel science investigations still in progress will also help define any additional effort desired.

It is believed that the results of this investigation to determine the effects of prolonged lunar exposure on a variety of materials and components, coupled with a similar investigation of the Surveyor III television camera presented in a companion report (Reference 1), may be directly applicable to future spacecraft design. It is therefore recommended that a careful review of the test data contained in this report be made in the course of design of future spacecraft. Accordingly, a wide dissemination of this report to space systems designers is suggested. Any additional tests required would thus be determined as appropriate for each particular application.

The principal conclusions of this study are summarized below. A list of major effects observed, as well as comments on some of the effects originally conjectured (Reference 2) but not observed, is presented in Section 2.2. Section 2.3 cites some examples of possible follow-on studies.

The most significant conclusion is that although changes occurred in many properties of the materials no change was found which would have prevented any material or any part from performing its task even after 2-1/2 years exposure to the rigorous lunar environment.

The second most significant conslusion was the discovery of a heavy coating of lunar dust on the exposed surfaces. This coating was to a large extent caused by the landing of the Apollo lunar module, in addition to the effect produced by the original abnormal landing of the Surveyor III. It is noteworthy that the Apollo lunar module descent engine was able to produce this effect from the relatively large distance of 500 feet between its landing area and the Surveyor III spacecraft.

Results of the surface discoloration and contamination studies indicated that this effect was primarily caused by radiation damage and lunar dust coverage, with a relatively minor contribution from organic deposits. The relative contributions of radiation and dust varied from all-dust in some areas to all-radiation in others, with the majority of exposed surface areas discolored by a combination of these two factors. Radiation-induced effects were proportional to the degree of solar exposure. The amount of dust deposited was generally higher than expected.

Future recoveries of valuable hardware from space should carefully consider landing techniques and protection of critical surfaces in light of the information desired. For example, if the interaction with the landing terrain is significant (e. g., lunar dust), the landing should be planned a sufficiently large distance away. If a study of the optical characteristics of the surfaces of the recovered parts is important, the returned parts should be carefully protected from the environmental conditions, such as air, light exposure, etc. In retrospect, it is believed that the results of the analysis of the retrieved Surveyor III parts would have been significantly more informative had it been possible to observe the above recommendations to a greater degree.

The results of the study also suggest a possible change in a material process for future applications. The use of inorganic paints on fiberglass structures should be avoided if exposure to severe thermal cycling is anticipated.

2.2 ASSESSMENT OF EFFECTS OF LUNAR EXPOSURE

The following sections of the report present a detailed analysis of the tests conducted and results obtained. These results generally fall in three categories: 1) observed changes due to the effects of the lunar environment which had been previously anticipated, 2) absence of these effects which were originally conjectured or anticipated, and 3) changes and effects which had not been originally expected.

The principal results obtained in these three categories are presented below in summary form in Tables 2-1, 2-2, and 2-3.

TABLE 2-1. ASSESSMENT OF EFFECTS OF LUNAR EXPOSURE – EXPECTED EFFECTS OBSERVED

Effects	Comment
Discoloration of white and blue paints	Attributable to radiation and coating with lunar dust (dust effect greater than anticipated)
Bleaching of degraded white paint	Attributable to exposure to laboratory fluorescent lighting
Discoloration of teflon FEP	Attributable to solar radiation and lunar dust coverage (relative contributions not separated)
Decrease of tensile strength of teflon FEP cable wrap (2 mil film)	Attributable to solar radiation
Discoloration of nylon ties	Attributable to solar radiation
Discoloration of epoxy adhesive on knots in nylon ties	Attributable to solar radiation
Surface cracking of teflon FEP	Attributable to solar radiation

TABLE 2-2. ASSESSMENT OF EFFECTS OF LUNAR EXPOSURE — EXPECTED EFFECTS NOT OBSERVED

Effect	Comment
Blistering of polished aluminum surfaces	Conjectured effect of solar wind protons Reported in some laboratory studies Effect not strongly anticipated
Significant pitting of metals and painted surfaces by micro-meteoroids	Only three possible primary impacts observed; only one on Surveyor III television camera*
Cold welding of mechanisms, gears, fasteners, and other metal surfaces	Similar results obtained on companion test program of Surveyor III camera (Reference 1)
Loss of adhesion and cohesion of inorganic paint	Since effect not strongly anticipated, results not surprising
Degradation of electrical properties of wires	Diagnostic tests conducted under ambient conditions only No tests conducted in vacuum
Changes in chemical structure of organic materials	Since effect not strongly anticipated, results not surprising.

*Reference 102 (see separate list of references for surface discoloration and contamination studies at end of this report).

TABLE 2-3. ASSESSMENT OF EFFECTS OF LUNAR EXPOSURE - UNEXPECTED EFFECTS OBSERVED

Effect	Comment
Increase in hardness of aluminum alloys • Polished tube • Painted tube	Due to thermal exposure at 250°F or higher for over 4000 hours
Strong adherence of lunar materials to one side of polished aluminum tube	Effect apparently incurred during landing of Surveyor III High velocity particles imbedded in aluminum
Severe "mud-cracking" of inorganic paint on fiberglass substrate	Due to thermal mismatch between paint and fiberglass substrate
Large amount of lunar material adhering to all surfaces of SM/SS scoop	Presumably caused by lunar material remaining in the scoop and falling out in transit
Difficulty experienced by astronaut on moon in attempt to cut polished tube section from Surveyor III flight control unit support structure	Cause remains unknown Analysis indicates that aluminum tube was of same construction as that subsequently severed by astronaut from radar antenna support

2.3 CANDIDATE FUTURE STUDIES

Examples of possible additional engineering tests on the returned Surveyor III parts are presented in this subsection. These possible areas of study that may be profitably conducted are submitted without any specific recommendations since, as noted previously, the conduct of such additional tests depends on the intended application. For any such specific future design application, a review in depth of the results presented in this report and of the candidate tests listed below will lead to the final selection. A further input to this decision is also expected to be forthcoming from the results of the parallel science investigations when they become available.

Additional measurement and analysis relative to the surface discoloration and contamination studies may be warranted. Examples of such specific tests include:

- Analysis of contamination on teflon FEP wrap from TV cable — not conducted within the limitations of this program
- Quantitative analysis of contamination of polished tube — not conducted because of restrictions on the use of the polished tube and because of program limitations *
- Such additional tests as may be warranted following completion of the organic determination and other science tests now in progress

Examples of additional candidate tests relative to surface discoloration are included in the companion report on the Surveyor III television camera (Reference 1).

Availability of the photographs of the Surveyor III spacecraft taken on the moon by the Apollo astronauts suggests that a critical analysis be conducted, based on further study of these photographs, to assess the condition of the spacecraft after 2-1/2 years of lunar exposure. Only a very brief review of these photographs was conducted in this program. A more extensive review beyond the scope of this program, based on a full assessment of the materials and processes employed in the construction of Surveyor III, may prove valuable.

Additional effort may be warranted to determine or to confirm the proposed cause of the observed degradation of physical properties of certain materials, including copper conductors of the external cable, teflon insulation, and others. Results of the study indicated that changes had occurred that may be important to long-life future space vehicles. However, both the exact nature of these changes and their causes remain somewhat inconclusive.

While no significant changes in the electrical properties of wires were observed during measurements made in air, the existence of significant effects of lunar exposure noticeable in measurements under vacuum conditions cannot be totally discounted. Such measurements, while considered beyond the scope of this program, may prove worthwhile.

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*Only a limited qualitative analysis of one heavily contaminated location on the polished aluminum tube was conducted.

3. DESCRIPTION AND INITIAL EXAMINATION OF RETURNED PARTS

This section describes the parts of the Surveyor III spacecraft returned by the astronauts which were tested and evaluated in the course of this program and presents the results of the initial visual and microscopic examination conducted prior to detailed testing. The parts described and visually examined include the scoop from the soil mechanics/surface sampler (SM/SS), the external cable from the Surveyor III television camera with its teflon wrap, a section of polished aluminum tube from the Surveyor III structure, and a section of aluminum tube from the television camera support painted with white inorganic paint. The painted tube and a section of the teflon FEP cable wrap were returned from the moon in a special sealed container. The other parts were returned in an ambient environment.

Also included in this section is a brief discussion of some of the photographs taken on the moon by the Apollo XII astronauts of other parts of the Surveyor III spacecraft.

3.1 SOIL MECHANICS/SURFACE SAMPLER (SM/SS) SCOOP

3.1.1 Description and Retrieval

The SM/SS, designed and built by Hughes, was one of the major payloads of Surveyor III. Its purpose was to perform certain lunar soil mechanics experiments in order to obtain scientific information on characteristics of the lunar surface and provide engineering data for subsequent Apollo landings.

The basic SM/SS mechanism consists of a bucket or scoop attached to the end of a "lazy-tongs" extension arm, shown in Figure 3-1. The arm is attached to a base which can be pivoted in elevation and azimuth with respect to the spaceframe. It is driven by three motors that control the azimuth, elevation, and extension motions. A fourth motor opens and closes the scoop door. The joints of the lazy tongs extension mechanism include torsion springs that provide the extension force. The retraction force is provided by a motor which winds up a steel tape attached to the scoop. The elevation drive motor includes a positive latching clutch which

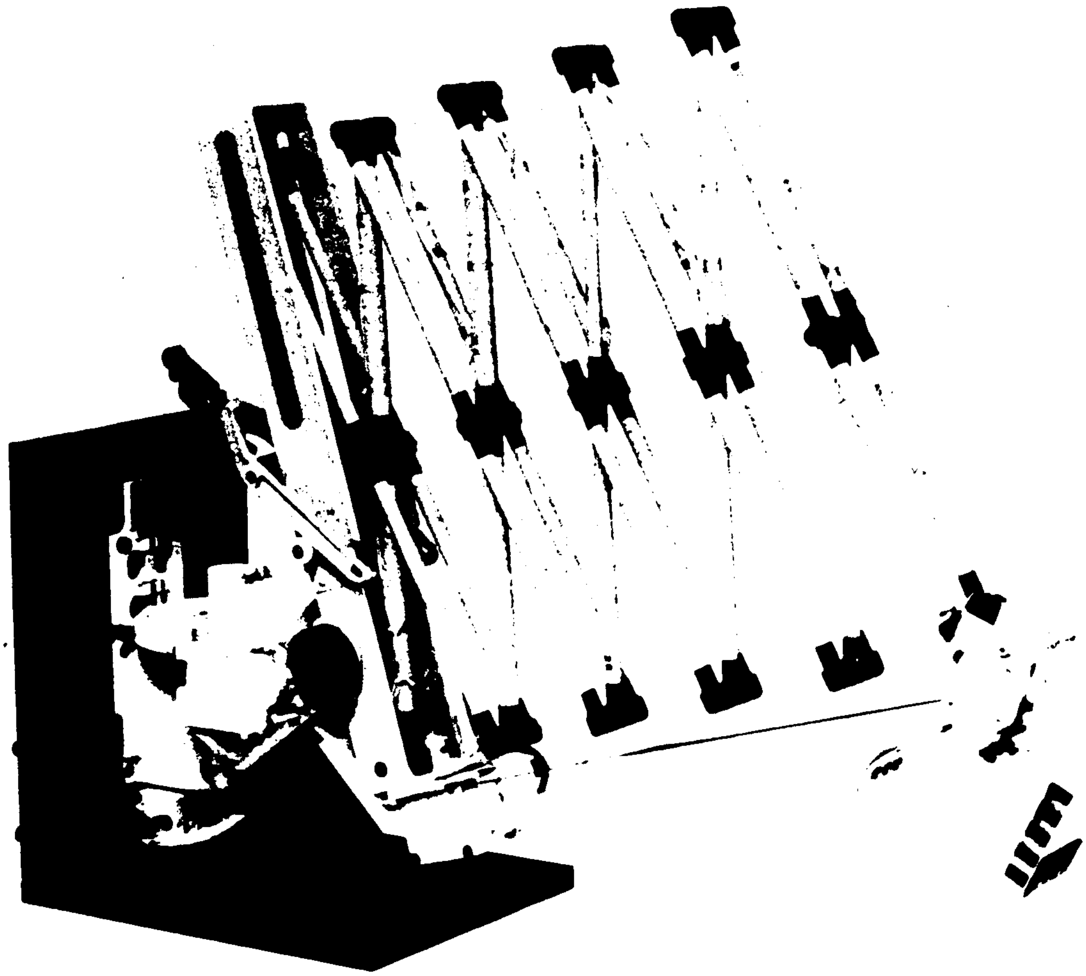

Figure 3-1. SM/SS·Scoop Mechanism (Photo R113487)

can be disengaged from the gear train by actuation of a solenoid; this allows the elevation torsion spring to drive the mechanism downward. Further details on the scoop motor are given in Section 4. 1.

After completion of the soil mechanics experiment on the lunar surface, the scoop was left in the raised, fully extended position (Figure 3-2). Before it was removed from the spacecraft, one of the astronauts manually pushed the scoop in toward the spacecraft without encountering difficulty; this indicated that significant cold welding had not occurred in the joints. The joints and bearing surfaces had been lubricated with MoS_2 compounds. When released by the astronauts, the scoop reextended itself easily, thereby indicating that the springs were still working well.

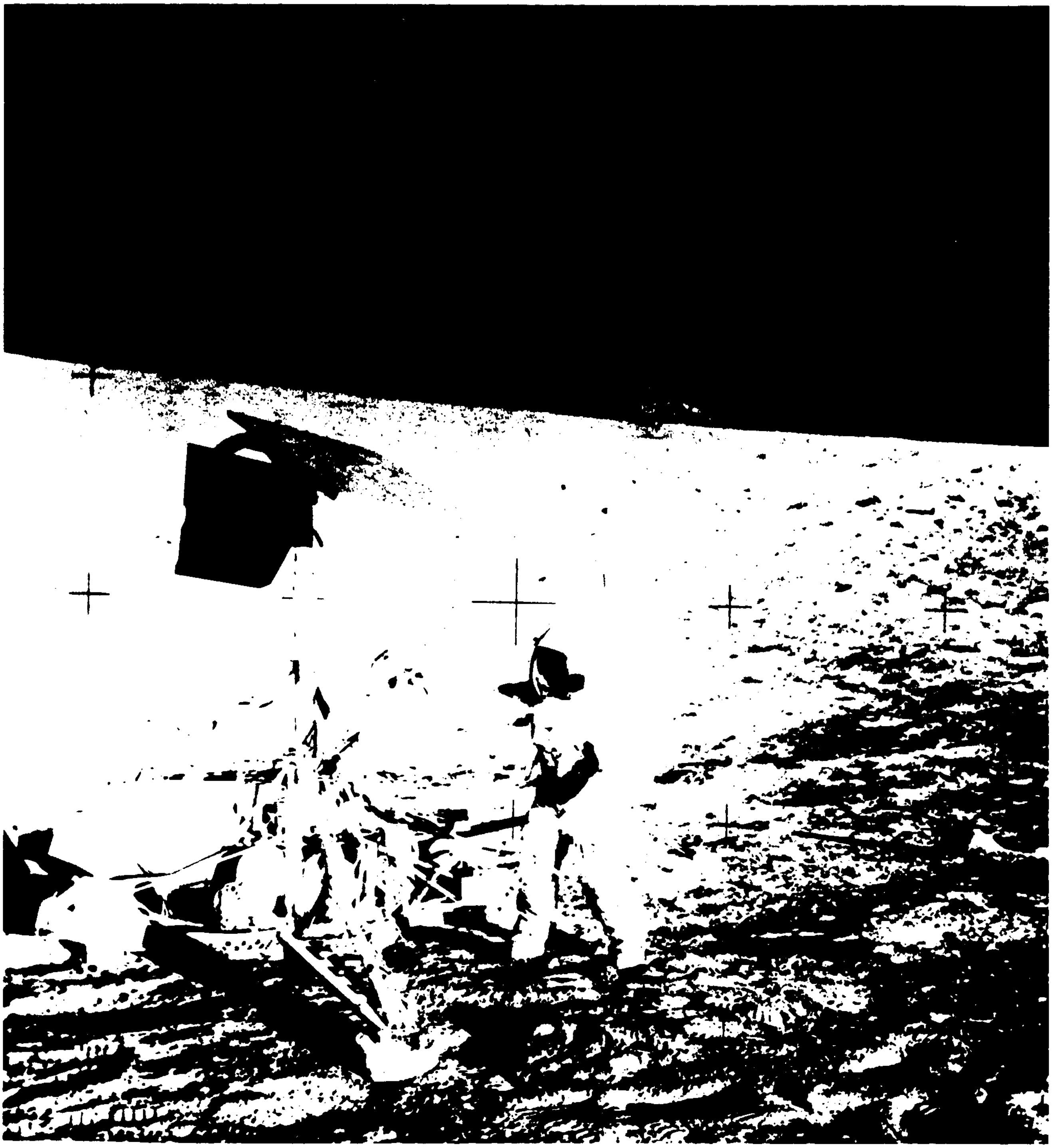

Figure 3-2. Retrieval of Surveyor III Parts, Showing SM/SS in Raised Position (NASA Photo AS-12-48-7133)

Figure 3-3. Retrieved Surveyor III SM/SS Scoop in Lunar Receiving Laboratory (Photo 4R14713)

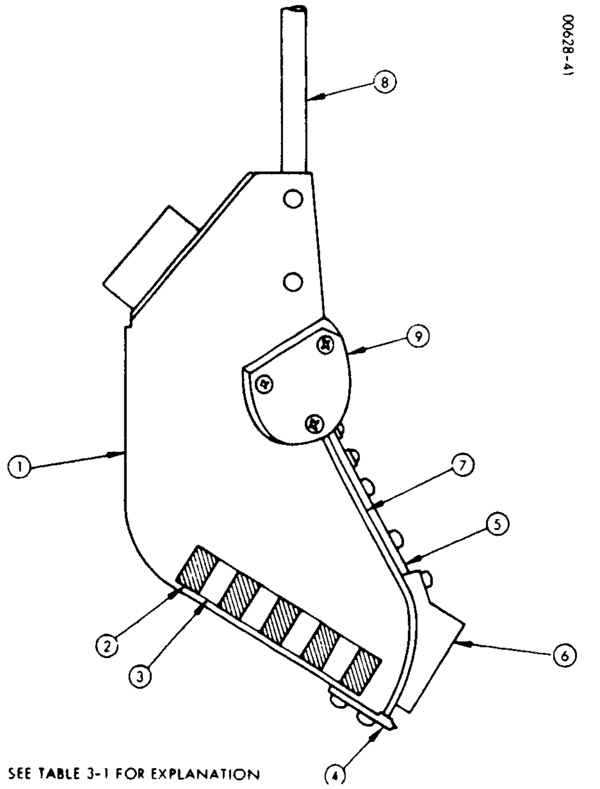

Figure 3-4. Location of Various Materials and Finishes on SM/SS Scoop

One possible difficulty anticipated in removing the scoop was cutting of the stainless steel retraction tape, which can be seen in Figure 3-1. The tape extended from the retraction motor and looped around a bracket on the scoop. It was spot welded onto itself about half way between the scoop and the retraction motor. After an unsuccessful attempt at cutting the tape with the bolt cutters, the astronaut apparently twisted the tape with a quick motion and broke it. It is believed that the tape broke at the spot weld. The tape then slipped through the scoop and onto the lunar surface.

The astronaut then cut the scoop arms behind the front joint with the bolt cutters. In all, three arms were cut. The four wires leading to the scoop motor were attached in the form of a wire bundle to one of the arms and were also cut in the process. Figure 3-3 shows the scoop, arms, and the first joint after unwrapping at the Manned Space Center in January 1970.

The scoop consists of the materials listed in Table 3-1 located as shown in Figure 3-4. The wires operating the scoop motor are four wires twisted together with a 1 inch pitch pattern. Each wire consists of 19 strands of 34 AWG silver-plated copper. The wire is insulated with 0.009 inch thick teflon TFE, wrapped and fused. The wire is rated at 22 AWG and 600 volts.

3.1.2 Visual Examination

The scoop storage bag was opened for initial visual examination 7 January 1970 at the Lunar Receiving Laboratory. This examination revealed the heavy lunar soil coating over all of the scoop, as seen in Figure 3-3. When the bag was split open, an unusual odor was detected. Later tests indicated that the odor was not associated with the heated polyethylene. It is believed that the odor was associated with the lunar material.

After numerous photographs were taken, the scoop was rewrapped in its polyethylene bag and transferred to Hughes for furthur studies. The next step was removal of the surface lunar soil. Prior to removal of the lunar material from the exterior surfaces, the scoop was subjected to a thorough visual and microscopic examination at Hughes. The lunar material from inside the scoop was then removed by Professor R. Scott for lunar soil mechanics investigation.* The scoop was again visually examined to determine any effects that might have been masked by the lunar material. The scoop was then transmitted to JPL for radiation counting as part of the associated science studies. Upon return to Hughes, the scoop was partially disassembled, and measurements were conducted on disassembled units such as the motor and the gear assembly. Some parts of the scoop were then examined in more detail with a scanning electron microscope (SEM). Results of this examination are discussed below.

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*California Institute of Technology. Results of analysis will be reported separately as part of the science report.

TABLE 3-1. SCOOP MATERIALS AND FINISHES

Item (See Figure 3-4)	Material	Specification
1	0.040 inch 6061-0 aluminum alloy sheet coated with blue paint*	QQ-A-250/11 (Aluminum Alloy)
2	Black anodized	MIL-A-8625, Type II, Class 2, Black
3	6061-0 aluminum	AA-A-250/11
4	250 low alloy steel H condition	MIL-H-6875
5	0.075 inch titanium sheet, 6Al-4V solution-treated and aged	MIL-T-9046, Type III, Composition C
6	0.062 inch plastic laminate sheet coated with blue paint*	L-P-509, Grade G11 (Plastic Laminate)
7	0.032 inch teflon TFE sheet	MIL-P-22242, Type I
8	Machined from 7075-T6 aluminum alloy bar stock coated with blue paint*	QQ-A-225/9 (Aluminum Alloy)
9	7075-T6 aluminum black anodized	QQ-A-225/9 MIL-A-8625, Type II, Class 2, Black

*The blue paint coating consisted of two coats of white inorganic paint and a top coat of blue inorganic paint. The total paint thickness was 8 units. The white paint had a china clay pigment (aluminum silicate) and a potassium silicate binder. The blue paint was similar except that a proprietary blue pigment was added.

Lunar Material

The scoop was heavily coated with lunar material, as can be seen in Figure 3-3. The lunar material adhered fairly well to the painted surfaces, partly because of the roughness of the paint. However, lunar material was noted to adhere well to smooth as well as rough surfaces. A uniform layer of dust was noted on the nonpainted surfaces, but the dust layer was heavier on the painted surfaces. The majority of the lunar material undoubtedly came from the scoop during handling in recovery and return. The dirt which fell out of the scoop was redistributed over all the surfaces.

The teflon TFE (item 7 in Figure 3-4) had somewhat less lunar material on it, but this material adhered when the scoop was turned upside down. The distribution of lunar material on the scoop is seen in Figures 3-5 and 3-6. The teflon FEP-insulated wires retained a slight amount of lunar material, as seen in Figure 3-6, but this was probably collected when loose material was redistributed during the return trip to earth. The lunar material did not adhere as well to the steel screw heads and to the black anodized aluminum, as seen in Figure 3-6, except in recesses and corners. It was noted later during disassembly that the lunar material adhering to the inside of the scoop was very uniform in thickness and distribution. The inside of the scoop was painted with inorganic paint.

Inorganic Paint Surfaces

The inorganic blue paint described in the footnote to Table 3-1 seemed mostly unaffected by the lunar exposure except for "mud-cracking" and for some chipping at corners. The mud-cracking was found only on the fiberglass surface (Figure 3-7). The mud-cracking has been attributed to the differences in the coefficients of thermal expansion between the inorganic paint and the substrate.

Chipping of the paint was noted on the ends of the tubes that were cut on the moon during the retrieval operations. This chipping was due to the brittleness of the paint. A tape test using a 3M 250 adhesive tape showed no evidence of reduction in adhesive or cohesive strength of the paint when tested away from the chipped area. The paint appeared to have faded slightly from its original blue color to a lighter shade of blue. This was the result of exposure to solar radiation.

Organic Paint Surfaces

The black areas on the tubing (Figure 3-5) are coated with a black organic paint — 3M Black Velvet, carbon pigmented, in a silicone alkyd binder. The coating of the paint was uniform. An overcoating layer of lunar material was noted which gave the coating a grayish appearance. A similar appearance would be expected of a black organic coating covered with any kind of dust. The 3M 250 tape test was conducted on the black paint, and no adhesion or cohesion failures were noted. An SEM examination was then conducted,with no unusual effects noted. It appeared that the coating had not been affected by the lunar environment except for its surface contamination. Results of optical property measurements of the black paint are included in the surface discoloration and contamination study, Section 11. Some increase in reflectance was found.

Black Anodized Aluminum Surfaces

Anodized aluminum, dyed black (Mil-A-8625, Type II, Class 2, Black), was used on areas designated as items 2 and 9 in Figure 3-4. No fading or degradation was noticed. Reflectance measurements were not made because of the small sample size and because of the desire to minimize destruction; the change in reflectance was small as estimated by eye and was considered as probably insignificant to the total solar absorptance.

Teflon TFE

A sheet of 0.032 inch thick teflon TFE was bonded to the base of the scoop jaw. No evidence of lunar exposure effects was noted other than a slight color change from its original milky white to a light yellow.

The TFE teflon insulation on the wires appeared to be only slightly affected by lunar exposure. Very slight cracking was observed. This may have been present prior to the lunar exposure. The bond line between the TFE teflon wraps was clearly visible and showed no indication of delamination or loosening.

Figure 3-5. Distribution of Lunar Material on SM/SS Scoop (Photo 4R14815)

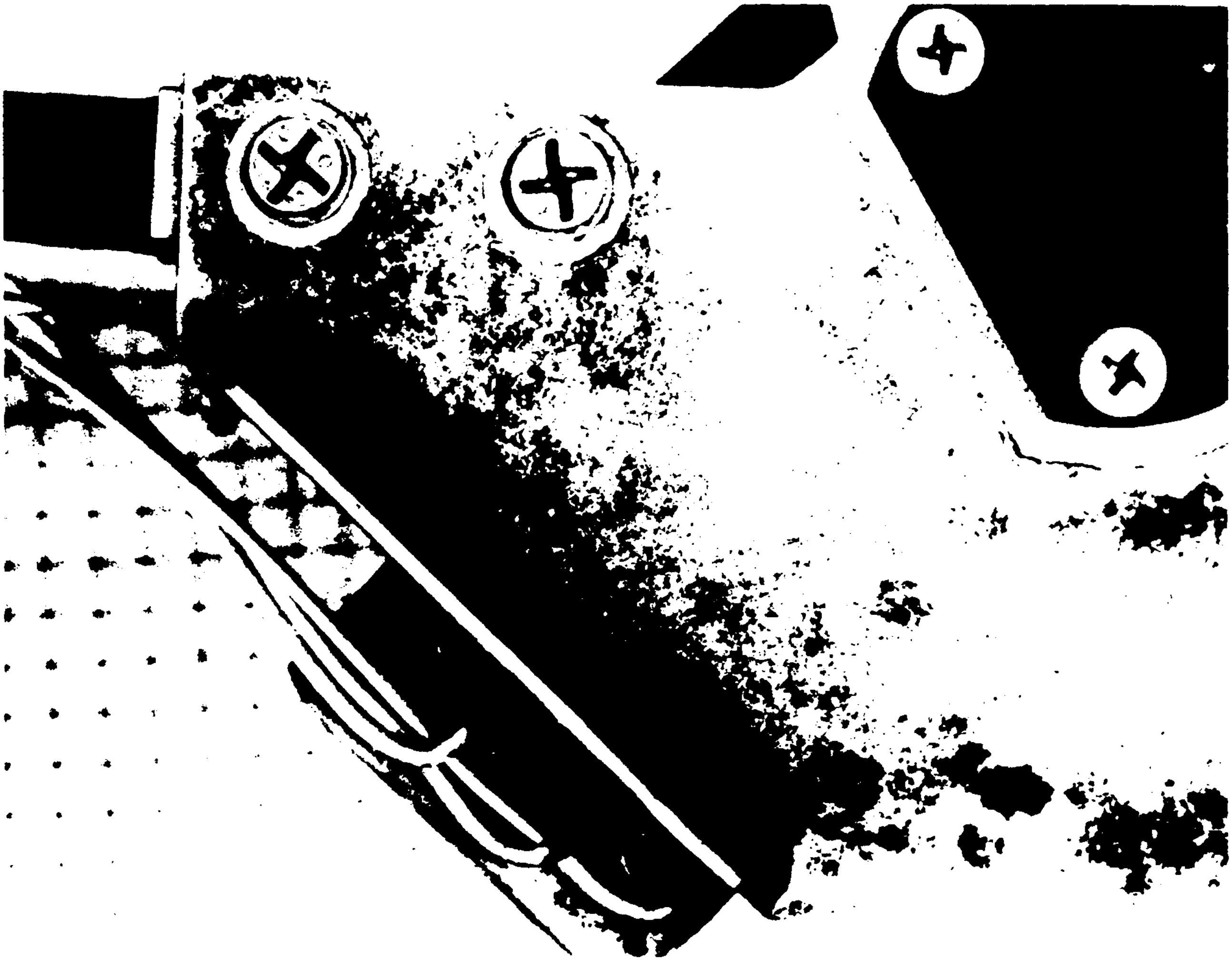

Figure 3-6. Enlarged View of SM/SS Scoop, Showing Lunar Material and Wiring (Photo 4R15123)

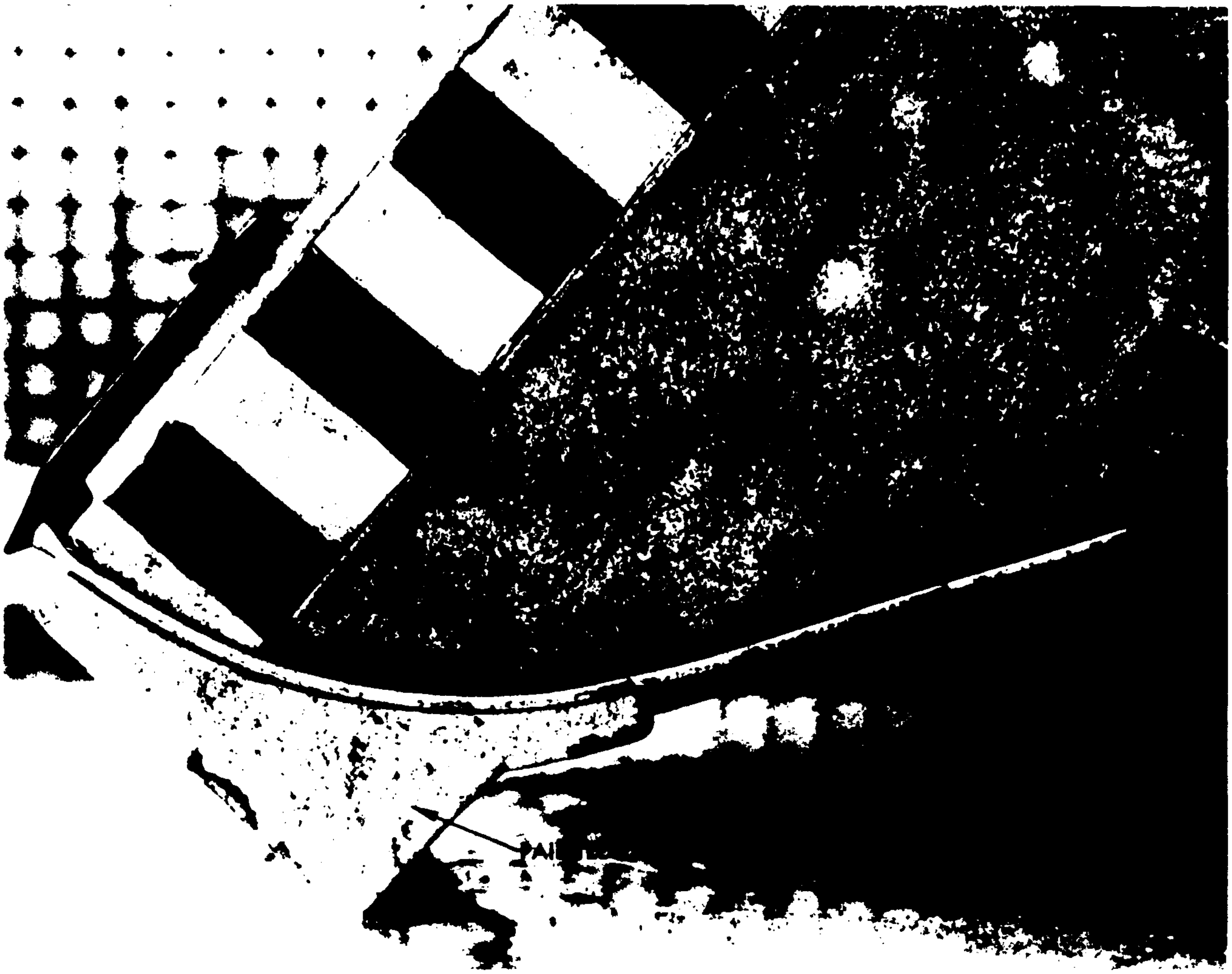

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Figure 3-7. "Mud-Cracking" of SM/SS Scoop Paint (Photo 4R15118)

3.2 TV CABLE

3.2.1 Description and Retrieval

The cable used in a portion of this study was removed from the Surveyor III television camera after its return to earth. The cable was located on the lunar southeast side of the lower shroud. This section was used for electrical and physical measurements. Reflectance measurements in vacuum were also planned for the aluminized teflon FEP used as an outer thermal control wrap of the cable. To accomplish this, a small section of the cable was cut from the Surveyor III camera during recovery on the moon and placed in the sample environmental sealed container (SESC), shown in Figure 3-8.* The various sections of the cable can be seen in Figure 3-9.* The position of the cable on the spacecraft is shown in Figure 3-10.

It had been planned to remove the cable section from the SESC under the original vacuum conditions and to mount a piece of the teflon FEP in a vacuum chamber for measurement of its spectral reflectance. However, a leak in the SESC was uncovered prior to its opening. Descriptions of the SESC, its opening, the nature of the leak, and its effect are presented in Section 11 and Appendix J. Despite this leak, the planned transfer was performed and the spectral reflectance measurements were conducted according to the original plan.

The cable section removed from the side of the television camera was about 7 inches long and 1/2 inch in diameter. The cable contained about 50 small conductors and 2 large coaxial conductors, 3/8 inch in diameter. Each of the small conductors was made of 19 strands of silver-plated copper or copper alloy twisted together and insulated with teflon FEP overcoated with a thin layer of polyimide. These small conductors are described in Table 4-15 (Section 4). The cable section also included a single solid nonmagnetic conductor having a high thermal and electrical resistance.

The wire bundle was held together with nylon cord. This wire bundle was then overwrapped with 0.00025 inch thick mylar, aluminized on one side. This served as an electrical shield for the cable. The mylar was held in place with nylon cord. The top covering of the cable was teflon FEP, 0.002 inch thick and aluminized on one side.

The aluminized teflon FEP tape used as the outer wrap of the cable was 0.002 inch thick and 1 inch wide, overlapped about 50 percent on each turn. The teflon FEP side faced outward and was used for thermal control

*The original photographs in the Surveyor Parts Test Program files are in color; black and white prints made of these originals are presented here. This comment applies to other photographs in the report, as indicated.

of the cable. Nylon cord was used to secure the teflon. The knot of the nylon cord was held with an unfilled epoxy polyamide adhesive. The teflon, nylon, and epoxy were directly exposed to solar radiation.

The individual materials were as follows:

1) Teflon FEP – This material was 0.002 inch thick film covered by Federal Specification L-P-523, Type I (General Purpose, Non-cementable). It was aluminized on one side to a thickness equivalent to a light transmittance of less than 1.0 percent in the wavelength region of 0.3 to 0.8 micron. It had an initial solar absorptance of 0.15 ±0.03 and a total normal emittance at 80°F of 0.70 ±0.05.

2) Nylon – The lacing cord is covered in Military Specification MIL-T-713, Type P, unwaxed (polyamide).

3) Epoxy Adhesive – The unfilled epoxy polyamide adhesive was prepared by Hughes; no general specifications for it are available.

4) Mylar – The mylar film is covered by Federal Specification L-P-377, Type II.

3.2.2 Visual Examination

Teflon FEP

The TV cable segment examined is shown in Figure 3-11.* Before the surface was unwrapped, it was examined microscopically at magnifications up to 40X. Some cracking was observed in the teflon on the side of the cable exposed to the solar radiation. The cracking occurred at high stress points, such as folds in the material. These cracks were clearly visible under a microscope but were difficult to photograph.** The wrap appeared to be reflective except on one side facing outward from the camera which appeared brown because of deposited material.

The nylon ties were cut, and some of the teflon was unwrapped and removed from the cable. This section of teflon from below the TV cable is shown in Figure 3-12,* where the brown area is clearly discernible. It was also noted that some aluminum coating on the teflon appeared to be quite thin or missing altogether. When held to light, it was obvious that the film had a significant transmission.

*Original in color.

**Photographs at 40X magnification are available in program files. These photographs were not included in the report because the quality of reproduction was not adequate to show the observed effects.

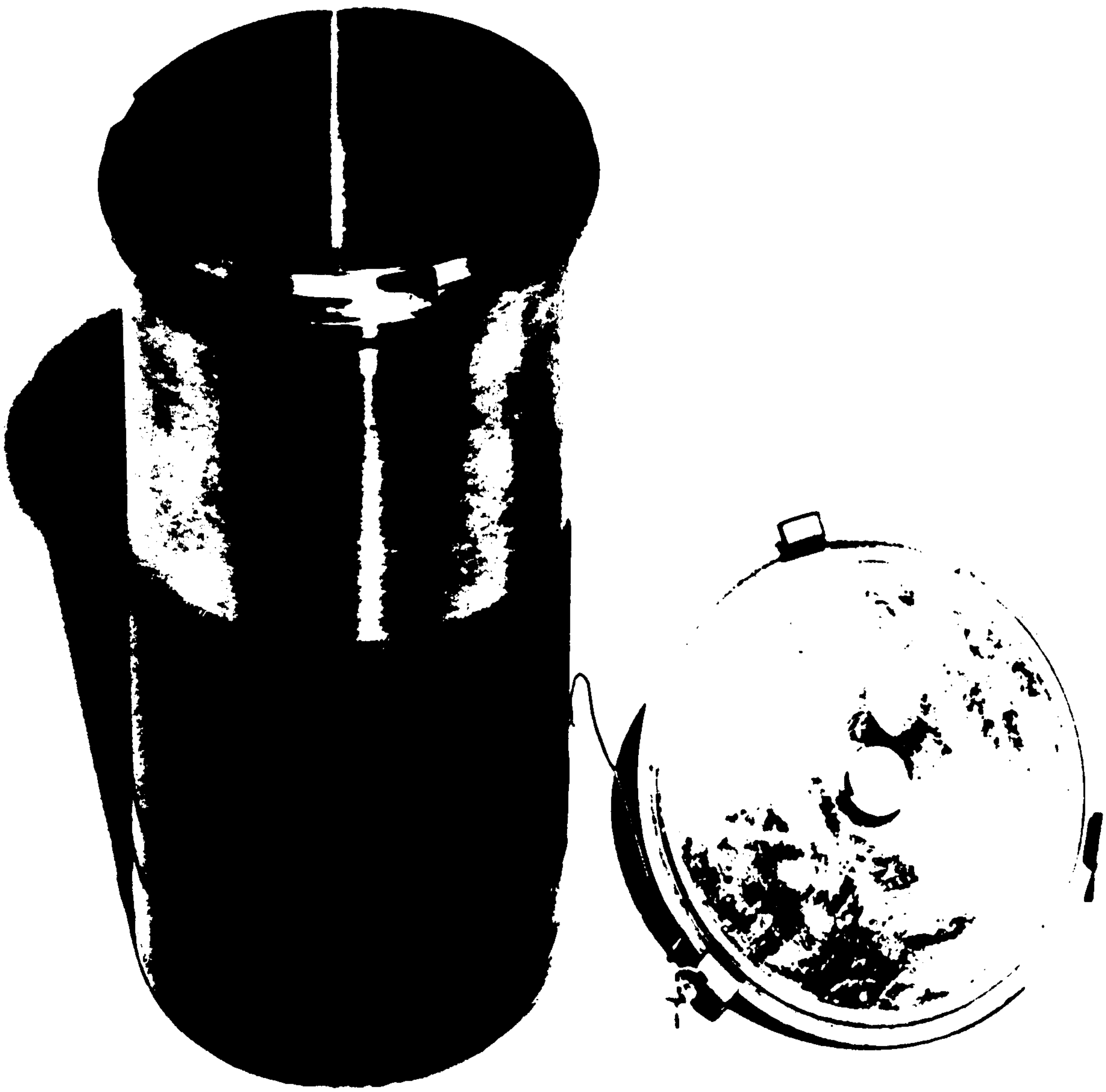


Figure 3-8. Sample Environmental Sealed Container (SESC) (NASA Photo S-70-21226)

Figure 3-9. Retrieved Surveyor III Television Camera (NASA Photo S-70-21152)

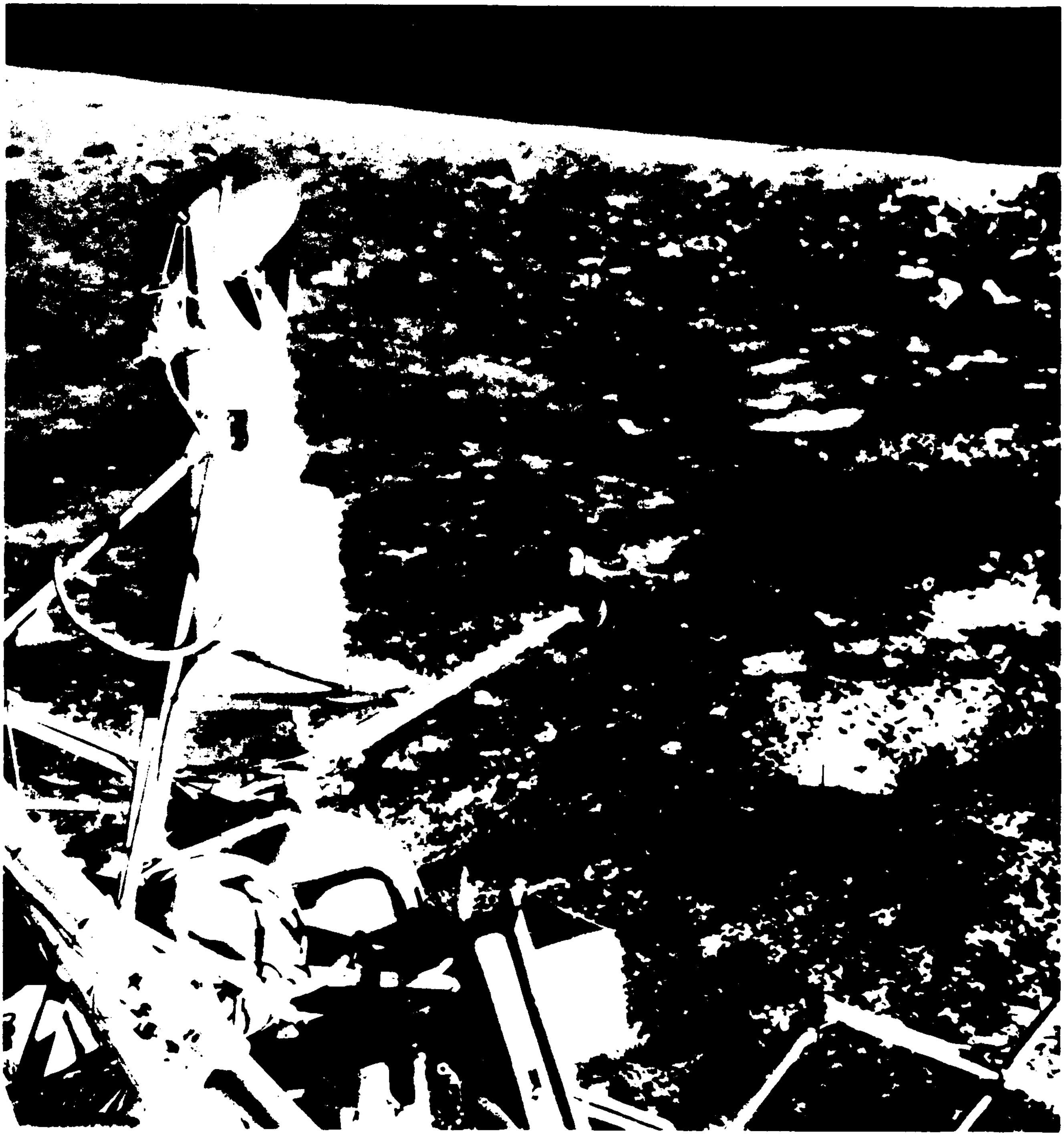


Figure 3-10. View of Surveyor III TV Camera on Moon, Showing External Cabling (NASA Photo AS12-48-7105)

Figure 3-11. Section of External Cable From Surveyor III TV Camera (Photo 70-5797)

Figure 3-12. Teflon Wrap Removed From External Cable of TV Camera (Photo 70-5758)

Several possibilities exist as to why the aluminization was so thin. One possibility is that inadequate metallization occurred in processing. The teflon was metallized in long rolls, and thin spots were occasionally found. There was some metal on the surface, and it is therefore quite possible that it appeared to be good when cut from the roll. Since each individual piece of material was not tested for specification conformance, unless a careful examination was conducted the thin metallized piece would have been placed on the spacecraft.

The second possibility is that the metal was abraded from the teflon during cable manufacturing or subsequent handling operations. Another possibility for the thinness or absence of metallization is a failure in the interlayer cohesion. If a thin batch was found during processing, it is likely that the metallizer would have reprocessed the batch by adding more aluminum. This could have resulted in poor adhesion which would later lead to separation. A final possibility is loss of aluminum due to thermal cycling on the lunar surface. Other areas of the camera were wrapped with the same type of material, and no loss of aluminum was noted. Thus, if the thermal cycling did cause this loss, it must be concluded that initial processing of the material was poor, leading to the later failure.

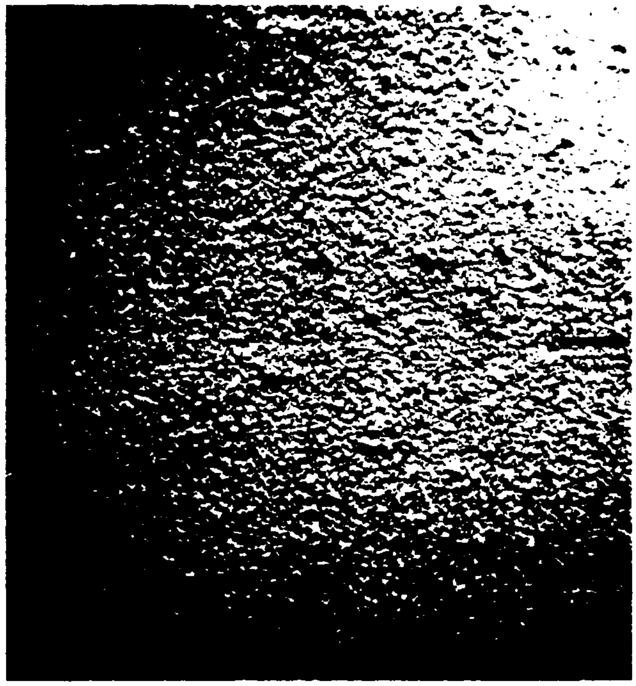
In any event, this thinness or absence of aluminum coating is considered to be a secondary result of lunar exposure. Only one small piece of the several sections examined evidenced this effect. Evaporation of the aluminum must also be ruled out since the temperatures reached on the moon were not sufficiently high for this to occur.

Sections of both the brownish area and the unaffected area of the teflon FEP were examined under an SEM to determine the origin of the discoloration. Figure 3-13a shows a typical area of the unaffected surface at a magnification of 105X. The marks seen on the surface appear to be scratches rather than cracks. Some debris, probably of lunar origin, can be seen – the black specks in the center of the photograph. Figure 3-13b, taken at a magnification of 110X, shows a brownish area. The surface is uniformly covered with debris. Figure 3-13c, taken at a magnification of 1080X, shows an area where some of the debris had been removed, revealing the characteristic appearance of the teflon FEP below. Figure 3-13d, taken at a magnification of 2150X, indicates the character of the debris.

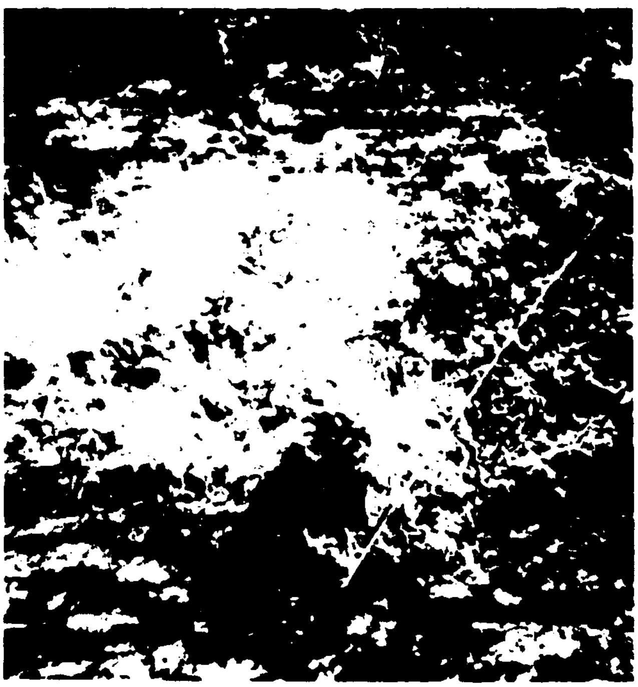
Nylon

It was noted that the nylon ties had turned from milky white to dark brown in the area which received the most solar radiation. It is believed that a large part of this discoloration may have been caused by the knot-securing adhesive which wicked around the tie cord. During chemical analysis, the darkened nylon was dissolved in formic acid; in this process, a dark brown insoluble mass precipitated. When the nylon was taken out of solution, it appeared milky white. When the nylon ties were removed from the cable, they were stiff and had lost their pliability in the darkened area and, to a lesser extent, in the lighter areas.

a) 105X Magnification (Photo 00628-13)



b) With Lunar Material (110X Magnification) (Photo 00628-14)



c) Lunar Material Partially Removed (1080X Magnification) (Photo 00628-15)

d) Enlargement of Figure 3-13c (2150X Magnification) (Photo 00628-16)

Figure 3-13. Surface of Teflon FEP Wrap of External Cable

After removal of the outer wrap of teflon FEP, it was noticed that the nylon tie cords used underneath the wrap had also discolored in an irregular pattern but to a lesser extent. This is attributable to exposure to solar radiation through the teflon FEP in areas where the aluminum coating was thin or missing, as shown in Figure 3-11.

An SEM examination was conducted of a darkened piece of nylon. The general weaving pattern is shown in Figure 3-14a at a magnification of 104X. Higher magnification photographs of individual strands are shown in Figures 3-14b and c at magnifications of 1050X and 2100X, respectively. The surface facing outward to the lunar environment is covered with a material, presumably epoxy.

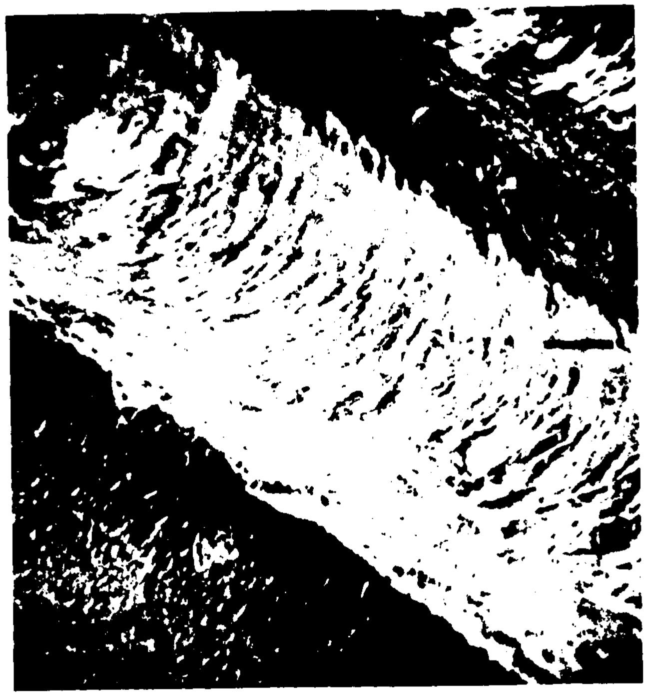
Epoxy

As previously noted, the epoxy was dark brown. This area had been exposed to solar radiation. This was also evident in areas where the adhesive had splashed onto the teflon FEP, as can be seen in Figure 3-11. No other visible damage appeared to have occurred, and SEM examination showed no evidence of cracking. A representative area is shown at a magnification of 595X in Figure 3-15.

a) General Weaving Pattern (104X Magnification) (Photo 00628-17)

Figure 3-14. Nylon Tie Cords of External Cable Wrap

b) Individual Fibers (1050X Magnification) (Photo 00628-18)



c) Individual Fibers (2100X Magnification) (Photo 00628-20)

Figure 3-14 (continued). Nylon Tie Cords of External Cable Wrap

Figure 3-15. Epoxy on Nylon Tie Wraps (595X Magnification) (Photo 00628-20)

Wires

Initial examination of the wires in the bundle under the teflon and mylar wraps of the external cable revealed nothing unusual. Later inspection revealed some cracking of the polyimide; however, this had been noted on wires prior to launch. The coaxial cable sections showed no visible evidence of change.

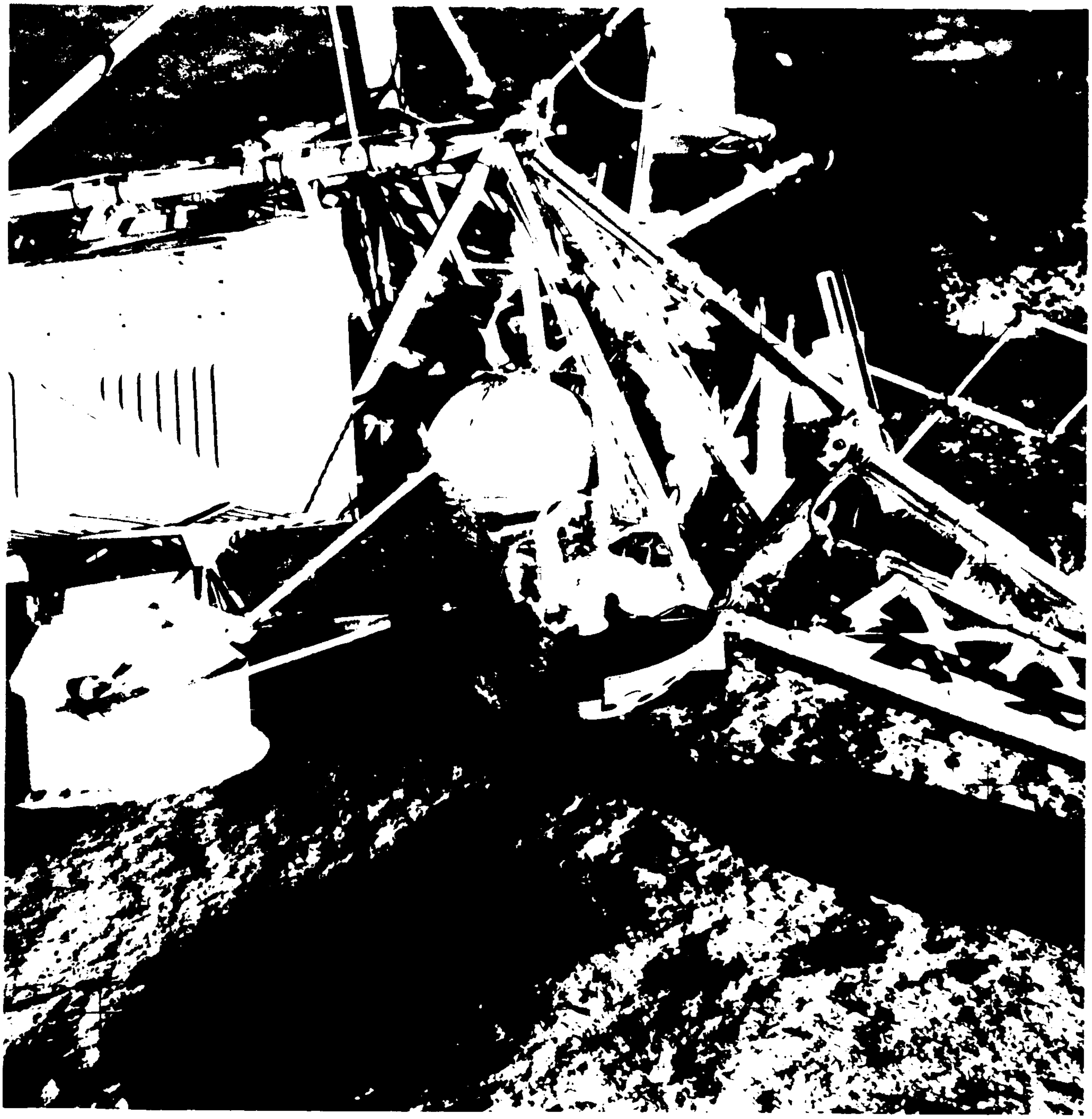
3.3 POLISHED TUBE

3.3.1 Description and Retrieval

A 7-3/4 inch section of polished aluminum tubing was cut from the Surveyor III spacecraft on the moon. This tubing was 0.5 inch in diameter and was made of 2024-T3 aluminum alloy, with a wall thickness of 0.035 inch per WW-T-700/3. The tube section is shown in Figure 3-16.* This section was cut from one of the radar antenna support struts. Its location on the spacecraft can be seen in Figure 3-17a. It is the longer tube extending from the cylindrical antenna in the lower left area of the spacecraft to the frame. The exact position along this support strut from which this section was removed is not known.

Figure 3-16. Returned Section of Polished Aluminum Tubing in Lunar Receiving Laboratory (NASA Photo S-70-21223)

*Original in color.



a) Showing Location of Removed Polished Tube (NASA Photo AS12-48-7114)

Figure 3-17. View of Surveyor III on Moon

b) Showing Area Where Removal of Polished Tube Originally Attempted (NASA Photo AS12-48-7125)

Figure 3-17 (continued). View of Surveyor III on Moon

Figure 3-17b shows the polished aluminum tube on the Surveyor spacecraft which was originally slated for removal by the astronauts. This tube was the nearer one of the two tubes supporting the Surveyor III flight control unit which houses the Canopus sensor mounted on its top.* This aluminum tube was of the same alloy, temper, diameter, and wall thickness as the radar antenna support tube actually severed by the astronauts, as confirmed by subsequent analysis of Surveyor III design records. The astronauts reported from the moon that they were unable to cut this tube although a few minutes later they successfully performed this cutting operation on the radar antenna support strut using the same cutters. The astronauts confirmed during their debriefing that they did not erroneously attempt to sever this flight control support tube through the thicker brackets at its extreme ends. The reason for this original failure to cut this particular polished aluminum tube remains unexplained.

The severed tube section was returned to LRL with the other retrieved Surveyor III parts. A visual examination was conducted 7 January 1970 by Hughes and NASA personnel when the parts were released for study. Extensive photographs were also taken at this time.

Examination of the tube for micrometeoroid impacts was then conducted by NASA personnel. Detailed examination of specific sections of the tube indicated the presence of possibly two hypervelocity impacts of 50 microns or longer. These areas were preserved for additional investigation; results of this work are expected to be published separately.

Following this examination, the tube was sectioned into six parts under NASA direction. Details of this sectioning, as well as of later sectioning at Hughes, are presented in Appendix A. Sections A and G taken from the two ends of the tube were delivered to Hughes for examination.

3.3.2 Visual Examination

Prior to the sectioning of the polished tube at MSC, the tube was subjected to a thorough visual examination. The most obvious surface characteristic was a brownish deposit on one side of the tube. The deposit was very heavy at one end of the tube (section G) and became gradually lighter toward the other end (section A).

Results of subsequent metallurgical and optical investigations, and of the contamination studies on this tube, are presented in Sections 4.5, 4.6, and 4.7, respectively. Figure 3-18 shows the contaminated side of

*The flight control unit was the equipment box, previously mentioned, which had a shattered mirror surface on top.

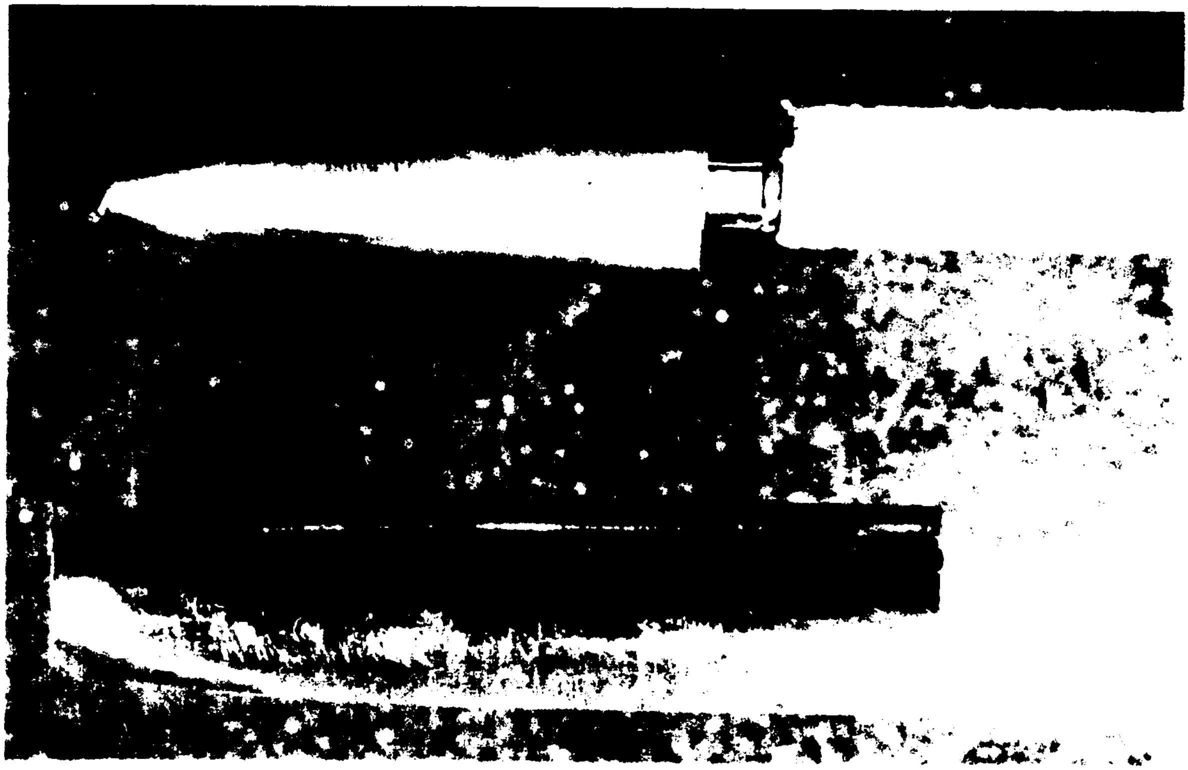


Figure 3-18. Contaminated Side of Sections A and G of Polished Tube (Photo 4R16634)

sections A and G of the polished tube, mounted on rods after sectioning. Section A is the shorter of the two sections. The contaminant strongly adhered to the surface.

Figure 3-19* shows an enlarged view of the "lunar-cut" end of section G. The jagged area near the top of the photograph is at the start of the lunar cut. Just below it is an indentation in the tube. This indentation was made by the bolt cutters at the time the tube was cut. Its significance is described in Section 4.5. It should be noted in Figure 3-19 that the contaminant remained as an unbroken film within this indentation and along the edge; this gives an indication of its adhesion.

*Original in color.

Figure 3-19. Enlarged View of End of Section G of Polished Tube Showing Contaminants (Photo 70-5549)

3.4 PAINTED TUBE

3.4.1 Description and Retrieval

A 4 inch section of aluminum tube coated with inorganic white paint was cut from one of the camera support struts with the bolt cutters by the astronaut, who then placed it in the SESC along with the cable section described in Section 3.2. An experiment was planned in which the optical properties of the white paint were to be measured while still in vacuum. Then, under carefully controlled conditions, the coating would be exposed to various amounts of air, followed by a regulated amount of light. A discussion of the tests actually conducted is given in Section 11 and Appendix J.

The inorganic white paint is a Hughes formulation,* consisting of a calcined clay pigment which is primarily aluminum silicate. The binder is potassium silicate. The coating is applied to a thickness of 5 to 8 mils. It had an initial solar absorptance of about 0.17 and a total normal emittance of about 0.92.

3.4.2 Visual Examination

The first visual examination was made when the SESC was opened. This was done under low level red light illumination. The basic observation made at this time was that the paint was still adhering to the tube. The tube was sectioned into two parts: one about 3 inches long and the other about 1 inch long. The 3 inch piece slated to be used in the optical studies was placed into its special container. The other piece was placed in a JPL container for science studies.

The next visual examination occurred at the end of the programmed testing. This examination was made with the tube section still in the quartz vacuum chamber used for the optical measurements.**

The paint was discolored to a yellowish-tan appearance. Variations in color were found around the tube. Similar color variations were observed on the struts attached to the TV camera support collar, as described in the companion report (Reference 1). The paint had adhered well except at the ends where the bolt cutters were used. There was also a small chip in the middle that had probably occurred within the SESC during transit from the moon.

3.5 ANALYSIS OF PHOTOGRAPHS AND CREW OBSERVATIONS OF SURVEYOR III

Numerous photographs of the Surveyor spacecraft were taken by the astronauts during recovery operations. Although a detailed analysis of these photographs is beyond the scope of this program,*** limited examination was conducted to assess, at least in a preliminary way, the condition of some of the parts and systems of Surveyor III not returned by the astronauts.

Figure 3-17b shows the top of the electronic equipment compartment B, the large rectangular compartment. The compartment was covered with aluminized Vycor 9710 second-surface mirrors bonded to a thin aluminum substrate with a silicone adhesive, RTV-11. Although some warping of the composite occurred as a result of the mismatch of the thermal expansion coefficients, the mirrors were still in place.

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*Reference 4.

**The tube section is still in this chamber.

***See Section 2.3 for suggested follow-on studies.

The top of the flight control box, previously noted and shown in Figure 3-17b, presents a striking contrast to the above observation. This box is located at the lower left side of the photograph. This surface is similar to that on top of compartment B except that the mirrors on this box were bonded with a hard epoxy adhesive. The mirrors were shattered, presumably as a result of thermal cycling during lunar days and nights.

Just to the right of the flight control box in Figure 3-17b is the Surveyor Canopus sensor. Markings which appear to be blisters can be seen on the side of the sunshield. This surface was aluminized teflon FEP film bonded in place. If these markings are indeed blisters, they were probably caused by bubbling of the adhesive.

All other areas of the spacecraft appear to be in good shape. Nylon wraps used to secure cables appear intact. Adhesively joined teflon, which covered propellant tanks, appears to be in nominal condition. The composite structures – solar panel, planar array antenna, and omni boom antenna – all appear normal. The paints used on the spacecraft also appear intact after the 2-1/2 year exposure to the lunar environment.

The above comments are indicative of a high degree of survival of the spacecraft. A more extensive analysis of the photographs may, however, alter some of these conclusions. Such an analysis would utilize in greater depth the knowledge of the materials and processes actually used in the construction of Surveyor III. A more comprehensive interpretation of these photographs could prove to be of direct value to future spacecraft designs.

4. TEST AND ANALYSIS OF RETURNED PARTS

A summary of the tests and analysis conducted on the returned Surveyor III parts is presented in this section.

Section 4.1 contains the results of tests and evaluation of the SM/SS scoop motor and gear assembly. Section 4.2 describes a special friction and wear test conducted on the pin of the scoop joint.

Results of chemical analysis conducted on the teflon FEP material of the cable wrap and on the nylon ties of the cable are presented in Section 4.3.

Section 4.4 gives the results of tests conducted on the wires and electrical insulation of the television camera cable and of the SM/SS scoop wires. These tests included measurements of electrical and physical characteristics.

Results of metallurgical analysis of the polished and painted aluminum tubes, including microscopic examination and microhardness measurements, are presented in Section 4.5. Section 4.6 gives the results of an analysis performed on the ends of the polished aluminum tube which led to the determination of its orientation on the Surveyor spacecraft prior to its removal.

Results of measurements of optical characteristics, i.e., spectral reflectance, transmittance, and infrared reflectance, on the aluminized teflon from the television camera cable wrap and on the polished aluminum tube are presented in Section 4.7. Aluminized teflon optical measurements included measurements on the wrap of the cable section returned under ambient conditions and vacuum measurements on the teflon wrap returned in the sealed container.

Results of the surface contamination studies are reported in Section 11 (and Appendix J). As a supplement to these studies, conducted jointly with the companion contract on the returned Surveyor III television camera (Reference 1), results of analysis of the contamination on the polished aluminum tube from Surveyor III are presented in Section 4.8.

As discussed in the respective subsections, tests of control samples were also conducted in many instances. These tests served as a basis for comparison to assist in the identification of changes that could be attributed to the effects of prolonged exposure of the retrieved Surveyor parts to the lunar environment. In addition to a description of the test conducted and results obtained, each subsection also includes an evaluation of the results, with primary emphasis on determination of the effects of this exposure. In addition to data obtained on control samples, past test data available from Surveyor program files, the literature, and materials specifications were used to assist in this evaluation.

4.1 EXAMINATION OF SCOOP MOTOR AND GEAR ASSEMBLY

Tests of the motor and gear assembly of the SM/SS scoop, described in Section 3.1.1, are discussed in this section.

4.1.1 Description

The high speed (13,000 rpm) dc scoop motor was built by AiResearch Manufacturing Company and modified by Hughes. One modification consisted of replacing the spring-loaded brushes with Boeing Hot Compact 046-45 brush material. The motor actuated the scoop door through a 1400:1 ratio gear train.

The composition of the brush material in the scoop motor is shown in Table 4-1. Traces of metallic carbides are also present as a result of the use of graphite-forming dies. The brush material is formed in an argon atmosphere at 1600°F in an isostatic press.

The Boeing compact was selected for the motor brushes over other candidates, such as silver-molybdenum disulfide, compacted niobium diselenide, silver-graphite, etc., because of low friction and wear in vacuum tests and because it permitted the motor to rotate at 20,000 rpm in the idle condition.

The drive unit was originally designed to function with an organic grease lubrication. Hughes degreased the ball bearings, removed the end covers, and spray-coated the unit with Lubeco 905.* The bearings were not disassembled for lubrication but were run in after spraying and curing the coating, and the debris was blown out of the bearings with clean dry filtered air.

*A proprietary bonded solid lubricant made by Lubeco Corporation, containing molybdenum disulfide, graphite, and lead sulfide.

TABLE 4-1. COMPOSITION OF SCOOP MOTOR BRUSH MATERIALS

Material	Composition (by weight), percent
Molybdenum disulfide	80
Molybdenum	15
Tantalum	5

The pinions and planet gears were all degreased, lightly sandblasted, rinsed, and coated with Lubeco 905 before assembly. They were burnished with rotating wire brushes, and the debris was removed by blowing with dry filtered nitrogen.

4.1.2 Initial Examination of Returned Part

X-Ray

The motor and gear assembly was X-rayed to detect any damage that might have occurred to the mechanism as a result of operation in the lunar environment. No damage was detected.

Resistance and Continuity of Motor

Prior to disassembly of the SM/SS scoop motor and gear train, the resistance of the windings and the resistance between the windings and the motor case were measured. The winding resistance was measured with a Wheatstone bridge (Shallcross Model 638-R_4) having an internal battery voltage of 4.5 volts dc. The resistance of the windings to the case was measured using a multimeter (Simpson Model 260). The results of these measurements are shown in Table 4-2. The results indicated no breaks in the wire and nominal resistance values. The motor was also found to be well insulated from the case.

4.1.3 Functional Checkout of Motor

This test was conducted to determine the functional characteristics of the SM/SS scoop motor and gear train assembly under starting conditions at two different values of applied torque (5 and 10 in-lb) and also under stall conditions. These determinations were made first in vacuum at 10^{-8} Torr and later at atmospheric pressure.

TABLE 4-2. RESISTANCE MEASUREMENTS OF WINDINGS OF SCOOP MOTOR

Motor Terminals*	Resistance	
	First Terminal - Negative	First Terminal - Positive
B-C	41.14 ohms	44.15 ohms
A-C	41.27 ohms	44.25 ohms
A-B	36.77 ohms	37.00 ohms
A, B, C to case	10 megohms	10 megohms

*Terminals A and B are for the clockwise and counterclockwise windings; C is the common ground.

Calibration

In order to be able to apply measured amounts of torque as a load on the output shaft of the gear train at a pressure of 10^{-8} Torr, an electromagnetic brake (Stearns Style SMB, Model 3, rated at 9 watts, 90 volts dc, and 60 in-lb) was calibrated at four pressures — atmospheric, 5×10^{-3} Torr, 10^{-4} Torr, and 5×10^{-6} Torr. Calibration was accomplished through the wall of the vacuum chamber using a mechanical feedthrough shaft strong enough to accommodate the torque. A torque arm 1 inch long was secured to the shaft outside the vacuum chamber. The torque was measured with a Chatillon torque watch, having 0.25 pound divisions and a full scale capability of 30 pounds. Voltage applied to the brake winding was measured by a digital voltmeter. Results of this calibration are shown in Table 4-3.

It was not possible to perform a direct calibration at 10^{-8} Torr because of the limitations of the seal associated with the mechanical feedthrough. However, calibration values were obtained by extrapolating a plot of the measured values. Calibration was further extended to 22 in-lb in anticipation of stall torque measurements. Minimum required stall torque of the scoop motor was given as 12 in-lb at 18.2 volts and 70°F. Since no maximum torque was given for these values, exact calibration could not be performed.

TABLE 4-3. CALIBRATION OF BRAKE USED FOR TESTING OF SCOOP MOTOR

Pressure	DC Voltage Applied to Brake Winding, volts	
	Torque: 5 ± 0.5 in-lb	Torque: 10 ±0.5 in-lb
Atmospheric	12.0	19.5
5×10^{-3} Torr	7.0	15.0
10^{-4} Torr	6.5	14.0
5×10^{-6} Torr	6.5	13.0
10^{-8} Torr*	6.0	10.0

*Not directly calibrated (see text).

Measurements

A fixture was designed and built to allow coupling of the gear train output shaft to the electromagnetic brake and mounting of the entire assembly on a vacuum chamber flange equipped with a viewing port.

Electrical connections for the motor, brake, and a small lamp for illumination of the chamber were brought out through a multipin hermetically sealed feedthrough. The vacuum chamber was evacuated to a pressure of 10^{-8} Torr and maintained at or below that pressure for 24 hours at room temperature before the test commenced.

The scoop motor was supplied with power from a 18.2 volt source capable of supplying a current of 1 ampere. A 15 ohm resistance, rated at 25 watts, was connected in series in the return line. Results of measurements were obtained and are shown sequentially in Table 4-4 for both counterclockwise (CCW) and clockwise (CW) motion. Although the preflight test value requirements were for atmospheric pressure, tests were first conducted on the returned part in vacuum to gain an insight as to how the motor would have performed if reactivated in vacuum. Test values for the scoop motor shown in Table 4-4 are compared with required values in Table 4-5.

The operation of the motor, gear train assembly, and electromagnetic brake was observed through the viewing port during all of the measurements of voltages, currents, speeds, and torques. Based upon the stated requirements, the motor functioned properly in every respect.

TABLE 4-4. SUMMARY OF RESULTS OF TESTS OF SM/SS SCOOP MOTOR AND GEAR TRAIN

Test Description	Pressure, Torr	Voltage		Current, ma		RPM		Torque, in-lb	
		CW	CCW	CW	CCW	CW	CCW	CW	CCW
Voltage and current required to start motor	10^{-8}	7.44	8.18	148	160	NA*	NA	NA	NA
Applied torque, 5 $\pm$0.5 in-lb Applied voltage, 18.2 volts dc	10^{-8}	18.2	18.2	180	215	7.5	8.6	5	5
Applied torque, 10 $\pm$0.5 in-lb Applied voltage, 18.2 volts dc	10^{-8}	18.2	18.2	185	225	7.5	7.9	10	10
Applied torque sufficient to stall motor at 18.2 volts dc	10^{-8}	18.2	18.2	350	380	NA	NA	55**	48**
Assembly returned to atmospheric pressure for 24 hours	—	—	—	—	—	—	—	—	—
Applied torque, 10 $\pm$0.5 in-lb Applied voltage, 18.2 volts dc	1 atm	18.2	18.2	205	250	6.7	6.8	10	10
Applied torque sufficient to stall motor at 18.2 volts dc	1 atm	18.2	18.2	370	390	NA	NA	21	18

*Not applicable.

**Since these stall-torque values were considerably beyond the maximum anticipated during calibration, they were obtained by extrapolation of calibration values.

TABLE 4-5. COMPARISON OF TEST RESULTS OF SCOOP MOTOR WITH REQUIREMENTS

Characteristic	Returned Surveyor III Part: Measured in Vacuum (10^{-8} Torr)	Returned Surveyor III Part: Measured at Atmospheric Pressure	Preflight Requirements (Minimum): Measured at Atmospheric Pressure
Insulation resistance, megohms	Not measured	10	2
Speed, rpm			
Applied voltage of 18.2 volts dc	7.5 (CW)	6.7 (CW)	1
Applied torque of 10 $\pm$0.5 in-lb	7.9 (CCW)	6.8 (CCW)	
Temperature of 70°F			
Load to stall motor at 18.2 volts dc at 70°F, in-lb	55 (CW) 48 (CCW)	21 (CW) 18 (CCW)	12

4.1.4 Examination of Gears and Bearings

After completion of the motor test, the motor and gear assembly was disassembled for detailed examination of the gears and bearings. During disassembly, no anomalies were noted; the motor was free of dust, and no evidence of cold welding could be detected. The various components were then examined, as described in the following paragraphs.

Brushes

The appearance of the brushes is shown in Figure 4-1. A large chip was observed at one corner of brush 1 (Figure 4-1a). It was not possible to determine whether this chipping occurred during original assembly, in operation, or during disassembly of the returned part. A similar small chip was missing from brush 2, as seen in Figure 4-1b. The brushes appeared quite smooth in the commutator contact areas, with no apparent sign of excessive wear. Some wear debris was visible on the coil spring and plate in the brush housing. The brushes were generally found to be in very good condition.

Commutator

The appearance of the worn brush contact surface and of the unworn portion of the surface is shown in Figure 4-2.* Sliding was in the direction of the striations and original machining marks. Analysis of Figure 4-2 confirms the anticipated lunar performance of the 046-45 brush material: low friction and wear and a smooth homogeneous transfer film of lubricant, as seen in the area on the left side of the figure. Two photomicrographs taken at a magnification of 50X (Figure 4-3) show closeups of the corresponding wear surfaces of brushes 1 and 2. The typical pitted appearance of worn composites is evident. This probably resulted from the plucking out of discrete masses of composite during sliding.

Housing

The condition of the housing at the commutator end is shown in Figure 4-4. Considerable black debris was found in the housing, particularly in the areas directly surrounding the commutator and the brushes. It was desirable to analyze the nature of this debris to determine whether any lunar material was present. This analysis was conducted using an arc emission spectrograph. Results are summarized in Table 4-6.

The method of analysis used was semiquantitative. The debris material was placed on a filter paper prior to analysis. The second column in Table 4-6 presents results which include the elements of the filter paper. For comparison, the brush material was similarly analyzed by breaking off a small amount of the brush and placing it on the filter paper. Results of this analysis of a "control" sample are shown in the third column of Table 4-6. The last column gives results of the analysis of the filter paper itself.

The brush material (type 046-045) is composed of 63 percent molybdenum, 32 percent sulphur, and 5 percent tantalum (no silicon). The fact that the debris appears to contain only 25 percent molybdenum, as seen in Table 4-6, is due to the addition of a relatively large copper content, resulting from wear of the copper commutator.

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*Original in color.

a) Brush 1 (Photo 00628-29)

b) Brush 2 (Photo 00628-30)

Figure 4-1. Surveyor III SM/SS Scoop Brushes

Figure 4-2. Contact Surface of Scoop Brush 1, Showing Transfer Film (88X Magnification) (Photo 00628-31)

a) Brush 1 (Photo 00628-32)

b) Brush 2 (Photo 00628-32X)

Figure 4-3. Contact Surfaces of Scoop Brushes, Showing Wear (50X Magnification)

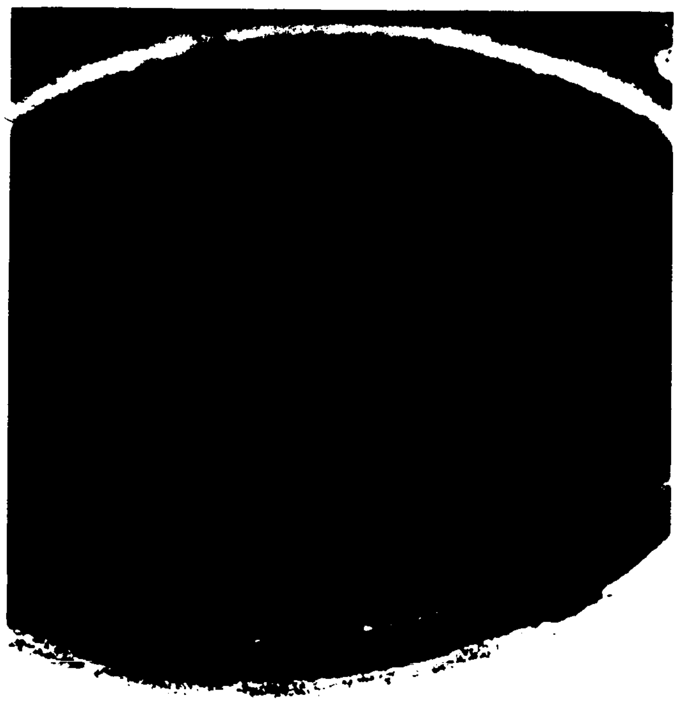

Figure 4-4. Scoop Motor Commutator Housing (Photo 00628-33)

TABLE 4-6. RESULTS OF ARC EMISSION SPECTROGRAPHIC ANALYSIS OF BRUSH AND BLACK DEBRIS IN MOTOR HOUSING

Element	Composition, percent*		
	Debris Plus Filter Paper	Brush Material Plus Filter Paper	Filter Paper (Control)
Molybdenum	25	55	Nil
Copper	24	0.77	1.6
Silicon	10	3.2	25
Iron	1.3	1.1	5.9
Calcium	0.87	0.77	6.5
Aluminum	2.8	0.22	Nil
Magnesium	0.38	0.15	9.6
Silver	0.13	0.55	Nil
Titanium	0.31	<0.05	Nil
Chromium	0.12	0.10	1.4
Cadmium	0.11	Nil	Nil
Boron	<0.05	Nil	Nil

*Not all elements present are included, notably oxygen (therefore, total is less than 100 percent).

The most conclusive evidence of the presence or absence of lunar dust is derivable from the observed ratio of silicon to iron and calcium to aluminum in the debris. Table 4-6 shows that the ratio of silicon to iron is 7.7; the corresponding ratio for lunar dust is 1.57. Similarly, Table 4-6 shows that the ratio of calcium to aluminum in the debris was 0.31; the corresponding ratio in the lunar dust is 1.79. It is therefore concluded that it is extremely unlikely that the debris contained any lunar dust at all.

Therefore, it is highly probable that the debris was composed of products of wear of the brush and the commutator, plus an indeterminate amount of earth dust, which probably accumulated in the housing during manufacture, overhaul, and test. Absence of lunar dust contamination is not surprising in view of the very small clearance between the motor shaft and housing.

Minor Hardware

Several nonfunctional items were visually examined:

- Insulator – Brush to End Cap. This phenolic laminate structure was partly covered with black debris, probably from the brushes.
- Screw – Gear Plate to End Cap and Gear Box Cover. Threads were apparently lubricated with some form of molybdenum disulfide and remained in good condition.
- End Cap. The blind hole contained a porous (oilite-type) steel bushing that was covered with light rust. Analysis of this part did not produce any significant findings.

Gears

The gears examined included pinions, planetary gears, and gears with internal splines. All of the gears were fabricated from 440-C corrosion-resistant steel. The gear train reduced the motor speed to the level required for the operation of the scoop.

All gears from the gear train were examined microscopically and found to be in excellent condition with respect to the amount of wear on the teeth. The lubricant coating in the contact zone (pitch line) appeared uniform, and only a very small amount of fine lubricant debris was found in the roots of the teeth. Neither galling nor metallic debris was observed.*

Photomicrographs indicating the condition of several typical gears are presented in Figure 4-5. By contrast, Figure 4-6 of the spline portion of the drive shaft shows areas where metallic contact occurred. This part had not been coated with Lubeco 905, nor did it appear to have any other form of lubrication.

*This was in strong contrast to some of the gears of the retrieved Surveyor III television camera, which were coated with a different film lubricant (Reference 1, Section 10.6).

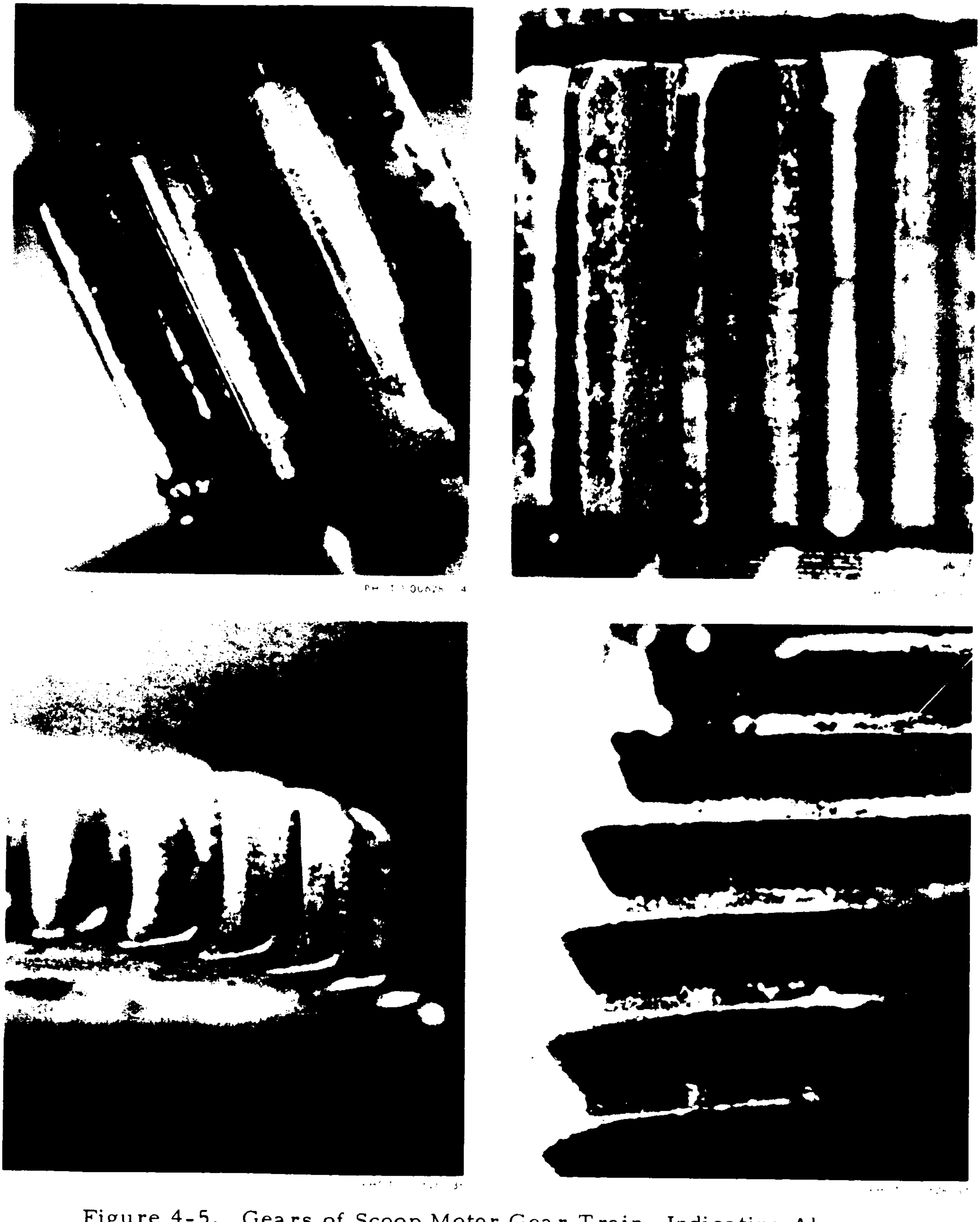

Figure 4-5. Gears of Scoop Motor Gear Train, Indicating Absence of Significant Wear

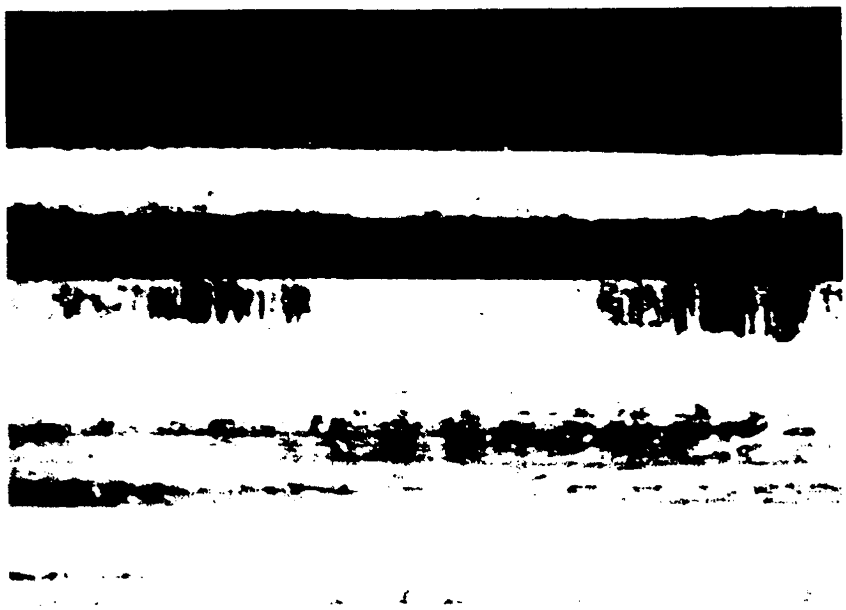

Figure 4-6. Spline Portion of Scoop Drive Shaft, Showing Metallic Contact (Photo 00628-38)

TABLE 4-7. LIST OF FIGURES 4-7 THROUGH 4-10 SHOWING DISASSEMBLED VIEW OF BEARINGS AND RACES

Figure	Description
4-7a	Support bearing, splined shaft drive, ball 1, 200 X (typical)
4-7b	Support bearing, splined shaft drive, ball 2, 200X (typical)
4-7c	Support bearing, splined shaft drive, inner race ball path, 100X
4-7d	Support bearing, splined shaft drive, outer race ball path, 18X
4-8a	Scoop motor bearing A, ball 1, 200X (typical)
4-8b	Scoop motor bearing A, inner race ball path, 100X
4-8c	Scoop motor bearing A, outer race ball path, 33X
4-9a	Scoop motor bearing C, ball, 200X (typical)
4-9b	Scoop motor bearing C, inner race ball path, 100X, area 1
4-9c	Scoop motor bearing C, inner race ball path, 100X, area 2
4-9d	Scoop motor bearing C, outer race ball path, 33X
4-10a	Scoop motor bearing D, ball, 200X (typical)
4-10b	Scoop motor bearing D, inner race ball path, 100X
4-10c	Scoop motor bearing D, outer race ball path, 33X

Bearings

Individual bearings, as well as those assembled in gears, were examined. The bearings were all radial ball bearings, open, with crown-type steel separators. All had been lubricated with Lubeco 905 prior to installation. The bearings supported the main drive shaft of the motor, the splines and pinions, and the planetary gears of the reduction gear train. No manufacturer's identification was found on most of the bearings.

The bearing surfaces were found to be too rough to perform torque measurements. This was presumably due to the unusual method of original application of the dry film lubricant, as described in Section 4.1.1. However, tests on a Barden Smootherator showed a dwell (roughness) level of 9 to 10 on a scale of 1 to 10; a good smooth bearing would have had a reading of 2 to 3 on this scale. A slight buildup of lubricants was noted at each ball position. This also could have resulted from the method of application.

A number of photomicrographs were taken of the disassembled bearings from the scoop motor and gear box. A list of these bearings and a brief description of each are given in Table 4-7, which also references the corresponding figures (4-7 through 4-10*) and gives the magnification used to obtain each photograph.

Examination of these photomicrographs shows that the transfer lubrication film on the balls and races was not uniform. This may account for the roughness of the bearings. Some of these bearings, primarily those still pressed into gears, contained very small quantities of a semitranslucent greenish substance on the race lands and on ball retainers. This material was not present in a quantity sufficient to have affected the performance of the bearings. The most likely source of this material is the original grease which was packed in the unit when it was received from the vendor (AiResearch). It is assumed that the grease was not entirely removed during the degreasing operation.

4.1.5 Discussion of Results

The following conclusions were drawn from the examination of the scoop motor and gear train:

1) After 2-1/2 years on the lunar surface, the motor and gear train would probably have functioned properly had it been reactivated on the lunar surface.

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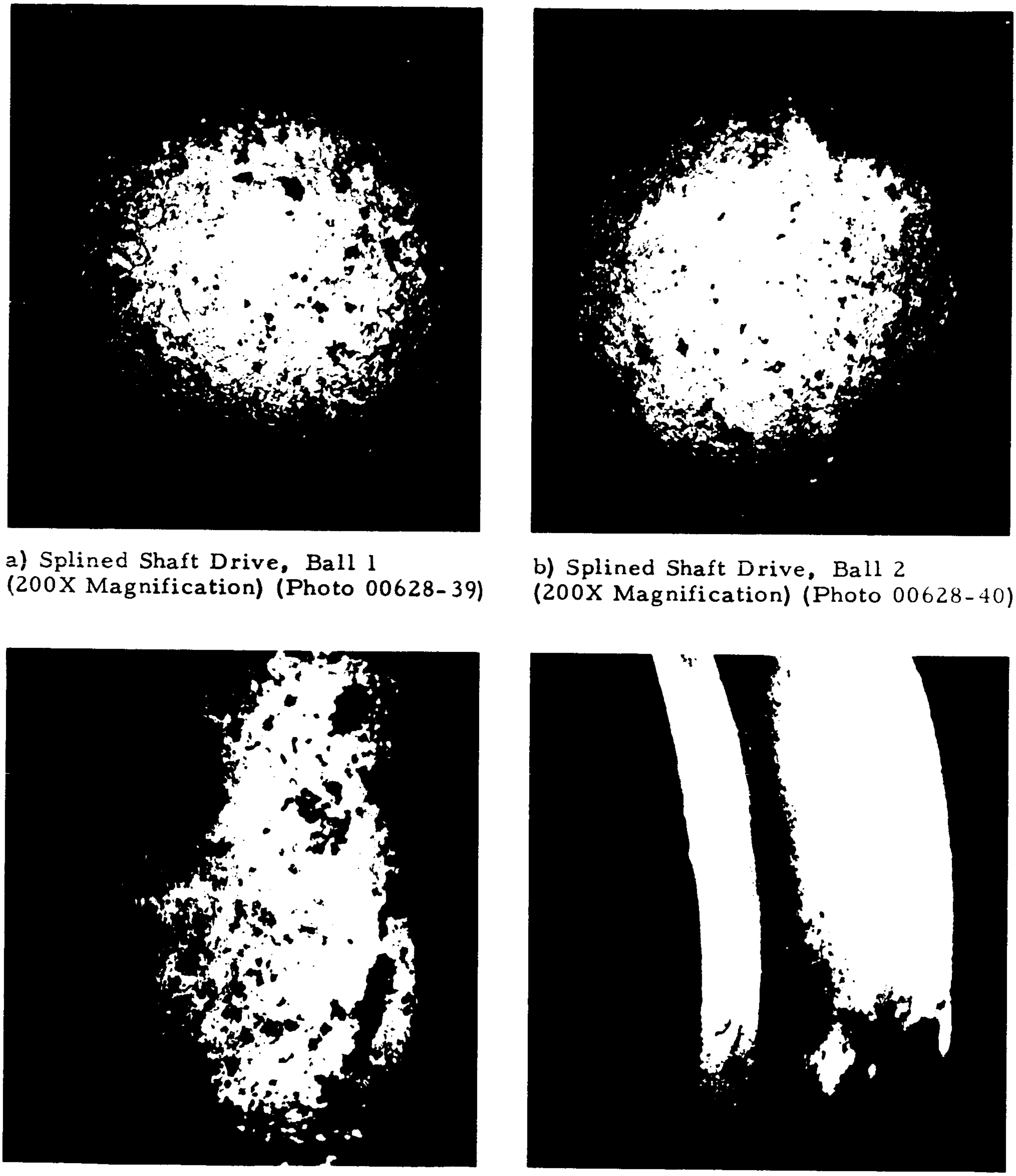
*Originals in color.



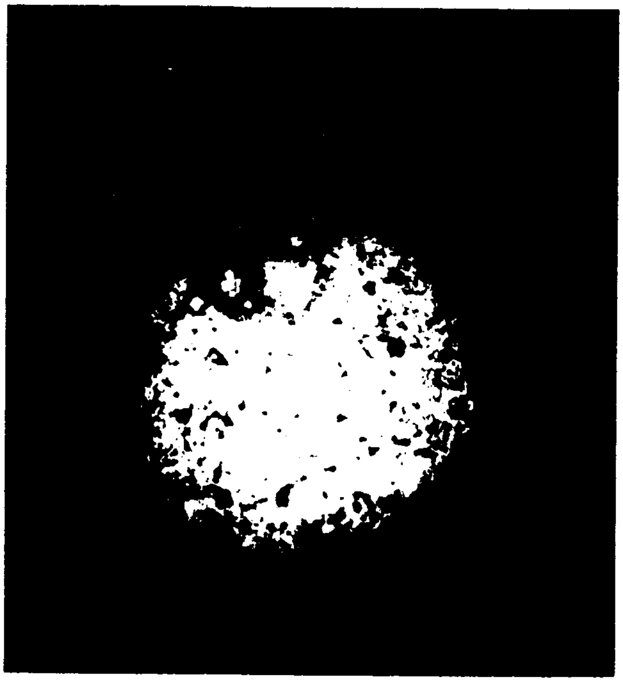
a) Splined Shaft Drive, Ball 1
(200X Magnification) (Photo 00628-39)

b) Splined Shaft Drive, Ball 2
(200X Magnification) (Photo 00628-40)

c) Splined Shaft Drive, Inner Race
Ball Path (200X Magnification)
(Photo 00628-41)

d) Splined Shaft Drive, Outer Race
Ball Path (18X Magnification)
(Photo 00628-42)

Figure 4-7. Photomicrographs of Disassembled Support Bearings



a) Ball (200X Magnification)
(Photo 00628-43)

b) Inner Race Ball Path (100X Magnification) (Photo 00628-44)

c) Outer Race Ball Path (33X Magnification) (Photo 00628-45)

Figure 4-8. Photomicrographs of Disassembled Scoop Motor Bearing A

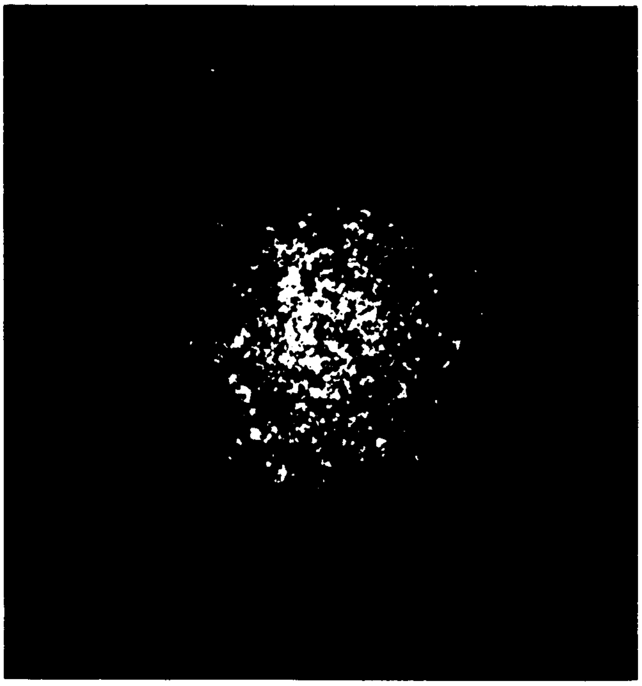
a) Ball (200X Magnification) (Photo 00628-46)

b) Inner Race Ball Path Area 1 (100X Magnification) (Photo 00628-47)

c) Inner Race Ball Path Area 2 (100X Magnification) (Photo 00628-48)

d) Outer Race Ball Path (33X Magnification) (Photo 00628-49)

Figure 4-9. Photomicrographs of Disassembled Scoop Motor Bearing C



a) Ball (200X Magnification)
(Photo 00628-50)

b) Inner Race Ball Path
(100X Magnification) (Photo 00628-51)

c) Outer Race Ball Path
(33X Magnification) (Photo 00628-52)

Figure 4-10. Photomicrographs of Disassembled Scoop Motor Bearing D

2) The method of application of the lubricant to the ball bearings would not have been satisfactory for this mission if the unit had been operated under a low torque condition. The preferred method would have been to completely disassemble the bearing and to lubricate and burnish only the races with less than 0.0001 inch of coating. An acceptable alternate would have been to use a bearing with a lubricative composite retainer.

3) Boeing Hot Compact 046-45 is a highly satisfactory brush material for use with copper commutators in high-speed dc motors.

4.2 FRICTION AND WEAR TEST OF SCOOP JOINT PIN

The MoS_2 lubricated pin was removed from the joint returned with the SM/SS scoop. Visual examination indicated wear tracks but did not yield information on the lubricative ability of the molybdenum disulfide. Therefore, a test was devised whereby the coefficient of friction and lifetime of the lubricant of the Surveyor III pin could be determined under vacuum conditions. The results of this test could be used to predict the remaining life of this lubricated pin had it been reactivated on the lunar surface.

4.2.1 Description

The joint of the SM/SS scoop, which can be seen in Figure 3-3 (Section 3), consisted of a pin rotating in a bushing. The pin is a 0.25 inch diameter rod 1.75 inches long. It is made from 403 CRES per Federal Specification QQ-S-763, CL 304, Condition A, passivated. The middle section of the pin is coated with Lubeco 905* over a length of about 0.7 inch. This section of the pin operated against the hard anodized bushing.

4.2.2 Visual Examination

Only nominal force was required to remove the pin, and there was no evidence that cold welding had occurred.

The pin was examined microscopically at various magnifications. Figure 4-11 shows a typical surface at a magnification of 5X. The wear pattern indicated that the coating had been subjected to uneven wear during service. The characteristic parallel wear marks indicate edge loading on the solid lubricant film. This is attributed to incomplete machining of the edges of the bushing.

The coating thickness was measured with a micrometer. The remaining film, uniform in thickness, was determined to be 0.0002 inch thick.

*Described in Section 4.1.1.

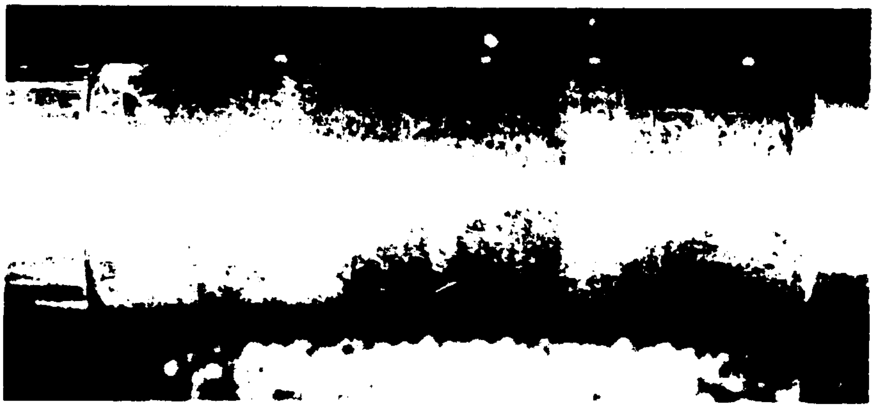


Figure 4-11. Pin From Surveyor III SM/SS Scoop Prior to Testing (5X Magnification) (Photo 00628-53)

4.2.3 Test Setup and Sample Preparation

The friction and wear test was conducted in a Hughes lubrication testing facility, using a "monorail" slider test configuration. This configuration was selected because of the small size of the Surveyor III part to be tested. The existing facility limited the test load achievable; modification of a larger test facility which would provide for higher test loads was beyond the scope of the program.

The monorail slider with attached weights totaling 224.4 grams was traversed axially back and forth over the coated portion of the pin. The oscillatory motion of the specimen mover was transmitted through a thin-walled forced transducer ring which sensed the frictional force. The individual components and the test setup are shown in Figure 4-12.

The longitudinal slot in the slider was machined to a radius smaller than that of the Surveyor pin. Consequently, the sliding contact during the axial motion occurred between the surface of the pin and the edges of the slider. Contact area was determined by measuring the actual wear area. The unit loads achieved in this test were only 24 psi, compared to 240 psi for actual operation of the pin in its intended function.

Test control pins were machined from 304 CRES to the same length as the lubricated portion of the Surveyor III pin. They were lubricated with Lubeco 905 and burnished with a Q-tip to a coating thickness of 0.0002 inch. Figure 4-13 shows the appearance of the finished control pin.

In actual operation, the Surveyor III pin was inserted into a hard anodized aluminum bushing. It would have been expensive and extremely difficult to machine aluminum for the slider. Accordingly, it was decided to fabricate the slider from stainless steel, rounding the leading edges to prevent scraping of the lubricant. In view of the fact that this investigation was concerned only with the lubricant, any convenient metal could have been chosen for the upper specimen without significantly affecting the results.

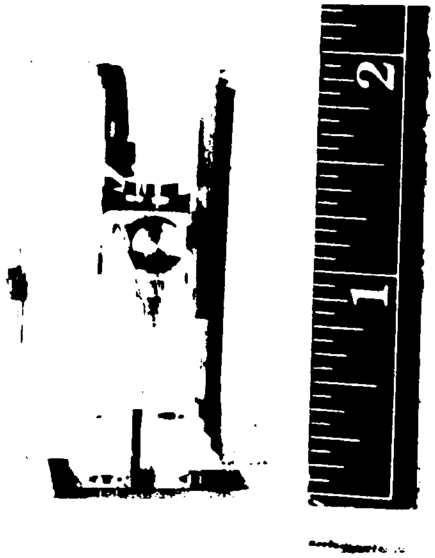


Figure 4-12. Test Setup for Wear Analysis of SM/SS Scoop Pin (Photo 00628-54)

Figure 4-13. Appearance of Control Pin Before Test (Photo 00628-55)

4.2.4 Discussion of Results

The coefficients of kinetic friction obtained during these tests are plotted in Figure 4-14. Figure 4-15a shows the photomicrographs of the sliding surfaces of the Surveyor III pin. This should be compared with the original appearance shown in Figure 4-11. The appearance of the control pin after the friction test is shown in Figure 4-15b. The significant observations resulting from these tests are summarized below, with reference to Figures 4-14 and 4-15.

The lubricant coating on the Surveyor III pin failed after approximately 100,000 cycles. The test on the control pin was terminated after 458,000 cycles; no sign of failure had occurred up to that point. It is estimated that the control coating would have withstood about twice this number of cycles.

The steady-state friction of the lubricated pin from the Surveyor III scoop was lower than that of the control pin. The explanation of this phenomenon lies in the previous histories of these coatings. The Surveyor III pin had been operated prior to launch for an unknown number of cycles under loads of 240 psi. The pin then experienced several hundred cycles of operation on the moon.

On the other hand, the only wear which the coating of the control pin experienced prior to the test was burnishing with a Q-tip. The friction of Lubeco 905 bonded solid lubricant does not reach a minimum steady-state value until the molybdenum disulfide lamellas are sufficiently oriented parallel to the sliding surfaces. This state can be brought about either by wear-in or by burnishing prior to use. It is unlikely that Q-tip burnishing imposed high enough unit loads to produce this preferred orientation. The test load of 24 psi was apparently insufficient to wear the freshly applied coating to the same degree as the operational loads.

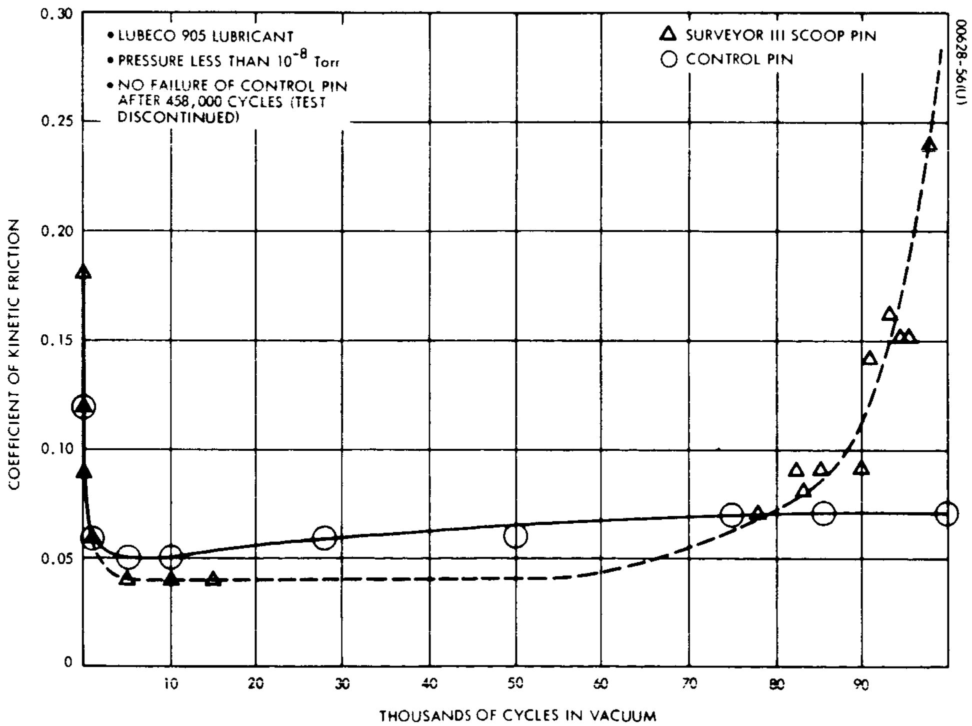
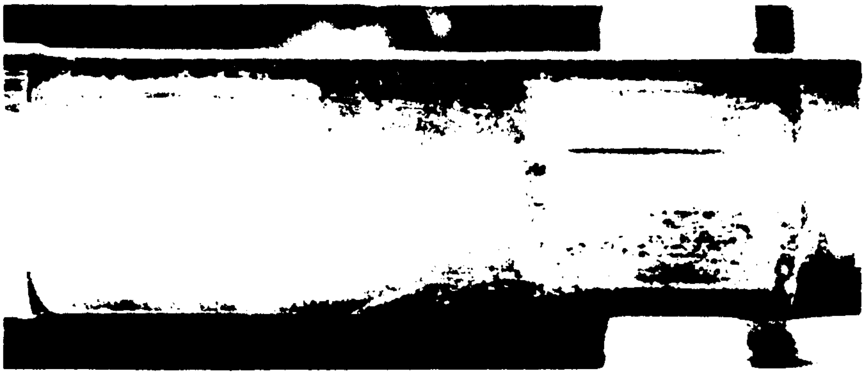
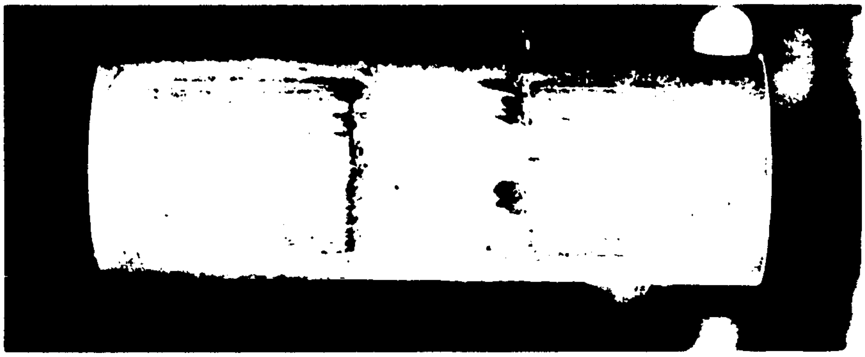


Figure 4-14. Friction Test in Vacuum of Surveyor III Scoop Pin and Control Pin

Coefficient of Kinetic Friction Versus Number of Cycles



a) Surveyor III Pin (Photo 00628-57)



b) Control Pin (Photo 00628-58)

Figure 4-15. Photomicrographs of SM/SS Scoop Pins After Friction and Wear Test

Failure of the Surveyor III pin coating was first noted at 85,000 cycles. During the next 15,000 cycles, the coefficient of friction increased until cold welding occurred at about 100,000 cycles as verified under a microscope after it was removed from the test chamber. Past experience indicates that under higher loads this failure would have occurred within a much shorter interval.

A stick-slip motion of the monorail slider was prevalent throughout both tests. During the incipient failure mode, this motion was magnified to a severe, steadily worsening, jerky motion. The appearance of the actual scoop pin and the monorail surfaces after the test showed clearly that metal-to-metal contact between the slider and the pin did occur. No evidence of metal-to-metal contact could be seen in the dummy specimen.

Reducing the cycling speed during the test from the normal 60 cpm to 3.5 cpm had only a negligible effect on the friction of either type of coating. This is not surprising since the investigations were performed in vacuum only. Past data indicate that variation of cycling frequency has a negligible effect on performance under vacuum test conditions. On the other hand, a slight reduction in friction is noticed at higher speeds in laboratory tests at atmospheric pressures.

The coefficient of friction was much lower in vacuum than in air. This is characteristic of molybdenum disulfide containing bonded solid lubricants.

The major difference between the life of the Surveyor III scoop pin and the control pin was due to the previous wear to which the scoop pin had been subjected during preflight testing and during the lunar operations. Although measurements of both pins indicated an equal thickness of lubricant (about 0.0002 inch), the volume of lubricant on the scoop pin was possibly much lower, as discussed below.

The thickness of the lubricant applied to the control pin was intentionally chosen to correspond to the 0.0002 inch thickness of the lubricant on the scoop pin, as measured by the micrometer. However, micrometer measurements record only the peak heights of the coating. As discussed in Reference 5, the lubricant is removed in chunks during the wear process rather than in uniform layers. Thus, the surface of the scoop pin lubricant coating actually had a formation of peaks and valleys — the latter corresponding to the area where chunks of lubricant had been removed in the course of its wear history.

From the above data, some estimate can also be made of the probable life expectancy of the scoop pin had it continued to be operated on the lunar surface. Such an attempt would most likely have resulted in the worn portion of the coating breaking down first. The pin joint would then probably have continued to operate for a number of additional cycles. Reference 6 indicates that the wear life of a bonded solid lubricant in oscillating motion is inversely proportional to load. Since the scoop pin failed in laboratory testing at approximately 100,000 cycles at 24 psi, it is estimated that it would probably have functioned for 10,000 cycles in the lunar environment beyond the number of cycles for which it had functioned at the end of the first lunar day.

4.3 CHEMICAL ANALYSIS OF ORGANIC MATERIALS

Tests were conducted to determine whether any detectable chemical changes occurred in the various organic materials as a result of lunar exposure. The materials tested included teflon FEP from the television cable wrap and nylon from the external ties of the cable.

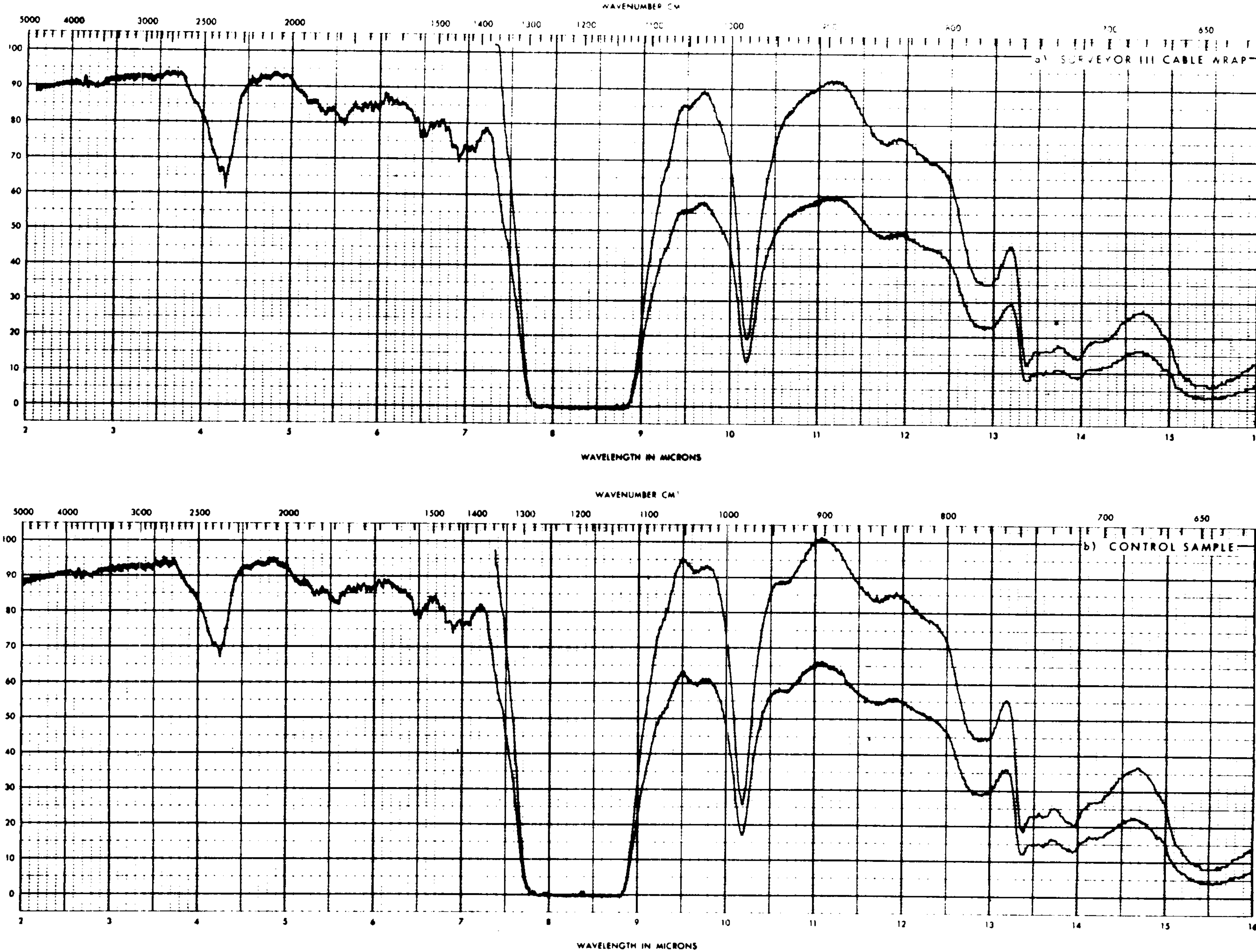


Figure 4-16. Infrared Transmission Spectra of Teflon FEP

The test series included infrared and ultraviolet transmission spectra elemental analysis, electron paramagnetic resonance measurements for spin density determination, differential thermal analysis, and viscosity measurements.

Chemical analysis of the other organic materials present in the returned Surveyor III hardware, teflon TFE, and polyimide of the wire insulation of the internal television camera harness is presented in Appendix I. 2 of the companion report (Reference 1).

4.3.1 Teflon FEP

Infrared transmission as a function of wavelength was measured on a sample of teflon FEP after the aluminum had been removed by wiping it with diluted hydrochloric acid. Results were then compared with tests of a similar piece of unflown material. Spectra from both the Surveyor III sample and the unflown control sample were virtually identical (Figure 4-16).

Transmission spectra were then measured on both samples in the ultraviolet and visible regions of the spectrum in the range from 200 to 750 millimicrons, using a Perkin Elmer 202 ultraviolet spectrometer. Figure 4-17 shows the results obtained for the Surveyor III specimen. A trace of an absorption peak can be seen at 215 millimicrons. This developing peak may be identified with the formation of isolated double bonds, indicative of defluorination. This could conceivably be the result of exposure to the solar wind: bombardment by hydrogen atoms could result in abstraction of fluorine and subsequent elimination of the fluorine radical (fluorideβ).

Elemental analysis was performed on the Surveyor III sample and on a non-flight control sample. The results are shown in Table 4-8.

The electron paramagnetic resonance (EPR) of the teflon FEP was measured in an attempt to detect possible radiation damage that might have resulted in the formation of free radicals. Three Surveyor III samples and an unflown sample were measured on an EPR spectrometer at room temperature and also at approximately -140°C. The maximum possible spin density (shown in Table 4-9), the significant parameter derived from the EPR measurements, is dependent on the sample size and sensitivity of the instrument, multiplied by the observed line width of the measured spectra. For the materials tested, the line width was on the order of 60 gauss. The sensitivity of the EPR spectrometer used was 6×10^{14} spins.

Because of the limited sensitivity of the spectrometer, quantitative conclusions on possible induced effects of the radiation environment could not be obtained. The microwave power saturation level of the spectrometer would mask any evidence of a small increase in the number of spin centers induced by radiation. Furthermore, the number of such spin centers would

TABLE 4-8. ELEMENTAL ANALYSIS OF TEFLON AND NYLON

Material	Percentage by Weight			
	Carbon	Hydrogen	Nitrogen	Fluorine
Teflon FEP (not flown)	24.04	0.08		71.72
Teflon FEP (Surveyor III)	23.81	0.13		72.33
Theoretical value	24.00	0	0	76.00
Nylon (Surveyor III)	62.00	9.43	11.43	
Theoretical value	63.69	9.80	12.33	

TABLE 4-9. SPIN DENSITY OF TEFLON FEP AND NYLON

Material	Sample Temperature, °C	Sample Mass, mg	Maximum Possible Spin Density, spins/cm^3
FEP (Surveyor III)	-140 and 25	335	4.0×10^{15}
FEP (Surveyor III)	-140 and 25	601	2.2×10^{15}
FEP (not flown)	25	452	2.9×10^{15}
Nylon (Surveyor III)	-140 and 25	106	6.2×10^{15}
Nylon (Surveyor III)	-140 and 25	94	7.1×10^{15}
Nylon (not flown)	-140	40	1.7×10^{16}

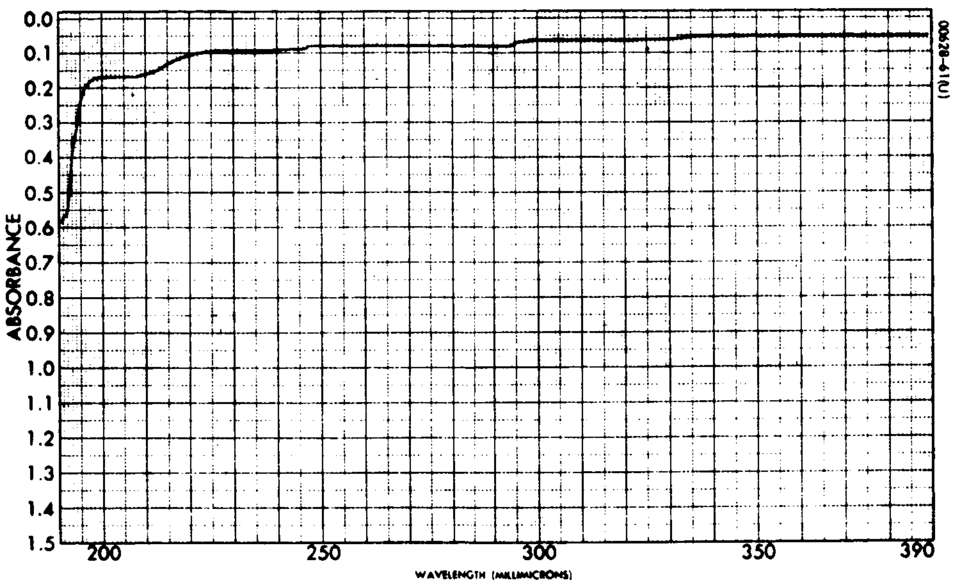


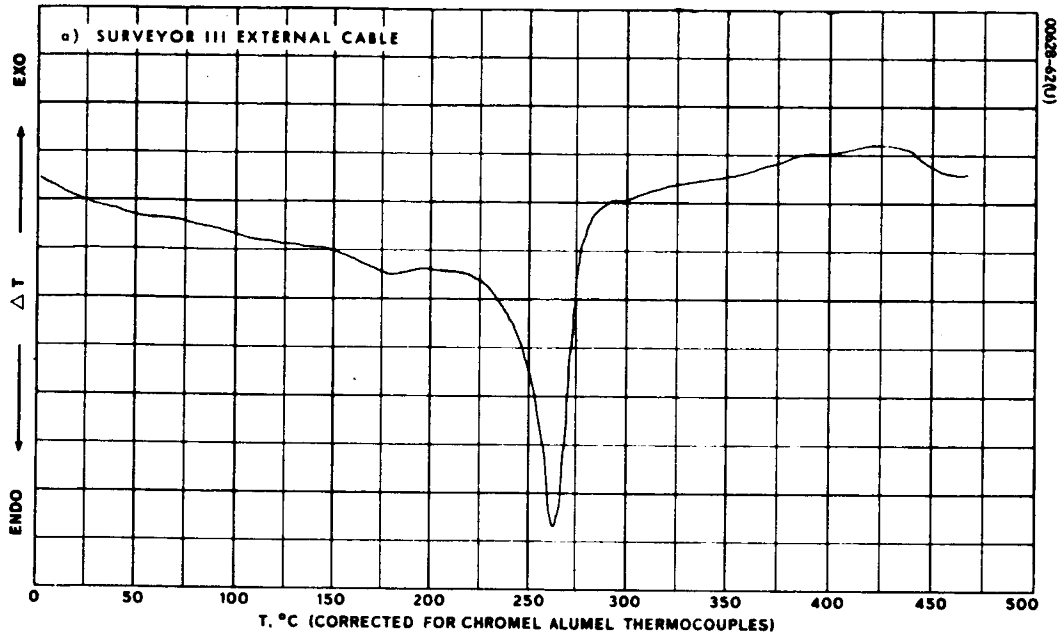
Figure 4-17. Ultraviolet Spectrum of Teflon FEP From Surveyor III Cable Wrap

Absorption versus wavelength

be reduced by the decay of free radicals over long periods of time in the air. Consequently, only a gross conclusion could be reached: i.e., within the sensitivity limitations of the instrument, no major degradation was observed. The capability of the EPR spectrometer bridge could be modified to operate in a low power configuration. However, it was felt that the additional effort required to provide for this improvement of the electron paramagnetic resonance measurement was not warranted.

Differential thermal analysis was conducted on the Surveyor III sample of teflon FEP and on the unflown sample to determine whether any changes occurred in thermal properties. Parameters such as the melting point, glass transition temperature, and decomposition point were measured by this technique; these, in turn, provided data on any changes in molecular weight or composition of these organic materials.

The differential thermal analysis test was conducted on the teflon FEP samples and on standard glass bead samples used as reference. The thermograms obtained for the Surveyor III sample and for the unflown sample are shown in Figure 4-18. No significant changes were noticed in the teflon FEP from the lunar exposure. The thermograms of the two teflon samples are seen to be virtually identical.



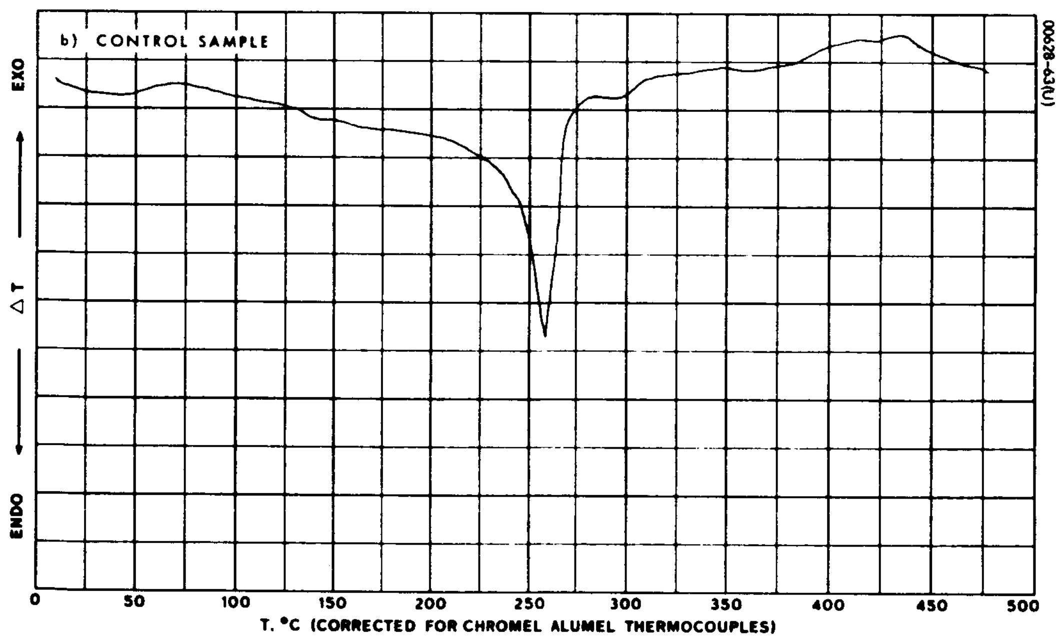


Figure 4-18. Thermograms of Teflon FEP

4.3.2 Nylon

A chemical analysis was conducted of the nylon from the exterior television cable ties. Both light and darkened pieces were examined.

Infrared spectra made of the nylon by the attenuated total reflectance method were not satisfactory. Samples were then made for infrared transmission measurements by suspending the material in potassium bromide pellets. Both light and dark areas appeared normal and virtually identical. This was true both for 6 nylon and for 6,6 nylon. Additional spectra were made of samples which had been dissolved and precipitated. Both the Surveyor III sample and the unflown sample appeared to be the same.

No changes were seen in the transmission of solutions of exposed nylon in formic acid, from which insoluble material was filtered. A broad peak (2670 to 2750 Å) found in the unexposed sample became more pronounced in the Surveyor III sample. This was probably due to the existence of hydrogen-bonded water or to a trace of solvent. This was consistent with the elemental analysis shown in Table 4-4 since the hydrogen content was lower in the Surveyor III sample. The reduction in percent weight of hydrogen to 9.43 is a significant change.

Molecular weight of a polymer can be correlated with the relative viscosity of its solutions. The difference in relative viscosity between two samples of the same structure can establish the relative values of molecular weight. Accordingly, a viscosity measurement was conducted on the nylon sample.

The nylon samples were dissolved in formic acid. Some insolubles were noted — possibly epoxy adhesive. These were filtered off, washed, and dried. The weight of insolubles was subtracted from the total weight to obtain the net weight of polymer in the solution. The viscosities of solution and solvent were determined by measuring the flow rate in a Model 100 Ostwald viscometer, loaded with 7 ml of solution. The measured elution period of each solution was reproduced with a maximum spread of 0.1 second at flow times of 85 to 100 seconds. The results indicated an estimated molecular weight of 26,000 for the Surveyor III sample and 20,000 for the unflown control sample.

Since samples of the flown and unflown nylon were from different lots, the molecular weight difference noted may not be highly significant; it was well within the expected lot-to-lot variation. However, the higher value of 26,000 for the Surveyor III sample could indicate a minor degree of polymer crosslinking caused by the lunar radiation environment.

Elemental analysis and electron paramagnetic resonance tests for spin density determination were also conducted on the nylon samples. Results of these measurements are shown in Tables 4-8 and 4-9. No significant changes resulting from the lunar exposure were uncovered. As seen in these tables, elemental analysis indicated no changes in the nylon tie materials, and spin density measurements showed no evidence of an increase in free radical density.

A sample of nylon was examined by differential thermal analysis to detect any changes in thermal properties as a result of lunar exposure. Comparison of the results with an unflown control sample indicated that no change in properties had occurred.

4.3.3 Epoxy

The epoxy used as a knot adhesive was not chemically analyzed because of the difficulty of separating it from the nylon.

4.4 PROPERTIES OF WIRE AND CABLE

Results of electrical and physical measurements of the returned Surveyor III television cable and its wrap, and the wires of the SM/SS scoop, are presented in this section. To evaluate the results obtained, tests on similar materials were conducted in some instances on control samples. In other cases, results were compared with specifications or with test results on similar wires and cables available from Surveyor program stores.

In some cases, only limited sample sizes were available. Results of tests on those samples must therefore be interpreted as approximations. This is particularly true for physical measurements since tests requiring standard sizes of specimen could not be performed. To partially compensate for this difficulty, the sizes of test specimen of control samples of similar materials were selected in those cases to be the same as the available retrieved Surveyor III samples.

4.4.1 Electrical Measurements

The electrical measurements of the television camera cable and the scoop wires are described below. Measurements included capacitance, insulation resistance, and conductor resistance. In addition, the dielectric strength of the scoop wires was determined.

In most cases, these measurements were compared with specifications. Some measurements were also made of the spare Surveyor television camera and parts available from stores for a direct comparison with the Surveyor III results. No data were available for comparison of results obtained for the capacitance of the SM/SS scoop wires.

Cable From TV Camera

The 7 inch section of TV cable (described in Section 3.2) was not disassembled for the preliminary electrical measurements. Before the measurements were made, the aluminized teflon FEP outer wrap on one-half of the 7 inch section was removed. On the opposite end, with the teflon still intact, approximately 1/4 inch was slit and folded back so the wires in the bundle could be identified.

The conductors were identified and marked with tags on one end. Twelve typical conductors and two coaxial cable sections were selected for electrical measurements. Capacitance readings were taken between adjacent conductors in the bundle and between the shield and the conductors of the coaxial cables. Nondestructive insulation resistance measurements were made between the same conductors at 100 volts dc. Resistivity of individual conductors was then measured.

Capacitance Measurements. The capacitance measurements were made using a direct reading Type 130 L-C meter manufactured by Tektronix, Inc. The test leads were kept as short as possible to reduce lead capacitance. Contacts to the wire ends of the cable sample were made with two heavy wire probes with sharp points that could be inserted between the strands of the conductor. Each wire probe was mounted in a fixture having a small lever which allowed movement of the wire probe to assure contact. The fixtures were held in position by a permanent magnet. Results of the measurements are presented in Table 4-10. For a comparison, similar measurements were made on a section of a cable from the interior of a Surveyor type acceptance test (TAT) camera available from Surveyor program stores having the same configuration and wires as the Surveyor III television camera. Values obtained were comparable to the Surveyor III sample, as evident from Table 4-10.

Insulation Resistance. The insulation resistance was measured between adjacent wires at 100 volts dc with a Model L-7 megohmmeter, manufactured by Industrial Instruments, Inc. The test at 100 volts was considered to be nondestructive. The test setup was similar to that used for capacitance measurements, with the Type 130 L-C meter replaced by the megohmmeter. The results of this test are given in Table 4-11. These values are all well in excess of the minimum specification value of 10^4 megohms.

Resistance Measurements. Resistance measurements of selected typical wires were conducted on a Leeds and Northrup 4286 Kelvin bridge. A sharp probe was inserted into each lead of each conductor. The levels of resistance were first checked with an ohmmeter to verify the contact between the probes and the wire. An additional probe was then inserted at each end for contact voltage drop, and resistance measurements were performed on the Kelvin bridge.

Results of the measurement for a few typical conductors are shown in Table 4-12. All of the values obtained were below the maximum specified for the copper alloy wire size used: 27.1 ohms/1000 ft.

SM/SS Scoop Wires

The scoop wires (described in Section 3.1) were directly exposed to solar radiation during the 32 lunar day-night cycles. Consequently, the effects on the electrical properties were of particular interest. The measurements conducted are described below.

TABLE 4-10. CAPACITANCE OF FEP-POLYIMIDE INSULATED WIRE FROM SURVEYOR III CABLE

Wire Configuration	Number of Samples Tested	Capacitance, picofarads/foot	
		TAT Cable	Surveyor III TV Cable
Two parallel wires, not twisted	11	9.3	6.2 to 9.8
Two wires, twisted	3	—	19 to 34
Coaxial cable (center to shield)	2	10.0	10.8, 10.9

TABLE 4-11. INSULATION RESISTANCE OF FEP-POLYIMIDE INSULATED WIRE FROM SURVEYOR III CABLE

Test Configuration	Number of Samples Tested	Insulation Resistance (7 inch sample)
Two parallel wires, not twisted	10	$>1 \times 10^7$ megohms
Two wires, twisted	1	0.8×10^7 megohms
Coaxial cable (center to shield)	2	$>1 \times 10^8$ megohms (not measurable)

TABLE 4-12. CONDUCTOR RESISTANCE OF SURVEYOR III CABLE

Sample	Conductor Resistance, ohms/1000 ft
1	23.6
2	23.8
3	23.9
4	24.2
5	23.6
6	22.8

Capacitance Measurements. Capacitance measurements were made with a Type 130 L-C capacitance meter manufactured by Tektronix, Inc. The test method was the same as that used for the external television camera cable, discussed above. The wires were not removed from the scoop arm during the test. The scoop arm was used as a ground for these tests. The scoop wires were arbitrarily numbered 1 through 4. Results are presented in Table 4-13.

Insulation Resistance. The insulation resistance between conductors was measured at 500 volts dc with a megohmmeter for a minimum of 1 minute. Results are shown in Table 4-14. All values exceeded the specified minimum of 1×10^7 megohms.

TABLE 4-13. CAPACITANCE OF SURVEYOR III SCOOP WIRES

Measurement Between Wires	Capacitance, picofarads
1 and 2	4.9
2 and 3	5.0
3 and 4	5.0
4 and 1	4.9
1 and ground	8.0
2 and ground	8.5
3 and ground	8.0
4 and ground	8.0
1 + 2 + 3 + 4 and ground	12.0
1 + 4 and 2 + 3	15.0
1 + 4 and ground	10.5
2 + 3 and ground	10.5

TABLE 4-14. INSULATION RESISTANCE AT 500 VOLTS DC OF SURVEYOR III SCOOP WIRES

Measurement Between Wires	Insulation Resistance, megohms
1 and 2	4×10^7
2 and 3	5×10^7
3 and 4	5×10^7
4 and 1	5×10^7
1 + 2 + 3 + 4 and ground	5×10^7

Dielectric Strength. Dielectric strength was measured between the various conductors. The applied 60 Hz ac voltage was increased at a rate of 100 volts/sec and then held for 1 minute at the maximum test voltage. The following wire combinations were tested: 1 and 2, 2 and 3, 3 and 4, 4 and 1, 1 and ground, 2 and ground, 3 and ground, and 4 and ground. Results indicated that the dielectric strength exceeded 3000 volts at 60 Hz in all cases. This was greater than the required specification value of 2200 volts dc for 1 minute.

Conductor Resistance. The resistance of three conductors was measured using a Leeds and Northrup Kelvin bridge. The test leads were soldered to the conductors being measured. The test length for two of the conductors was 7.75 inches. The resistance values obtained for these conductors were 13.9 and 12.1 ohms/1000 ft. The resistance of the third conductor was measured to be 14.7 ohms/1000 ft for a test length of 3.03 inches. All of the above values were within the specified resistance of 14.8 ohms/1000 ft, maximum.

4.4.2 Physical Tests

This subsection describes tests conducted to determine the physical properties of the wire, insulation, and other materials of the retrieved television camera cable and SM/SS scoop wires. These tests included measurements of tensile strength and elongation on an Instron tester. In addition, cut-through resistance was measured on the wire insulation.

Comparison tests of control samples of similar materials were conducted, as applicable. As mentioned earlier, these samples were of the same size as the Surveyor III samples, which in many instances were of limited size. It was felt that assessment of changes brought about by the lunar environment could in many cases be made more appropriately by comparison with control samples rather than with specifications, since non-standard specimens may not produce specification values.

Television Camera Cable

Tensile Strength and Elongation Measurements. The tensile strength and elongation measurements obtained on materials from the television cable and on control samples are summarized in Tables 4-15, 4-16, and 4-17. Table 4-15 presents results of the measurements of tensile strength and elongation of the bare wire conductors. Table 4-16 summarizes similar measurements on the various electrical insulation materials. Table 4-17 shows tensile strength and elongation measurements for the teflon FEP and mylar cable wraps.

Attempts to obtain tensile strength and elongation data on samples of the lacing tape were unsuccessful. All samples available were less than 1 inch long and could not be held securely in the test grips without damage to individual strands of the tape.

TABLE 4-15. PHYSICAL PROPERTIES OF BARE CONDUCTOR WIRES FROM TELEVISION CABLE

Item	Ultimate Breaking Strength pounds,	Ultimate Tensile Strength, psi	Elongation, percent
Copper clad steel wire from coaxial cable			
Surveyor III flight sample	15.7	71,300	9.0
Control sample (non-flight)	16.7	75,800	9.0
22 AWG conductor made of 19 strands of silver-coated OFHC copper (each strand 0.0063 inch diameter)			
Sample from Surveyor III	19.0	32,100	28
Specification value	—	32,100 to 35,000	45 to 55
24 AWG conductor made of 19 strands of silver-coated alloyed (chromium, cadmium) copper (each strand 0.005 inch diameter)			
Sample from Surveyor III	20.1	53,900	6
Specification (chromium-copper - hard)	—	62,000	12

TABLE 4-16. PHYSICAL PROPERTIES OF CONDUCTOR INSULATION FROM CAMERA CABLE

Item	Ultimate Breaking Strength, pounds	Ultimate Tensile Strength, psi	Elongation, percent
FEP insulation on coaxial cable			
Surveyor III sample	10.5	985	156
Control sample	13.0	1,225	256
Polyimide coating from FEP-polyimide insulation			
Surveyor III sample	2.4	10,000	14
Control sample	3.1	14,000	56
Polyimide coating from FEP-polyimide insulation			
Surveyor III sample	1.9	3,720	400
Control sample	2.2	4,330	351

No significant change was observed in the copper-clad steel wire and in the OFHC annealed copper conductor, as seen in Table 4-15. However, a reduction in tensile strength of the alloyed copper conductor was noted. This reduction was apparently due to the long thermal annealing which this wire experienced on the moon. It is estimated that the wire was subjected to an average temperature between 200° and 250°F for an accumulated time of about 4000 hours.

Results of tests of physical properties of conductor insulation shown in Table 4-16 indicate a reasonable correlation with the values obtained for the control samples of the same size. The thickness of the FEP insulation was about 9 mils. However, the values obtained for both the Surveyor III samples and the control samples are not totally consistent with specification values for this material (not shown on the table). This is a clear illustration of the previously discussed effect of the limited size available for test and supports the validity of the selected technique of comparing tests of these limited size samples with corresponding sizes of control samples. The consistency of results between Surveyor III and control samples indicates

TABLE 4-17. TENSILE STRENGTH AND ELONGATION OF TEFLON FEP AND MYLAR FROM SURVEYOR III CAMERA CABLE

Sample Description	Ultimate Breaking Strength, pounds	Ultimate Tensile Strength, psi	Elongation, in 1.0 inch
FEP sample 1 from Surveyor III	0.76	1,267	95
FEP sample 2 from Surveyor III	1.21	2,017	107
FEP control sample 1	2.02	3,367	370
FEP control sample 2	2.04	3,400	380
Specification requirement (L-P-523)	–	2,500 minimum	250 minimum
Mylar sample 1 from Surveyor III	0.74	12,000	36
Mylar sample 2 from Surveyor III	0.97	12,900	21
Specification requirement	–	25,000 minimum	70 to 130

that no significant effects can be attributed to the lunar exposure. The polyimide data indicate a reduction in strength for the Surveyor sample. The sample was difficult to obtain, and variations in tests were large. Thus, values shown are only approximations. The differences between the physical properties of the Surveyor III FEP insulation sample and control sample on Table 4-16 are considered well within the expected data scatter for such sample sizes*.

Tensile strength and elongation were measured on two samples of the 0.002 inch thick teflon FEP aluminized on one side from the TV cable. This material was the outer wrap of the cable; the teflon side had been directly exposed to the sun. Two adjacent samples were cut from one section of the Surveyor III teflon FEP wrap, each 0.300 inch wide by 1 inch long. The

*For comparison, the expected ultimate tensile strength of the FEP insulation is greater than 2500 psi.

samples were tested in an Instron testing machine. The method used was ASTM D-838. Two control samples of fresh aluminized teflon FEP were cut to the same size as the Surveyor III samples and tested in the same manner.

The reduction in elongation and tensile strength of the teflon FEP shown in Table 4-17 is consistent with the anticipated effects of radiation in the teflon FEP and the cracking observed in the teflon during visual examination.

A sharp decrease in both tensile strength and elongation of the 0.00025 inch mylar was measured. This was not caused by solar radiation since the mylar was protected by 0.004 inch of teflon, which effectively shielded out all the low energy protons of the solar wind as well as the ultraviolet. The reduced values were attributed to the "crumpling" that occurred in the material. There were a great many folds in this material, which could have resulted in significant weakening. It should also be noted that the reduced strength of the mylar wrap did not impair its ability to function as an effective electrical shield for the cable.

Cut-Through Insulation Measurements. Cut-through tests were conducted on the FEP polyimide-insulated wires from the camera cable. Two techniques were used to evaluate the cut-through strength. First, the static load necessary to immediately cut through the insulation to the conductor was determined. Second, the static load for cut-through of the insulation 24 hours after loading was determined. Both measurements were made by placing a 90 degree wedge with a 0.01 inch radius at the V on the surface of the wire at right angles to the conductor. Loads were applied to the top of the wedge while the sample was at room temperature. A control sample was measured for comparison with the Surveyor III sample.

The polyimide-FEP insulated Surveyor III wire was found capable of supporting 180 grams for 24 hours before cut-through, while the control sample supported 280 grams for the same length of time. This result was in apparent conflict with the tensile strength measurements, which showed no significant difference in the tensile strength of the insulation between the Surveyor III and control samples.

The apparent difference can be readily explained when it is noted that the polyimide coating over the teflon on the wires from the Surveyor III cable was found to have been cracked and crazed in many places. The polyimide coating was intended to provide the basic toughness to the insulation. With this cracked and crazed coating, the estimated value of the cut-through was expected to be that of the FEP alone, i.e., on the order of 150 grams. This estimate was very close to the measured value of 180 grams. Thus, the cut-through measurement, in effect, verified the poor performance of the polyimide coating process.

SM/SS Scoop Wires

Tensile strength and elongation measurements were made of the electrical insulation and the bare conductor from the scoop wires using an Instron tester. The results of these tests are summarized in Table 4-18. Comparison with specifications in Table 4-18 indicates that no significant changes can be attributed to the lunar exposure of either material.

Insulation cut-through measurements were conducted on the scoop wires using the method described in the previous subsection. The cut-through value of 140 grams obtained after a 24 hour exposure is consistent with expectations for this teflon TFE insulation. This result is therefore consistent with the above conclusion that the tensile strength of the electrical insulation of the SM/SS scoop wires was not significantly affected by the lunar exposure.

4.4.3 Discussion of Results

Electrical Measurements

Review of the data presented in Section 4.4.1 leads to the general conclusion that no significant changes were noted in the electrical properties of the television cable wires and of the SM/SS scoop wires that could be attributed to exposure to the lunar environment. Any deviations noted were either minor or most likely attributable to the test limitations associated with the limited lengths of samples available.

Insulation resistances were well within specification limitations, as were conductor resistances. Similarly, the dielectric strength measurements of the scoop wires yielded nominal results. The only apparent discrepancy was the somewhat lower value obtained for the capacitance of the cable wires compared to those measured on a similar spare cable from Surveyor stores. It is most likely that this discrepancy reflects the above-mentioned limitation of available lengths of samples. The capacitance of the scoop wires appeared normal; no direct comparison could be made with other similar wire configurations because of nonavailability of similar insulated wires in an identical configuration.

Physical Property Measurements

Results of the tests described in Section 4.4.2 indicate that a number of changes traceable to the effects of lunar exposure occurred in some of the physical properties of both the conductor wires and the cable wraps. However, these changes were in no instance large enough to impair the ability of any of the materials tested to function in full compliance with design requirements.

TABLE 4-18. TENSILE STRENGTH AND ELONGATION OF SCOOP WIRES FROM SURVEYOR III

Test Sample 6	Ultimate Breaking Strength, pounds	Ultimate Tensile Strength, psi	Elongation, Percent
22 AWG conductor made of 19 strands of silver-coated OFHC copper (each strand 0.0063 inch diameter)			
Sample from Surveyor III	10.4	30,000	25
Specification value	—	32,000 to 35,000	45 to 55
Insulation, teflon TFE			
Sample from Surveyor III	5.63	5000	250
Specification value	—	2500 to 6500	250 to 350

The reduction in tensile strength of the alloyed copper is considered to be the result of thermal annealing. On the other hand, the soft copper (OFHC) was fully annealed prior to its flight application; thus, no changes resulting from the lunar exposure would be expected. This was confirmed by test results.

The apparently lower tensile strength of mylar can be attributed to handling during the manufacture of the cable and during tests of the cable. It is unlikely that any reduction occurred as a result of lunar exposure. The effect of such prelaunch handling could undoubtedly lead to physical cracks or tears in the mylar. Caution in the handling of this thin material is prudent.

A review of the results of measurements of the physical properties of the teflon insulation indicates that the teflon FEP material from the television cable wrap experienced a 50 percent decrease in tensile strength, while the teflon TFE insulation from the scoop wire and teflon FEP-polyimide insulation from the internal wires of the camera cable experienced at most only a small reduction in tensile strength.

The loss in tensile strength of the teflon FEP is attributed to the radiation environment, namely, the low energy protons of the solar wind. The teflon FEP cable wrap and the teflon TFE insulation from the scoop wires were directly exposed to this radiation environment, while the insulation on the cable wires was shielded by the overwraps. The difference in measured tensile strength between the two samples directly exposed to the radiation environment cannot be explained by a difference in intrinsic susceptibility of the two types of teflon to radiation since both have about the same sensitivity to radiation (Reference 7).

It is difficult to explain this observed difference between the degradation of the 2 mil teflon FEP cable wrap and the 9 mil teflon TFE insulation of the scoop wires. After a considerable amount of analysis, including outside consultation, the only possible explanation suggested for this observed difference is discussed below. This explanation is, in part, based on recent work at Hughes involving charged carrier migration in dielectric solids*.

The explanation attributes the observed degradation to solar wind protons and to the migration of the resultant charged carriers produced by the protons. Although the low-energy solar wind protons have only a range of a few microns in teflon, the charged carriers produced are estimated to migrate a distance on the order of 1 mil through the material in the course of prolonged lunar exposure. This phenomenon is compatible with the observed migration of the charged carriers produced along the proton track in dielectric solids. The effect of these charged carriers is increased cross-linking in the teflon, resulting in increased brittleness.

When the teflon FEP was unwrapped from the cable, it was observed to be somewhat stiff. This unwrapping of the partially embrittled teflon FEP material may have caused some fractures in the layer, thus reducing its original thickness by as much as one-half and consequently reducing its strength by 50 percent. The teflon insulation from the wire would be expected to show a reduction in tensile strength of about 10 percent. It was difficult to observe this degree of change in tests of these samples of limited size.

The above hypothesis is qualitative in nature and is based on the extrapolation of data available for dielectric solids to teflon. However, in the absence of other plausible explanations, the hypothesis seems reasonable and is fully consistent with the observed experimental results.

If the above hypothesis is valid, a significant consequence arises relative to possible future applications. Had the cable wrapped with teflon FEP been required to move or to flex during or after the 2-1/2 years of its lunar exposure, it is possible that significant cracking in the teflon wrap would have occurred.

Results of the cut-through tests of both the wires from the television cable and the wires from the SM/SS scoop appeared consistent. The lower than anticipated value obtained for the FEP-polyimide wire was in agreement with the observation that the polyimide coating was fractured in many areas.

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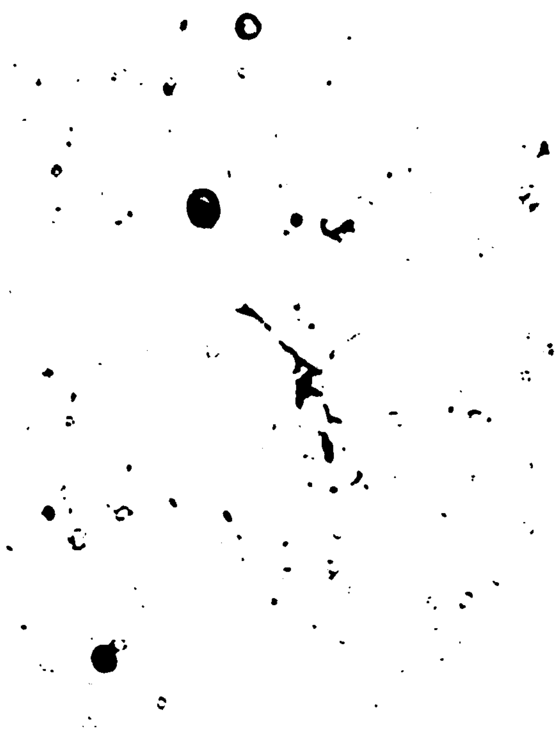
*Conducted by H. Levin in the Materials Technology Department of Hughes Aircraft Company.

4.5 METALLURGICAL ANALYSIS

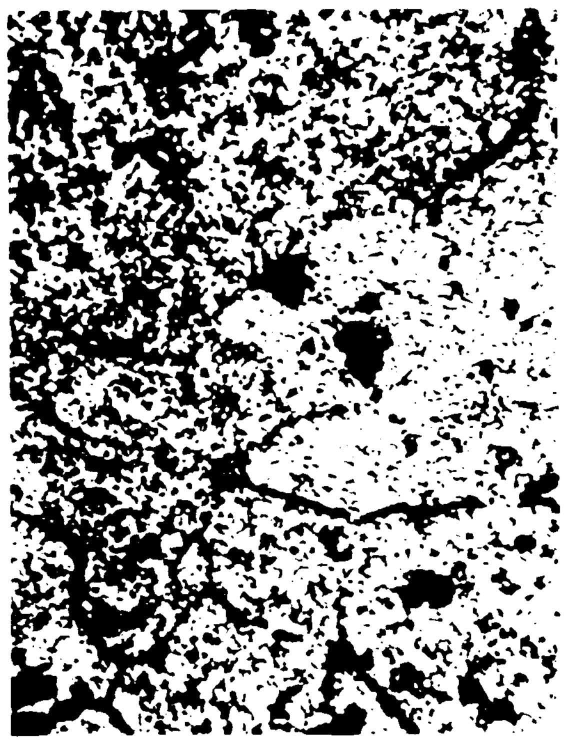
Metallurgical analyses of samples of aluminum alloy from the various returned parts of the Surveyor III Spacecraft and control samples are discussed in this subsection. The samples of aluminum alloys tested and their origin on the retrieved Surveyor III parts are summarized in Table 4-19. The principal tests conducted were microscopic examinations and measurements of microhardness.

4.5.1 Polished Aluminum Tube

Photomicrographs of a cross section of the Surveyor III polished aluminum tube and of a control sample taken from a tube of the same size, alloy, and temper are presented in Figures 4-19 and 4-20.

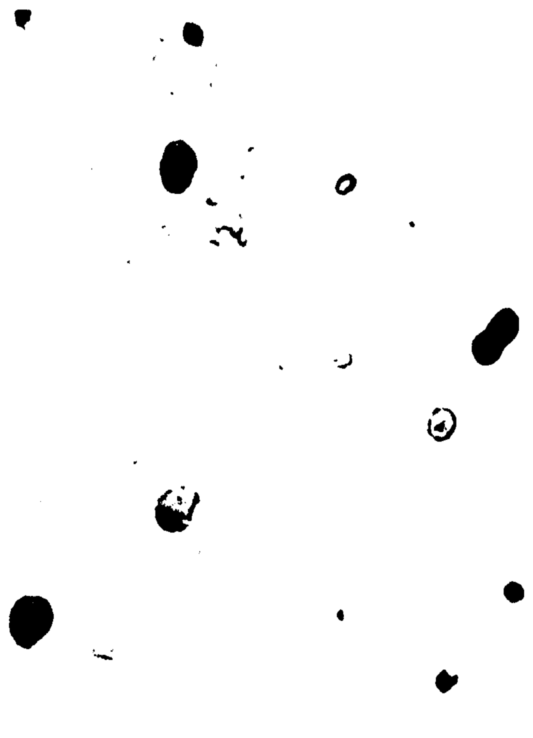


a) No Etching (Photo 00628-64)



b) Keller's Etch (Photo 00628-65)

Figure 4-19. Microstructure of Polished Aluminum Tube From Surveyor III (1000X Magnification)



a) No Etching (Photo 00628-66)

b) Keller's Etch (Photo 00628-67)

Figure 4-20. Microstructure of Control Sample of Aluminum Tube (1000X Magnification)

TABLE 4-19. ALUMINUM ALLOY SAMPLES SELECTED FOR METALLURGICAL ANALYSIS

Aluminum Alloy	Source of Sample
2024-T3 WW-T-700/3	Section G, Surveyor III polished tube (spacecraft structure)
2024-T3 WW-T-700/3	Support strut for Surveyor III television camera
7075-T6 QQ-A-225/9	Scoop arm (machined from bar stock)

The grain boundaries in the microstructure prior to etching can be seen in Figure 4-19a. Figure 4-19b shows that this microstructure was attacked abnormally upon a very light application of the etchant. The sample was not repolished after etching and is available for further tests. The normal microstructure of the 2024-T3 control sample is shown in Figure 4-20. No grain boundaries are visible in this control sample in the unetched condition in Figure 4-20a. The grain boundaries become evident in the control sample after etching in Figure 4-20b. However, the general structure is not attacked as severely as that of the Surveyor III polished tube section shown in Figure 4-19b.

It is evident from the above comparison that additional grain boundary precipitation of the precipitation hardening compounds, or overaging, occurred during the lunar exposure. Prolonged exposure at 250°F of aluminum 2024-T3 will cause increased hardness resulting from increased precipitation at the grain boundaries (Reference 8); this increased precipitation will be evident in the unetched condition.

Microhardness surveys using a 50 gram Knoop indenter revealed that the average hardness of the Surveyor III polished tube was 137.5, expressed in terms of Brinell hardness numbers. The corresponding value for the control tube sample was 124.0. The nominal hardness for this alloy in the T3 temper is considered to be in the range of 110 to 130 on the Brinell scale. No significant variation in hardness was seen from the edge to the center of the cross section of the polished tube. The above measurements led to the conclusion that the increase in hardness of the Surveyor III polished aluminum tube was caused by the lunar thermal environment.

Separate thermal analysis conducted by Hughes and JPL indicated that the maximum temperature which the polished aluminum tube reached during its stay on the lunar surface was 250°F ±25°. The mechanical properties of Alclad 2024-T3 aluminum alloy after thermal exposure for periods up to 6000 hours is given in Reference 8*. At 250°F, increased tensile and yield strengths are noted for exposures as short as 600 hours. The increased tensile strength is modest; but the increase in yield strength is greater, reaching 25 percent after 6000 hours exposure.

4.5.2 Painted Tube

The unedged microstructure of a longitudinal section of the painted tube was similar to that taken of the control sample shown in Figure 4-20a. The microstructure of the painted tube after etching is shown in Figure 4-21. The appearance is normal and similar to that of the etched control sample shown in Figure 4-20b. The grains are more elongated in Figure 4-21 due to the sample orientation.

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*Figure 21, page 229; although these data are based on Alclad aluminum, similar strengthening would occur with unclad aluminum since the 2024 base alloy and not the cladding is subject to the precipitation hardening.

Figure 4-21. Microstructure of Painted Aluminum Tube From Surveyor III (1000X Magnification)

Keller's etch (Photo 00628-68)

Thirteen microhardness measurements were conducted on a sample of the painted tube. The measured values were converted to Brinell hardness numbers, using standard tables, in the same manner as was done for the polished aluminum tube. The resultant average Brinell hardness number was found to be 133; the spread was reasonably small. This value falls between the Brinell hardness numbers obtained for the Surveyor III polished tube and for the control sample.

It should be noted that the painted tube is expected to have had a lower equilibrium temperature on the moon than the polished tube because of the presence of its thermal coating. Since the above hardness measurements represent averages of a number of measurements with relatively close grouping, reasonable credence can be attributed to their significance. Thus, it could be inferred from these measurements that the painted tube had undergone some additional aging during its lunar exposure relative to that of the polished aluminum tube although this conclusion is not evident from the photomicrographs.

4.5.3 Scoop Arm

Microstructural examinations and hardness measurements were conducted on both ends of the SM/SS scoop arm, made of 7075-T6 aluminum, as indicated in Table 4-19. One end of this tube, which was severed by the astronauts on the moon, was unpainted and anodized. The other end, severed in the laboratory for this measurement, was painted with the original blue paint. Microstructure examination and hardness measurements were also conducted on a control sample of this material.

Results of microstructure examinations indicated a striking similarity in appearance of both ends of the scoop arm and of the control sample. Hardness measurements, conducted in the same manner as those for the polished aluminum sample, yielded the following results in terms of Brinell hardness numbers: 150 for the control sample, 157 for the unpainted end, and 156 for the painted end. The hardness values of the painted and unpainted ends are well within the typical hardness range for 7075-T6 aluminum.

Results of hardness measurements could be attributed to the normal variation of the 7075 alloy, which is not as temperature-resistant as the 2024 alloy. On the other hand, they could be the result of lunar exposure. Reference 8* shows that a slight strengthening of the 7075 alloy occurs after about 500 hours exposure at the lowest reported temperature of 225°F and that a decrease in mechanical properties occurs upon continued exposure in excess of 1000 hours. At higher temperatures below 225°F, it is conceivable that this alloy was strengthened by aging at lower temperatures.

4.6 ANALYSIS OF LUNAR-CUT ENDS OF POLISHED TUBE

An analysis was conducted on the two ends of the Surveyor III polished aluminum tube severed by the astronauts on the moon. These two ends are referred to as "lunar-cut" ends. Results of this analysis, including a metallurgical evaluation, a study of the characteristics of the lunar cut ends, and an evaluation of the original orientation of the polished tube relative to the Surveyor spacecraft inferred from the above study are presented in this section.

This analysis was motivated by the desire to compare the metallurgical properties evident from the cut performed on the moon with those characteristic of similar cuts under ambient conditions, by the desire to obtain a better understanding of the resulting characteristics of the deformed, cut ends, and by the desire to affirm the orientation of the tube for subsequent surface contamination studies. The two ends available for this study were sections A and G of the tube; as discussed in Appendix A, these were made available to Hughes.

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*Figure 23, page 231.

4.6.1 Analysis of Cut

An examination was performed of the lunar-cut ends of the polished tube section. The appearance of the lunar-cut surface of section G of the polished tube is shown in Figure 4-22a. Figure 4-22b is a side view of this section looking at the side shown at the bottom of Figure 4-22a.

As can be seen in Figure 4-22a, cutting of the tube distorted it into an oval or pear-shaped cross section. The appearance of this surface indicates that, as the tube flattened, the cutting tool indented the metal and partially sheared the wall on the flattened sides. As the wall was thinned by the cutting action and the forces imposed by the cutting tool increased, the tube deformed; final rupture of the wall occurred by fracture. An indentation caused by the cutting tool just below the cut surface and extending across one side of the tube can be seen in Figure 4-22b.

a) End View (Photo 00628-69)   b) Side View (Photo 00628-70)

Figure 4-22. Severed Surveyor III Polished Aluminum Tube (7X Magnification)

The cut surface was examined extensively by the SEM, and selected photos are shown in Figures 4-23 through 4-27. Figure 4-23 is an enlarged view of Figure 4-22a and reveals some areas of the lunar cut in greater detail.

Figure 4-24 shows the indentation made by the cutting tool previously shown in Figure 4-22b. A very small sphere having a diameter of 0.0003 inch is shown on the indented surface of Figure 4-24c. Lack of charge buildup on the specimen in the SEM indicates that this sphere is metallic.* Similar spheres have been observed on the fracture faces of various metals.

Figures 4-25 through 4-27 show typical areas of the fracture observed on the lunar-cut end from section G. Figure 4-25 corresponds to the bottom (6 o'clock) area of Figure 4-23. On the left is the smooth surface made by the cutting action of the tool. The surface on the right is where the fracture propagated by tearing after stress buildup under deformation by the cutting tool. This torn area shows the dimple fracture characteristic of a ductile break. The dimple fracture is shown in greater detail in Figure 4-26.

Figure 4-27 shows in greater detail the area on the left in Figure 4-23 (9 o'clock position) which was folded over by the cutting tool. Scoring of the surface in the direction in which the cutting blade was moving is clearly visible.

A tube of the same alloy (aluminum 2024-T3), size, and temper as the Surveyor III tube and cut with the same type of tool is shown in Figure 4-28a. While this cut surface is not identical to that of Figure 4-22a and 4-23, it contains the same features of sheared metal part way through the wall and ductile tearing through the remainder of the wall. Also, the indentation on the wall seen in the lunar-cut sample below the cut was noted in some areas of this control sample.

SEM photographs of portions of Figure 4-28a are shown in Figures 4-28b and c. Figure 4-28b is an enlargement of the radial crack in the wall on the left (9 o'clock position) of Figure 4-28a. Figure 4-28c is an enlargement of the bottom (5 o'clock position) of Figure 4-28a and shows the results of a combined shearing and tearing action caused by the cutting. This is similar in appearance to the corresponding areas on the lunar cut previously shown on Figure 4-25.

Analysis of the above figures indicates no distinctive differences between the cuts made on the moon and the cuts made in the laboratory using a tool similar to that used by the astronauts. The only exception is the crack in the 9 o'clock position of Figure 4-28a on the sample cut in the laboratory. The contour or deformation of the retrieved tube and the control tube at the cuts are slightly dissimilar, but this is strictly a function of the position of the tube cutter at the time the cut was made.

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*Otherwise, the sphere would appear very bright. It is unlikely that this sphere is lunar material although this cannot be proven conclusively.

4.6.2 Orientation of Polished Tube on Spacecraft

This similarity in appearance of the surfaces of the retrieved aluminum tube and of the control sample cut with similar cutters, along with the unique shape of the cut tubes, give rise to the possibility of determining the approximate orientation of the polished aluminum tube while on the lunar surface. This orientation could be established conclusively if a characteristic pattern resulting from these cutting operations could be identified. Determination of this orientation would be useful for solar wind studies and for the analysis of the nature and source of the brownish contamination on one side of the Surveyor III polished tube.

Accordingly, an analysis of the action of, and the resulting patterns obtained from, the use of the cutting tool was conducted. The cutting tool is sketched in Figure 4-29. Its action can be described as follows: Both blades of the tool squeeze the tube fairly uniformly as the tube assumes an oval shape. As the tube deforms, the blades uniformly indent the flattening sides of the tube for about 75 percent of the circumference of the tube before rupture commences. If the tube is positioned between the blades close to the fulcrum, the tube will be oval-shaped after cutting. If the tube is positioned away from the junction of the blades nearest the fulcrum, the tube will be pear-shaped, with the apex at the end farthest from the fulcrum. In the latter case, rupture commences at the small pinched end.

Both blades appear to cut or indent equally. The fracture of the tube does not always follow the path of the blade. Observation of a cut as fracture-initiated revealed the characteristic pattern sketched in Figure 4-30. Sometimes the fracture followed one of the cracks, leaving an indented surface intact. Thus, the indentation observed on one side of the lunar-cut tube was not abnormal.

It was considered likely that, while one astronaut was cutting the tube, the other astronaut grasped the previously cut and hence free end of the tube and bent it to facilitate its removal. Accordingly, tests were conducted to determine if a combination of cutting and bending produced any identifying features on the cut surface. It was observed that in cutting samples without bending one out of seven samples had the indentation previously described. With samples that were partially cut and then broken off by bending, six out of nine tubes exhibited the indentation on the side toward which the bend was made.

The above tube-cutting experiments led to the following conclusions:

1) If the contour of the cut end of the tube is pear-shaped, the apex of the tube is the point farthest from the fulcrum of the cutting tool.

2) If an indentation offset from the fracture is present, the probability that the tube was bent to assist the separation is higher than the probability that the tube was completely sheared through. On bent tubes, the indentation occurred on the side toward which the bend was made.

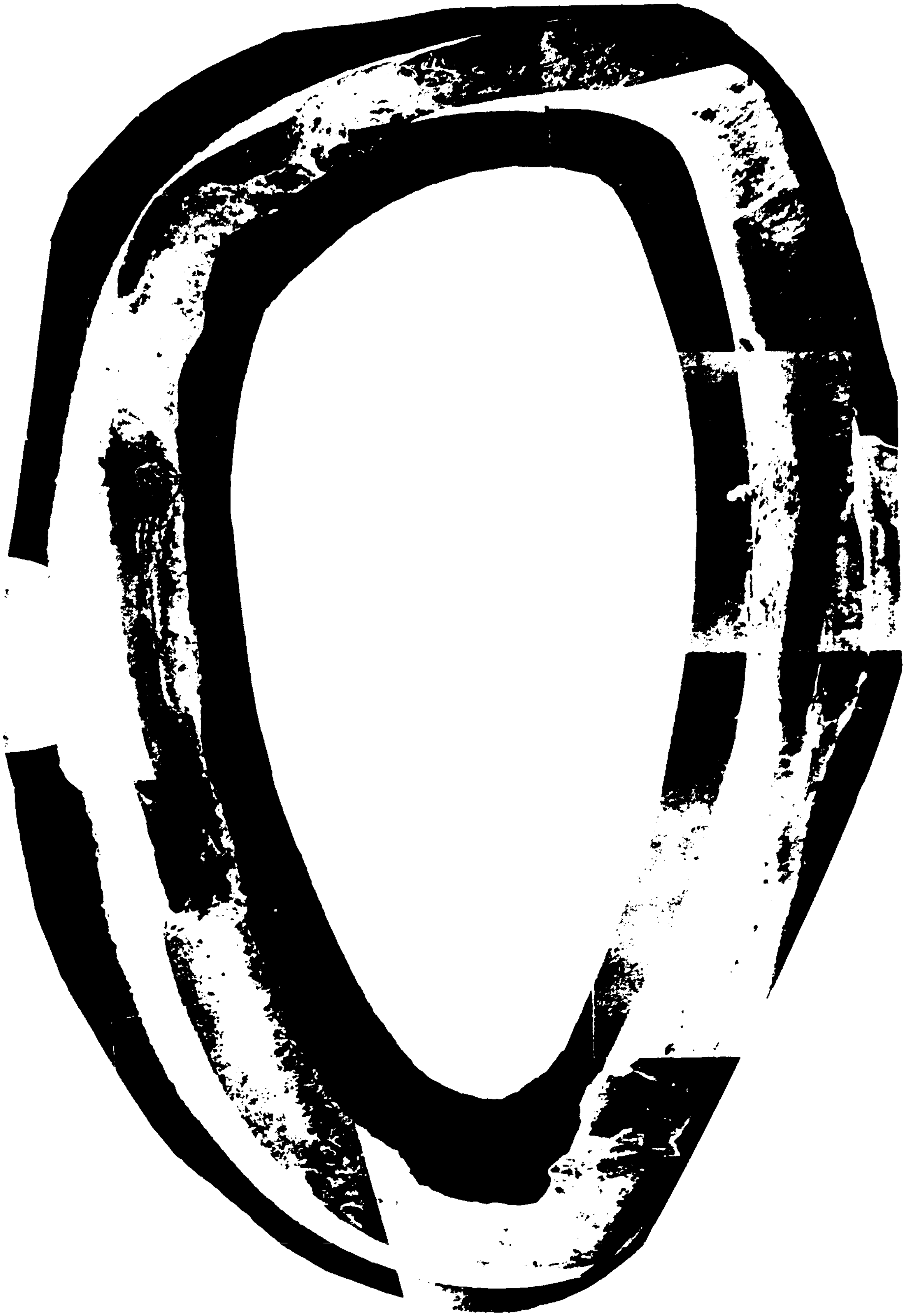
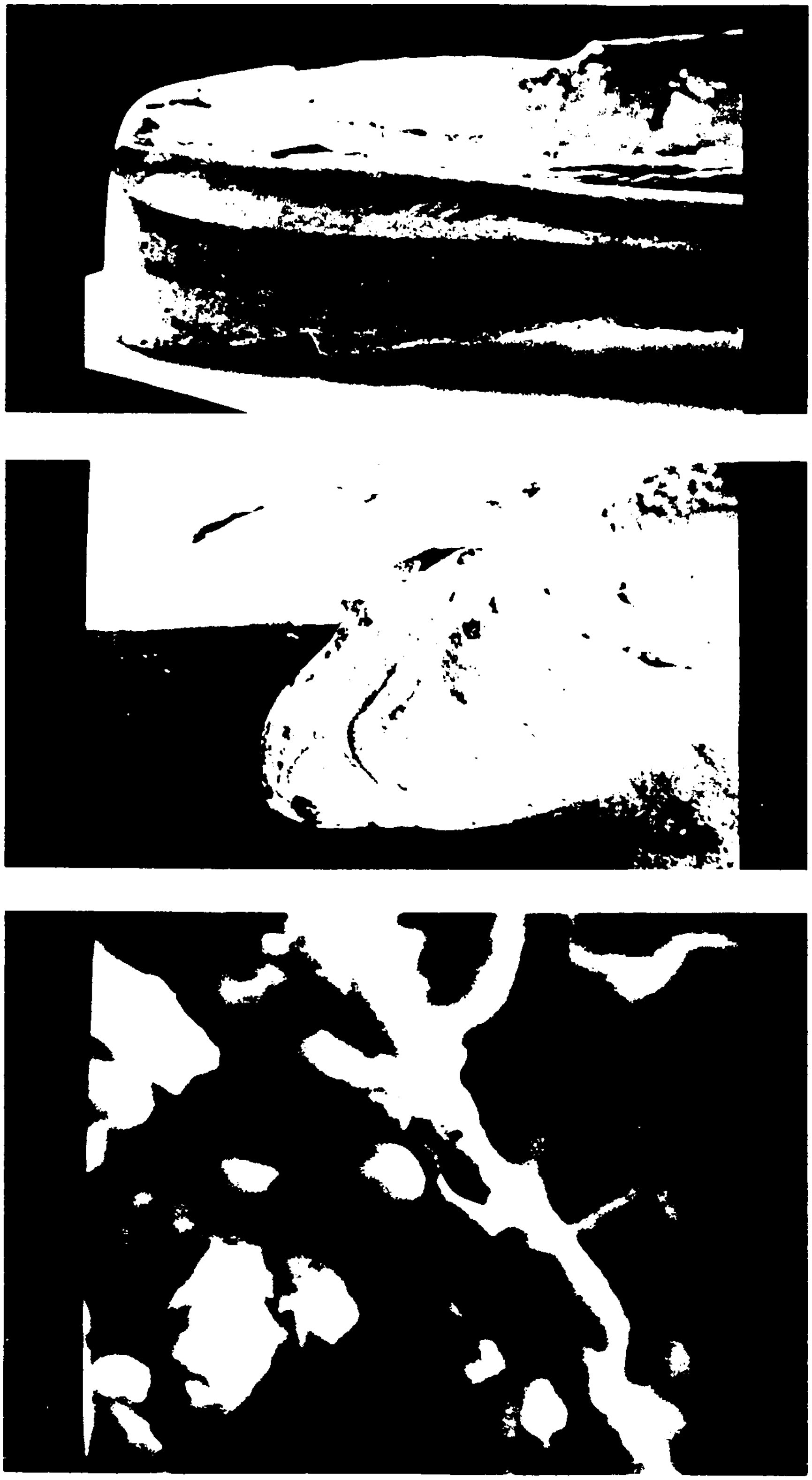


Figure 4-23. Enlarged View of Figure 4-22a (21X Magnification) (Photo 00628-71)



a) 21X Magnification
(Photo 00628-72)

b) 78X Magnification
(Photo 00628-73)

c) 16,000X Magnification
(Photo 00628-74)

Figure 4-24. Indentations on Surveyor III Polished Aluminum Tube Made by Cutting Tool

Figure 4-25. Enlarged View of Bottom Area of Figure 4-23 (525X Magnification) (Photo 00628-75)

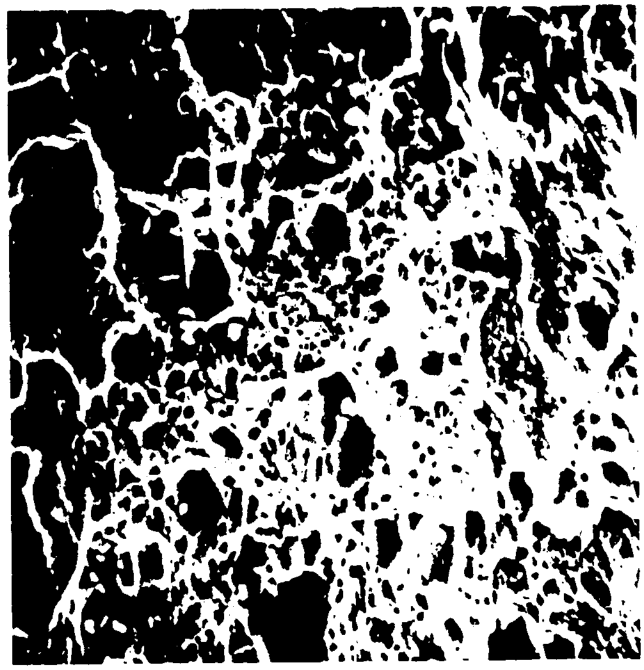


Figure 4-26. Enlarged View of Right Area of Figure 4-25 (2100X Magnification) (Photo 00628-76)

Figure 4-27. Enlarged View of Left Area of Figure 4-23, Showing Scoring Caused by Cutting Tool (1050X Magnification) (Photo 00628-77)

a) End View (7X Magnification) (Photo 00628-78)

b) Left Area of Figure 4-28a, Showing Crack (28X Magnification) (Photo 00628-79)

c) Bottom of Figure 4-28a, Showing Combined Shearing and Tearing Caused by Cutting (720X Magnification) (Photo 00628-80)

Figure 4-28. Control Sample of Polished Aluminum Tubing

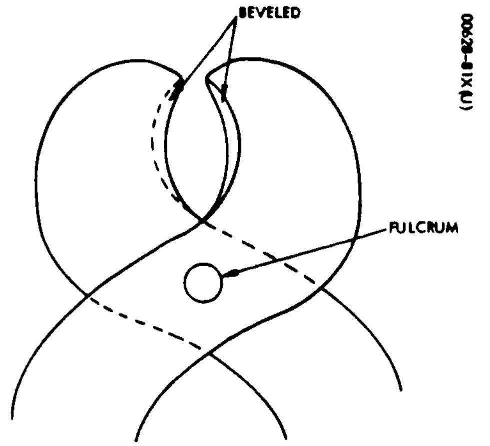


Figure 4-29. Sketch of Cutting Tool

Cable cutter HKP 8690FS for copper and aluminum; same model as used by astronauts on moon

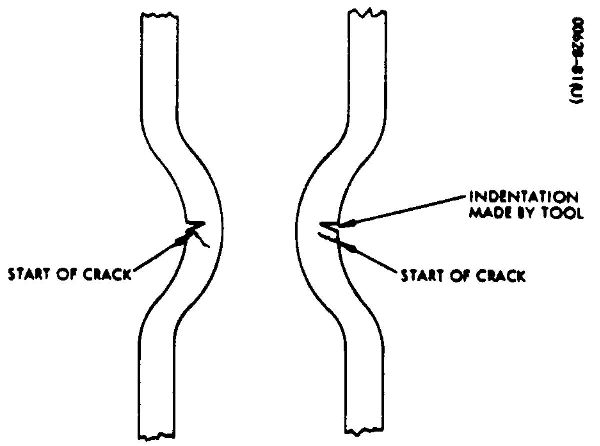


Figure 4-30. Sketch of Fracture During Tube Cutting Operation

With reference to Figure 4-23, the first conclusion strongly indicates that the top of the tube section G was nearest the fulcrum of the tool when the tube was cut on the moon. Thus, this flat region was closest to and facing toward the astronaut.

Examination of the severed end of the cut section of the Surveyor III tube, section A, revealed that this cut was made at an angle of about 70 degrees with respect to the tube axis. No continuous blade indentation could be seen on either side of this tube, nor was there any distinct pear shape to identify the position of the tube in the cutting tool at the time of the cut. Based on the above discussion, this end of the polished aluminum tube, section A, was the first to be cut on the lunar surface.

The cutting sequence of the polished tube on the moon was described in the following manner by the astronauts during their debriefing: The astronaut who performed the first cut of the right end of the tube moved to his left while facing the tube; the second astronaut at that time moved to the right. The second astronaut held the tube section and removed it as the first astronaut made the second cut.

A final description of the probable nature and sequence of the cutting operations on the moon can now be inferred. The uphill side of the polished aluminum tube which was the support strut of the Surveyor radar antenna was cut first. This strut was about 3 feet above the lunar surface. The cutters were probably held downward at an angle of about 45 degrees from the horizontal. The astronaut must have reached over to his right in order to cut this end (section A) at the 70 degree angle. It appears that the astronaut then moved to the left to cut the other end of the tube while the second astronaut moved in to hold the severed section A in his hand. The second cut, section G, shows an indentation on the side of the tube facing the astronaut. This indentation probably occurred because the second astronaut was holding the previously cut section A and bent it slightly toward him before cutting of the second section, G, was completed.

The brownish contamination on the polished aluminum tube was located on the side of the tube which corresponds to the apex of the pear shape of section G in Figure 4-23. This deposit was, therefore, on the side away from the fulcrum of the cutting tool, that is, from the astronaut, as discussed above. This places the brownish contamination on the inboard side of the tube in its original position on the moon, that is, the side facing the spacecraft.

4.7 OPTICAL PROPERTY MEASUREMENTS

Results of measurements of optical properties of aluminized teflon FEP and of the polished aluminum tube are presented in this subsection. These measurements were not originally considered to be a part of the surface discoloration and contamination studies reported in Section 11 and Appendix J. However, they could be considered to supplement the results of optical measurements conducted on various other surfaces of the retrieved Surveyor III parts and of the external surfaces of the retrieved Surveyor III television camera, presented in those sections.

TABLE 4-20. RESULTS OF REFLECTANCE AND TRANSMITTANCE MEASUREMENTS OF ALUMINIZED TEFLON FEP FROM THE SURVEYOR III TELEVISION CAMERA CABLE WRAP

Area 1 – Taken from "Contaminated" Surface
Area 7 – Taken from "Clean" Surface
Reflectance of Control Sample Measured for Comparison

Wavelength, microns	Reflectance, percent			Wavelength, microns	Reflectance, percent			Wavelength, microns	Hemispherical Transmittance, percent	
	Surveyor III Sample (Teflon Side)		Control Sample		Surveyor III Sample (Teflon Side)		Control Sample		Surveyor III Sample	
	Area 1	Area 7			Area 1	Area 7			Area 1	Area 7
0.295	26.0	52.0	70.0	0.718	56.0	60.0	83.0	0.295	9.0	10.0
0.330	30.0	55.0	73.0	0.738	56.0	60.0	82.0	0.355	9.0	8.0
0.355	32.0	56.0	79.0	0.759	56.0	60.0	82.0	0.400	10.0	8.5
0.377	33.0	57.5	81.0	0.981	56.0	60.0	82.0	0.430	11.0	5.0
0.400	36.0	57.5	82.0	0.804	57.0	60.0	82.0	0.458	11.5	3.5
0.415	38.0	58.0	83.0	0.824	58.0	61.0	82.0	0.484	12.0	7.5
0.430	41.0	58.0	83.0	0.853	58.0	61.0	82.0	0.511	13.5	7.0
0.445	42.0	59.0	83.0	0.880	58.0	61.0	82.0	0.541	14.0	7.0
0.458	44.0	59.0	83.0	0.910	58.0	62.0	85.0	0.569	14.0	6.0
0.471	45.0	61.0	83.0	0.940	59.0	63.0	86.0	0.598	15.0	6.5
0.484	46.0	61.0	83.0	0.974	60.0	63.0	87.0	0.630	16.5	5.5
0.497	47.0	61.0	83.0	1.011	62.0	64.0	88.0	0.664	16.0	7.0
0.511	49.0	61.0	83.0	1.052	64.0	64.0	89.0	0.700	16.5	6.0
0.526	51.0	61.0	83.0	1.096	64.0	66.0	90.0	0.738	17.0	7.0
0.540	51.5	60.0	83.0	1.148	64.0	66.0	91.0	0.781	19.0	7.0
0.554	51.5	60.0	83.0	1.200	64.0	68.0	92.0	0.828	15.0	7.0
0.569	52.0	60.0	83.0	1.267	64.0	68.0	92.0	0.880	14.0	7.0
0.584	52.0	61.0	83.0	1.341	66.0	68.0	92.0	0.940	16.0	7.5
0.598	52.5	60.0	83.0	1.428	62.0	68.0	92.0	0.974	14.5	8.0
0.614	53.0	60.0	83.0	1.536	62.0	68.0	92.0	1.096	15.0	8.5
0.630	55.0	60.0	83.0	1.671	62.0	68.0	92.0	1.200	16.5	8.5
0.646	56.0	60.0	83.0	1.854	62.0	68.0	93.0	1.341	15.0	8.0
0.664	56.0	60.0	83.0	2.120	63.0	68.0	93.0	1.536	15.5	10.0
0.681	56.0	60.0	83.0	2.600	69.0	69.0	97.0	1.854	15.5	9.0
0.700	56.0	60.0	83.0					2.600	17.0	8.5

The optical properties of the painted tube are reported in Section 11 and Appendix J. The data on the tube reflectance were considered to be a portion of the surface contamination study.

The optical properties of the paint used on the SM/SS scoop were not measured. The paint was heavily coated with lunar soil. To make the measurement, it would have been necessary to cut a sample from the scoop. This destructive test was not warranted since the blue paint used on the scoop was very specialized and not in general use. Also, as described in Section 11, interpretation and separation of the lunar dust effect from the paint requires supporting studies that were beyond the scope of this program. No significant data were lost by not making this measurement, and destructive testing of the scoop was thereby minimized.

4.7.1 Aluminized Teflon FEP

Several spectral reflectance measurements were made on samples of the aluminized teflon FEP used as an outer wrap on the TV camera cable. The wrap removed from the cable returned with the camera was previously described as having a thinner than normal layer of aluminum. Reflectance measurements were made on this sample, as well as on a comparison sample having a normal aluminization. In addition, spectral and total hemispherical transmittance were measured on a sample having a thin aluminization.

Reflectance and transmittance measurements were made using a Gier-Dunkle integrating sphere. Infrared reflectance measurements were made using a Gier-Dunkle heated hohlraum cavity, and normal emittance values were calculated.

In addition, a vacuum test was conducted on samples of the teflon FEP returned in the SESC.* The spectral measurements were performed in an integrating sphere of the Edwards design.**

Reflectance and Transmittance Measurements

Results of measurements of reflectance and transmittance of aluminized teflon FEP from the Surveyor III television camera cable wrap are shown in Table 4-20. Reflectance measurements were conducted on two areas on the teflon side of the aluminized teflon FEP: Area 1 was taken from the side of the wrap that faced outward from the camera cable; it was covered with a brownish contamination. Area 7 was taken from the portion of the cable wrap which faced towards the camera cable; this sample was relatively clean. For comparison, reflectance measurements on a control sample of teflon FEP are also included in Table 4-20. The last two columns of the table include results of the hemispherical transmittance measurements conducted on the two samples from the Surveyor III cable wrap.

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*SESC operations are discussed in Appendix J.4.2.

**Performed by TRW under a Hughes subcontract.

As noted in Section 3.2.2, the aluminization of this teflon FEP was quite thin and missing in some areas. With the proper thickness of aluminum coating, values of transmittance on the order of 1 percent or less would be expected. Results of transmittance measurements in Table 4-20 indicate much higher values, as high as 9 to 19 percent for area 1. This increase in transmittance is attributable to and a measure of the magnitude of reduced aluminization.

Reflectance measurements with the Gier-Dunkle integrating sphere were conducted with a sample backed with a black surface of low reflectance (less than 3 percent). The measured reflectance, shown in Table 4-20, is therefore that of the aluminized teflon; with the teflon side out, the transmitted light was eliminated by absorption in the black backing.

The reflectance of both of the Surveyor III samples is lower than that of the control sample. This lower reflectance of the Surveyor III teflon FEP is attributable to the following factors: some loss of aluminization from the transmittance data, the presence of the brownish contamination, and the effect of radiation damage. These contributory factors cannot be separated. It had originally been hoped that the surface discoloration and contamination study, discussed in Section 11 and Appendix J, would provide information that could lead to the separation of these contributory causes; but the limited scope and time of the study did not permit this.

In addition to the spectral reflectance and transmittance, infrared reflectance was measured on a sample of teflon FEP from the Surveyor III cable as well as on a control sample. Results of these measurements are presented in Table 4-21. The sample tested had been adjacent to area 1 of Table 4-20. This sample had a brownish contamination on its surface similar to that on area 1, but not as heavy.

The brownish contamination is believed to be lunar material. One qualitative electron microprobe measurement was made on a sample from the teflon wrap, but results were inconclusive. Further analysis of this brownish contamination, using electron microprobe or other suitable techniques, may be warranted.

The change in infrared reflectance, shown in Table 4-21, was due to the presence of the brownish contamination and to the reduced aluminization, as previously discussed.

Separation of these two effects was beyond the scope of the current program. Additional work is warranted on the teflon FEP. This work would entail the measurement of ultraviolet, visible, and infrared transmittance of the teflon FEP after cleaning off the brownish contamination, the aluminization, and both, in selected areas. These tests could then serve to firmly establish the degree of optical discoloration in the teflon attributable to the effects of solar radiation.

TABLE 4-21. RESULTS OF INFRARED REFLECTANCE MEASUREMENTS OF ALUMINIZED TEFLON FEP FROM SURVEYOR III TV CAMERA CABLE WRAP, TEFLON SIDE

Wavelength, microns	Reflectance, percent	
	Surveyor III Sample	Control Sample
2.5	81.0	92.0
3.1	78.0	92.0
3.55	78.0	93.0
4.0	63.0	59.0
4.4	64.0	84.0
4.82	76.0	90.0
6.26	65.0	73.0
7.12	51.5	—
7.83	3.0	2.0
8.46	7.5	11.0
9.06	10.0	13.0
9.65	38.5	35.0
10.24	11.5	11.0
10.84	40.5	38.0
11.46	34.5	34.0
12.10	21.0	22.0
12.78	13.0	13.0
13.51	7.5	2.0
14.29	7.0	5.0
15.12	6.0	3.0
16.05	8.0	5.0
17.11	8.0	5.0
18.30	8.0	5.0
19.70	11.0	10.0
21.42	21.0	20.0
23.50	50.5	56.0
26.17	54.0	60.0
Integrated normal emittance	0.71	0.70

Vacuum Measurements of SESC Sample

Two pieces of the TV cable outer teflon wrap from the SESC* were cut and transferred under low level red light illumination and in an inert atmosphere to the quartz vacuum chamber for measurement. One sample was mounted with the teflon side out and the other with the aluminized side out.

The quartz tube was attached through a tee to a Varian vac-ion pump. The assembly was then pumped down to 10^{-7} Torr by sorption and ion pumping. The samples were kept in the dark during these operations and during the following measurements.

The teflon side had an area which had been exposed to the space environment and an area which had been protected from direct irradiation by an overwrapped piece of aluminized teflon. The sample was positioned visually using dim red light. Physical measurements were made so that the positions could be reproduced during subsequent spectral reflectance measurements.

The first series of spectral reflectance measurements** was made at a pressure of approximately 10^{-6} Torr. Using a sensitive leak valve, air was bled in until the pressure was approximately 10^{-2} Torr. The measurements were then repeated. Air was then admitted to the chamber, and the measurements were repeated at 1 atm pressure. The samples were then exposed for 48 hours to the irradiation of a xenon lamp through a filter which transmitted only at wavelengths greater than 0.4 micron. The irradiance was measured at the sample position using a calibrated radiometer. The irradiance was 214 mw/cm^2.

The tested samples of the cable wrap and the test conditions corresponding to the above figures are summarized in Table 4-22. Results of these tests are presented in Figure 4-31.

4.7.2 Polished Tube

Reflectance measurements over the visible and near-infrared spectral regions were conducted on sections of the Surveyor III polished tube. The purpose of these tests was to determine the extent and orientation of the brownish contaminant noted on one side of the tube.

*See Appendix J.4.2 for discussion of the opening of the SESC.

**Performed by TRW under a Hughes subcontract.

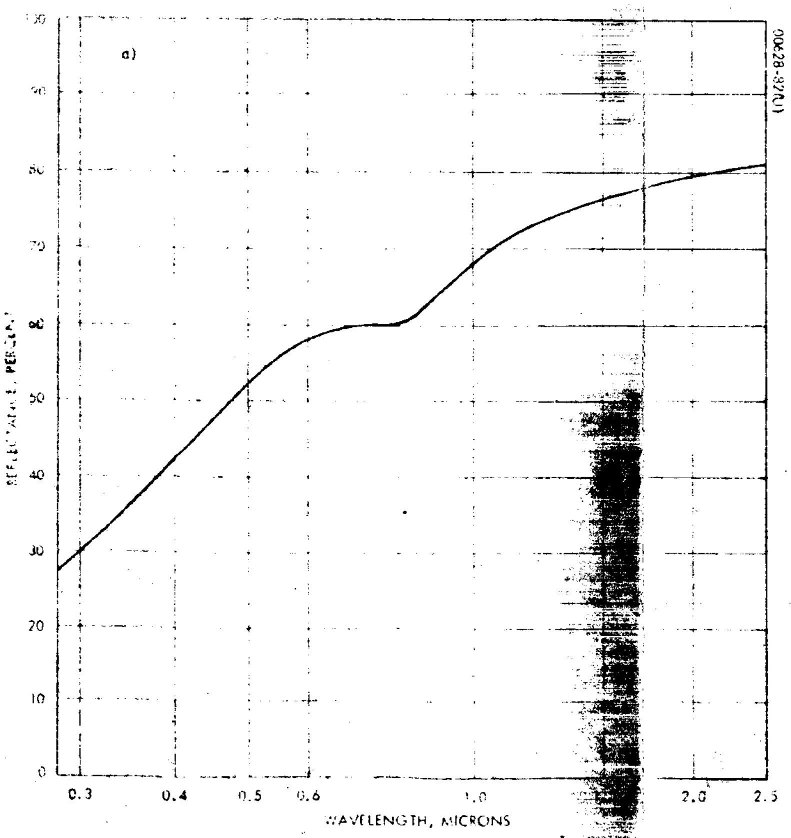
TABLE 4-22. SUMMARY OF SAMPLES AND CONDITIONS OF SPECTRAL REFLECTANCE MEASUREMENTS OF ALUMINIZED TEFLON FEP FROM SURVEYOR III CABLE WRAP

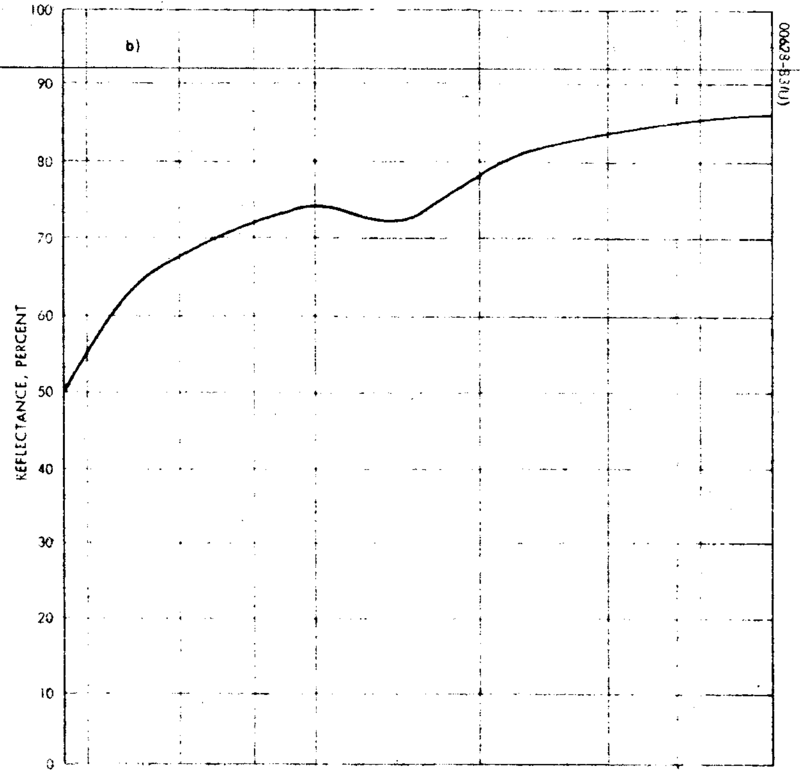
FIGURE NO. 4-31	LOCATION OF TESTED AREA*	EXPOSURE TO SOLAR RADIATION**	PRESSURE DURING REFLECTANCE MEASUREMENTS	DURATION OF ULTRAVIOLET EXPOSURE
a)	E	T	4×10^{-4} Torr	NONE
b)	P	T	4×10^{-4} Torr	NONE
c)	P	A	4×10^{-4} Torr	NONE
d)	E	T	3×10^{-1} Torr	NONE
e)	P	T	3×10^{-1} Torr	NONE
f)	P	A	3×10^{-1} Torr	NONE
g)	E	T	1 ATM	NONE
h)	P	T	1 ATM	NONE
i)	P	A	1 ATM	NONE
j)	E	T	1 ATM***	NONE
k)	E	T	1 ATM	48 hr
l)	P	T	1 ATM	48 hr
m)	P	A	1 ATM	48 hr

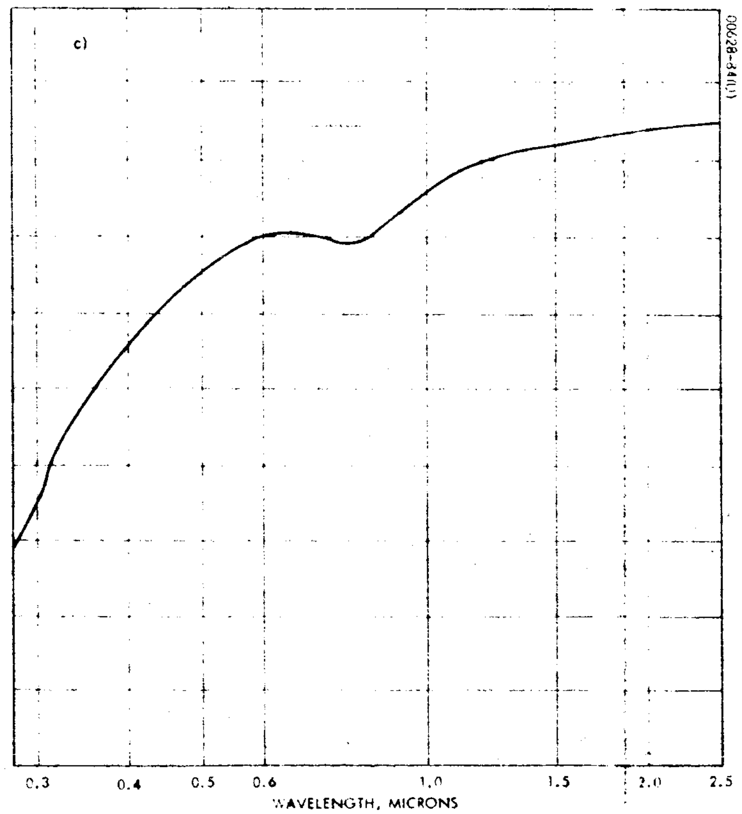
*E - AREA EXPOSED TO SOLAR RADIATION ON THE MOON
P - PROTECTED AREA

**T - TEFLON SIDE
A - ALUMINIZED SIDE

***AFTER [illegible] DAYS







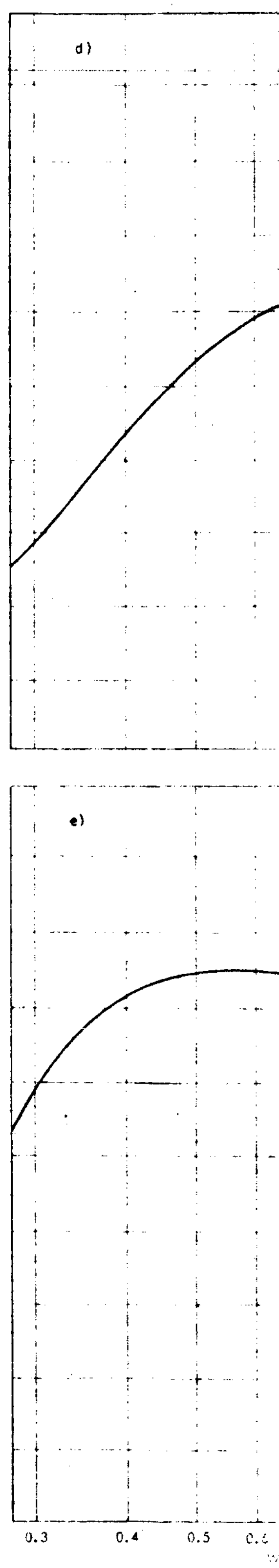
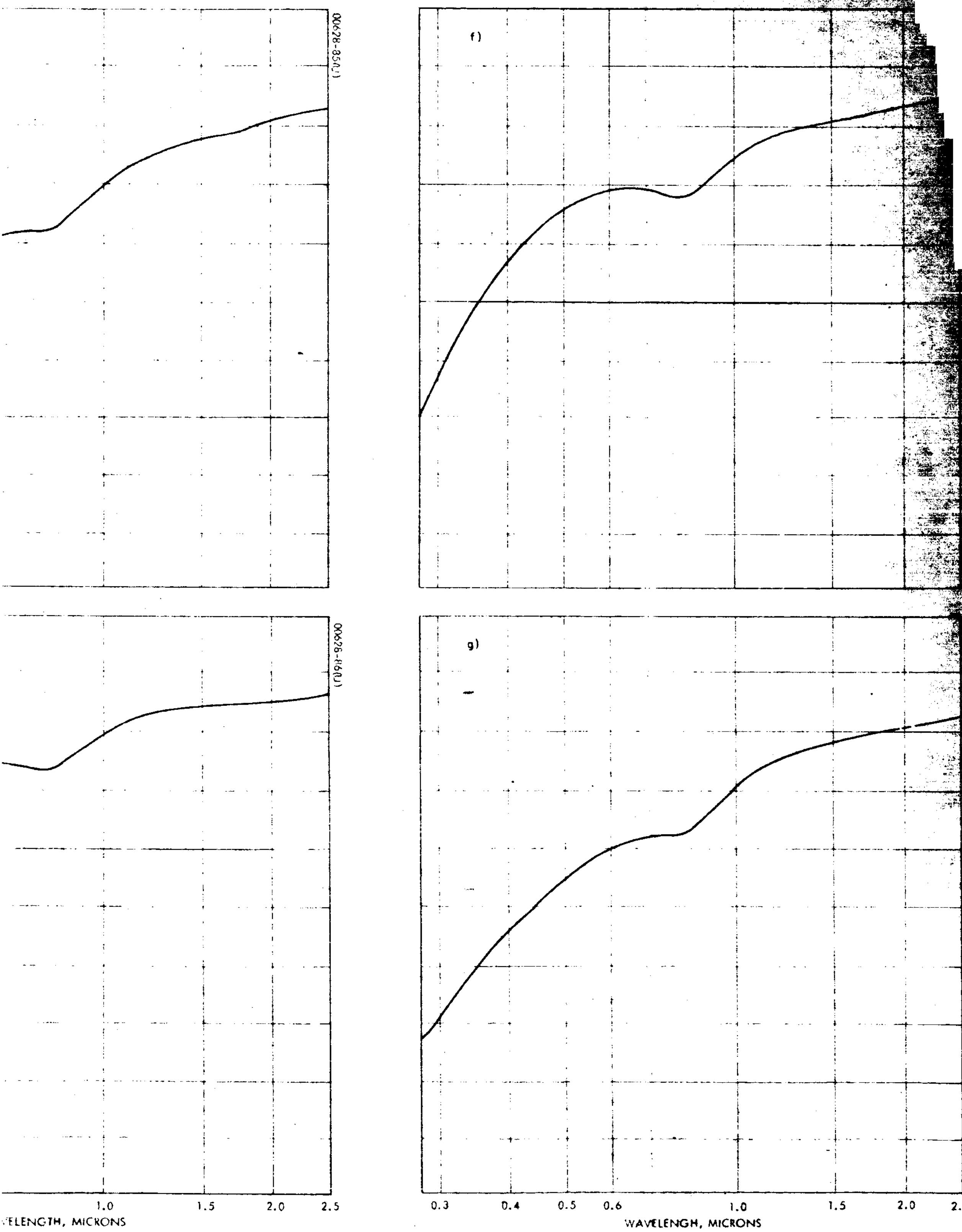
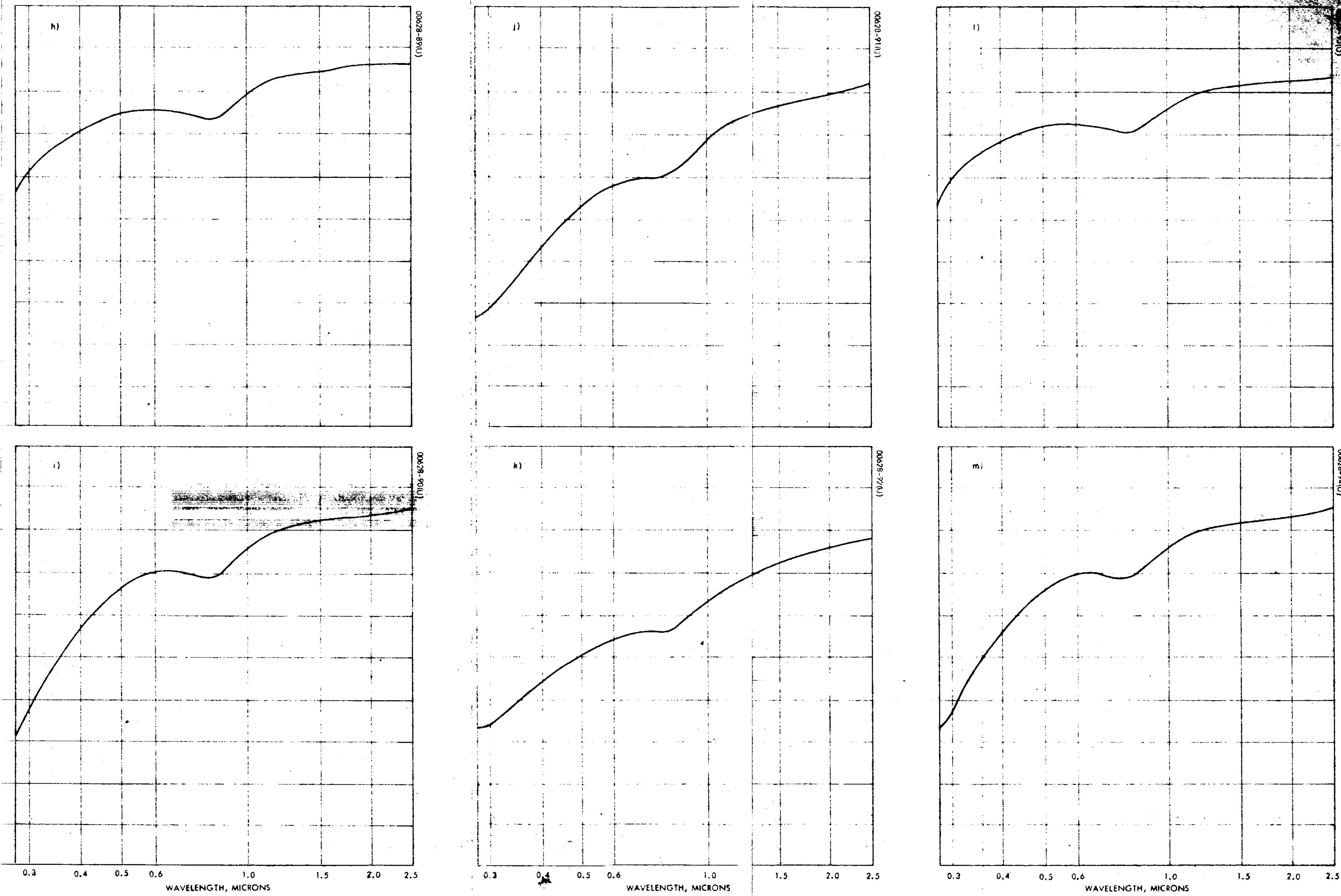


Figure 4-31. Spectral Reflectance Measurements of Aluminized Teflon FEP From Surveyor III Cable Wrap

FOLD-OUT #1


00628-85(U)
f)
00628-86(U)
g)
1.0
1.5
2.0
2.5
0.3
0.4
0.5
0.6
1.0
1.5
2.0
2.5
WAVELENGH, MICRONS

FOLD-OUT #2


h)
00628-89(U)
j)
00628-91(U)
l)
i)
00628-90(U)
k)
00628-92(U)
m)
00628-94(U)
0.3 0.4 0.5 0.6 1.0 1.5 2.0 2.5
WAVELENGTH, MICRONS
0.3 0.4 0.5 0.6 1.0 1.5 2.0 2.5
WAVELENGTH, MICRONS
0.3 0.4 0.5 0.6 1.0 1.5 2.0 2.5
WAVELENGTH, MICRONS

FOLD-OUT #3

The tube was cut into several sections, as described in Appendix A. Reflectance measurements were obtained on sections A and G, which had been made available to Hughes. The contamination on the tube was on only one side of the tube and heavier on section G than on section A. As concluded in Section 4.6, the contaminated side of this tube pointed inboard toward the spacecraft and down about 45 degrees from the horizontal. Section G came from the end of the tube closest to the spacecraft radar antenna.

The extent of contamination along the length of each tube section was determined by measuring the reflectance along the contaminated side. These measurements were made by placing each tube section vertically in a Gier-Dunkle integrating sphere. Separate reflectance measurements were made every 1/4 inch along the tube at a single wavelength of 0.47 micron. The reflectance at the circumferential position of heaviest contamination of section G was found to be about 11 to 13 percent. Along section A, the reflectance was measured to be about 38 percent. No axial gradient was found on either section of tube.

The reflectance of each tube section was then measured around the circumference. The measurement was made at the center of each tube (between the two ends) at a constant wavelength of 0.47 micron. Reflectance measurements were made every 8 degrees. The measurements obtained are shown in Figure 4-32a and b for sections A and G, respectively. Locations of all measurements were designated with reference to the scribe line, noted on these figures. This scribe line was made at the LRL prior to sectioning to serve as a reference. This is described in further detail in Appendix A.

The spectral reflectance measurements were then made as a function of wavelength over a range from 0.3 to 2.6 microns. These measurements were made at the center of each tube section (between the two ends). Two measurements were conducted: one along the scribe line and one 180 degrees from the scribe line at the spot of heaviest contamination.

Results of these measurements are shown in Table 4-23. The reflectance of the uncontaminated side was less than expected for polished aluminum. Further tests are planned* to determine whether any lunar contamination is present on this side of the polished aluminum tube which would account for this reduction in reflectance.

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*Tests now in progress at JPL.

TABLE 4-23. PERCENT REFLECTANCE AS FUNCTION OF WAVELENGTH FOR BOTH CONTAMINATED AND UNCONTAMINATED SIDES OF POLISHED TUBE SECTIONS

Wavelength, microns	Percent Reflectance			
	Contaminated Side		Uncontaminated Side	
	Section A	Section G	Section A	Section G
0.295	25.0	7.0	35.0	33.0
0.355	26.0	8.0	44.0	41.0
0.400	34.5	10.5	51.0	52.0
0.430	35.0	10.0	55.0	59.0
0.450	37.5	12.0	58.0	60.5
0.484	37.5	12.0	60.0	62.0
0.511	37.5	14.0	60.0	65.0
0.540	38.5	15.0	60.0	66.0
0.569	40.0	16.0	61.0	66.0
0.598	41.5	16.0	62.0	68.0
0.630	41.5	17.5	62.0	67.5
0.664	42.0	17.5	63.0	68.5
0.700	42.0	19.5	62.5	68.0
0.738	43.0	20.0	63.0	68.0
0.781	44.0	21.5	64.0	68.0
0.828	46.0	23.0	64.0	70.0
0.880	47.0	25.0	66.0	73.5
0.940	47.5	26.5	70.0	74.5
1.011	52.0	32.0	74.5	78.5
1.096	55.0	33.0	75.5	82.0
1.200	57.0	38.0	77.5	83.5
1.341	62.0	42.0	83.0	85.0
1.536	63.0	46.0	86.0	86.5
1.854	71.0	54.5	88.0	88.0
2.600	80.0	60.0	90.0	90.0

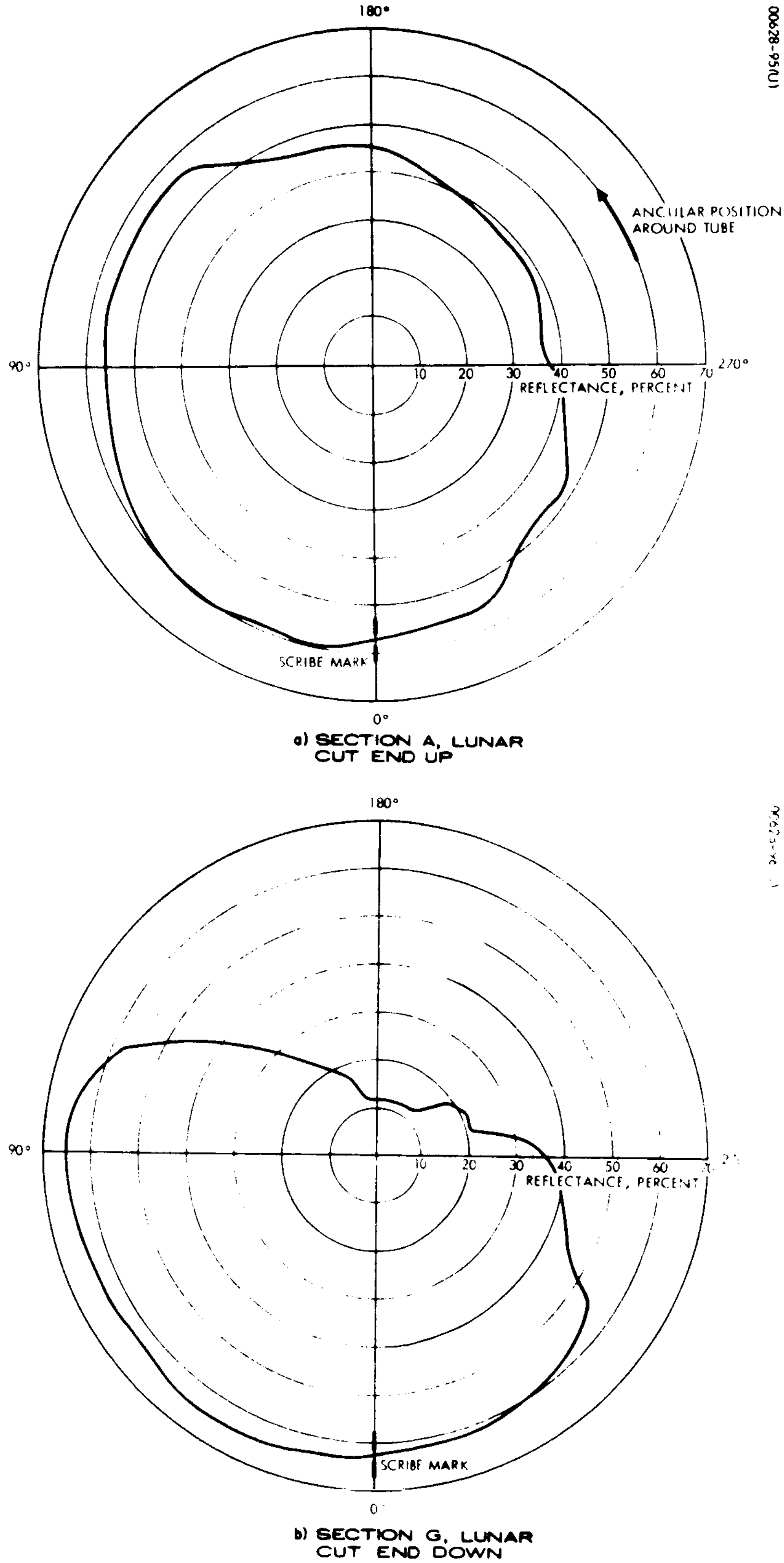

Figure 4-32. Percent Reflectance of Surveyor III Polished Tube Around Its Circumference

TABLE 4-24. ELECTRON MICROPROBE ANALYSIS OF CONTAMINATION ON SECTION G OF SURVEYOR III POLISHED TUBE (COMPARISON WITH LUNAR MATERIAL)

Element	Electron Microprobe Counts per 10 Second Interval		Percent Composition*		
	Contaminated Side	Clean Side	Apollo XII Fines	Apollo XI Fines	Al 2024
C	259	0			
O	1, 645	6, 548			
Na	8	0	0. 30	0. 33	
Mg	918	695	7. 2	4. 6	1. 2 - 1. 8
Al	32, 260	85, 904	7. 4	7. 3	Balance
Si	569	335	19. 6	20. 2	0. 5 max.
P	17	0		0. 14	
S	30	6			
Cl	0	91			
K	87	59	0. 15	0. 11	
Ca	2, 145	0	7. 1	9. 6	
Sc	0	0			
Ti	516	0	1. 9	4. 1	
V	0	0			
Cr	0	0	0. 28	0. 20	0. 1 max.
Mn	0	93	0. 19	0. 16	0. 3 - 0. 9
Fe	594	8	13. 2	12. 5	0. 5 max.
Co	0	0			
Ni	0	0			
Cu	Not tested	Not tested			3. 8 - 4. 9
Zn	Not tested	Not tested			0. 25 max.

*Extracted from References 8 and 9; not all elements present are included in the table.

4.8 ANALYSIS OF CONTAMINATION OF POLISHED TUBE

An analysis of the nature and source of the contamination of the retrieved Surveyor III polished aluminum tube was conducted and is summarized in this subsection. This analysis supplements the surface contamination and discoloration studies of the other retrieved Surveyor III parts conducted jointly on this and the companion Surveyor III TV camera test program (Reference 1). As mentioned previously, results of these joint studies are contained in Section 11 and Appendix J.

Study of the contamination of the polished tube is reported here separately because it is somewhat more unique to the material presented in this study. Results presented in this subsection should be viewed in light of the analysis of the orientation of the polished aluminum tube on the Surveyor III spacecraft (discussed in Section 4.6).

Two methods were used in an attempt to analyze the brownish contamination on the polished tube sections. First, the infrared reflectance of the the contaminant on the tube was measured. Second, an electron microprobe analysis of the contaminant was conducted.

In order to obtain the infrared spectrum of the contaminant without removing it from the tube, section G of the polished tube was placed at the crystal position of an attenuated total reflectance (ATR) holder. The mirrors of the holder were adjusted so that as much of the reflected light from the tube as possible was directed toward the entrance slits of the spectrophotometer. A spectral trace was then made. A normalizing trace was obtained by placing a clean polished aluminum tube at the same position.

Data from the two spectra were compared; a plot of the resultant data for the contaminant is given in Figure 4-33. No evidence of organic bands is seen in the figure. It should be noted that the experimental techniques used may have reduced the sensitivity to the presence of organics. While no definite conclusions can be drawn regarding presence of some organics, results strongly suggest that the heavy contamination was not dominantly organic in nature, such as resulting from significant outgassing of organic materials on the spacecraft.

A small amount of dust that had previously fallen from the SM/SS scoop was placed on aluminum foil, and its infrared spectrum was obtained using the ATR. This spectrum is shown in Figure 4-34. Comparison of the two spectra of Figures 4-33 and 4-34 indicates that the contaminant is probably lunar material.

An electron microprobe examination was conducted on a small amount of the brownish contaminant on the lunar-cut end of section G. This end had previously been removed from section G for metallurgical study and had been examined in an SEM. In addition, an uncontaminated area of Section G was examined. The results are presented in Table 4-24.

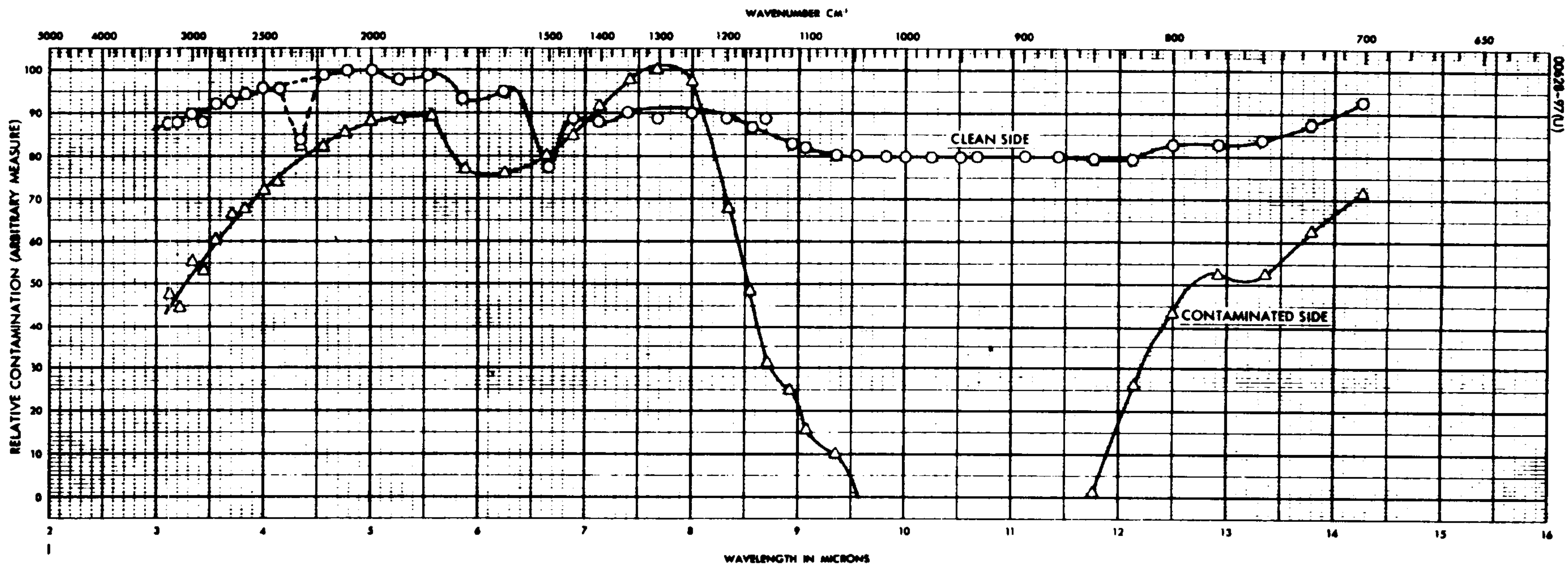

Figure 4-33. Infrared Reflectance Spectra of Contaminated and Clean Sides of Section G of Polished Aluminum Tube

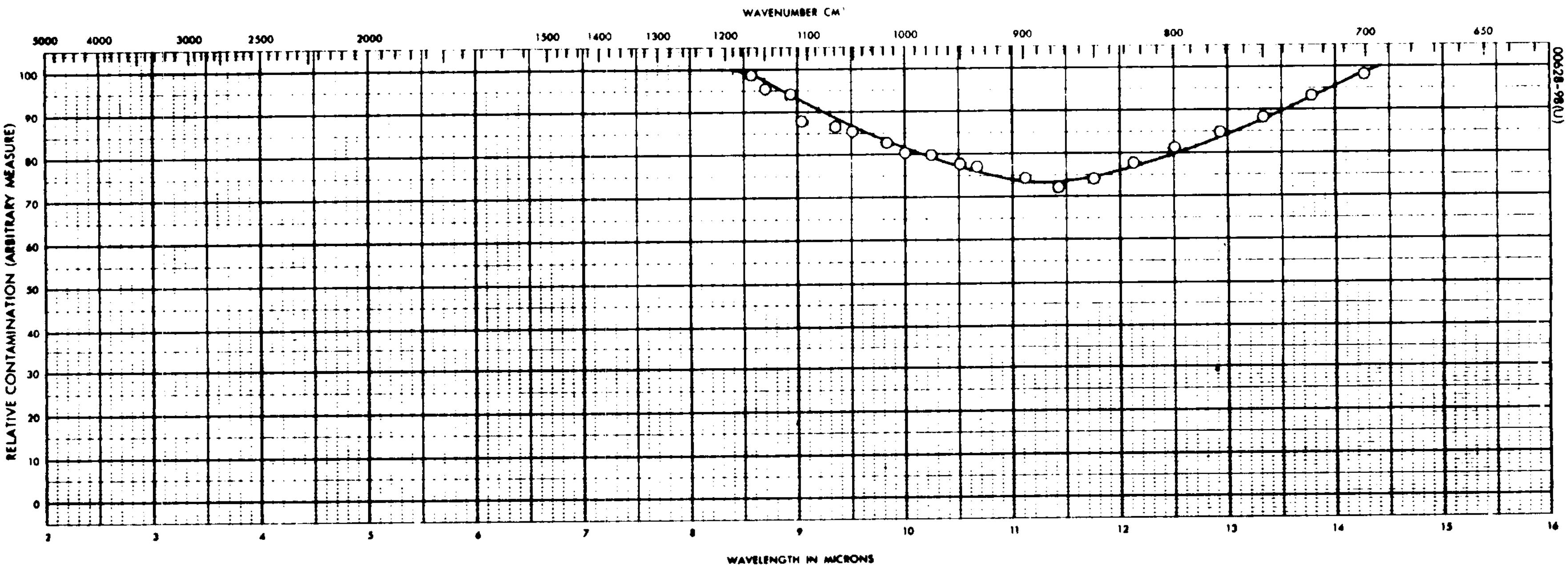

Figure 4-34. Infrared Reflectance Spectrum of Lunar Dirt From SM/SS Scoop

The high count for aluminum indicated in Table 4-24 is due to the base material. The other high readings – titanium, magnesium, iron, calcium, and silicon – are characteristic of the lunar material. The above results were compared with the analysis of lunar material returned by Apollo XII (Reference 9) and Apollo XI (Reference 10). Results of this analysis indicate that the brownish contamination on the polished aluminum tube was lunar in origin.

11. SURFACE DISCOLORATION AND CONTAMINATION STUDIES

11.1 INTRODUCTION

Results of surface discoloration and contamination studies, designated as DOR studies,* are presented in this section and supporting data in Appendix J. These studies were conducted as a joint effort** on the two Hughes contracts on the returned Surveyor III parts: the TV camera (JPL contract) and other parts (NASA-MSC contract).

The studies were undertaken as a result of the initial observation that significant discoloration occurred on the external painted and polished surfaces of the television camera and on the polished aluminum tube from the spacecraft structure. The sealed container in which the painted tube section was returned was not opened until later.

Initial observations indicated both the extensive and complex nature of the discoloration and the difficulty in understanding its nature and separating the contributory causes. During the visual examination of the television camera at the LRL in January 1970, it became apparent that the discoloration of the painted surfaces was greater than had been anticipated. Expected patterns of radiation damage were not present. In addition, unique surface shadow patterns were noticed.*** It was obvious that measurement of spectral reflectance of the inorganic white paint would not sufficiently describe what had occurred to these surfaces during their lunar exposure.

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*The letters D O R denote the suspected major contributions to surface effects — lunar dust, contamination by organic materials, radiation effects — after effects of micrometeroid impacts were found to be of relatively small significance.

**This section and its corresponding appendix are labeled 11 and J, respectively, in the sequential context of the TV camera contract Final Report. These two parts of the report and a separate references page are incorporated verbatim for ease of publication into the Final Reports on both contracts.

***These patterns were not those that would be expected from radiation darkening of the paint, as determined by the geometry associated with the incident sunlight.

Preliminary analysis indicated that discoloration of the surfaces was caused by some combination of the following three factors:

1) Dust from the lunar surface — from Surveyor III or lunar module landing, or both

2) Organic contamination — outgassed from Surveyor III or deposited from prelaunch environments; also contamination from rocket exhaust

3) Solar radiation affecting the paints and/or the organic or other contaminants present

A special task was established to study this problem by analysis, supporting tests, and coordination with pertinent efforts conducted as part of the parallel science studies. The study was motivated by the desire to understand the nature and cause of this discoloration in order to assess the effects of lunar exposure for possible applications to future designs.

Contamination of surfaces is important to optical systems. Transport of lunar fines and their associated effects on thermal control surfaces are significant for future lunar operations. Analysis of the discoloration and contamination effects could also help obtain reasonable estimates of the thermal history of the camera, which would be of importance to biology and engineering investigations and other science studies.

An initial plan of attack was developed but had to be abandoned later on. This plan was based on physical removal of successive layers of dust and other contaminants from the surfaces by a variety of postulated techniques. It was thought that this sequence would permit the identification and separate examination of the contributions of the various sources of discoloration. Preliminary tests conducted revealed that the surface structure of the paint and its porosity would preclude such removal techniques.

The plan finally pursued (discussed in Section 11.3) was based on an alternate approach which proved reasonably successful. This plan entailed careful selection of a variety of samples and selective measurements supported by analytical studies of the total properties of these surfaces. The separation of the contributory factors would thus be accomplished by analysis and by interpretation of the test data obtained by the various techniques employed, using to the maximum possible advantage the knowledge of the relative locations of the selected samples at which the contributory effects were present in significantly different amounts.

The test and analysis program included spectral reflectance studies at Hughes, supported by measurements at TRW, Inc. under a Hughes subcontract; analytical studies at JPL; and use of supporting data obtained from parallel science investigations coordinated by JPL. Results of these contributory inputs were then assessed by Hughes and JPL, leading to the preliminary results reported here. It should be emphasized that the study is by no means complete. While significant progress has been made and an initial general understanding of the nature and causes of discoloration achieved with a reasonable assurance of validity, much additional work may be warranted. In particular, further inputs from the yet incomplete preliminary science investigations may be of specific import.

Results of the study reported here include numerous reflectance measurements of the surfaces conducted by Hughes. Associated with these reflectance measurements were studies of optical and thermal bleachings associated with the radiation damage. A methodical analysis of the reflectance data, conducted by JPL, is also summarized. Results of this study were used in conjunction with the reflectance measurements to separate the relative effects of lunar dust and radiation.

Inputs from the parallel science investigations, approved by NASA and coordinated by JPL, are also included. The ion microprobe studies conducted at the GCA Corporation* were helpful in indicating the amounts of lunar material on the painted and other surfaces, the depth of lunar material penetration, and the presence of other materials. Measurements of the quantity of trapped solar wind gas, conducted at the State University of New York (SUNY),** were also used to advantage in indicating relative amounts of lunar materials on the various surfaces***. Results of these parallel science studies at GCA and SUNY are only briefly discussed here; details of their investigations are expected to be published separately at a later date.

11.2 DATA AVAILABLE FROM PRELAUNCH, LANDING, AND POST-RECOVERY EXAMINATION

A summary assessment of the data available prior to the finalization of the DOR study and test plan is presented in this section. Subsequent discussion of the plan itself and of the test results obtained is to a large extent based on this information. Available data included prelaunch operations and their effects, effects and observations during the lunar recovery operations and during the return of the parts to earth, and results of visual examination of the returned parts.

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*By Dr. F.G. Satkiewicz.

**By Professor O. Schaeffer.

***This approach was originally suggested by F. Fanali of JPL.

11.2.1 Prelaunch Effects

The exterior surfaces of the Surveyor III camera were, for the most part, coated with white inorganic paint used as the primary temperature control coating. The inorganic white paint was used on the exterior surfaces of the lower shroud, upper shroud, and mirror housing.

The paint consisted of a calcined china clay pigment, primarily an aluminum silicate, in a potassium silicate binder. The coating was applied to a thickness of 6 to 8 mils on a 6061-T4 aluminum alloy substrate. The paint was characterized by a low initial solar absorptance and a high initial emittance.

Prior to launch, the Surveyor III camera was exposed to many possible sources of contamination, including those incurred in manufacturing and during thermal-vacuum testing. A rework of the thermal control surfaces was conducted on all Surveyors, including Surveyor III, just prior to launch in order to remove all visible contamination. Areas where the paint was missing were touched up with an organic coating. Other areas of discoloration were sanded down. Further details of prelaunch operations on the painted surfaces are presented in Appendix J-I.

Two subsequent observations which have a definite relationship to the above prelaunch operations should be noted. The areas touched up with organic paint were observed on the returned camera to have discolored less than the adjacent areas covered with inorganic white paint. The scope of the study did not permit an exhaustive analysis of this effect, and further work may be warranted. However, it is postulated that the likely explanation of this apparent anomaly is that lunar dust does not adhere to organic paints as well as it does to inorganic paints.

The second observation during the visual examination of the camera also related to the prelaunch touching up operations. Areas of inorganic white paint which had been sanded down appeared to have discolored less than the unsanded areas. Similarly, the scope of the program did not allow a more extensive pursuit of this phenomenon, and further work may be warranted.*

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*One of the suggested follow-on tests in the Final Report of the Surveyor III camera tests, Section 1.6.3. One postulated mechanism is that the inorganic white paint was originally contaminated with some organic materials which were removed by the sanding operation; hence, the contribution total discoloration attributable to radiation would be less for the sanded areas. This, however, conflicts with the fact that no significant traces of organics were found on the discolored inorganic white surfaces in the course of the study, as discussed later.

It is believed that no contamination of the external surfaces occurred during the prelaunch and transit phases. The spacecraft was covered with a protective shroud at launch. This shroud was ejected 203 seconds after launch.

11.2.2 Lunar and Recovery Operations

Surveyor III landed in a cloud of dust. The landing was abnormal: the Surveyor bounced three times along the slope of the crater. Details of the orientation of the spacecraft and of the camera are presented in Appendix J.1. The dust generated during the landing affected the condition of the surfaces of the Surveyor III camera. One evidence of this effect was the considerable veiling glare noted in the television pictures obtained by the spacecraft during its lunar day operations.

No major events are known to have occurred in the adjacent areas during the 2-1/2 years of residence of Surveyor III on the lunar surface until the arrival of the Apollo XII lunar module.*

The lunar module approached the Surveyor III spacecraft from the east, passed to the north of it, and landed 535 feet away. Details of the landing operations and of the landing configuration are presented in Appendix J.1. Again, the important observation is that a significant amount of dust appears to have been deposited on the Surveyor III spacecraft as a result of this landing.

During the second extravehicular activity period, the astronauts of Apollo XII arrived at the Surveyor III site and removed the various recovered items. A piece of a painted tube and several cable sections cut from the spacecraft were placed in a special container called the sample environmental sealed container (SESC), which was tightly sealed and returned in vacuum and darkness. All of the remaining parts, which were cut free of the spacecraft, including the television camera, a section of polished aluminum tubing, and the soil mechanics/surface sampler (SM/SS) scoop, were placed in separate pockets of the backpack.

In photographing the spacecraft in the course of the above operations, the astronauts reported it had an extensive brown appearance. This report was repeated during the postflight debriefing when the astronauts described the Surveyor III spacecraft as "looking like it had been driven down a dusty road, rained upon, and finally left in the sun to bake".

Upon return to the lunar module, the astronauts stored the backpack under a shelf. All parts were later transferred to the command module and

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*See Appendix J.1.2. Also effects of landing of nearby meteroids, while purely speculative, cannot be totally discounted.

strapped into position. Thus complete immobilization was not achieved. For example, it is believed that the two dents in the sun visor of the camera seen in the frontispiece* were probably incurred at the time of the hard landing of the command module in the Pacific Ocean.

The parts were exposed to the oxygen environment of the command module during the return to earth at a pressure of about 3 to 4 psi. The backpack containing the parts was transferred to the NASA Houston Lunar Receiving Laboratory (LRL) with the astronauts. Early in the quarantine period, the parts were taken out of the backpack. They were first photographed and then double-bagged in heat-sealed polyethylene until their release from quarantine on 7 January 1970.

11.2.3 Visual Observation

Visual observation of the returned parts was conducted at the LRL in early January by Hughes, JPL, and NASA personnel. More detailed results of the visual observation conducted, insofar as it applies to the surface discoloration studies, are presented in Appendix J.2. A more comprehensive discussion of the visual examination of the television camera is presented in Section 3.4.** The highlights of this examination are summarized below.

Both extensive and non-uniform discoloration of the camera were noted, including unique shadow patterns mentioned earlier. These surface shadow patterns provided the basic background used to develop the surface discoloration and contamination study test plan.

Discoloration was observed on all surfaces of the television camera, with colors ranging from gray to light tan. It was generally darker than expected. Shadow patterns were discovered on the painted surface on the side of the camera facing the lunar northwest. These areas were associated with surface protrusions, such as screw heads, and overlying parts, such as wires, cables, and struts. The television camera mirror was hazy.

The shadow patterns appeared to be related uniquely to the location of the lunar module relative to the Surveyor III camera. It was assumed as a result of the visual examination that the landing of the lunar module caused a severe shower of lunar dust which "sandblasted" the unshielded Surveyor III surfaces, eroding away previously darkened surfaces.

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*Frontispiece of the JPL contract (Television Camera Test Program) Final Report; not included in the NASA-MSC contract Final Report.

**Not included in the NASA-MSC contract Final Report.

It should be noted that discoloration by solar radiation had been expected for the white painted surfaces. Return of the camera in the air environment was not expected to cause bleaching. It was conjectured that exposure to light would eventually cause bleaching. It was originally recommended by Hughes and JPL that all parts, including the television camera, be returned in light-tight vacuum containers. This, however, was not possible for reasons of weight, space, and schedule.

11.3 EVOLUTION OF TEST PLAN

As noted earlier, the surface discoloration study plan underwent several cycles of changes. The process of arriving at the test plan was guided largely by the understanding of the mechanisms of damage, as it evolved, and by the applicability of the various test techniques considered. As these mechanisms became more evident, appropriate changes in the plan were instituted. The final test plan thus reflects the eventually postulated mechanisms of damage.

This section briefly summarizes the evolution of the final test plan, leading to a summary outline of the test program conducted, described in the succeeding section. It is considered appropriate and useful to the understanding of the final plan to review the factors that were involved in its development.

A preliminary model of surface damage was postulated before the recovery of the Surveyor III parts as part of the original planning operations, discussed in Reference 101.* This earlier model considered meteroid damage as possibly significant and relegated lunar dust to a second-order effect. However, visual examination of the returned camera indicated that meteoroids were not significant; only one primary meteroid impact on the entire camera surface was reported by NASA (Reference 102). The lunar dust was found to be a significant factor, as noted in the previous discussion of visual observations.

Based on the above, the following preliminary damage model was then proposed: Some organic contamination had been deposited on the spacecraft prior to launch. This contamination was not removed during the cleanup operations on the thermal finish. During the landing on the moon, some solid matter from rocket exhaust was deposited on the various surfaces. The gaseous products from the vernier descent engines, which had a high vapor pressure, are not believed to have been deposited. During the landing of Surveyor III, some small amount of dust was deposited on the spacecraft. In the course of the succeeding 2-1/2 years prior to the landing of Apollo XII, ultraviolet radiation and low energy protons (1 kev) degraded

*References for Section 11 and Appendix J are common to both reports and listed apart from other references at the end of the volume.

the optical properties of the surfaces. The extent of this degradation depended on the amount of exposure of each surface to sunlight, as noted in the discussion in Appendix J. 1. 2. In addition, organic materials were deposited on the various painted surfaces of the spacecraft as a result of outgassing from nearby parts of the spacecraft. These, too, were degraded by radiation. The landing of the Apollo XII lunar module was a major event, resulting in the showering of the Surveyor III with dust particles. Resultant shadow patterns are uniquely related to the relative location and orientation of the lunar module on the lunar surface. It was believed that the majority of the dust present on the surfaces of Surveyor III was deposited at the time of the landing of the Apollo XII lunar module.

The initial test plan was based on the preliminary damage model just described. This plan entailed the sequential removal of the various deposited materials (organics and dust) by means of several proposed techniques. It had been hoped that this would separate out each constituent of the damage. With proper selection of surface samples, a reasonably quantitative model could thus be constructed.

The various techniques proposed for the removal of the dust were tapes, collodion casts, and nonaqueous liquid wash. Solvent soak was proposed for the removal of organics and dust. Upon removal of the organics and dust, it was hoped that only the effects of radiation damage to the paint would remain. This procedure was to be supplemented with several analytical techniques used prior to, in the course of, and after the removal of the various deposited contaminants. These techniques included scanning electron microscope (SEM) studies, various elemental probes, mass spectral analysis. The plan was not successful because it was impossible to separate the various contaminant levels. For example, collodion casts removed not only the large particles of lunar debris but the paint as well. Very fine lunar dust particles caught in the cracks and pores of the rough surfaces of the inorganic paint could be removed. As another example, SEM studies of the samples cut from the painted surfaces proved futile. Lunar material could not be separated against dielectric paint background, except in the case of unique spherelike particles.

The final test plan developed and pursued entailed a direct analysis of carefully selected samples, with only localized disturbances of surface conditions. Selective separation of contributory factors was accomplished by use of different techniques selected to emphasize the presence of particular sources of contamination, by selection of different samples exposed to predominantly different sources of contamination, and by supporting analytical techniques which were of assistance in correlating and separating the contributory effects.

In summary, the test and analysis plan, finally embarked upon, included the following parts:

1) Careful selection of samples from various surfaces of the television camera:

   a) Separate lunar module dust effects from Surveyor dust effects

   b) Separate areas of high incident solar radiation from areas of no solar radiation

   c) Separate areas of possible high organic contamination from no organic contamination

2) Measurements of spectral reflectance of the various surfaces as a primary test technique

3) Use of supplementary measurements* to attempt to isolate and define the extent of specific contributory factors:

   a) Ion microprobe studies for analysis of contaminants

   b) Measurement of trapped helium to determine the amount of lunar material present

   c) Measurements to determine the amount of organic materials present

4) Analysis:

   a) Direct analysis of the above experimental data

   b) Mathematical analysis, furnished by JPL, of the contributory effects of lunar dust to spectral reflectance

The proper selection of samples was of major importance. Since the northern side of the camera apparently received a great deal of dust from the lunar module, while the southern side had received little or no dust, samples from both sides were selected. Since one of the major suspected contributors to deposition of organic materials was the backside of the solar panel coated with an epoxy paint which could readily outgas, a sample of the top of the

*These measurements, conducted by various science investigators as part of the parallel science program, were coordinated by JPL. Selected inputs from these studies were furnished to Hughes for possible inclusion in this assessment.

television camera directly under the solar panel was included. Similarly, samples were selected from areas of both high and low incident solar radiation.

The ion microprobe analysis of selected samples was conducted by the GCA Corporation.* This technique consisted of sputtering surface materials and analyzing the formed ions. Sputtering continued to remove material at the rate of 400 Å/min. Thus, depth profiles of contaminants such as dust, organics, etc., on the surface of the paint could be obtained.

Direct analysis of the amount of the lunar material present on the various surfaces was conducted at SUNY.** Lunar fines, very rich in helium, have been deposited by the solar wind over the centuries. By measuring the helium content of samples, the volume of lunar material present could be determined for the various surfaces (Reference 11-3).

Organic analysis was conducted at the University of California, Berkeley,*** on samples prepared by Hughes. Experimental results have not yet been reported and were not available for inclusion in this analysis.

Spectral reflectance measurements were conducted prior to submittal of all samples to outside investigators. Extensive spectral reflectance tests were also conducted by Hughes on many of the other samples, as discussed in the following subsection. Some measurements were conducted at a TRW facility under a Hughes subcontract.

In addition, controlled photo bleaching and thermal exposures were conducted by Hughes on samples in an attempt to selectively bleach out the radiation damage. These experiments became necessary when it was observed that the discoloration of the painted surfaces exposed to room light was disappearing with time. This effect is also described in detail in the next section.

11.4 SUMMARY OF TEST RESULTS

This subsection contains a summary of the results of the tests conducted in accordance with the general plan outlined in Section 11.3. The basic data gathered in these studies are presented in Appendix J.4. The bulk of the material presented here pertains to the measurements of spectral reflectance of samples of returned Surveyor III parts, as well as

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*Dr. F.G. Satkiewicz.

**Dr. Oliver Schaeffer.

***Dr. A. L. Burlingame.

of control laboratory samples of surfaces painted with the same type of white inorganic paint. The measurements include results obtained during various attempts to intentionally alter the reflectance of selected control samples by chemical, thermal, and optical techniques in order to obtain supporting data. Also included in this section is a summary of the analysis conducted by JPL of the relation of lunar dust to the degradation of spectral reflectance. A mathematical expression was derived, which, coupled with experimental data, could be used to separate dust effects from radiation effects. Further details of this analysis are presented in Appendix J. 5.

A summary of the results of chemical analysis conducted as part of the science effort by SUNY and GCA Corporation, coordinated by JPL, is also included. The reflectance measurements of the Surveyor III samples submitted to these investigators are discussed in Appendix J. 4. 6.

11.4.1 Spectral Reflectance Measurements

Initial Measurements

The reflectance of the lower shroud of the television camera was measured at seven locations (Figure 11-1). Throughout this subsection, these numbered positions are referred to as "TRW positions". Positions 5, 6, and 7 were on the side of the shroud facing the landing site of the lunar module. Positions 1 and 2 corresponded to the front of the shroud, which faced the lunar northeast.

The reflectance of the lower shroud was measured in April 1970 over the range from 0. 3 to 2. 6 microns. The technique used was substitutional, with the shroud placed at the wall of an integrating sphere since sample cutting was prohibited at that time. These are the only measurements reported in this document where this technique was used. All other measurements were made by placing the sample at the center of a Gier-Dunkle integrating sphere. The data taken in this series of tests are self-consistent but must be modified when comparing to the later measurements. These first measurements were approximately 5 percent high.

A decrease in reflectance over original values at 1. 5 microns was found on most surfaces. This was not seen on TRW position 1 of Figure 11-1. This location was protected from the lunar environment by a bracket, whose photographs are shown in Appendix J (Figures J-19 and J-20). Laboratory studies have shown that neither ultraviolet nor solar wind protons will cause a reflectance decrease at 1. 5 microns for this clay-silicate inorganic paint. Thus, the reflectance drop is attributed to lunar dust. Organic contaminants were ruled out as discussed later. The variance in the magnitude of the reflectance at 1. 5 microns is a measure of the amount of lunar material present on the surface. Table 11-1 summarizes the significant results obtained. An expression relating dust coverage to the reflectance is presented in Section 11. 4. 2.

TABLE 11-1. REFLECTANCE MEASUREMENTS OF SAMPLES FROM LOWER SHROUD OF SURVEYOR III CAMERA

Measured in April 1970

Wavelength, microns	Percent Reflectance at TRW Positions (see Figure 11-1)					
	1 Beneath Bracket	7 Rear Toward LM	5 Side Toward LM	4 Side Away From LM	3 Side Away From LM	2 Front Facing Lunar East
0.4	85	18	33	48	59	32
0.5	90	28	43	63	76	45
0.6	90	36	47	70	83	51
0.7	90	40	50	75	86	56
0.8	90	44	53	77	88	60
1.0	90	50	58	80	89	63
1.2	90	56	63	82	89	70
1.5	90	62	67	84	89	73

*LM = Apollo XII lunar module.

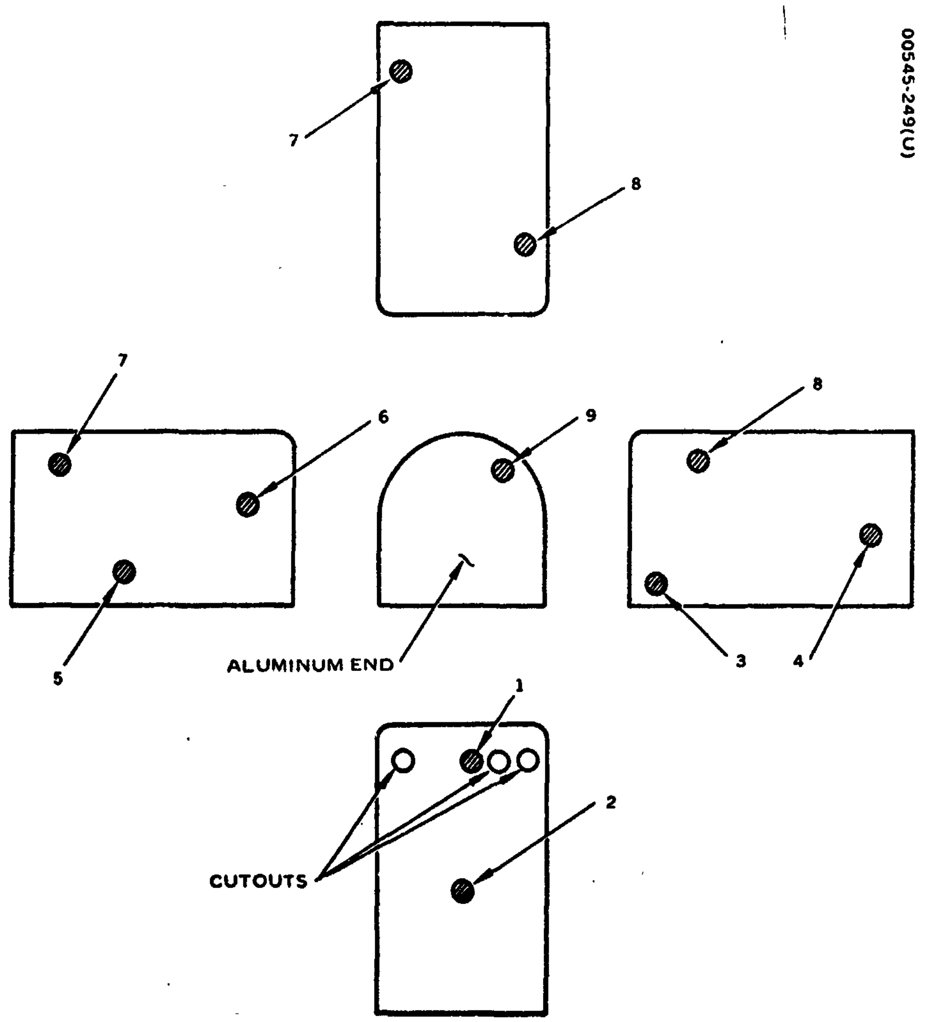

Figure 11-1. Lower Shroud of Surveyor III Camera, Showing TRW Measurement Positions

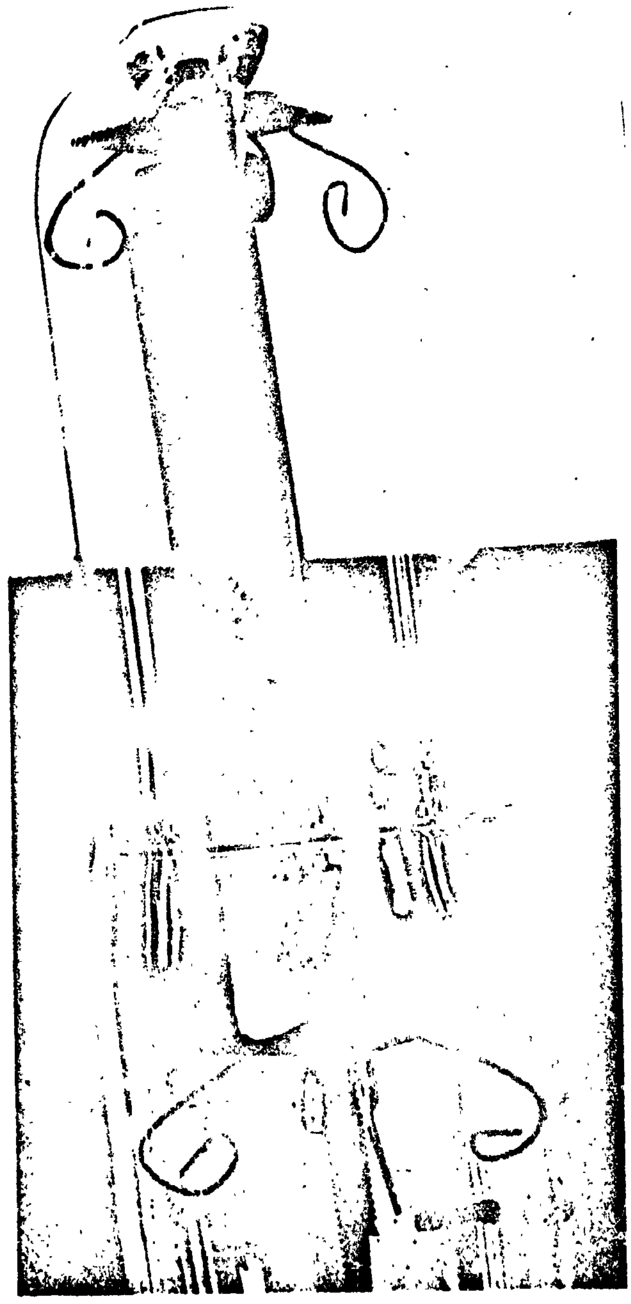

Figure 11-2. White Painted Tube Section Returned From Moon in SESC in Quartz Vacuum Chamber (Photo 00545-292)

Measurement of Tube Section From SESC

An important spectral reflectance test was planned for the white painted tube sample returned in vacuum by the Apollo XII astronauts. This tube was cut from one of the struts of the tripod bracket of the camera support collar and was to be tested in vacuum and then in air. However, a leak was found in the SESC. The proposed test was conducted even though it could no longer be assumed that the part had been returned in vacuum. The white painted tube found in the SESC was cut, and a section was transferred to a quartz vacuum chamber made light-tight with an external shroud. This is shown in Figure 11-2. The transfer was accomplished in an argon atmosphere, and the quartz chamber was then evacuated. The reflectance of the white painted tube was measured in vacuum (1×10^{-7} Torr), in partial vacuum, and then at 1 atm. Several days later, for the first time since return to earth, the tube was exposed for 48 hours to bring light free from ultraviolet. Its reflectance was then remeasured.

No effect was noted on the reflectance as a result of the increase in pressure, first to 12 microns and then to 1 atm. This is consistent with earlier work by Hughes and others, which indicated that this paint did not exhibit atmospheric bleaching. Had the white painted tube been at 1 atm previously as a result of the leak in the SESC, vacuum bleaching would not have been noted in this test.

No white light was allowed to strike the sample during these tests of the white painted tube section. When light was necessary, low level red illumination was used. Any photo-induced bleaching could thus be studied under controlled conditions.

The photo bleaching test was conducted while the tube was at 1 atm. No bleaching occurred at 1.5 microns, but an increase of approximately percent was found at 0.4 micron. The tube, which was dark yellow when returned from the moon, lost its yellow appearance and turned a dirty gray over the half exposed to the white light; the other half reamined a uniform dark yellow. This increase in reflectance (i.e., loss of yellow color) is due to the photo bleaching of the radiation damage within the paint.

No additional work was done with the tube. It was exposed briefly for photography (photofloods) and then returned to its light-tight container.

Tests of Section of Camera Tube Stored in Dark

A parallel experiment was conducted on another tube from the support collar. This collar was removed from the camera at LRL in January 1970 and was immediately stored in the dark. The collar was removed from the dark storage, and a section of the tube was cut off. Visual examination of this tube revealed that it was yellow with two regions parallel to the axis — one dark yellow and the other gray.

The tests conducted on this tube are discussed in detail in Appendix J.4.4. The tests consisted of measurements of spectral reflectance before and after the following two consecutive operations: a carbon tetrachloride soak and a thermal bleach. Results of these measurements, summarized below, are discussed in Appendix J and plotted in Figure J-25 for the three regions of the tube (gray, light yellow, and dark yellow). It is recognized that some changes in the values of reflectance obtained in successive measurements may be attributed to the loss of lunar material or to the failure to perform the measurements at identical sample positions.

The carbon tetrachloride soak was performed in an attempt to remove organics from the surface. Measurements after the soaking revealed a very small increase in reflectance. Thus, results of this test indicated either an absence of organic materials or, at the very least, the absence of such organic materials that were removed by carbon tetrachloride. Subsequent ion microprobe tests conducted at GCA indicated little organic material on the surface of the camera. Additional mass spectrometer tests now in progress as part of the science investigation may shed further light when results are reported.

A thermal bleach test using this tube section was then conducted. The tube section was raised to about 430°F for 18 hours in air. Remeasurement of the spectral reflectance indicated a significant increase in reflectance in the visible portion of the spectrum. The yellow color disappeared and the tube appeared dirty gray-white, similar to the tube that was photo bleached.

It was also noted that following the thermal bleach, unlike the photo bleach, the reflectance increased at wavelengths longer than about 1 micron. This is not surprising. The same increase was found at wavelengths longer than 1.3 microns in similar laboratory tests of unexposed Surveyor inorganic white paint. The increase can be attributed to the loss of water, loosely bound within the silicate structure.

These bleaching tests were undertaken in an attempt to remove the effect of radiation on the optical properties of the white paint, leaving only the dust discoloration. On the basis of the laboratory ultraviolet exposure of a sample of the same white paint, it does not appear that 18 hours at 450°F is sufficient to completely bleach out all the radiation damage. Tests at higher temperatures were not conducted.

. Effects of Thermal and Photo Bleaching

It is apparent from the observed gradual bleaching of the lower shroud of the camera that a complete isolation of the returned materials from light and excessive heat was required. When this apparent lightening of color first became apparent, it was tentatively attributed to a gradual loss of deposited lunar material, or to bleaching of the paint. Optical measurements made as late as November 1970 showed that the reflectance at 1.5 microns remained nearly constant, indicating that very little lunar dust had been lost. The lightening of the surface must therefore be attributed to photo bleaching of the paint.

The magnitude of this was clearly established in May 1970 when the cable bracket from the lower shroud was examined. This bracket had been kept dark since its removal from the camera in January 1970. Photographs of the bracket and lower shroud showed at that time that both had the same brownish yellow color. However, in May the shroud appeared grayish white, while the bracket retained the brownish color previously noted.

Samples cut from the lower shroud were exposed in November 1970 to the thermal annealing test conducted on the two tube sections. No increase in reflectance was observed. Time-dependent photo bleaching by ambient (room) lighting had already raised the reflectance. This can be seen in Table 11-2, which summarizes the results of these tests. Very little change with time occurred at 1.5 microns. It is surmised that the reflectance at 0.4 micron at the time of return from the moon must have been still lower than 27 percent, the value shown in Table 11-2 for the April 1970 measurement. Based on the measurements of the tube returned in the SESC and the bracket which had been previously exposed to light, the reflectance is estimated to have been about 20 percent at the time of return to earth. It should be noted that this sample was taken from a region facing east, a surface which was exposed to maximum solar radiation.

Four samples were cut from the cable bracket (also facing east) in May 1970, and their spectral reflectance was measured. The samples were then returned to dark storage until August 1970 when the spectral reflectance was remeasured. No increase in reflectance was found. The spectral reflectance was remeasured in November 1970 after additional dark storage. There was still no change in reflectance. It therefore appears that dark storage preserved the optical conditions for many months.

Two samples from the cable bracket were then exposed in November 1970 to the same light as the television camera, i.e., the fluorescent lighting of a laminar flow bench. The intensity of the light at the unprotected sample surface was 200 watts/cm^2. One sample was protected by 0.002 inch of clear teflon FEP film and the other by the teflon and 0.012 inch of polyethylene. The polyethylene simulated the condition in which the television camera was maintained from the time of return until 6 January 1970. Actual room lighting conditions during the storage were not known. The light intensity reaching the samples was about 170 watts/cm^2.

The spectral reflectance increased about 1 percent after 72 hours of exposure to the light. After 17 days, significant bleaching occurred, with an increase in reflectance of 13 percent at 0.4 micron for both samples. This experiment may be interpreted to mean that the television camera probably saw very little light during its LRL quarantine period since the camera was quite brown when first viewed in January 1970.

TABLE 11-2. VARIATION OF REFLECTANCE WITH TIME AS A RESULT OF PHOTO BLEACHING

Lower Shroud Sample: TRW Position 2 (See Figure 11-1)

Wavelength, microns	Reflectance, Percent Measured at Successive Dates			
	April 1970*	July 1970	October 1970	After Thermal Annealing (Late October 1970)
0.4	27	36	37	38
0.6	46	48	51	52
1.0	60	63	64	66
1.5	68	68	70	71

*April 1970 data adjusted (see text).

A set of experiments was conducted to further assess the effect of thermal soak on reflectance and to determine the role attributable to the presence of oxygen in this process. Results are summarized in Table 11-3, with additional details in Appendix J.4. Laboratory samples previously exposed to ultraviolet radiation and a sample of the returned Surveyor III camera were tested. As seen in Table 11-3, some of the samples were exposed in vacuum and some in air. All thermal soaks were performed for 18 hours at 450°F.

Thermal soak in air of the laboratory samples gave results similar to those obtained for the returned lunar sample. While some restoration of reflectance was produced, exposure in air for 18 hours at 450°F did not completely restore the optical properties.

As seen in Table 11-3, an entirely different result was obtained when the laboratory and the lunar samples were thermally exposed in vacuum. The reflectance of both samples was found to decrease significantly. Measurements of reflectance following the thermal exposure in vacuum were made in air. Subsequent thermal soak in air of the laboratory sample, which had been subjected to heat in vacuum, resulted in restoration of its reflectance to the same values obtained for the sample exposed only to air and heat. This can also be seen in Table 11-3.

Reduction of reflectance as a result of thermal exposure in vacuum is not understood. It was originally thought that the reflectance of these samples would rise as the trapped electrons (color centers) were thermally depleted. For that reason, the presence of oxygen was not considered significant; results of thermal exposure in air and in vacuum had been expected to be identical. Evidently, this was not the case. However, this unexpected result had no direct bearing on the surface discoloration and contamination studies of the returned samples. This result may be unique to the clay-silicate paint. Further tests may be warranted if it is desired to explain the results of thermal bleaching in vacuum.

11.4.2 Analysis

The discoloration model postulated that the loss of reflectance was due to a combination of two effects: solar radiation and surface coating by a layer of lunar dust. The latter reduction of spectral reflectance occurred when the incident light passed through the dust layer and after reflection of the light from the painted surface in transmission through the dust.

An analysis was conducted at JPL to attempt to derive a mathematical expression for the contribution of the lunar dust to the overall decrease of reflectance. Results of this analysis are described in Appendix J.5. As

TABLE 11-3. EFFECT OF THERMAL BLEACHING (VACUUM VERSUS AIR) ON SPECTRAL REFLECTANCE OF IRRADIATED SAMPLES OF INORGANIC WHITE PAINT USED FOR SURVEYORS

Wavelength, microns	Reflectance, Percent						
	Laboratory Sample Exposed to Ultraviolet		Laboratory Sample Exposed to Ultraviolet			Surveyor III Sample (Log 909 — Test Log Book)	
	Before Thermal Bleaching	After Thermal Bleaching - Air	Before Thermal Bleaching	After Thermal Bleaching - Vacuum	After Thermal Bleaching - Air	Before Thermal Bleaching	After Thermal Bleaching - Vacuum
0.4	52	71	50	43	71	33	18
0.5	66	77	63	56	78	47	28
0.7	78	80	77	67	82	62	40
1.0	80	81	81	78	81	69	56
1:5	76	78	80	78	80	73	67

shown there, the measured reflectance at any one wavelength can be effectively expressed as

$$\rho_m = \rho_o D (1 - KA_d)^2$$

where

ρ_m = measured spectral reflectance of surface

ρ_o = original spectral reflectance of painted surface

D = ratio of reflectance of surface degraded by solar radiation and contamination (other than dust) to original reflectance

K = experimentally determined constant (function of wavelength)

A_d = fraction of area covered by dust

Using the above expression, it is possible to separate analytically the effects of dust from those due to radiation and contamination (term D). To do so, the factor KA_d must be determined experimentally in addition to the measurement of the final spectral reflectance and the knowledge of the original spectral reflectance.

An example of the results obtained by this technique is shown in Figure 11-3. Curve A shows the original reflectance of the paint, and curve B shows the measured reflectance of one of the samples of the returned Surveyor III camera.* Curve C shows what the reflectance of the surface of the sample would be if the dust were removed. Thus, curve C indicates the degradation caused by radiation damage only. Similarly, curve D shows what the reflectance of this sample would be in the absence of radiation damage and with degradation by dust only.

It should be noted that the same evidence is apparent from the measurements discussed in Appendix J.4.1. In particular, results obtained for the two samples, shown in Figures J-10c and J-10f, should be compared with the results shown in Figure 11-3. Figure J-10c applies to the samples whose reflectance degradation is predominantly attributable to radiation,

*Designated as 521 in Program Test Log Book.

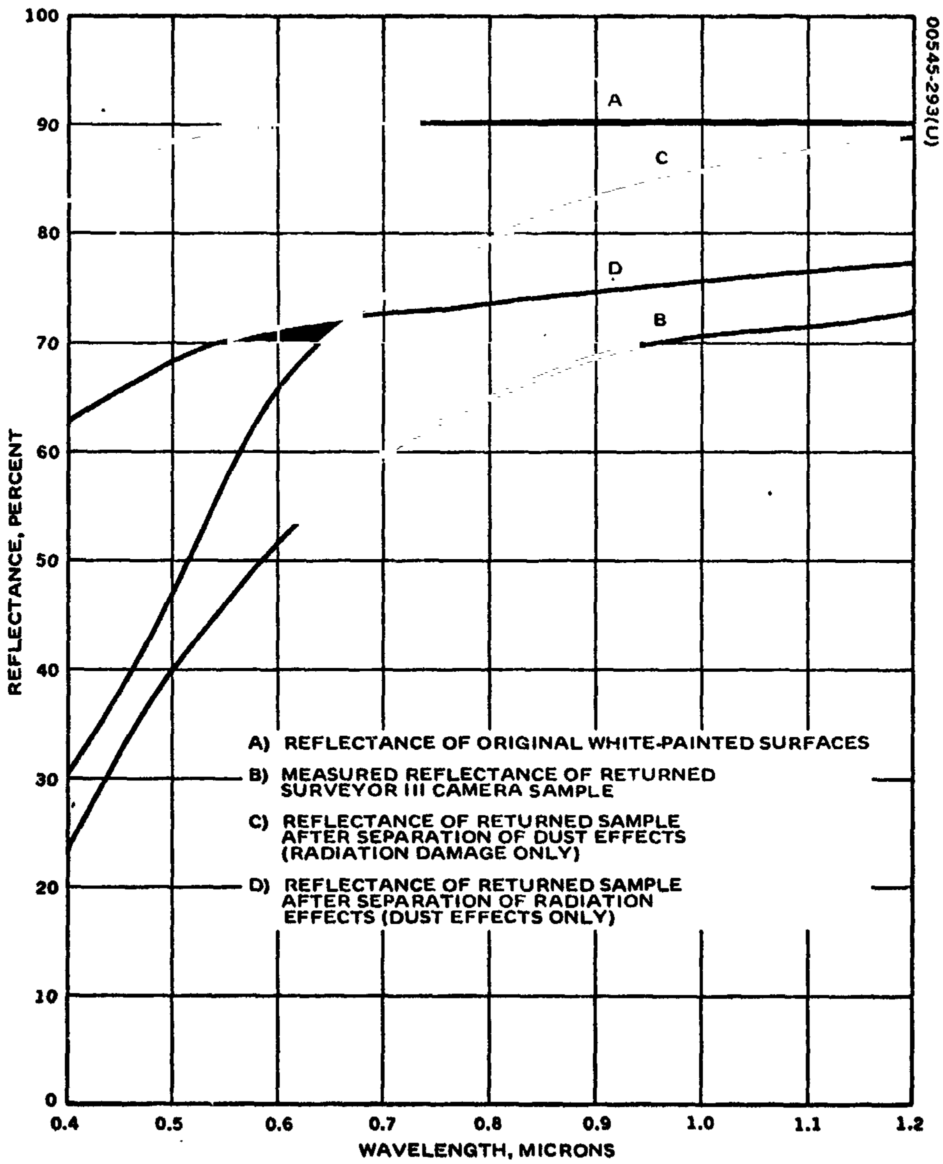

Figure 11-3. Separated Radiation and Dust Effects on Spectral Reflectance. White inorganic painted surfaces of Surveyor III camera

while Figure J-10f applies to a sample primarily degraded by lunar dust. Comparison of Figure J-10c and Figure 11-3c illustrates the photo bleaching effect described in Section 11.4.1.

11.4.3 Results of Related Investigations

As described earlier, the surface discoloration and contamination studies utilized to the maximum extent possible the results of the effort conducted as part of the parallel science investigations under JPL coordination. Results of these investigations will be reported separately.

Some of the results obtained by using inputs available to date from the science investigators are summarized here. Table 11-4 compares results obtained by several techniques for a number of samples from the returned Surveyor III camera. The samples include surfaces covered by inorganic white paint, as well as a polished aluminum surface from the bottom of the lunar shroud. This particular comparison, shown here as an example, relates to the calculation of the fraction of the area covered by lunar dust at several locations. This calculation was made using total reflectance measurements as the basic raw data. For each technique listed in Table 11-4, location A is taken as a reference. The three techniques compared are the analytical technique described in Section 11.3.2, the trapped helium experiments conducted at SUNY, and the ion microprobe work conducted at GCA.

With the exception of the value obtained from reflectance analysis for location D (polished aluminum), the results in Table 11-4 show decreasing amounts of lunar dust on the various surfaces in the order shown. An additional exception from ion microprobe data, not shown in Table 11-4, indicates highest dust coverage on location B for a depth less than 0.4 micron.

The values for location D were computed from Equation 4, Appendix J.5, using experimentally determined values of K_λ for painted surfaces. The polished aluminum is a smooth surface and a specular reflector, while the painted surface is rough and a diffuse reflector. Thus, the assumption of equivalent K_λ is in error by an undetermined amount.* Determination of K_λ for the aluminum surface and resolution of the apparent inconsistency would not alter or improve the understanding of the discoloration. If warranted, additional measurements could be made in the future.

Since K_2 and K_3 of Equation 1 in Appendix J.5 are proportional to the transmission through the lunar particles, the apparent heavier coating of fines for location B (not shown in Table 11-4) is not inconsistent with reflectance determinations: the smaller particles would absorb less light.

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*It was possible to determine A_d as equal to approximately 0.14 for the polished surface from scanning electron microsopy.

TABLE 11-4. COMPARISON OF SEVERAL TECHNIQUES FOR ASSESSMENT OF FRACTIONAL AREA COVERED BY LUNAR DUST

Various Samples From Surface of Surveyor III Camera

Sample Location	Area Covered by Lunar Dust (Fractional Area Relative to Area in Location A)			
	Total Reflectance Measurement at 1 Micron	Reflectance Analysis (Appendix J. 5)	Trapped Helium (SUNY)	Ion Microprobe (GCA)
Location A **Top of hood** **(inorganic white paint)**	1.0	1.0	1.0	1.0
Location B **Side facing LM*** **(inorganic white paint)**	0.87	0.87	0.75	0.95
Location C **Side away from LM** **(inorganic white paint)**	0.67	0.37	0.42	0.79
Location D **Bottom of lower shroud** **(polished aluminum)**	0.72	0.40	0.29	0.29

***Lunar module.**

11.5 DAMAGE MODEL

11.5.1 General Assessment

An overall assessment of results to date of the surface discoloration and contamination studies, initiated and conducted with an awareness of the complexity of the problem and with due reservations, can now be attempted. It is believed that a reasonably good damage model has been obtained within the limits of the scope of this program and the time available.

The model proposes that the discoloration of the surfaces of the returned Surveyor III hardware is attributable to a combination of two dominant effects: radiation damage and lunar dust, the latter both from the original Surveyor landing and from the landing of the Apollo lunar module. There is some still inconclusive evidence of organic contamination, but its contribution to the total discoloration is believed to be minor.

The camera painted surfaces showed an overall dirty color in varying degrees, shades, and tones. This variation is the result of the two contributory effects: radiation damage to the paint and lunar dust coverage. While some areas are primarily affected by one or the other source, the majority of areas indicate varying contributions from both sources.

The contribution attributable to radiation damage is proportional to the extent of solar exposure experienced. The dust coverage was significantly greater than originally anticipated. Interaction of the lunar model descent engine with the lunar terrain disturbed the surface material and caused a major interaction with the Surveyor spacecraft even though the landing site was over 500 feet away.

The proposed model has been quantitatively demonstrated to be a reasonably correct one at several selected areas of the affected Surveyor III surfaces. The model has not been fully tested for all of the surfaces in order to synthesize the total complex discoloration pattern. Further investigation may be warranted if the additional degree of detailed knowledge is desired. Science studies currently under way may yield additional information of value to this model.

The dust effects on reflectance and the lunar interaction effects may be of value for future lunar operations. The radiation damage information for the specific thermal coatings used on the Surveyor was not expected to have a significant impact on future space or lunar operations.

A summary discussion of the above contributing factors is presented in the remainder of this section.

11.5.2 Effects of Lunar Dust

With the exception of one small area designated in Figure 11-1 as TRW position 3, described below, all exposed surfaces of the camera had a coating of fine lunar material. The amount of this coating varied from area to area: the "dirtiest" area was estimated to be about four to five times more heavily coated than the "cleanest" area. The various sources of lunar dust are listed in Table 11-5. These variations in the degree of cleanliness may thus be attributed to the quantity of dust imparted from the various sources to the differences in the adhesion of the dust to camera surfaces and to the various mechanisms of removal of the dust: prior to camera retrieval, during return, and during subsequent handling. In addition, there was some variation in surface roughness of the paint; the rougher areas tended to hold more material during deposition and during disturbances in handling.

As discussed in Appendix J.1.3, the surfaces on the northwest side of the camera exposed to the lunar module landing site were substantially lighter than the immediately adjacent areas protected by projecting hardware such as struts. This difference in color was largely due to the removal of adhering lunar material from these exposed surfaces probably by the "sandblasting" effect of material disturbed by the lunar module (LM) landing. These lighter areas on the LM side were darker than the overall color of the opposite side of the camera (away from the LM, facing southeast). Analysis indicated that less than half as much lunar material was present on the side away from LM as on the sandblasted areas facing the LM. These differences may be the result of one or more of the following: a much higher initial coverage on the LM side (Table 11-5, sources 1, 2, or 3a), incomplete removal by the LM effect of sandblasting, and deposition of particles disturbed by the LM, arriving later (Table 11-5, source 3a).

The front of the lower shroud showed slightly less dust than the sandblasted parts facing the LM but still approximately twice as much as the side away from the LM. The differences between front and sides, toward and away from the LM, may be due to differences in geometry or adhesion during sources 1 and/or 2 (Table 11-5). The side of the camera's lower shroud away from the LM landing site was in the view of the approaching LM, until the LM was several hundred feet east of its final landing site and at an altitude of 200 to 300 feet. The front was exposed at a small angle with respect to the location at which the "first visible dust" was noted. This is discussed in Appendix J.1.3 and can be seen in Figure J-4.

Although it might be argued that all of the contrast was due to dust stirred by the approach of the lunar modules, the absence of localized asymmetry around protrusions on the side away from LM indicates that the contribution from LM approach was minimal on that side. It is not possible to conclude that the LM contribution was minimal on the front.

TABLE 11-5. POSSIBLE SOURCES OF DUST CONTRIBUTION TO DISCOLORATION

Number	Possible Source
1	Surveyor landing
2	Lunar transport (i.e., secondary debris from meteoroid impacts)
3	Lunar module
	a) Approach
	b) Final descent ("sandblasting" effect)
	c) Late arriving fines from final descent
4	Redistribution during return and handling

The camera hood showed more dust than the lower shroud, with the highest concentration on the top and the side facing the LM. The paint in this area had a rougher texture, which would tend to trap and hold deposited dust more effectively. However, particles from any of several sources with a high ballistic trajectory, sources 1, 2, 3b, and 3c in Table 11-5, would deposit preferentially on top of the hood.

The mirror was known to have been dusty and/or pitted as a result of the abnormal landing of Surveyor III, as discussed in Appendix J. 1. 2. Comparison of the amount of dust present immediately after the Surveyor landing to that present at the time of the retrieval of the camera is under study as part of the parallel science investigation and will be reported separately. Any increase noted would be the result of sources 2 or 3a in Table 11-5.

A small area on the side away from LM, designated as TRW position 3 in Figure 11-1, appeared to be free of dust. This area was beneath the cable running from the front, along the left side of the camera.* The absence of dust may be due to "shadowing" of the surface from the incident dust or caused by a removal mechanism not fully understood.

*Seen in the frontispiece of the JPL contract Final Report; not included in the NASA-MSC Contract Final Report.

Preliminary examination of screws from various parts of the camera showed quantities of lunar material that were in general agreement with the amounts on the painted surfaces, discussed above. These examinations were informative since the dielectric lunar material could be identified on metallic surfaces but not on the dielectric paint. The screw head surfaces, partially exposed to the LM sandblast, showed asymmetry in dust coverage, with less material on the exposed than on the shadowed portions. Screws from the opposite side of the camera showed less material than the sand-blasted surfaces. These studies are being pursued as part of the science tests. They have not yet been completed and will be reported separately.

Shadow patterns due to dust coverage are not apparent on the side of the lower shroud away from LM. Sources 3a, b, and c in Table 11-5 would produce asymmetry if they are significant contributors to dust coverage. Asymmetry is not obvious from the examination to date of the screws from this side of the camera. Redistribution of dust (source 4 in Table 11-5) did not appear to be a major factor. The lunar material on the side away from the LM landing site was therefore most probably the result of the initial Surveyor landing although lunar transport cannot be totally disregarded.

11.5.3 Organic Contamination

One of the findings of the study was that the contribution of organic contamination to the discoloration appeared insignificant compared to the radiation and dust effects. Some evidence of minor organic contamination on some surfaces was reported in the parallel science studies, as noted in Reference 104, but this was not believed to have a significant bearing on the overall assessment presented here. Samples are still being analyzed for organic materials by science investigators, and results will be reported separately when available.

It should be recognized that the organic contaminants, even if small enough to be of no significance to the discoloration of the Surveyor III camera, could be important to the design of optical instruments for future spacecraft. Analysis of their presence and identification of their sources may therefore be required.

11.5.4 Radiation Damage

Radiation damage to the white paint was originally anticipated to be a major factor in the discoloration of the surfaces of the Surveyor III television camera. It was expected that the solar absorptance, and hence the amount of discoloration, would bear a direct relationship to the degree of solar exposure determined by the geometry of the Surveyor spacecraft on the moon. However, the patterns expected were not evident during the initial examination.

As reported above, it was reasonably possible to isolate by measurement and analysis the contributions of the lunar dust coverage from the total reflectance from the painted surfaces. This made it possible to separately analyze the patterns of discoloration and damage attributable to solar radiation only. As illustrated in Figure 11-4, it was then verified that the discoloration in the paint attributable to radiation effects is indeed proportional to the degree of solar exposure. The two locations on the lower shroud of the camera, positions 2 and 5 in Figure 11-4, correspond to areas of near-maximum and near-minimum solar exposure, respectively.

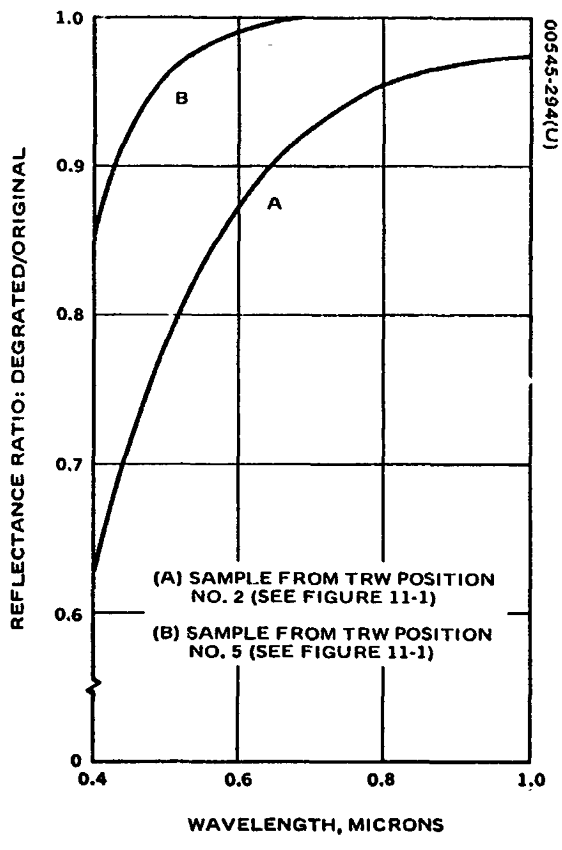

Figure 11-4. Effect of Radiation on Spectral Reflectance of White Inorganic Painted Surfaces of Surveyor III Camera (Contributions of Lunar Dust Removed Analytically)

APPENDIX A. SECTIONING OF POLISHED TUBE

During the initial examination of the polished tube at MSC, identifying scribe lines and letters were made on the tube to provide an orientation reference, and the tube was sectioned.

The polished tube is sketched in Figure A-1, which indicates the identifying scribe lines and the lettered segments subsequently sectioned. The tube ends were pinched during the lunar cutting operations into oval or pear shapes, as described in Section 4. 5. 2. Two scribe lines were made on the tube close to each other, one light and one heavy, from apex to apex. Only one of these lines is indicated in the figure. The two scribe lines cross each other several times; in some places, there were separated by as much as 1/16 inch.

The six sections into which the tube was then sectioned and the identifying letters for each section marked on the polished tube prior to sectioning are shown in Figure A-1. The lengths of each section are also indicated. Figure A-2* is a photograph of the tube after the identifying marks were made and prior to its sectioning.

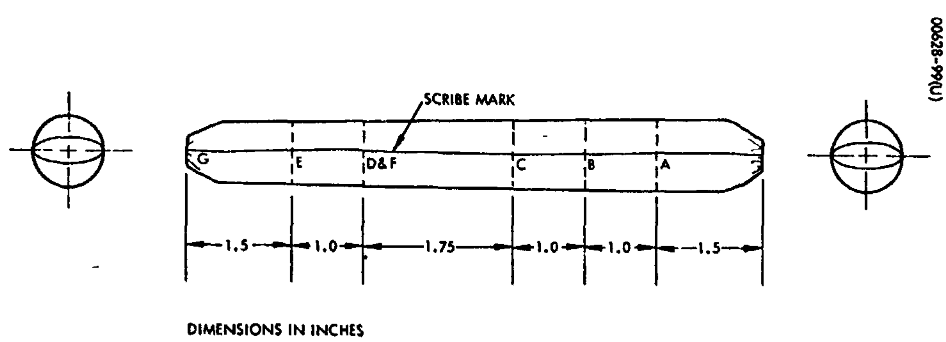

Figure A-1. Sectioning Arrangement for Polished Aluminum Tube

*Original in color.

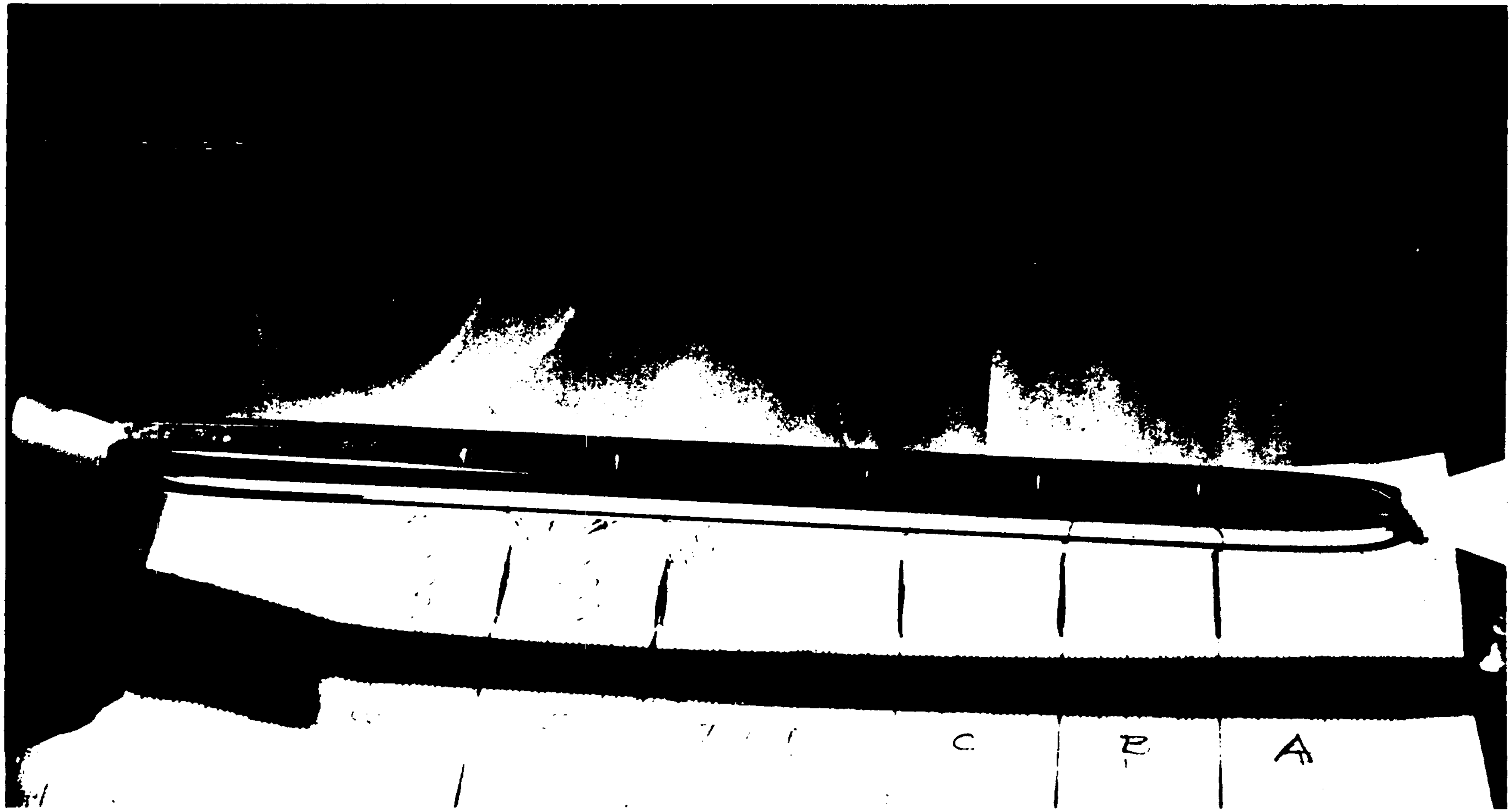

Figure A-2. Polished Aluminum Tube, Showing Identifying Marks
(NASA Photo S-70-22656)

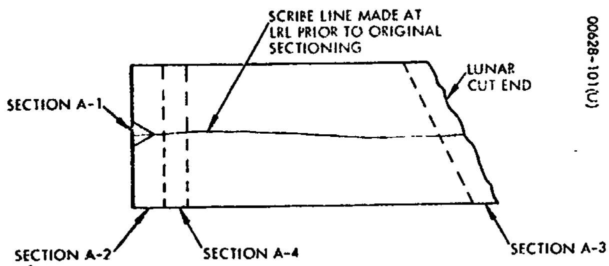

Figure A-3. Section A of Polished Aluminum Tube Shown in Figure A-1, Indicating Further Subsections Removed at Hughes

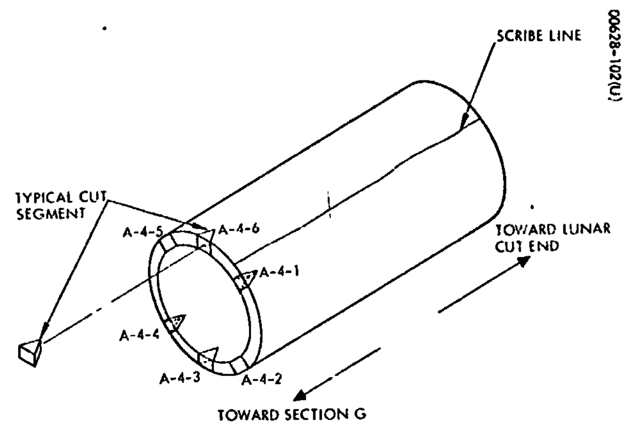

Figure A-4. Section A-4 of Polished Aluminum Tube Shown in Figure A-3, Showing Further Segments Removed at Hughes

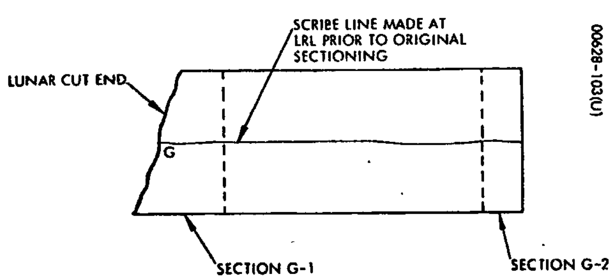

Figure A-5. Section G of Polished Aluminum Tube Shown in Figure A-1, Indicating Further Subsections Removed at Hughes

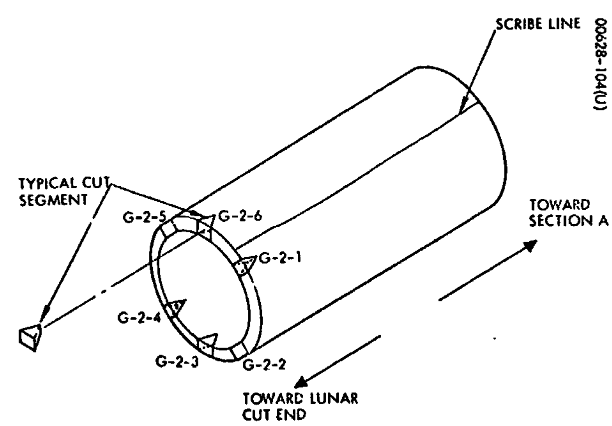

Figure A-6. Section G-2 of Polished Aluminum Tube Shown in Figure A-5, Showing Further Segments Removed at Hughes

Sections A and G were transferred to Hughes for the studies reported in this document. The other sections were distributed elsewhere for scientific investigation. During subsequent analysis at Hughes, sections A and G were eventually subdivided further, as indicated in Figures A-3 through A-6.

APPENDIX B. LIST OF LABORATORY LOG BOOKS CONTAINING TEST DATA

Hughes Technical Journal Number	Title
F 1762	Physical Properties
F 2287	Chemical Properties
F 2640	Chemical Properties
F 2639	TV Cable
F 2285	Painted Tube
F 2288	Polished Tube
F 1764	SM/SS Scoop
F 2453	SM/SS Scoop
F 2290	Dust Coloration and Contamination Study

APPENDIX J. SUPPORTING DATA FOR SURFACE EFFECTS STUDY

J.1 BACKGROUND DATA ON SURVEYOR SURFACE CONDITIONS AND LANDING OPERATIONS

J.1.1 Prelaunch Surface History of Surveyor III

Surveyor III underwent extensive testing prior to launch, during which it was exposed to thermal-vacuum tests in an oil-pumped vacuum chamber (liquid nitrogen trapped). For almost all of the prelaunch testing, the TV camera was not on the spacecraft. The flight camera was placed on Surveyor III in February 1967. The camera also underwent thermal-vacuum testing in a similar vacuum chamber. There were opportunities for contaminants of many types to deposit on the camera prior to launch.

A thermal control surface inspection and rework were held just before launch. Repair of damaged paint surfaces was conducted at this time. These repaired spots were found upon return of the camera. The discoloration of these spots was different than that of the surrounding paint and always appeared lighter in color. The paint used to coat the repaired spots was an organic white (TiO_2 in an acrylic binder), not the inorganic paint used on the rest of the camera.

The clamp which held the camera in place provided a unique spot to observe the apparent effect of the prelaunch contamination. The cleaning procedure for the inorganic white paint was to lightly sand the surface so as to remove the visible contamination. The back side of the clamp had been partially cleaned in this manner and was not repainted. It was uniform in whiteness after cleaning. Upon return of the camera to earth, the cleaned spot was seen to be lighter in color, and where the sanding had stopped the discoloration became deeper. This difference in coloration is attributed to prelaunch contaminants (probably organic) on the surface of the unsanded paint that discolored to a greater degree upon exposure to the lunar environment.*

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*This observation is in conflict with other conclusions of the contamination study and should be examined further in possible future studies.

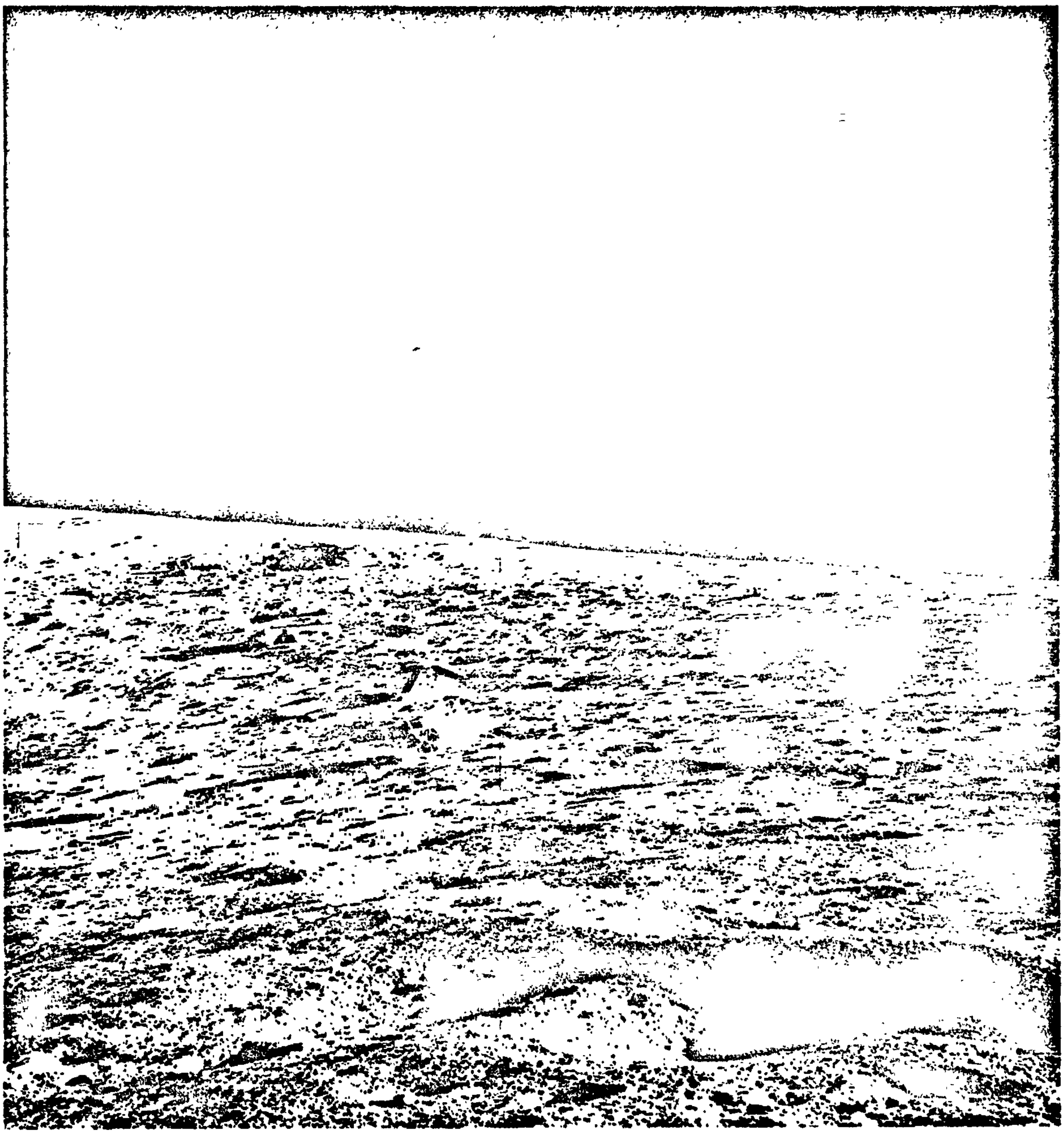


Figure J-1. Surveyor III on Crater Wall (NASA Photo AS12-48-7087)

J. 1. 2 Lunar Landing and Configuration of Surveyor III

The Surveyor III spacecraft was launched 17 April 1967 and landed on the lunar surface in the Ocean of Storms 20 April 1967. The landing site as determined from Surveyor data was 2.94°S latitude and 23.34°W longitude. The mission details and scientific results, landing site, etc., are described in detail in Reference 105.

The vernier engines remained on through the first two lunar touchdowns of Surveyor III at a thrust level equal to approximately 90 percent of the spacecraft lunar weight. This caused the spacecraft to rebound each time from the lunar surface. The vernier engines were shut down by ground command approximately 1 second before the third touchdown, and the spacecraft came to rest. The spacecraft did not rotate during this maneuver. The uphill leg (2) impacted first on each landing.

There were anomalies in the analog telemetry data after landing which required use of a correction factor to establish the thermal status of the spacecraft and precluded accurate comparison with post-return conditions. Within the limits of the accuracy of the data, Surveyor III appeared to react thermally like Surveyor I except for some differences that could be attributed to landing orientation (Surveyor III was tilted and in a crater). Within the limits possible, there appeared to be a "lack of any thermally significant dust on the compartment faces" (Reference 105). Thus, the presence of dust immediately after landing can neither be ruled out nor verified except as indicated by veiling glare and contrast attenuation observed for the Surveyor III mirror.

Surveyor III came to rest on the sloping wall of a crater about 200 meters in diameter and 15 meters deep. The spacecraft landed on the southeastern wall of the crater almost halfway between the center and the rim crest. The mean elevation of the foot pads was about 7 meters below the mean elevation of the rim crest. The spacecraft was tilted very nearly toward the center of the crater at an angle somewhat steeper than the mean local slope of the crater wall, as seen in Figure J-1 and the cover photograph. Figure J-2 shows the orientation of Surveyor III in the lunar crater.

The spacecraft's camera mirror assembly was rotated through a series of azimuth positions (and the camera mirror rotated through multiple elevation angles) during the TV photography sequence. Thus, the exposure of the mirror assembly to the various elements of the lunar environment during this operation was really a complex summation of its individual exposures during the various azimuth and elevation positions. No effort was made to analyze this portion of the exposure because it constituted such a small part of the total exposure of the camera to the lunar environment during the 2-1/2 years it remained on the moon.

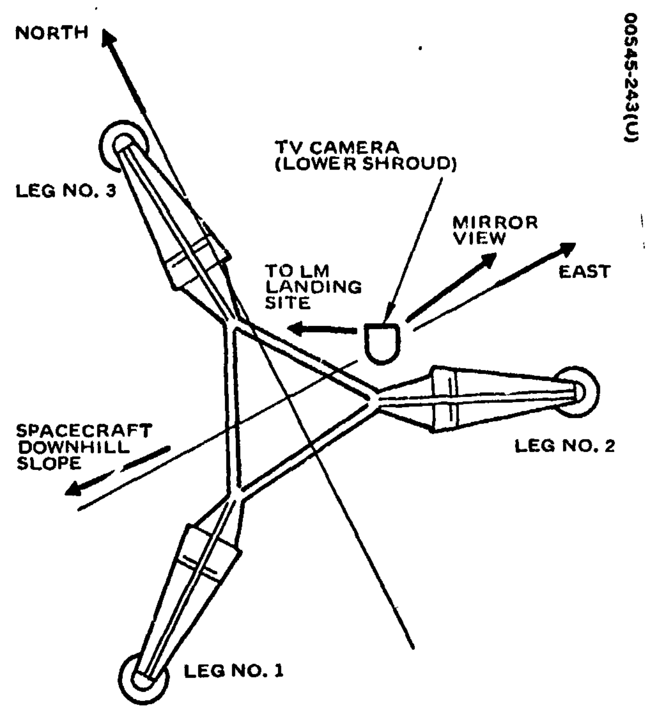


Figure J-2. Orientation of Surveyor III in Crater

The last Surveyor III picture was taken at -39 degrees azimuth of a feature on the eastern horizon illuminated by the setting sun. Following this picture, the camera was stepped 4 or 5 times in elevation to either -28 or -33 degrees elevation position (there is some confusion in the command log). An additional exposure was commanded in this position but, as expected, showed no image of the darkened lunar surface. The Surveyor III spacecraft was apparently in good condition when secured for the lunar night on 4 May 1967, 14 days after touchdown.

No major events occurred in the adjacent area during the 2-1/2 years that Surveyor III was on the moon (Reference 106). Micrometeoroids were not a significant factor. Photographs taken during the recovery of the camera indicate sharp outlines of the imprints of Surveyor III landing pads and the SM/SS trenches, with no erosion noted.

The camera was installed on the spacecraft with its vertical axis skewed with respect to the spacecraft vertical axis and this, combined with the spacecraft tilt (~12 degrees), produced a tilt of the camera vertical axis of 23.5 degrees with respect to local vertical in a direction 43 degrees west of north. The plane of the flat front face of the lower shroud of the camera was nearly vertical and faced approximately 43 degrees east of north. The -39 degree azimuth position of the mirror assembly left it "looking" a few degrees (5 to 15 degrees) north of local east.

A scale model of Surveyor was set up at JPL for a photographic sequence simulating a lunar day. The model was set at a tilt and position duplicating the Surveyor III attitude and orientation on the crater slope.

Figure J-3. Shadow Photograph of Surveyor III Model, Simulating Position of Sun at 10 Degrees Before Sunset, Viewed from Lunar Module Position (Photo 211-4068B)

A collimated model sun was oriented such that it traversed the same relative path over the model as the real sun over Surveyor III. Photographs were then taken of the Surveyor model at three different viewing locations. Photographs were made at every 10 degrees of sun elevation and at 2 degrees after sunrise and before sunset. The series of photographs is available from JPL (photographs 211-4042B and 211-4046A through 211-4073B).

Figure J-3* is one photograph from this sequence. Viewing position is from the lunar module landing spot with the sun at 170 degrees (10 degrees before sunset).

J.1.3 Lunar Module Landing

The Apollo XII terminal descent is described in detail in Reference 107 and summarized in Figure J-4. The Apollo landing site was approximately 535 feet northwest of the Surveyor spacecraft.

*Original in color.

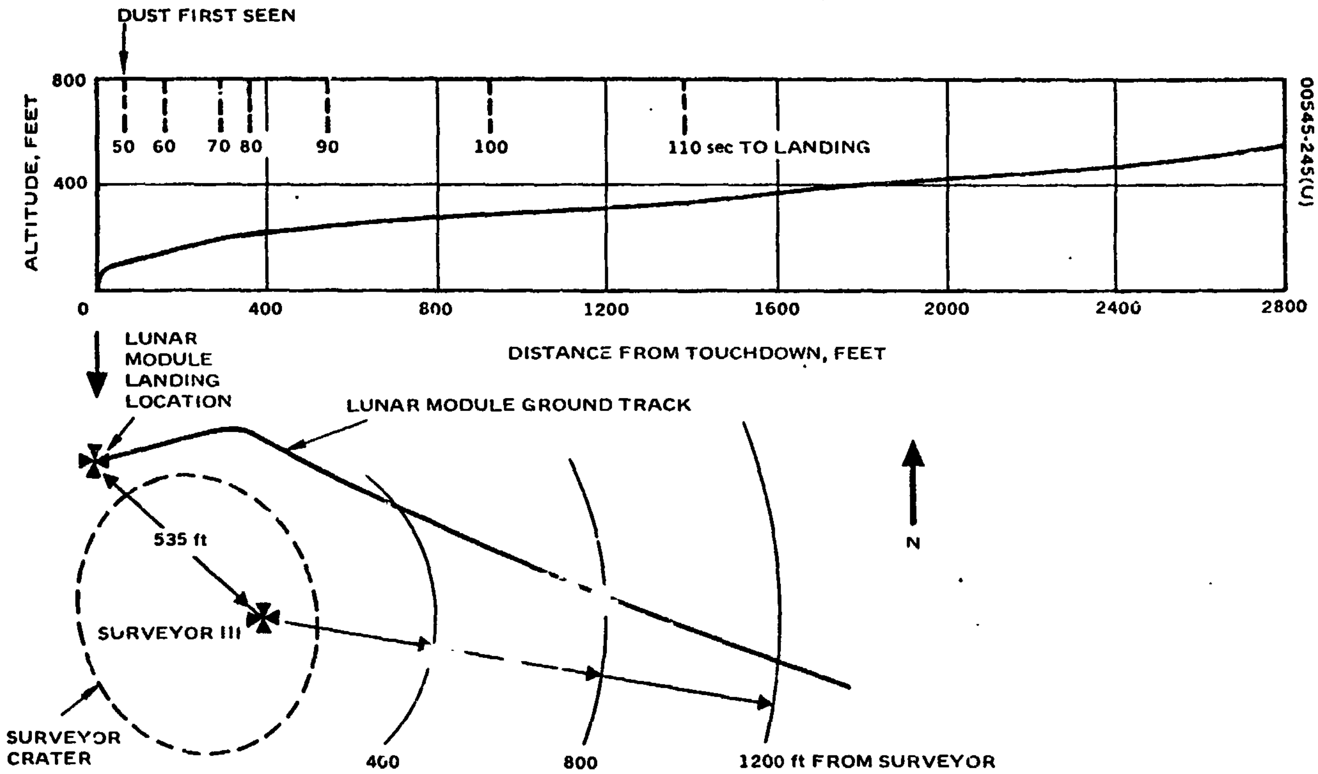


Figure J-4. Approach and Landing Configuration of Lunar Module Relative to Surveyor III

During the terminal descent of the lunar module, the first visible dust was noted approximately 50 seconds before final touchdown and approximately 80 feet east of the final landing site. Subsequent examination of lunar surface photos, discussed in Reference 108, showed clear evidence of surface erosion at least 40 to 50 feet east of the lunar module landing site. If it reached the Surveyor, this dust could have contaminated the front of the lower shroud. It is reasonable to assume that disturbance of the lunar surface and projection of fine particulate material in all directions occurred even earlier, and disturbance early enough to deposit fines on the mirror can not be precluded. In order for the particles disturbed by the lunar module to reach the mirror, they would have to have originated from a location approximately 700 feet east of the lunar module landing site (approximately 300 feet east of Surveyor III) at an altitude of 250 to 275 feet. The relative locations of the lunar module and Surveyor III are illustrated in Figure J-5 and can also be seen on the report cover.

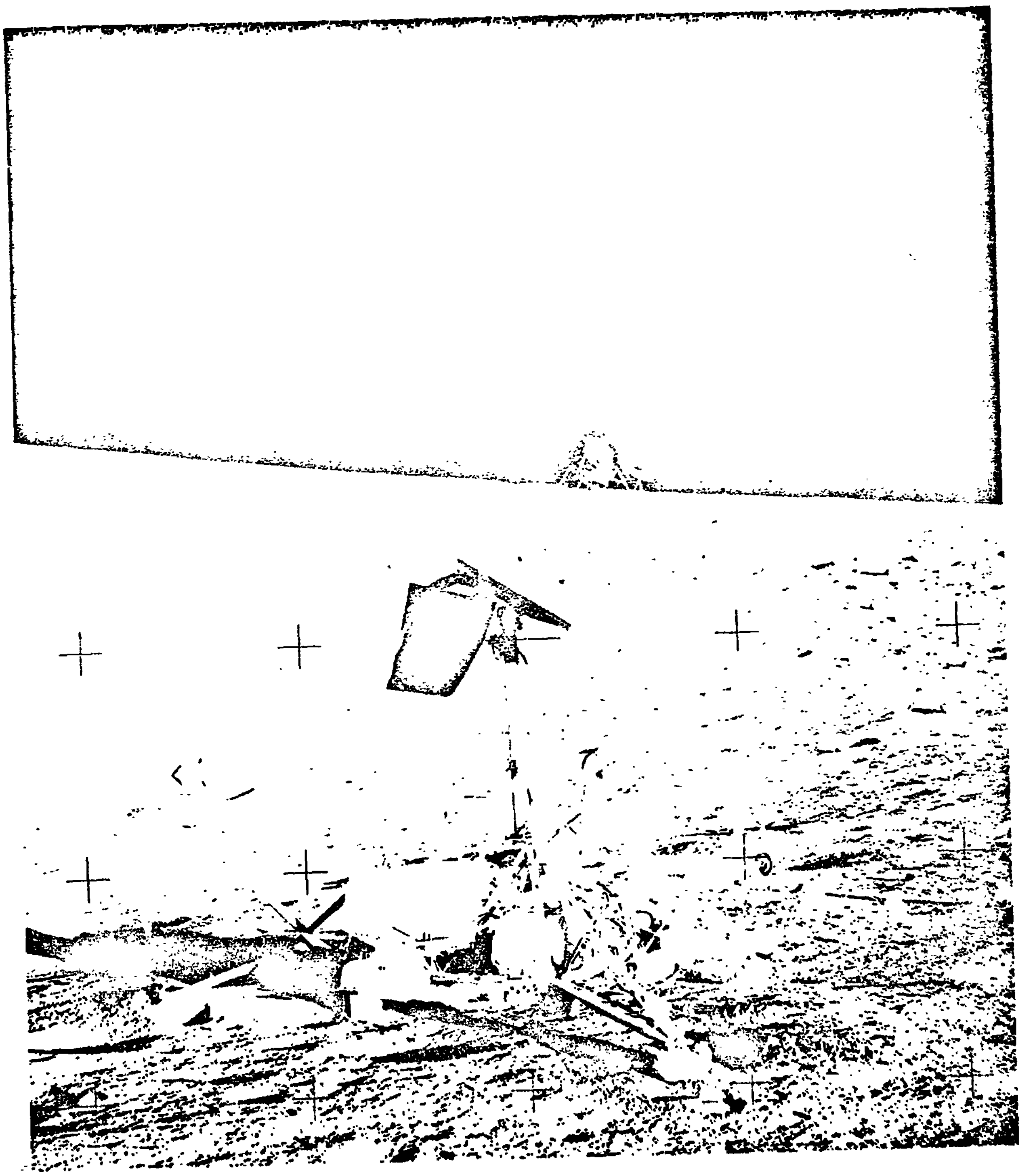


Figure J-5. View of Relative Locations on Lunar Surface of Surveyor III and Lunar Module (NASA Photo AS12-48-7100)

J.2 VISUAL OBSERVATION OF DISCOLORATION

The first indication that severe discoloration had occurred on the surfaces of Surveyor III came during the visit by the Apollo 12 astronauts to the landing site. To them, the once bright white paint and shiny polished aluminum appeared a uniform brown. The spacecraft condition described by the astronauts from the moon did not appear to be any different than anticipated since radiation, discoloration, and some dust coverage were expected in the white paint, as discussed in Section J.3. This aluminum silicate (china clay)/potassium silicate paint did not have superior radiation stability. However, when the parts were returned to earth and viewed for the first time, it was realized that the surfaces were extremely discolored, more so than could be attributed to radiation damage in the paint.

Prior to the Surveyor III parts recovery, it was hoped that two conditions on return of parts could be achieved: 1) to return parts in total darkness and 2) to return parts in vacuum. Except for a piece of painted tube and a cable section, these conditions were not possible because of weight, space, and schedule commitments. Therefore, the parts were returned in November 1969 exposed to air and some light. At the LRL in Houston, the parts were removed from the astronaut's backpack and, after a brief viewing, were double bagged in heat-sealed polyethylene. They were stored until 6 Jaunary 1970, when they were released from quarantine.

At this point in time, there was no great concern over the lack of vacuum environment around the parts since tests conducted by Hughes and others showed that the clay-silicate paint did not demonstrate any oxygen (or air) sensitive bleaching in its optical reflectance. What effect lack of light protection would have was unknown. It could only be hypothesized that there would be some effect. Since the parts were immediately exposed to light upon their return and were photographed at that time and again during survey operation at LRL following release from quarantine, interest in eliminating light exposure to the surface was reduced. As a backup, the white painted tube section was still in the vacuum-tight, light-tight container.

The TV camera was coated over most of its surface with the inorganic white paint. When the camera was removed from its double bag, the extent of discoloration became apparent. In addition, it was observed that significant variations in discoloration occurred over the entire surface. The side of the camera on which the mirror was located was a uniform tan or deep yellow-brown. The top and sides of the mirror hood were gray. The other portions of the camera varied in coloration between these two extremes. As mentioned earlier, the expected patterns of radiation damage were absent. The mirror surface was quite hazy, or diffuse, leading to the conclusion at this early stage of the investigation that the entire camera was covered with a contaminant (probably dust).

The camera was photographed after being placed in a laminar flow bench. Visual examination of the camera was made at this time prior to dismantling for microbiological examination. During this examination, the first shadow patterns were observed. These patterns are unique in that areas prctected to some degree from direct exposure to the outside environment, such as below a wire which was very close to the surface, were darker in coloration than the surrounding area. As the visual examination continued, numerous examples of the shadow patterns were found. All of the shadows were found on the north (lunar) side of the camera.

Partial dismantling occurred next with the removal of the lower shroud to allow microbiological work on the interior of camera. As part of this dismantling, the support collar and the mounting bracket on the lower shroud (through which the three connectors passed) were removed, wrapped in teflon film, and placed in a carrying case. These parts were not exposed to any significant light until May, 4 months after removal from the camera. On the north side of the bracket at the interface between the bracket and the lower shroud, a large amount of dark gray debris was noted.

On the front half of the support collar, located on the north side of the camera, was a hole approximately 1 inch in diameter. The surface of the camera beneath the support collar was unpainted aluminum. When the collar was removed, an image of the hole was noted on the aluminum surface. The image was offset and appeared to be formed by something passing through the hole in the collar off normal. This is shown in Figure J-6.

The image itself was fairly bright, with the area surrounding the image brownish and diffuse. When the support collar was removed, several milligrams of dark gray to black debris were found on the aluminum surface. Some of this debris was brushed into a bottle for arc emission spectrographic analysis, and the majority was picked up on clear pressure-sensitive tape. Analysis indicated that the debris was lunar dust.

When the support collar was removed, a new set of shadow patterns was found, again on the north (lunar) side of the camera, as shown in Figure 11-2 (Section 11). These patterns were associated with the struts which attach the camera to the spacecraft. Again, very sharp images of the struts appear on the painted surface of the camera and are much darker than the surrounding area.

Portions of the TV cabling were still attached to the camera lower shroud. When these were removed, shadow patterns were found on the north side of the camera below this cable which was located quite close to

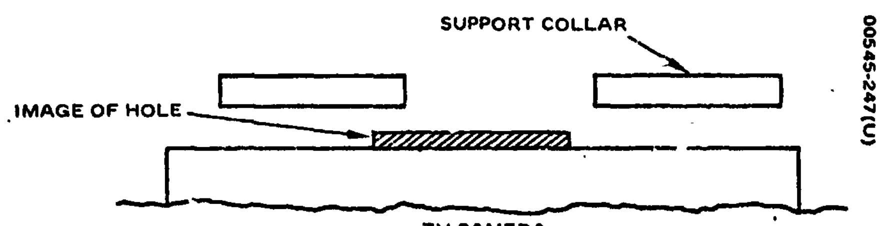


Figure J-6. Illustration of Shadow Through Hole in Camera Clamp

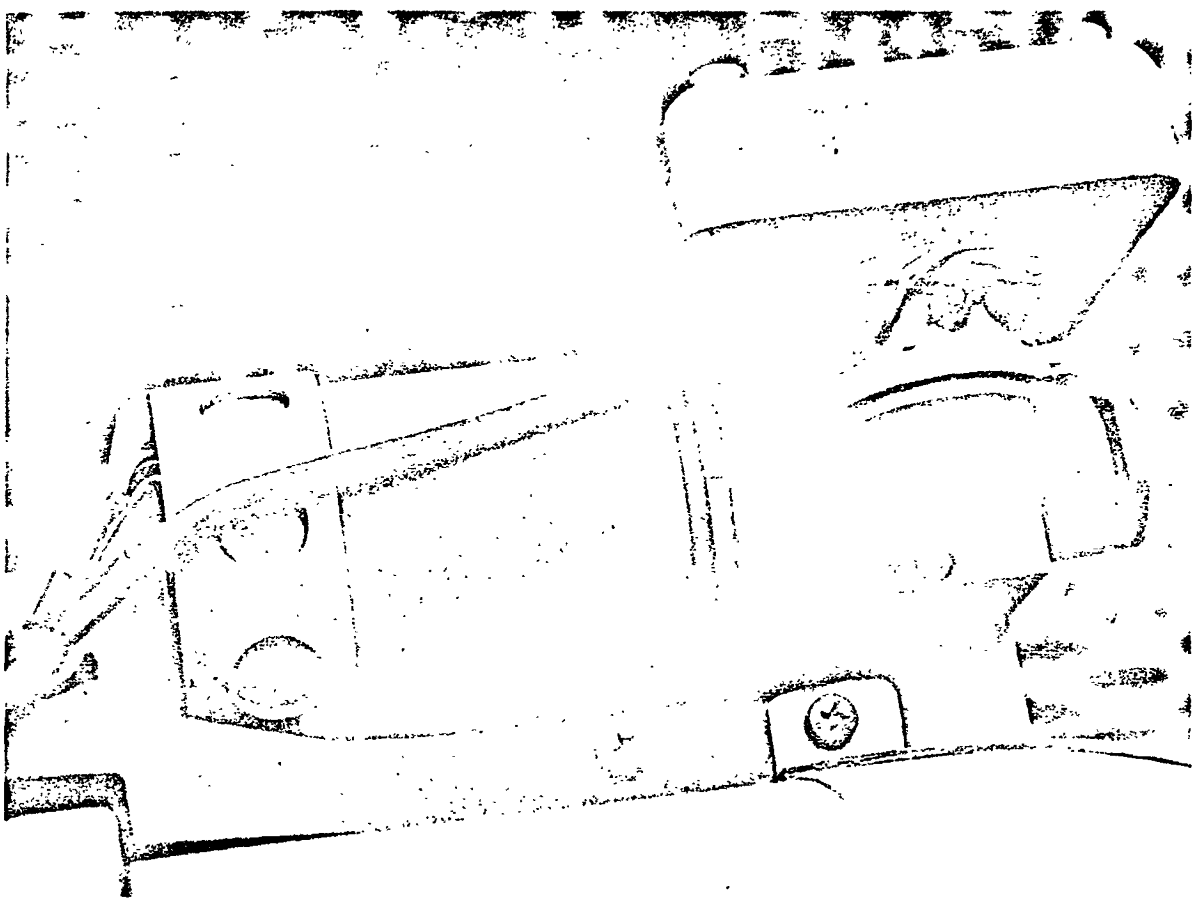


Figure J-7. Shadow Patterns on Elevation Drive Motor Housing (NASA Photo S-70-21149)

the surface. Portions of this cable had been cut free during recovery, but the image of the cable remained on the surface where the cable had been during the camera's lunar stay.

Another set of clear shadow patterns was found to be associated with the elevation motor housing located on the mirror assembly on the north (lunar) side of the camera as shown in Figure J-7.* A clear pattern, much darker, is seen just below the wire running alongside the motor.

Investigation of these shadow patterns dominated the early stages of visual examination of the camera. Heads of the various screws were found imaged on the north side of the camera in the darkened painted surface. These patterns provided the first evidence that all of the shadows had a unique directional characteristic. By visual sighting, it was possible to take a position such that all the darkened patterns disappeared behind the object which they imaged. It was independently discovered by Hughes and by MSC personnel that the shadow patterns were uniquely associated

*Original in color.

with the lunar module landing position. It was assumed at that time that the landing of the lunar module caused a severe dust storm which impinged upon the Surveyor III and sandblasted the surface, removing either earlier deposited debris (dust) or radiation damaged paint and/or contaminants. Subsequent measurements by L. D. Jaffe (JPL) at Hughes identified the coordinates of the origin of the shadows as approximately 90 degrees azimuth and 29 degrees elevation (camera lower shroud coordinates).

J.3 OPTICAL DAMAGE OF SURVEYOR INORGANIC WHITE PAINT

Laboratory tests were conducted before Surveyor launch to determine the ultraviolet radiation stability of the Surveyor inorganic white paint. Ultraviolet tests were conducted at Hughes up to 1000 hours duration, as discussed in Reference 109 using a type BH6 mercury arc lamp. The spectral reflectance measurements were made in air. In 1966, an ultraviolet test was conducted at Hughes with spectral reflectance measurements made in vacuum (Reference 110). This test was also conducted using a mercury arc lamp.

These test data indicate an increase in solar absorptance of the paint of ~0.05 in 1000 hours. More important, the test showed that this paint did not exhibit any air bleaching as a result of ultraviolet irradiation.

In 1967, a test was conducted at the Illinois Institute of Technology Research Institute for 2800 hours, using a mercury arc lamp. This test, discussed in Reference 111, was performed with all spectral reflectance measurements made in vacuum. Confirmation was obtained that upon admitting air to the chamber the coating did not show any bleaching or ultraviolet damage.

The spectral character of the damage in the Surveyor inorganic white paint is illustrated in Figure J-8.

The influence of low energy protons, a significant lunar environment factor, on the Surveyor inorganic white paint had not been determined prior to flight. With the return of the Surveyor parts, the question arose concerning the effect of solar wind protons. A test was conducted at Hughes (1970) on a sample painted in 1965 and stored in the dark, free of airborne contaminants. The sample was irradiated at a flux of 1.3×10^{11} protons/cm^2/sec to a total fluence of 2.2×10^{16} protons/cm^2. The optical properties were measured in air to simulate return of the Surveyor parts. It was found that there was no optical damage over the spectral region of interest, 0.3 to 2.6 microns.

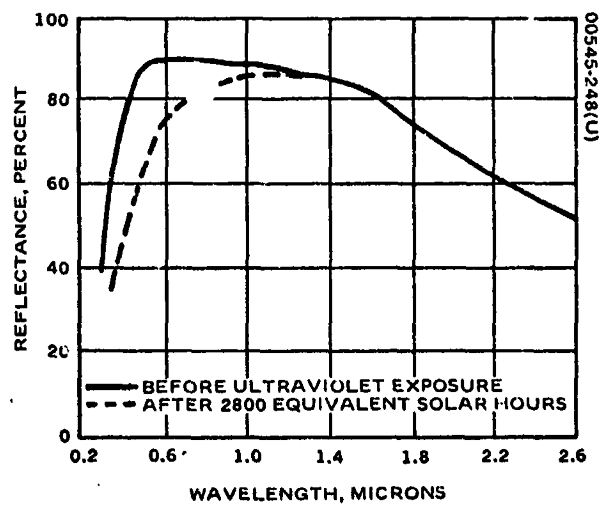


Figure J-8. Spectral Reflectance of White Inorganic Paint Before and After Laboratory Ultraviolet Exposure

J.4 DISCUSSION OF TEST RESULTS

A number of tests were conducted in support of the contamination study. These tests are described in this appendix, and detailed data obtained from each test are presented. The tests are presented in order of actual accomplishment.

J.4.1 Reflectance Measurements of Lower Shroud*

The first series of spectral reflectance measurements on the camera was made on the lower shroud on 28 April 1970. From January 1970 until that time, the shroud was exposed to the fluorescent lighting of a laminar flow bench. It was, however, shielded from the blowing air by a shield of teflon film.

*Conducted by TRW, Inc. on a Hughes subcontract.

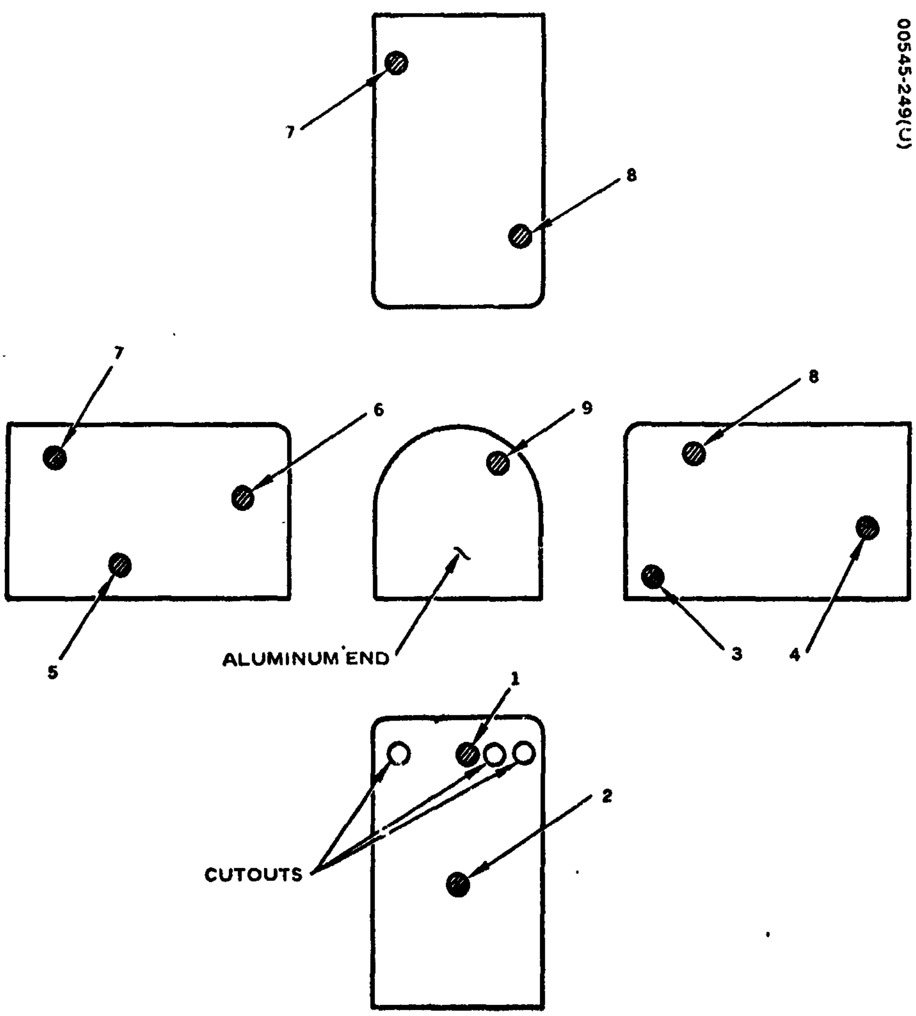


Figure J-9. Lower Shroud of Surveyor III Camera, Showing TRW Measurement Positions (See Text)

This set of measurements was made by TRW at a number of positions on the lower shroud, using a wall-mount integrating sphere. The positions of each measurement are sketched on Figure J-9. Figure J-10 presents spectral plots of these measurements. Table J-1 shows the emittance of each position as measured using a Gier-Dunkle emittance inspection device, model DB-100.

J.4.2 White Painted Tube Section Returned in Vacuum

A 4 inch section from a TV camera support strut was removed by the astronauts and placed in a sample environmental sealed container (SESC). Also included in this container was a section of the teflon wrapped cable from the camera. It was the intent of this experiment to remove both the white painted (inorganic) tube and the teflon FEP cable wrap from the sealed container for a series of optical measurements. The parts were to be maintained under vacuum with no exposure to light. The original test plan called for removal of both test parts from the SESC in a vacuum environment (glove box) and subsequent transfer to vacuum containers for optical measurements (spectral reflectance from 0.25 to 2.5 microns). The transfer was to be accomplished under low level red light illumination, thereby minimizing any photo-induced bleaching.

TABLE J-1. NORMAL EMITTANCE MEASURED ON LOWER SHROUD SURFACE

TRW Position (see Figure J-9)	Normal Emittance
1	0.92_0*
2	0.92_8
3	0.92_0
4	0.92_9
5	0.92_6
6	0.92_0
7	0.92_5
8	0.92_7
9**	0.09_3
Reference paint sample	0.92_0

*Although the accuracy of the measuring instruments does not justify three significant figures, the third figure is retained depressed to indicate trends.

**Note that this was polished aluminum surface.

Lack of equipment availability precluded the transfer of parts in vacuum; thus, the transfer was to be done under inert atmosphere (argon). The facilities, leak checking, and opening of the SESC were provided by and done at JPL. The sectioning of the tube and teflon and the placement of samples in the new test chambers were performed by Hughes and TRW. All facilities and techniques employed including leak checking are described in Reference 112 and are only summarized in this report.

Prior to opening, the SESC was leak checked in May 1970. The returned container from the neon was placed into a vacuum-tight container which was evacuated. This container was then backfilled with SF_6 at 100 mm of mercury over atmospheric pressure and held for 30 hours. The SESC was removed and leak checked; a major leak was found in the SESC in the area of the indium seal. The conclusion was that the leak had existed for some time and had probably been returned from the moon in this condition. Thus, the white paint and teflon both were exposed to air for several months. The vacuum test was lost. However, it was decided to conduct the test sequence per plan; accordingly, the SESC was opened and the samples placed into vacuum chambers.

The interior of the inert atmosphere chamber was sterilized prior to establishment of the inert atmosphere. The O_2, H_2, N_2, H_2O, and hydrocarbon content of the inert gas was monitored during the opening. Total impurities were less than 20 ppm.

The SESC was opened 29 May 1970. The H_2O level rose to 50 ppm and the O_2 to 11 ppm. It was suspected that higher readings of O_2 were not obtained because of the presence of SF_6 in the container, displacing most of the O_2.

A section of white painted tube about 4 inches long was found in the container. The tube was cut into two sections with a jeweler's saw. The longer section (about 3 inches) was placed in a quartz vacuum chamber (Figure J-11) to which a high vacuum valve was connected. The tube section was firmly mounted in place and sealed shut, enclosing the argon inside. A light-tight envelope was placed around the quartz tube.

A section of the teflon wrap was cut from the cable for mounting in a similar vacuum tube. Two sections of teflon about 1 inch by 1 inch were firmly mounted in the second vacuum-tight quartz tube. The chamber was sealed and made light-tight.

The above operations were conducted under very low red light illumination.

The two sealed chambers containing the test specimens were removed from the inert atmosphere chamber and taken to TRW where the initial optical measurements were to be made.* Shortly after reaching TRW, the chambers were evacuated without allowing any oxygen to reach the samples. The samples were retained in darkness, and grounded screens

*These measurements were made at TRW, Inc. under a Hughes subcontract.

FOLDOUT FRAME

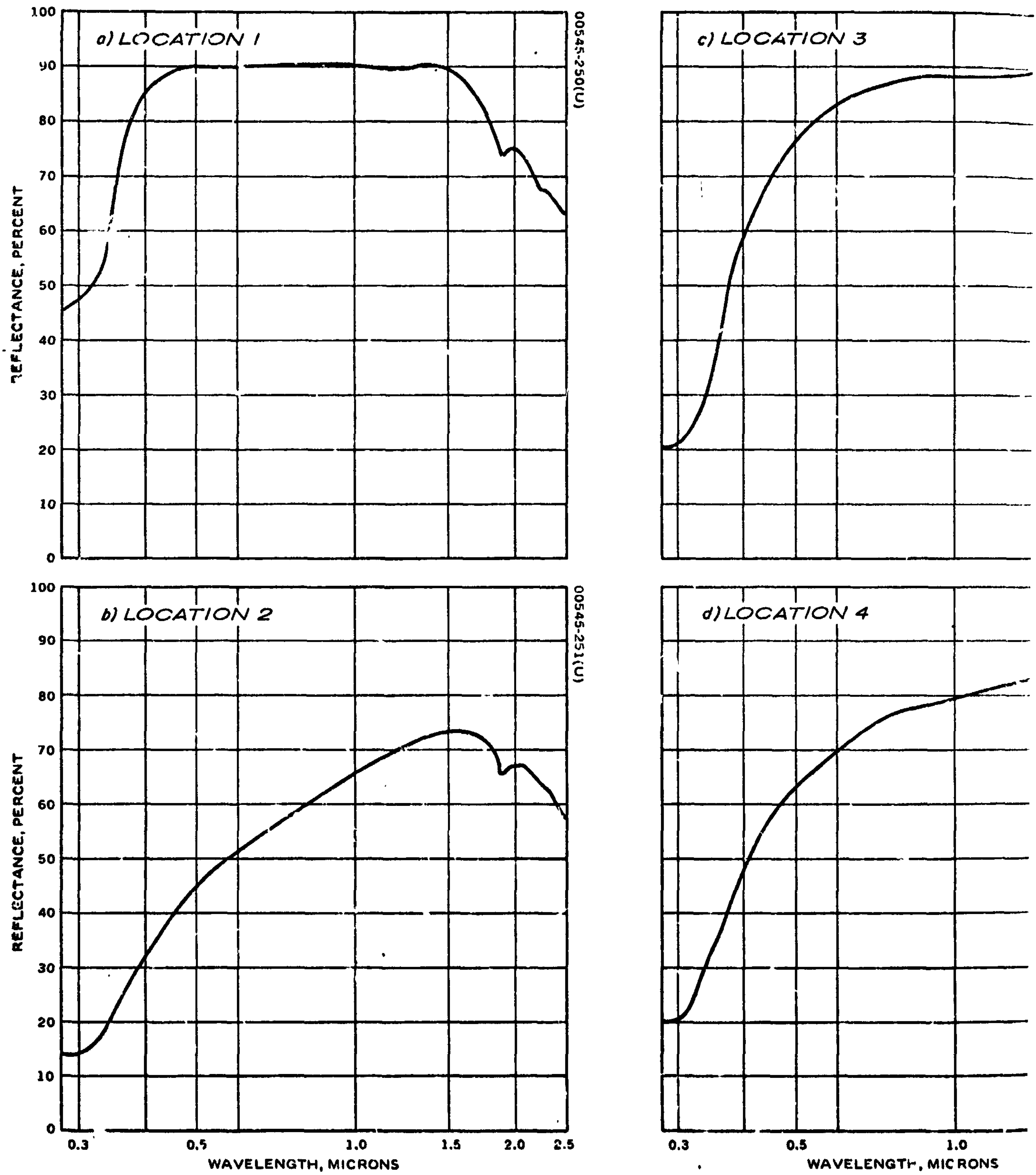
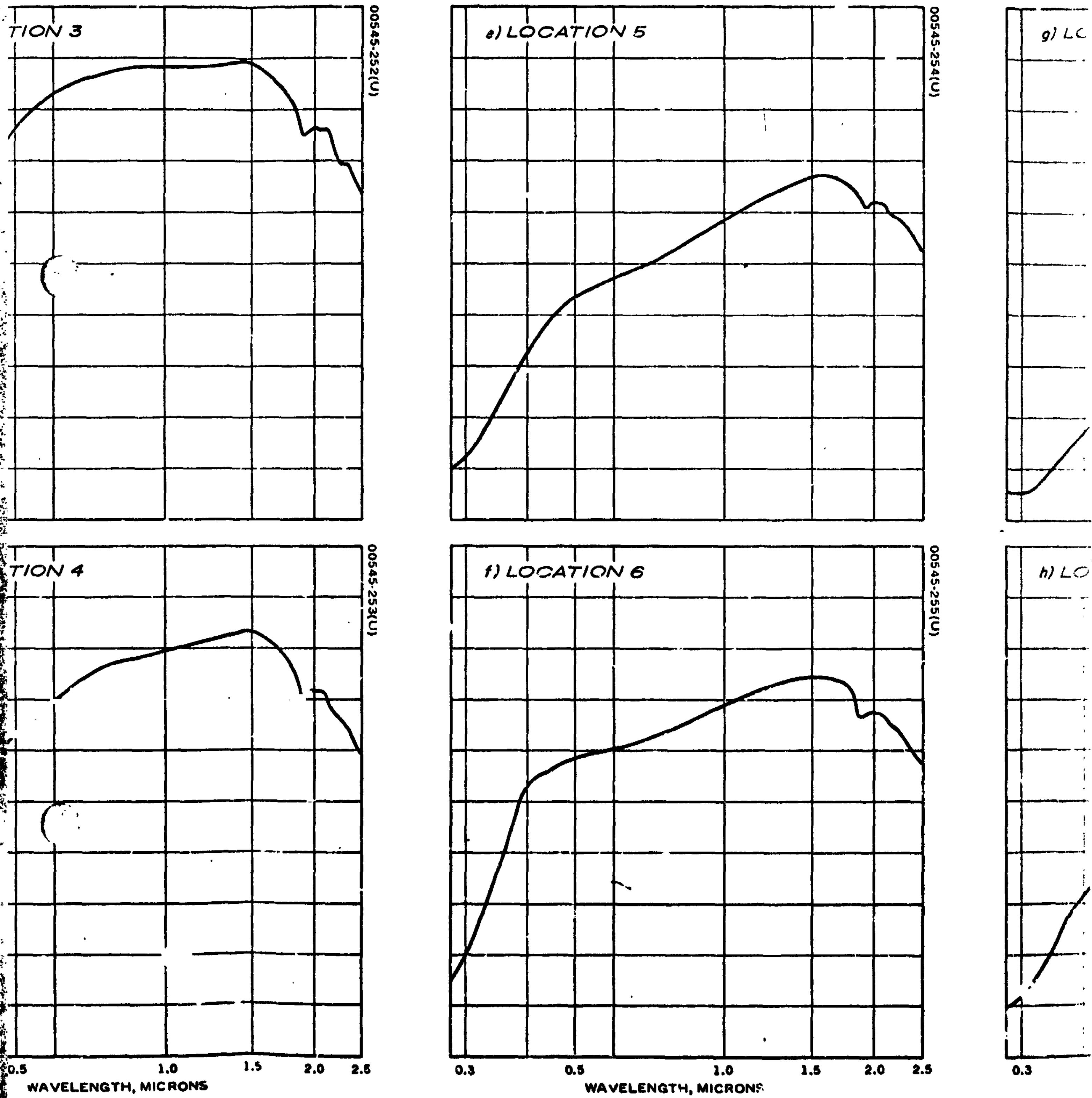


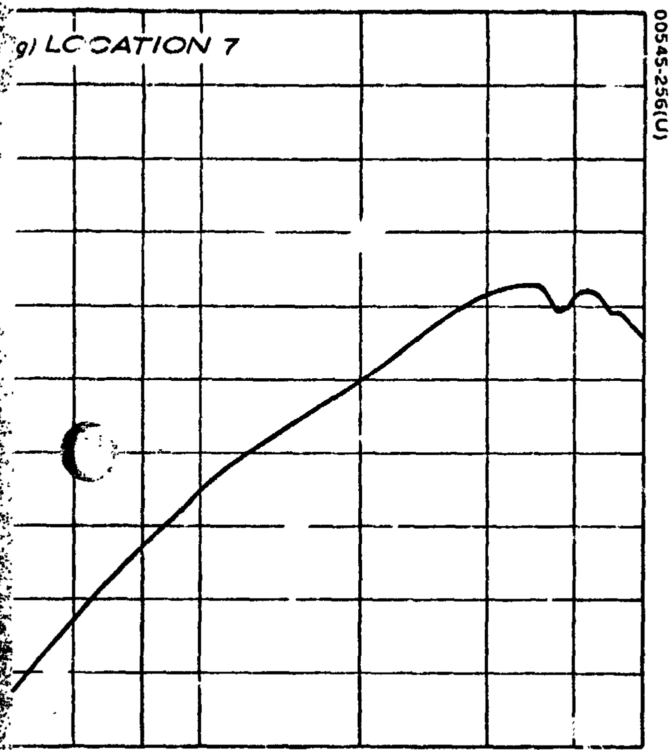
Figure J-10. Reflectance Versus Wavelength of Surveyor III Camera Lower Shroud at Various TRW Locations Show

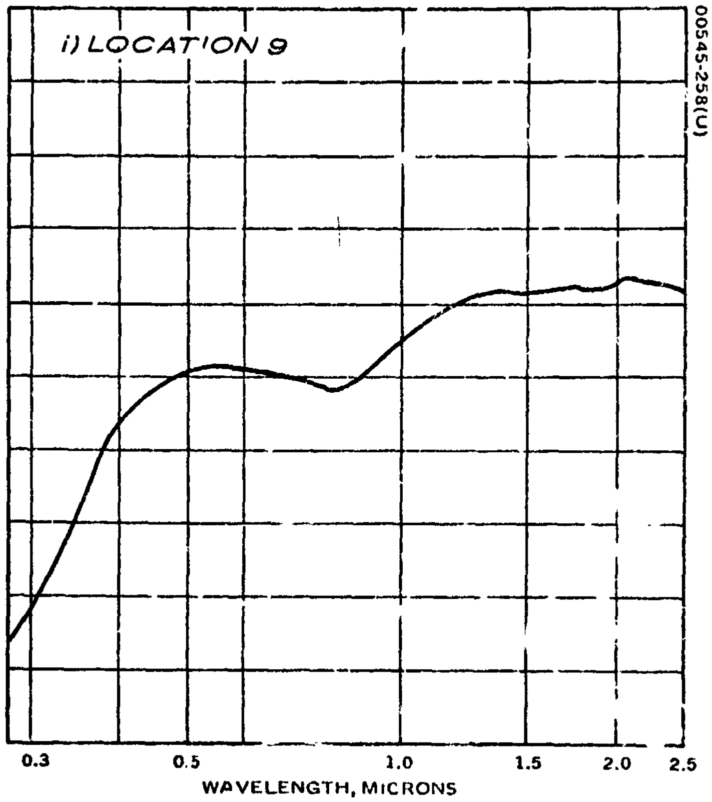
FOLDOUT FRAME 2

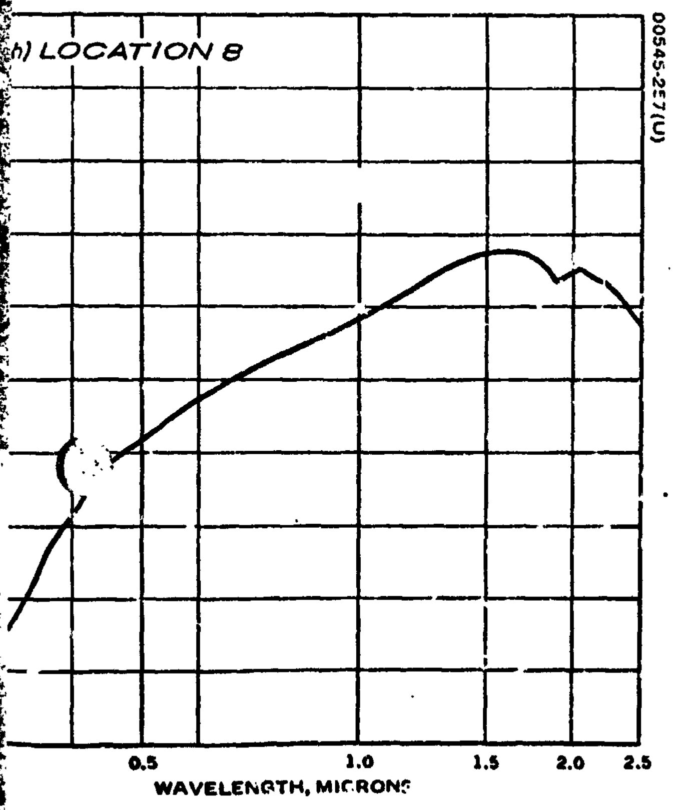


t Various TRW Locations Shown in Figure J-9

FOLDOUT FRAME 3







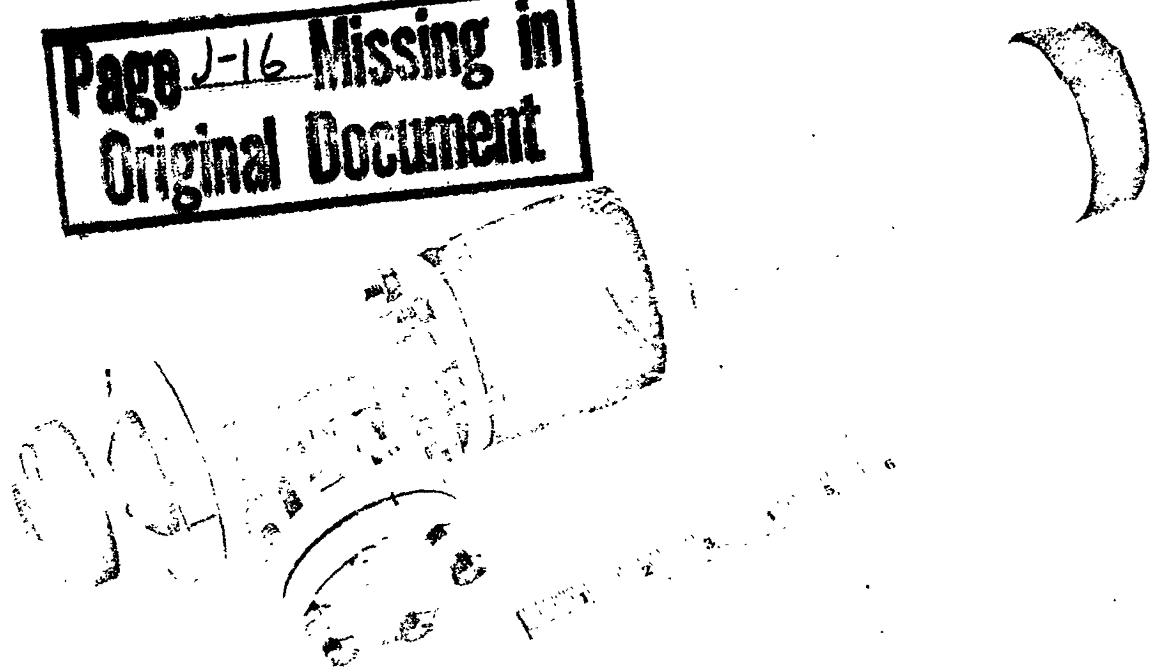


Figure J-11. Quartz Chamber With Light-Tight Shield for Vacuum Tests of White Painted Tube (Photo 4R18635)

were placed in the ion pump throats to ensure that the samples were not exposed to the glow discharge during startup of the ion pump.

The spectral reflectance of the tube was measured around the circumference at 90 degree increments, while the sample was maintained at 5×10^{-7} Torr. The measurements were made by positioning the quartz chamber in an Edwards integrating sphere. Room lights were off during these operations; only dim red light was used to position the sample. It was not possible to rotate the quartz chamber so that each measurement would be made in the same plane. The chamber was raised and lowered so that about 0.63 inch separated the uppermost and lowest measurement. Figure J-12 is a sketch of the tube showing measurement orientation.

At the completion of these vacuum measurements, a leak valve attached to the system was opened and the pressure in the quartz tube was raised to about 10 microns of Hg (10^{-2} Torr). Each sample position was remeasured for optical reflectance. Again, no light was allowed to reach the sample tube except that of the monochromatic spectrophotometer beam. Following this set of measurements, air was admitted to the chamber, bringing the pressure up to 1 atm. The spectral reflectance at four sample positions was measured again. The samples then sat at 1 atm for 6 days in the dark.

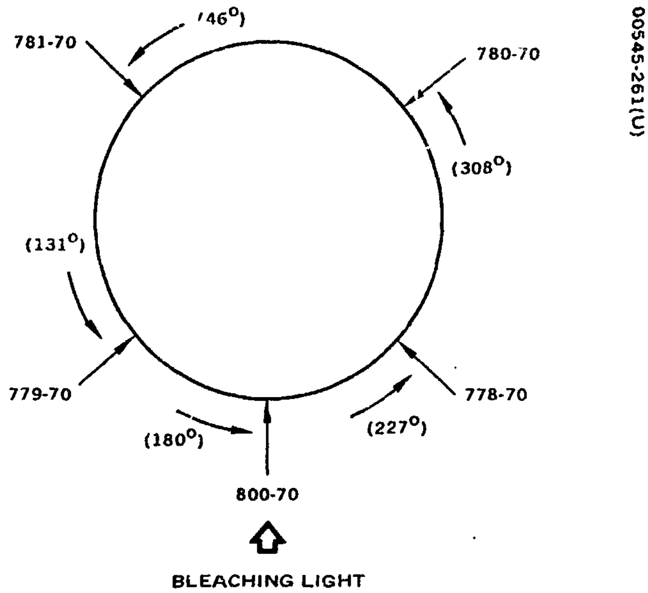


Figure J-12. Sketch of White Painted Section of Tube Returned in SESC Showing Measurement Positions

The spectral reflectance was again measured of the sample position 778-70 shown in Figure J-12. The tube was then exposed to light at position 800-70 from a xenon arc lamp through a Corning CS3-74 yellow filter. This filter removed all illuminating wavelengths less than 0.4 micron. The irradiance for the 48 hour period was 214 mw/cm^2. The surface of the sample tube closest to the irradiating source (Figure J-12) was halfway between two of the positions which had previously been measured. Following the 48 hour exposure spectral reflectance measurements were again made at the four positions previously measured. A measurement was also made at the surface closest to the irradiating source (sample position 800-70 on Figure J-12).

Results of the measurements of the spectral reflectance of the white painted tube, discussed above, are presented in Figures J-13 through J-18. Figure J-13 shows the reflectance versus wave length of the four samples measured in vacuum prior to exposure. Figure J-14 shows the reflectance after partial pressurization at relatively low pressures. Figure J-15 shows reflectance of the four samples after they were exposed to 1 atm, still prior to any light exposure. Figure J-16 shows the reflectance of one of the samples after 6 days exposure at 1 atm. Figure J-17 shows reflectance of another sample from a different portion of Figure J-12 taken after an exposure to light for 48 hours at 1 atm. Figure J-18 shows reflectance of the original four samples at 1 atm after they had been exposed to 48 hours of light.

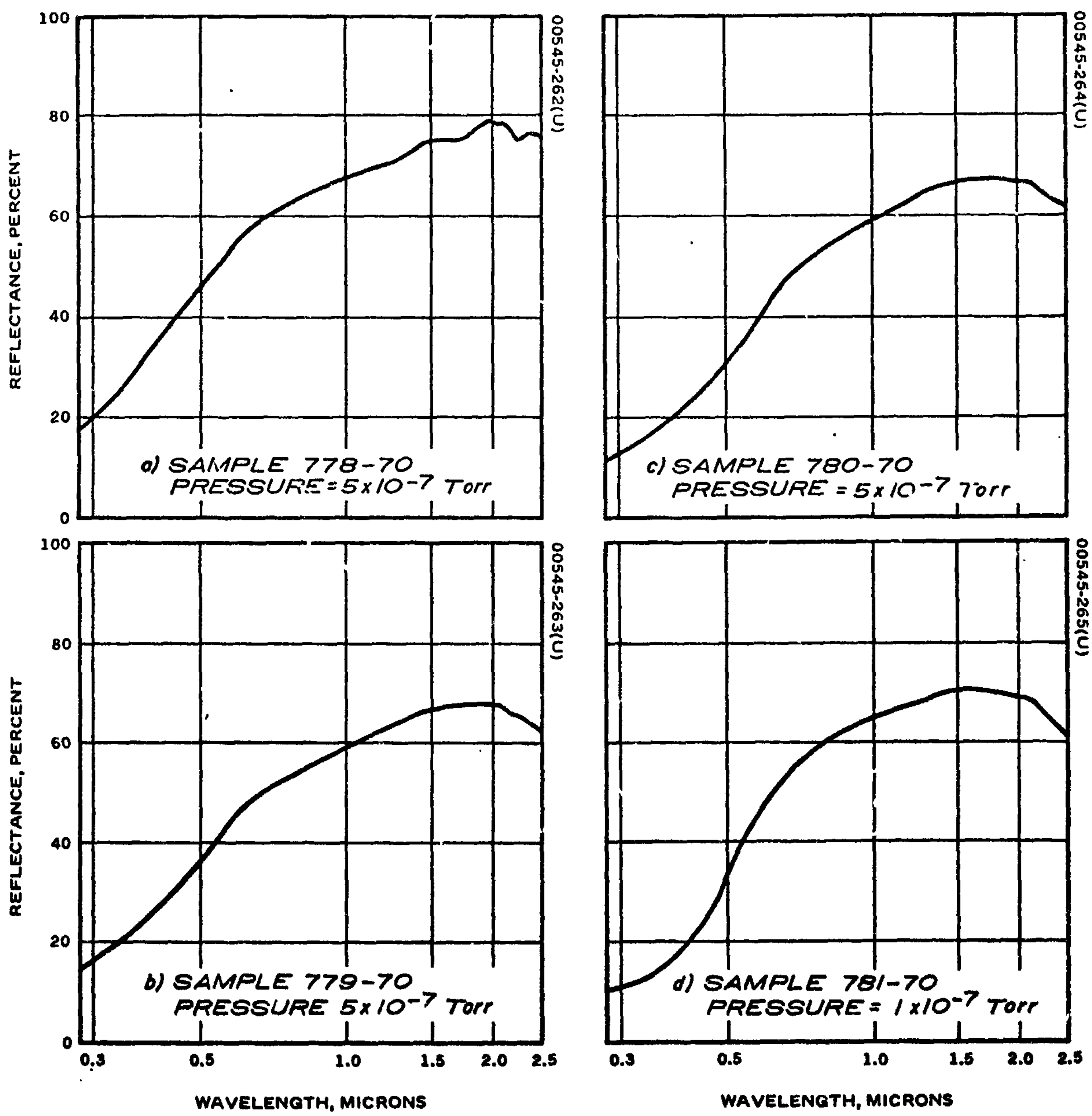


Figure J-13. Spectral Reflectance Versus Wavelength of Four Samples of White Painted Tube — High Vacuum, Prior to Light Exposure

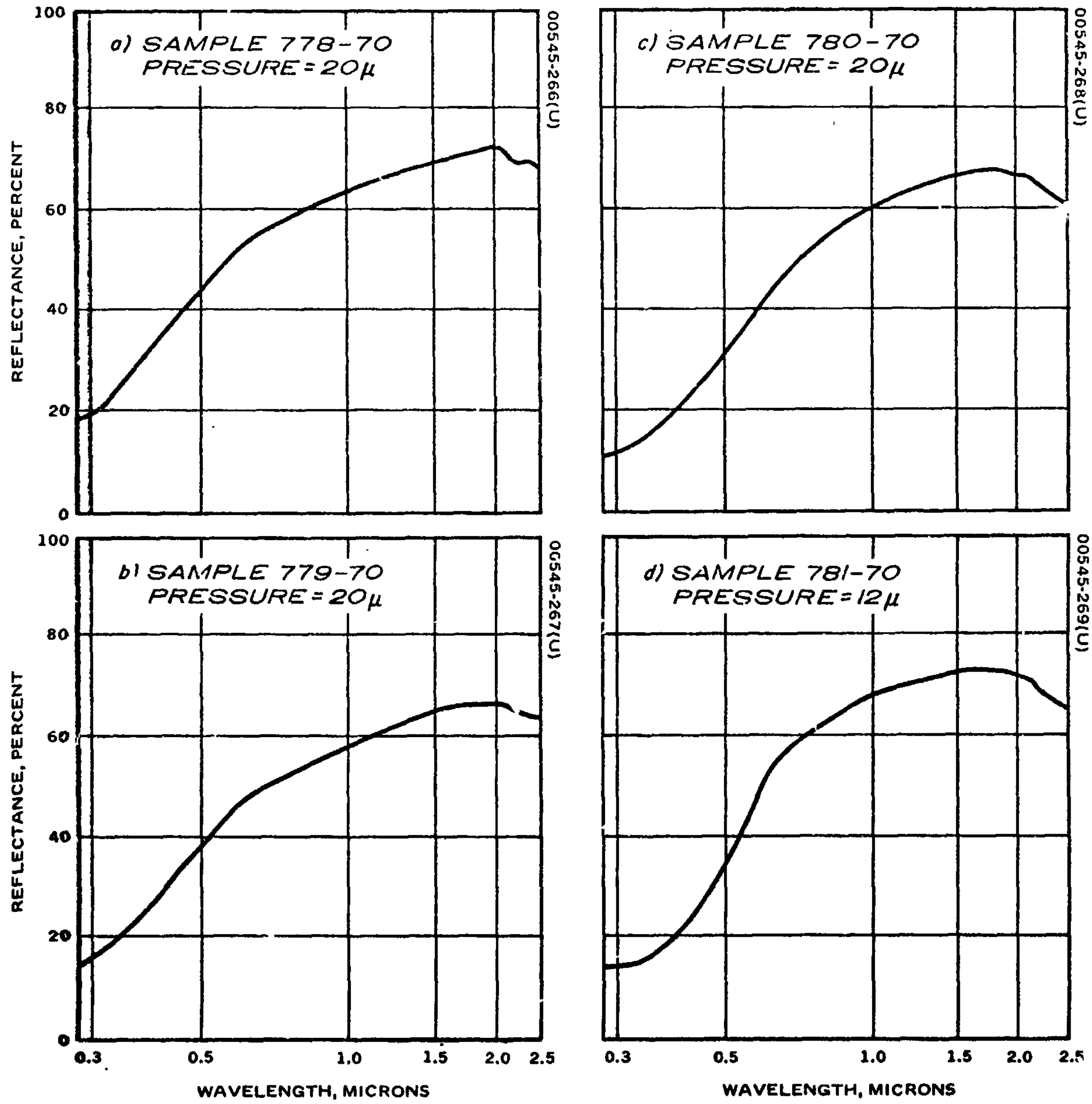


Figure J-14. Spectral Reflectance Versus Wavelength of Four Samples of White Painted Tube – Medium Vacuum, Prior to Light Expcsure

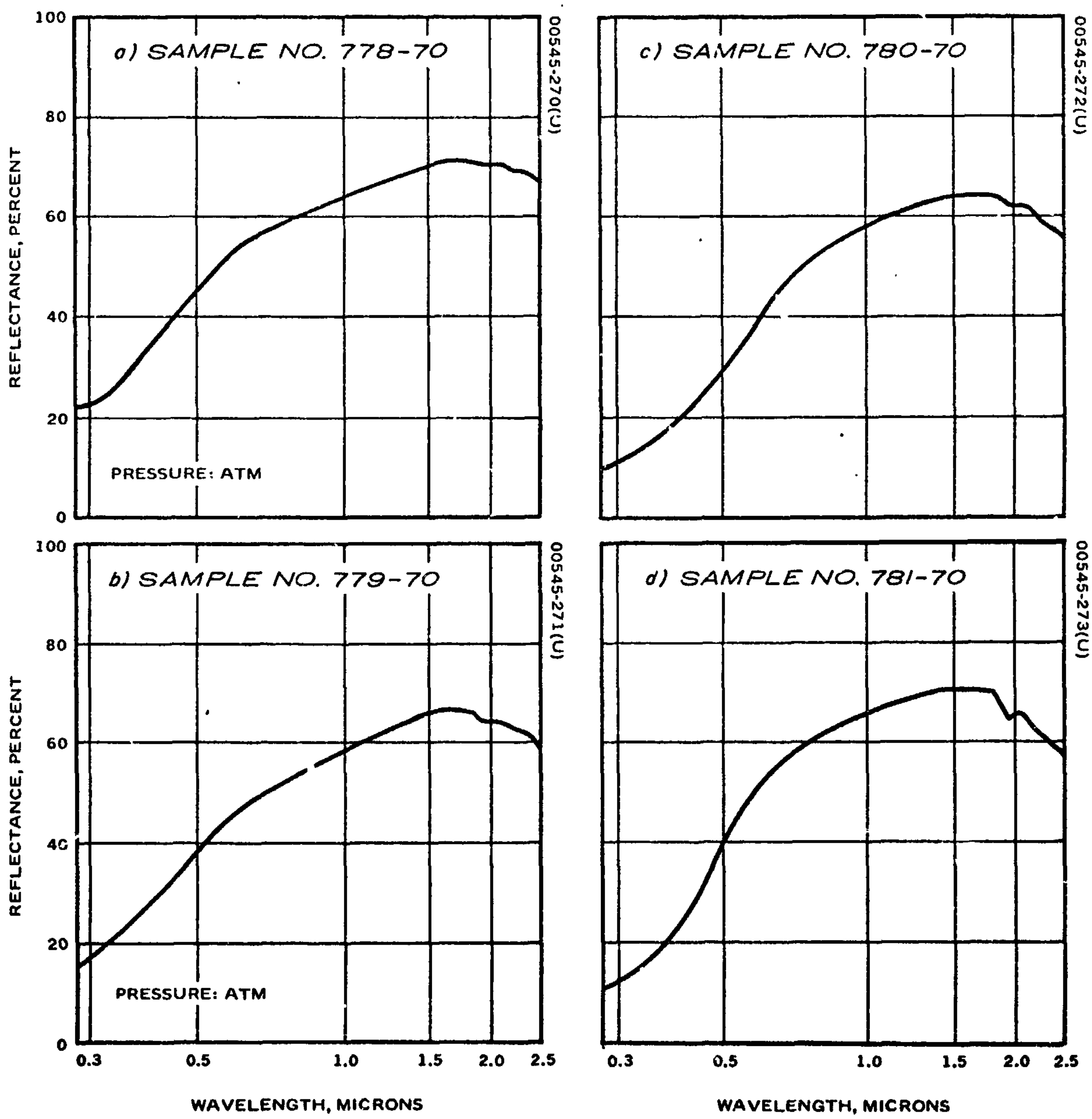


Figure J-15. Spectral Reflectance Versus Wavelength of Four Samples of White Painted Tube – 1 Atmosphere, Prior to Light Exposure

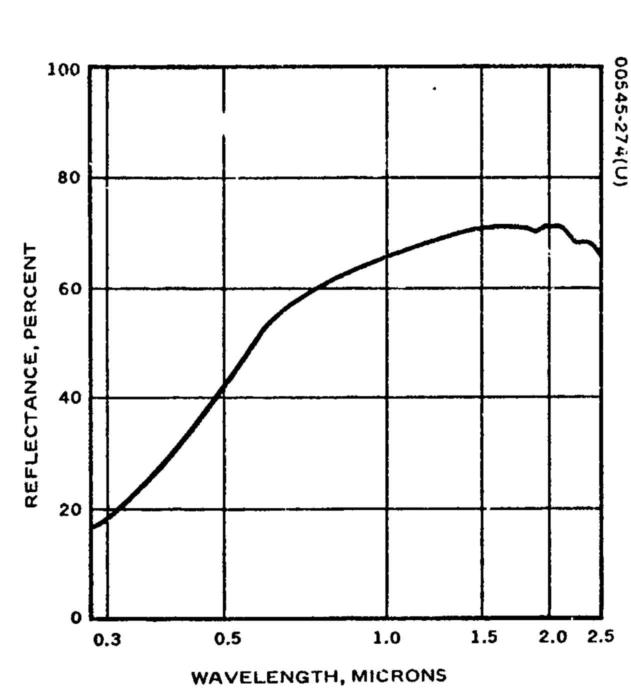


Figure J-16. Spectral Reflectance Versus Wavelength of One Sample of White Painted Tube: Sample 778-70 After 6 Days at 1 Atmosphere. Prior to Light Exposure

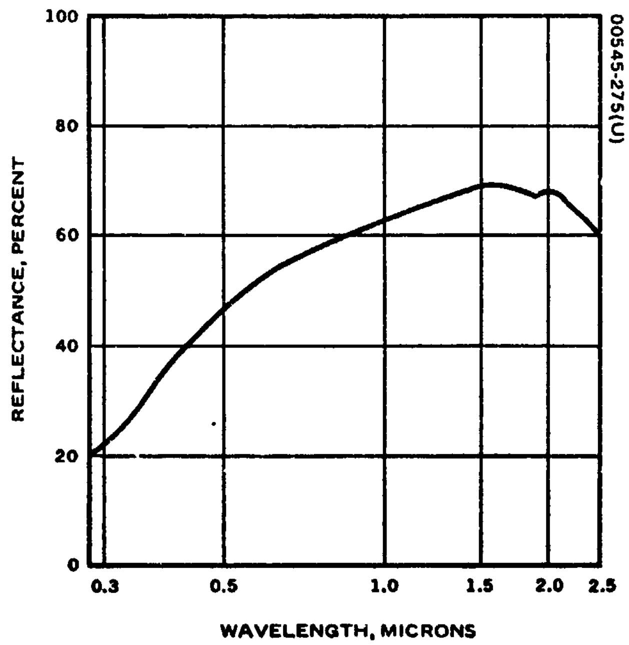


Figure J-17. Spectral Reflectance Versus Wavelength of a Different Sample of White Painted Tube: Sample 800-70 in Figure J-12 After 48 Hours Exposure to Light at 1 Atmosphere

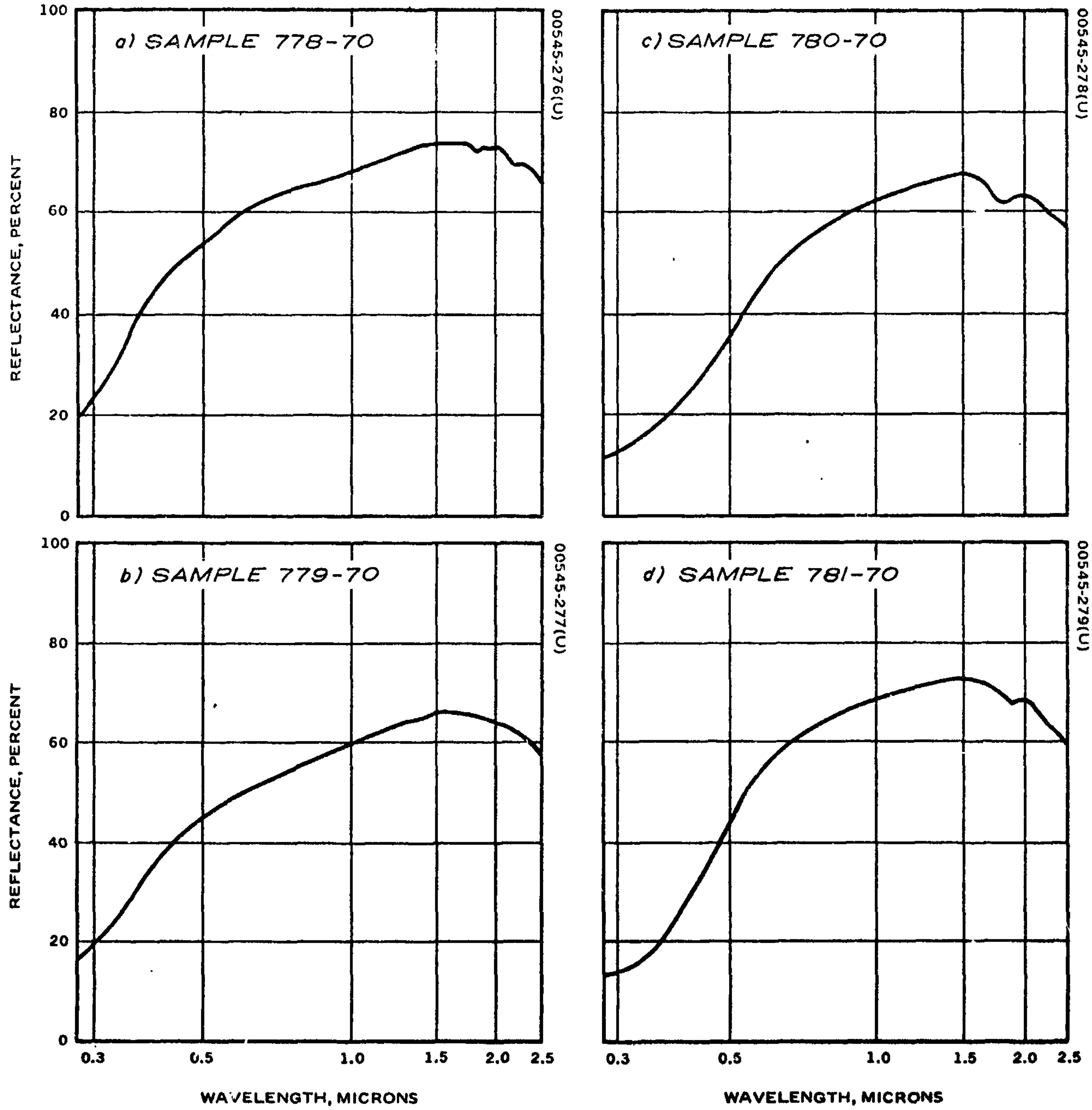


Figure J-18. Spectral Reflectance Versus Wavelength of Four Samples of White Painted Tube After 48 Hours Exposure to Light at 1 Atmosphere

J.4.3 Reflectance of Cable Bracket From Lower Shroud

The bracket shown in Figure J-19* used to attach the TV camera cables to the lower shroud was removed from the camera at the LRL on 6 January 1970. It was wrapped in teflon FEP film and stored in the dark. In May 1970, the bracket was removed from the dark for examination. A large disparity was found in the color of the bracket and that of the lower shroud of the camera. When the bracket was removed initially, the surface of the camera and bracket were a similar brown tone. In May, the shroud was found to be much lighter, with the bracket appearing to be the same color as it was upon the first viewing of the Surveyor III hardware in January 1970. This difference in color is shown in Figure J-20.*

The four test coupons were cut from the bracket, as shown in Figure J-21. Each sample was 1 by 2 cm. The spectral reflectance of these four coupons was measured. One sample, 518 in Figure J-21, was examined with a scanning electron microscope for the presence of lunar soil. Lunar material could not be distinguished from the paint. This was due to the charge buildup in the paint and lunar soil. All samples were then stored in the dark for 3-1/2 months, after which the spectral reflectance was remeasured. The original measurements of spectral reflectance versus wavelength conducted in May 1970 on one of the above samples, 518 mentioned above, are plotted in Figure J-22. Results obtained 3-1/2 months later in August 1970 showed no appreciable change. Results of spectral

*Original in color.

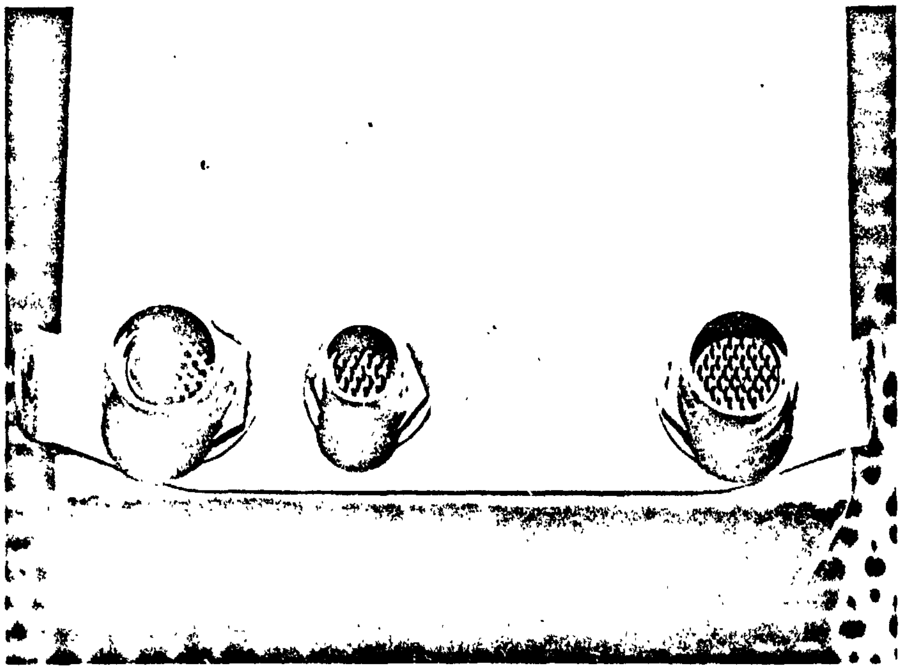


Figure J-19. Lower Shroud of Surveyor III Camera With Attached Cable Bracket Upon Return From Moon (NASA Photo S-70-21142) reflectance on the other three samples both in May and in August 1970 were similar to those of Figure J-22.

In November 1970, samples 519 and 521 were selected for controlled exposure to fluorescent lights. The samples were remeasured (they were still in dark storage) for spectral reflectance and then exposed to fluorescent light of a laminar flow bench for 72 hours. One sample (521) was double-bagged in polyethylene, with a total thickness of 0.012 inch of clear polyethylene bag separating the sample from the fluorescent lighting. Both

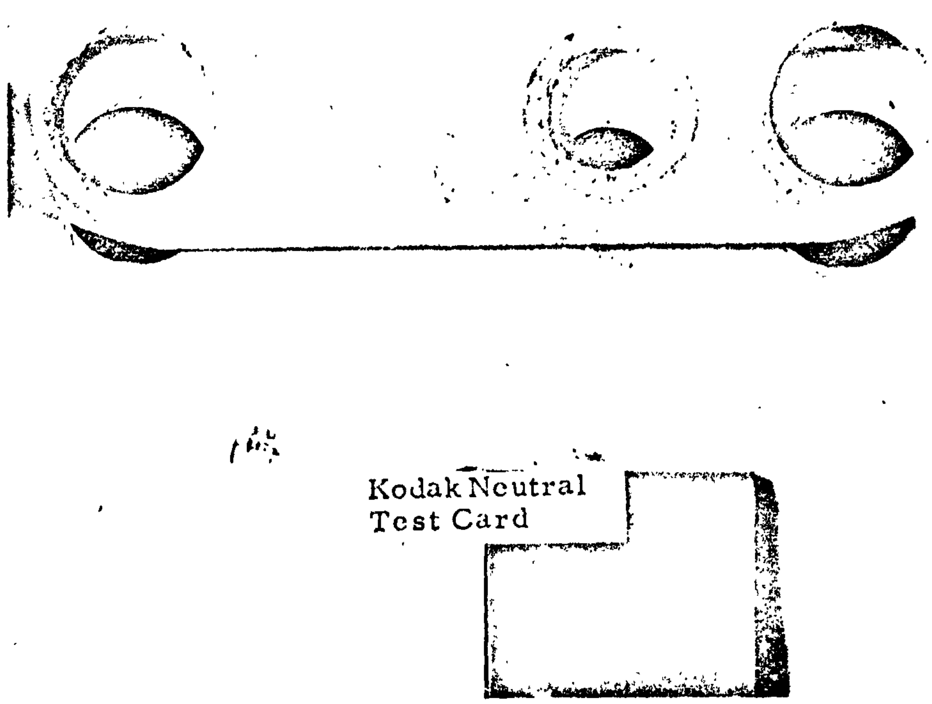


Figure J-20. Cable Bracket Superimposed on Lower Shroud of Surveyor III Television Camera: Shroud Exposed to Light for About 5 Months, Cable Bracket Unexposed (Photo 70-5364)

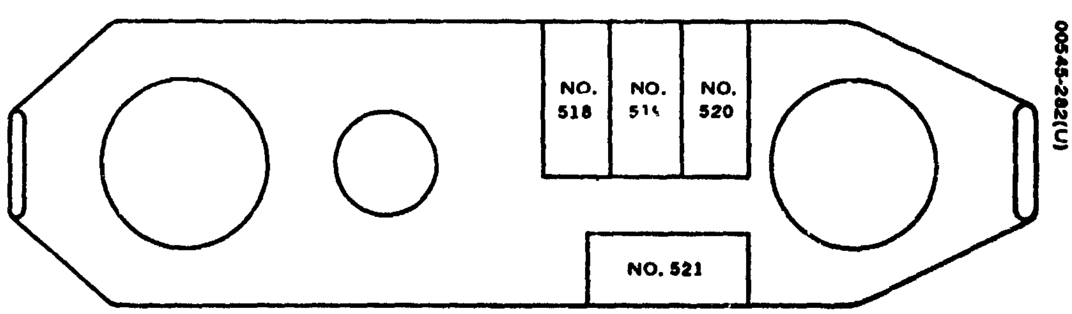


Figure J-21. Location of Samples Cut From Cable Bracket

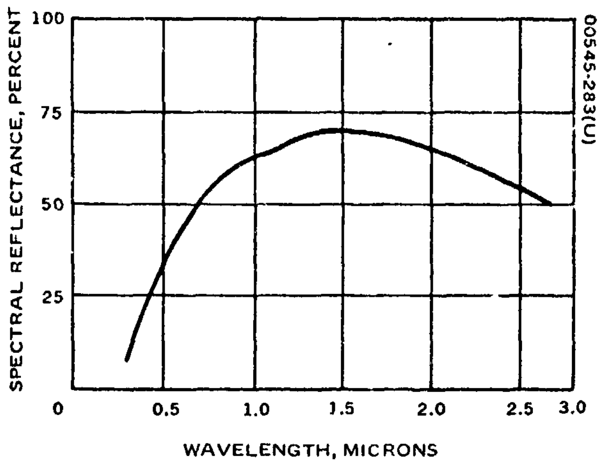


Figure J-22. Spectral Reflectance Versus Wavelength of Sample of Camera Cable Bracket: Sample 518 of Figure J-21: Measurements Taken in May 1970 Prior to Light Exposure

samples were protected with a 0.002 inch thickness of clear teflon FEP film to prevent dust fallout during storage and transit. The irradiance of white light reaching each sample was ~170 mw/cm^2. Following this exposure, the spectral reflectance of each sample was remeasured. The samples were returned to the laminar flow bench for an additional 14 days of exposure (17 days total) and then remeasured. Results of these measurements are shown in Table J-2.

J.4.4 Measurements of Samples of Camera Bipod Bracket Support Tube

In January 1970 when the TV camera was first disassembled, the support collar (Figure J-23)* which was used to attach the camera to the spaceframe was removed, wrapped in teflon FEP film, and stored in the dark. In July 1970, the long tube from the bipod bracket side of the clamp on the left side of Figure J-23 was cut off the assembly for a series of tests.

The bipod side of this assembly was located on the southern side of the spacecraft on the moon, and can be seen in Figure J-24 taken by the astronauts during Surveyor III hardware recovery.

The spectral reflectance of the tube was measured by mounting the tube vertically in a Gier-Dunkle integrating sphere. The tube had three different colors. The general overall color of the tube was light yellow. A dark gray region was noted on the westerly side of the tube, and a very dark yellow region was found on the easterly side. The reflectance was measured in each of these regions.

*Original in color.

TABLE J-2. PERCENT OF SPECTRAL REFLECTANCE VERSUS WAVELENGTH OF SAMPLES FROM SURVEYOR III CAMERA CONNECTOR BRACKET AFTER EXPOSURE TO WHITE LIGHT PHOTO BLEACHING

Wavelength, microns	Spectral Reflectance, percent					
	Before Exposure to Light		After 72 Hours Exposure to Light		After 17 Days Exposure to Light	
	Sample 519*	Sample 521**	Sample 519	Sample 521	Sample 519	Sample 521
0.295	9.0	10.0	12.0	10.0	17.0	14.0
0.355	20.0	18.0	18.0	16.5	28.0	28.0
0.400	25.0	22.0	26.0	23.0	39.0	36.0
0.430	28.5	27.0	28.0	29.5	46.0	45.0
0.458	33.0	33.5	35.0	35.5	47.0	47.5
0.484	35.5	37.0	39.0	38.5	49.0	47.0
0.511	40.5	40.0	42.0	42.0	56.0	50.0
0.540	44.0	45.0	46.0	46.0	56.0	[illegible]
0.569	47.0	49.0	49.0	49.5	56.0	55.5
0.598	49.0	52.0	51.5	51.0	62.0	58.0
0.630	52.0	53.5	54.5	55.0	63.0	60.0
0.664	55.0	58.0	58.0	58.0	64.0	60.0
0.700	60.0	58.0	59.0	58.0	67.0	61.0
0.738	60.0	59.0	60.0	60.0	67.0	62.0
0.781	67.0	62.0	62.0	62.0	70.0	63.0
0.828	66.0	66.0	65.0	64.0	70.0	63.0
0.880	67.0	65.5	67.0	65.0	72.0	64.0
0.940	70.0	67.0	69.0	68.5	73.9	66.0
1.011	71.0	68.0	70.0	70.0	74.0	67.0
1.096	71.0	72.0	72.0	72.0	75.0	71.0
1.200	74.0	75.0	75.0	73.0	75.0	74.0
1.341	75.0	75.0	74.0	73.0	75.0	74.0
1.536	74.0	72.5	73.5	74.0	75.0	70.0
1.854	68.5	65.5	67.0	68.0	71.0	68.0
2.600	55.0	55.0	57.0	56.5	51.0	56.0

*Sample 519 (Figure J-21) wrapped in polyethylene film.
**Sample 521 (Figure J-21) unwrapped.

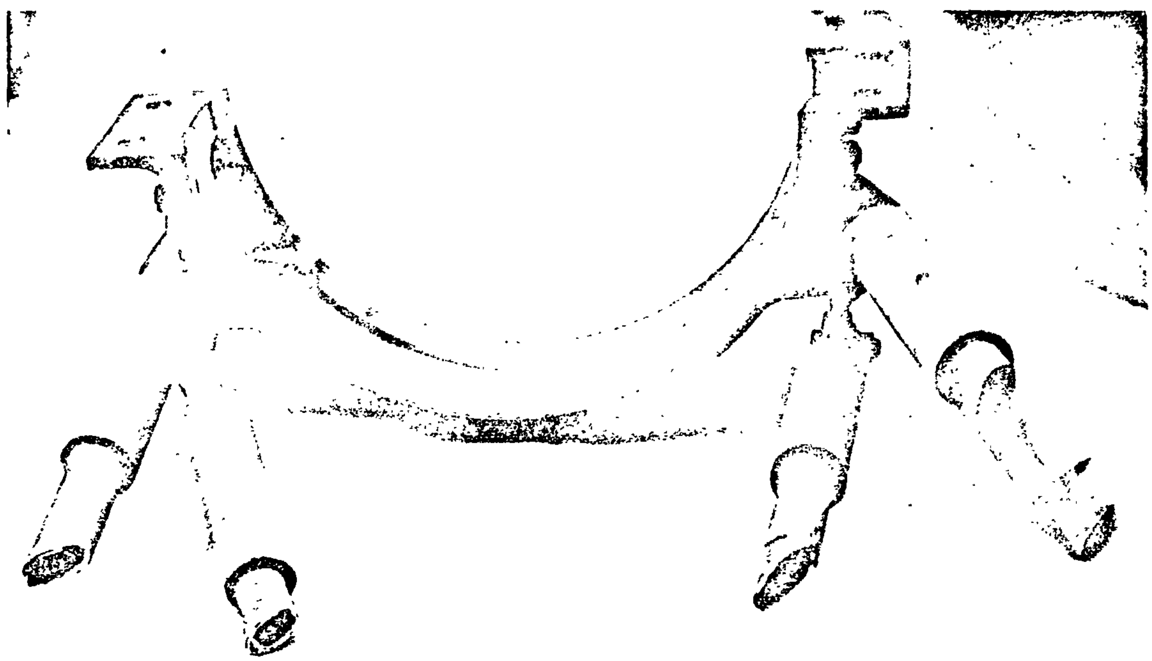


Figure J-23. Support Collar of Surveyor III Television Camera (NASA Photo S-70-21157)

The tube was then suspended in a beaker containing CCl_4 and soaked for 1 hour. To minimize the washing away of any lunar material on the surface, the tube was not agitated. The tube was gently removed from the beaker, air dried, and soaked again in fresh CCl_4, this time for 1-1/2 hours. During these experiments, the tube was maintained in the dark.

The CCl_4 was boiled down and evaporated on an NaCl window for infrared analysis. After the second soak in fresh CCl_4, no organic contaminant was found in the residue. Evidence of silicone was found in the residue from the first wash, but it is believed that faulty technique caused this contamination.

The spectral reflectance of the tube was remeasured at the same three positions on the tube following the CCl_4 soak. Following the solvent soak experiment, the sample was returned to dark storage.

In September 1970, the tube section was used in another experiment. The sample was suspended in air and heated overnight. The tube section was mounted in a glass test tube that was packed at the open end with glass

Figure J-24. Photograph of Surveyor III on the Moon, Showing TV Support Tubing (NASA Photo AS12-48-7115) wool to minimize air currents. A thermocouple was mechanically attached to the tube. The tube temperature was raised to 450°F. Fifteen hours later the temperature had fallen to 420°F due to room cooling. The average temperature for the 15 hours was about 425°F. The tube was maintained in the dark during this experiment. The sample was removed from the tube and the reflectance remeasured at the same three positions.

The data from all three reflectance versus wavelength measurements are shown in Figure J-25.

J.4.5 Thermal Annealing of Unexposed Surveyor White Paint

A thermal annealing test was conducted on a Surveyor inorganic white paint sample that had been stored free of airborne contaminant since painting in 1965. The sample was held in air overnight at 435°F, a time of about 18 hours. The spectral reflectance of this sample was measured before and after thermal exposure in a Gier-Dunkle integrating sphere. No significant spectral difference was noted from 0.3 to 1.3 micron. However, beyond 1.3, a significant increase occurred in the reflectance spectrum, with the reflectance at 2.6 microns increasing 14 percent. This increase was due to the release of chemically combined water in the clay-silicate system.

J.4.6 Reflectance of Surveyor III Samples Used in Science Studies

In accordance with the test plan, a number of samples were cut from the shrouds of the TV camera in July 1970 for use in science studies. The sample cutting is documented in proper files. The samples were photographed and then examined under a light microscope to 40X. The spectral reflectance of these samples was then measured in a Gier-Dunkle integrating sphere. The measurements were made during July 1970. Sample size for each experiment was 1 by 2 cm. Some samples were taken from positions on the lower shroud where earlier spectral reflectance measurements had been made (by TRW). Thus, a time comparison could be made of any change in reflectance from April to July 1970. Table J-3 lists the samples cut in July 1970, location on TV camera, and the corresponding TRW measurement position, if any. The spectral reflectance data for these samples are given in Table J-4. All samples but 894 were painted on the exterior with the Surveyor inorganic white paint. Sample 894 was polished aluminum. Samples 906, 907, 908, and 909 were coated on the interior side with an organic optical black paint. The reflectance of both sides of these samples was measured.

Additional samples were selected and removed from the lower shroud for spectral reflectance measurements in October 1970. Position selection was as close as possible to the TRW positions shown in Figure J-9. Sample size was again 1 by 2 cm. Reflectance measurements were made in

FOLDOUT FRAME 1

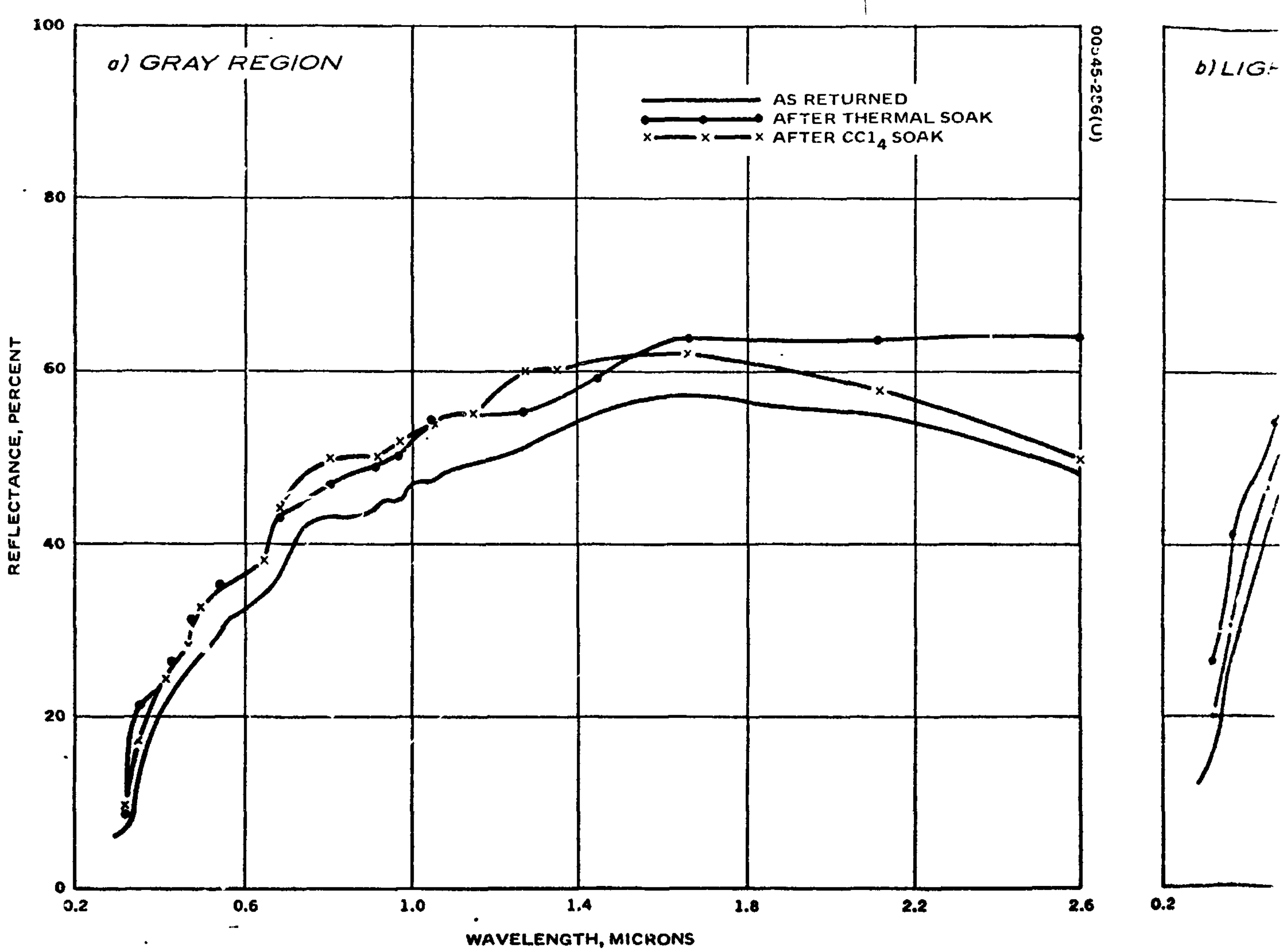
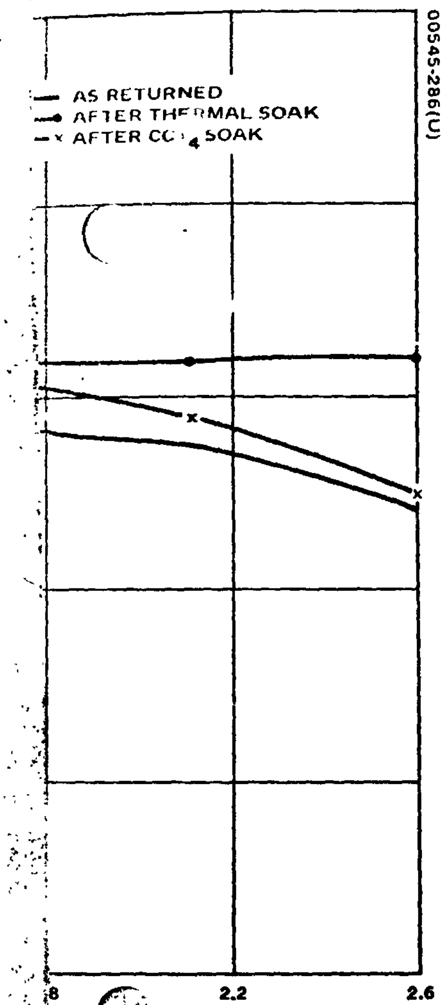
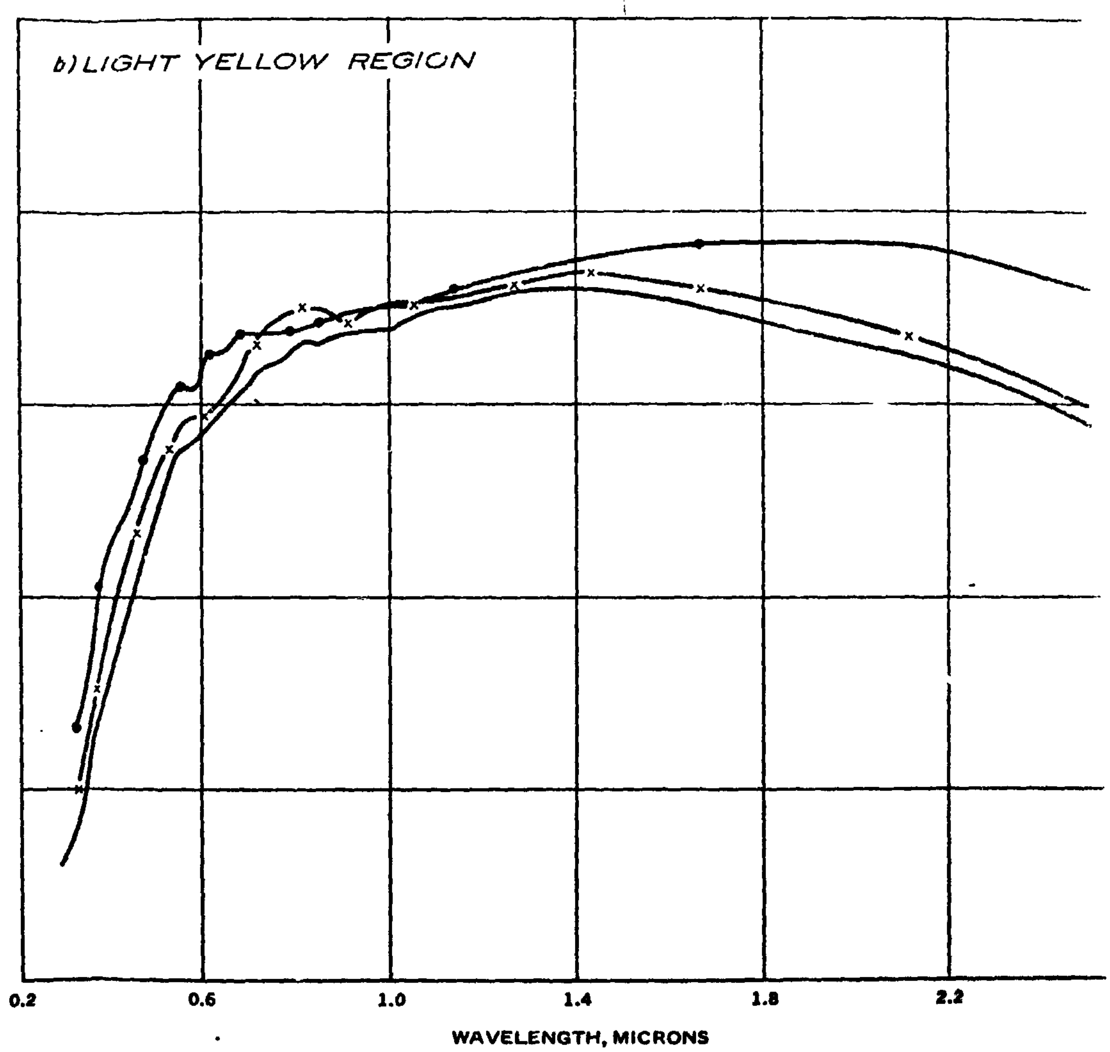


Figure J-25. Reflectance of Bipod Bracket Tube

FOLDOUT FRAME 2





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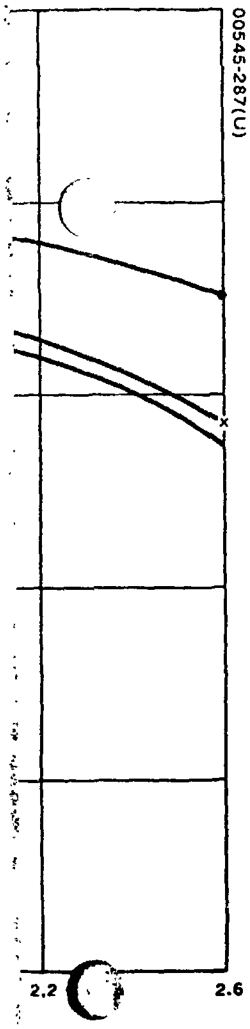
FOLDOUT FRAME 3



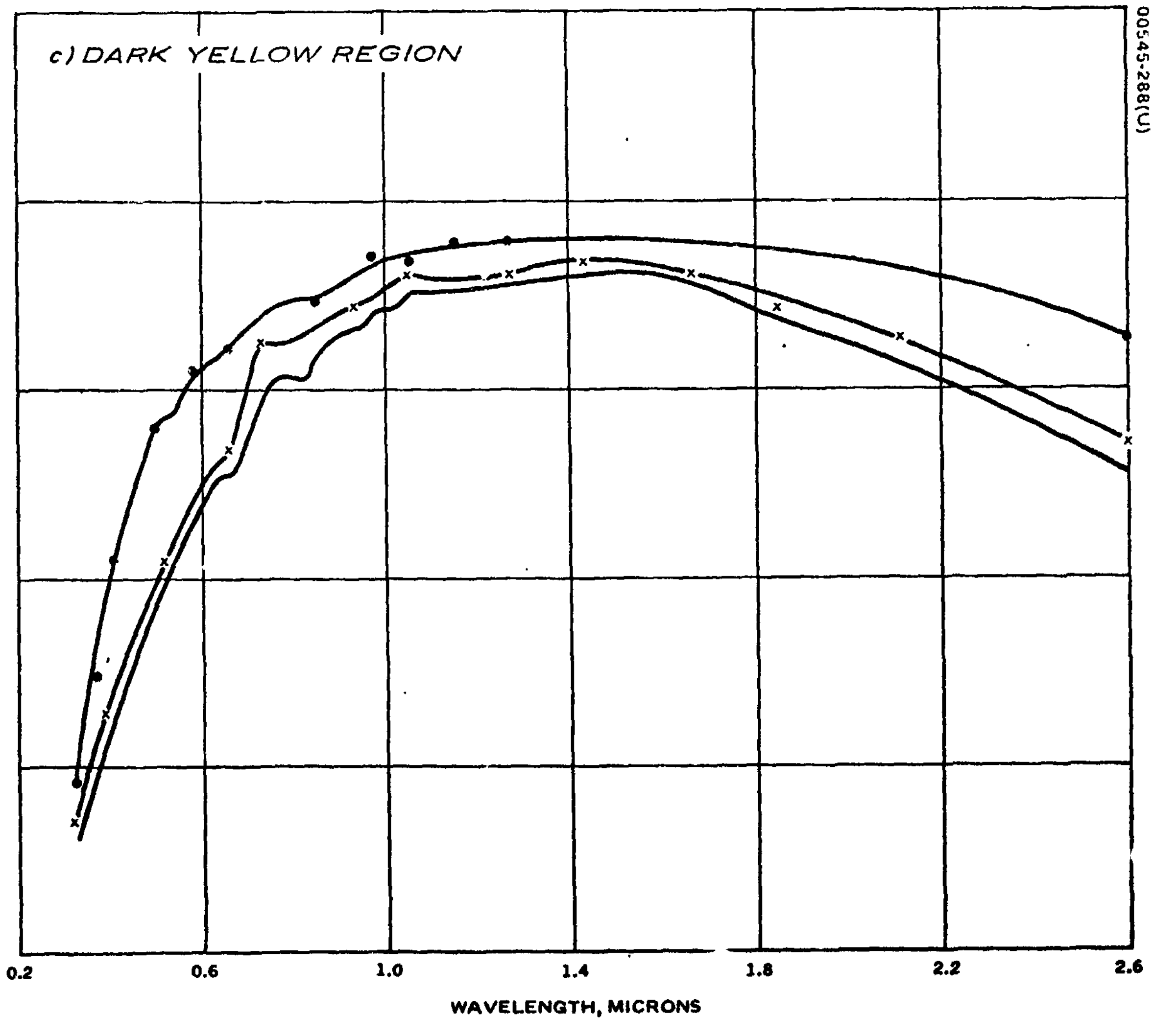


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TABLE J-3. SAMPLES OF SURVEYOR III CAMERA SHROUD CUT IN JULY 1970 FOR SCIENCE STUDIES

Sample Designation		Sample Location on the Surveyor III Camera Shroud
Log Number (Program Test Files)	TRW Measurement Position (see Figure J-9)	
893	2	Lower shroud, front (flat side) facing northeast (lunar), near center
894	9	Lower shroud, bottom, facing lunar surface, polished aluminum, near back or curved side
898	5	Lower shroud, northwest (lunar) side facing lunar module landing site
900	4	Lower shroud, southeast (lunar) side facing away from lunar module landing site
906	None	Sun visor, top, facing up, centered (opposite side painted with organic optical black)
907	None	Mirror assembly hood, south (lunar) side, facing away from lunar module landing site (opposite side painted with organic optical black)
908	None	Mirror assembly hood, north (lunar) side, facing lunar module landing site (opposite side painted with organic optical black)
909	None	Mirror assembly hood, east (lunar) side, highest solar irradiance (opposite side painted with organic optical black)

TABLE J-4. PERCENT REFLECTANCE OF SAMPLES FROM SURVEYOR III CAMERA SHROUD CUT FOR SCIENCE STUDIES IN JULY 1970

Wavelengths, microns	Sample Designation (see Table J-3)											
					906		907		908		909	
	893	894	898	900	White Paint Side	Black Paint Side	White Paint Side	Black Paint Side	White Paint Side	Black Paint Side	White Paint Side	Black Paint Side
0.295	20.0	-	18.0	20.0	20.0	4.0	16.0	5.0	16.0	4.0	12.0	4.0
0.355	28.0	30.0	26.0	39.0	22.0	4.0	31.0	4.0	25.0	4.0	22.0	4.0
0.400	36.5	40.0	33.0	50.0	24.0	4.0	42.0	4.0	30.0	3.0	33.0	3.5
0.430	38.5	44.0	34.5	54.0	28.0	5.0	44.0	4.0	32.5	4.0	38.0	4.0
0.458	40.0	45.0	40.0	57.5	30.0	4.0	48.0	4.5	34.5	4.0	42.0	4.0
0.484	42.0	46.0	40.0	60.0	32.0	4.5	49.0	4.5	35.5	4.0	46.0	4.0
0.511	43.5	47.5	40.0	61.0	33.5	3.5	50.0	4.5	37.0	4.0	48.0	4.0
0.540	46.0	50.0	42.0	63.0	35.0	3.5	54.0	4.5	38.0	4.0	50.0	4.0
0.569	47.5	50.0	43.0	65.0	36.0	4.0	55.0	4.5	39.0	4.0	52.0	4.0
0.598	48.5	52.0	44.0	65.0	37.0	4.0	55.0	4.0	39.0	4.0	54.0	4.0
0.630	50.5	52.0	46.0	66.0	39.0	4.0	56.5	4.5	40.0	4.5	56.0	4.5
0.664	52.0	52.0	47.5	67.0	40.0	4.0	57.0	5.0	41.0	4.5	56.0	5.0
0.700	54.0	52.0	48.0	67.0	40.0	5.0	57.0	6.0	41.5	5.0	59.0	6.0
0.738	54.0	52.0	50.0	70.0	40.0	5.0	58.0	6.0	43.0	5.0	61.0	6.0
0.78[illegible]	56.0	52.0	52.0	72.0	46.0	5.0	60.0	6.0	45.0	5.0	65.0	6.0
0.82[illegible]	56.0	52.0	54.0	74.0	48.0	5.0	63.0	5.0	45.0	5.0	66.0	5.0
0.880	60.0	54.0	54.0	74.0	50.0	5.0	64.0	5.0	47.0	4.0	67.0	4.0
0.940	60.0	60.0	57.0	74.0	50.0	5.0	64.0	5.0	48.0	4.0	68.0	4.0
1.011	63.0	62.0	58.0	75.0	50.0	4.0	66.0	5.0	50.0	4.0	69.0	4.0
1.096	65.0	64.0	59.0	76.0	52.0	4.0	69.0	5.0	51.0	4.0	70.0	4.0
1.200	67.0	65.0	61.0	76.0	56.0	3.0	69.0	5.0	52.0	4.0	70.0	4.0
1.341	68.0	67.0	64.0	77.0	58.0	2.5	69.0	4.0	54.0	3.5	72.0	3.5
1.536	68.0	67.0	64.0	77.0	59.0	3.0	70.5	4.0	55.5	3.5	71.0	3.5
1.854	64.0	74.0	61.0	68.0	58.0	3.0	63.0	4.0	54.0	4.0	66.0	4.0
2.600	50.0	76.0	49.0	53.0	54.0	7.0	56.0	7.0	46.0	5.0	50.0	5.0

a Gier-Dunkle integrating sphere. The shroud had been continuously exposed to fluorescent lighting since the earlier TRW measurements (April 1970) and, in fact, since 6 January 1970, when the television camera was released from quarantine at the LRL. Table J-5 lists samples, corresponding TRW positions, and reflectance data.

J.4.7 Thermal Annealing of Surveyor III Samples

Thermal annealing of several Surveyor III samples was conducted both in air and in vacuum. This section describes the tests conducted on these samples and presents the reflectance data obtained before and after these tests.

In November 1970, three samples that were cut and measured in October 1970 were thermally annealed in air. The samples were thermally exposed in the same manner as the bipod bracket support tube, discussed in Section J.4.4. Temperature of the samples was raised to 450°F and maintained for 18 hours. The reflectance was measured after the thermal exposure. The samples tested were Surveyor III samples 1030 (TRW measurement position 2*), 1031 (TRW position 3), and 1035 (TRW position 7). As described earlier, these samples cut from the lower shroud were continuously exposed to light until their removal from the shroud in October 1970. Until this test, they were stored in the dark. Spectral reflectance values before and after exposure are given in Table J-6.

Vacuum-thermal annealing tests were conducted on a Surveyor III part, designated as sample 909 in Table J-3, and on an inorganic white painted sample previously tested in the Surveyor laboratories at Hughes. The laboratory-tested sample had been exposed to ultraviolet radiation.

Surveyor part 909 was cut from the front of the mirror housing. This part faced east (lunar) while in the Surveyor crater. The exterior surface was coated with inorganic white paint, and the back (inward facing) surface was coated with an organic optical black paint (3M black velvet).

The sample previously exposed to ultraviolet in the Hughes laboratory was painted in January 1965. The ultraviolet source was a BH6 high pressure mercury arc. The sample had been exposed at five times the solar ultraviolet flux for 65 hours at a temperature of 250°F while in vacuum. Following this ultraviolet exposure in 1965, the sample was stored in the dark until November 1970.

The spectral reflectance of both the Surveyor III and the laboratory samples was measured just before test and immediately after test. The two samples were placed in individual glass tubes that were evacuated to 10^{-6} Torr. The samples were then heated to 450°F and held for approximately 18 hours. The samples were then removed from the vacuum chambers and their spectral reflectance was remeasured. Results of these measurements are presented in Table J-7.

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*See Figure J-9.

TABLE J-5. PERCENT REFLECTANCE OF SAMPLES FROM SURVEYOR III CAMERA SHROUD CUT FOR SCIENCE STUDIES IN OCTOBER 1970

Wavelength, microns	Sample Designation { Upper Row: Program Log Number; Lower Row: TRW Position Number (see Figure J-9)							
	1029	1030	1031	1032	1033	1034	1035	1036
	1	2	3	4	5	6	7	8
0.295	26.0	17.0	23.0	24.0	13.0	17.0	10.0	14.0
0.355	58.0	29.5	44.0	48.0	26.5	32.0	16.0	24.0
0.400	73.0	37.0	60.0	62.0	36.5	38.0	24.5	35.5
0.430	78.0	41.5	66.5	68.0	39.5	44.0	27.5	37.0
0.458	80.0	45.0	70.0	70.5	42.5	48.0	30.5	40.0
0.484	80.0	45.0	70.5	72.0	44.0	48.0	32.5	42.0
0.511	82.5	48.0	74.0	73.0	46.5	48.0	34.0	43.0
0.540	82.5	49.0	75.0	75.0	47.0	50.0	35.0	44.0
0.569	83.0	49.0	76.5	76.0	49.0	51.0	37.0	47.0
0.598	84.0	51.0	78.0	77.0	55.0	53.0	37.5	47.0
0.630	84.0	53.0	78.0	78.0	55.0	53.0	38.5	47.5
0.664	86.0	54.0	78.0	78.0	55.0	54.0	39.0	48.0
0.700	86.0	56.0	79.0	79.0	58.0	57.0	40.0	49.0
0.738	88.0	57.0	79.0	80.5	60.0	59.0	43.0	50.0
0.781	88.0	59.0	80.0	83.0	60.5	59.0	45.0	51.0
0.828	87.0	60.0	80.0	83.0	62.0	60.0	46.0	53.0
0.880	87.0	62.0	82.0	83.0	62.0	60.0	47.0	55.0
0.940	86.0	62.0	81.5	82.5	62.0	61.5	50.0	57.0
1.011	86.0	64.5	81.5	83.0	62.0	65.0	53.0	58.0
1.096	85.5	65.0	82.0	82.5	67.0	66.0	53.0	61.0
1.200	84.5	66.5	81.5	83.5	68.0	69.0	56.0	63.0
1.341	84.0	68.0	82.5	82.5	67.0	69.0	59.0	65.0
1.536	81.0	70.0	81.0	81.5	64.0	68.0	60.5	64.0
1.854	73.0	[illegible]	73.0	71.5	60.0	65.0	57.0	61.0
2.600	55.0	55.0	56.0	55.0	50.0	56.0	[illegible]	57.0

TABLE J-6. EFFECT OF THERMAL ANNEALING IN AIR ON SPECTRAL REFLECTANCE OF SAMPLES CUT FROM LOWER SHROUD OF SURVEYOR III CAMERA IN OCTOBER 1970

Wavelength, microns	Spectral Reflectance, percent					
	Program Log 1030, TRW Position 2*		Program Log 1031, TRW Position 3		Program Log 1032 TRW Position 7	
	Before Annealing	After Annealing	Before Annealing	After Annealing	Before Annealing	After Annealing
0.295	17.0	16.0	23.0	25.0	10.0	13.0
0.355	29.5	29.0	44.0	45.0	16.0	20.0
0.400	37.0	38.0	60.0	57.0	24.5	25.0
0.430	41.5	42.0	66.5	65.0	27.5	28.0
0.458	45.0	44.5	70.0	68.0	30.5	31.0
0.484	45.0	46.5	70.5	71.0	32.5	32.0
0.511	48.0	46.5	74.0	73.0	34.0	33.5
0.540	49.0	49.0	75.0	73.0	35.0	35.5
0.569	49.0	49.5	76.5	75.0	37.0	37.5
0.598	51.0	52.0	78.0	77.0	37.5	40.0
0.630	53.0	53.0	78.0	77.0	38.5	41.0
0.664	54.0	53.0	78.0	79.0	39.0	42.0
0.700	56.0	55.0	79.0	80.0	40.0	44.0
0.738	57.0	58.0	79.0	80.0	43.0	47.5
0.781	59.0	60.0	80.0	80.0	45.0	50.0
0.828	60.0	62.0	80.0	80.0	46.0	53.0
0.880	62.0	63.0	82.0	80.0	47.0	55.0
0.940	62.0	65.0	81.5	80.0	50.0	55.0
1.011	64.5	66.0	81.5	81.0	53.0	56.0
1.096	65.0	68.0	82.0	81.0	53.0	57.0
1.200	66.5	70.0	81.5	80.0	56.0	58.0
1.341	68.0	72.0	82.5	85.0	59.0	63.0
1.536	70.0	71.0	81.0	81.0	60.5	64.0
1.854	63.0	70.0	73.0	78.0	57.0	64.0
2.600	55.0	62.0	56.0	65.0	51.0	57.5

*See Figure J-9.

TABLE J-7. EFFECT OF THERMAL ANNEALING IN VACUUM ON SPECTRAL REFLECTANCE OF SURVEYOR III CAMERA AND LABORATORY SAMPLES OF WHITE INORGANIC PAINTED SURFACES

All Thermal Exposures in Air: 18 Hours at 450°F

Wavelength, microns	Spectral Reflectance, percent						
	Surveyor III Camera Sample A*		Laboratory Sample B**			Laboratory Sample C***	
	Before Thermal-Vacuum Exposure	After Thermal-Vacuum Exposure	Before Thermal-Vacuum Exposure	After Thermal-Vacuum Exposure	After Thermal Exposure in Air	Before Thermal-Vacuum Exposure	After Thermal Exposure in Air
0.295	12.0	9.0	20.0	20.0	28.0	22.0	30.0
0.355	22.0	14.5	37.0	34.0	56.0	44.0	56.0
0.400	33.0	18.0	50.0	43.5	71.5	52.0	71.0
0.430	38.0	22.0	55.0	47.0	75.0	58.0	76.0
0.458	41.0	25.0	56.0	49.5	77.0	62.5	77.0
0.484	45.5	26.0	56.0	53.0	78.0	64.0	76.5
0.511	47.0	26.0	63.0	56.0	78.0	66.0	77.0
0.540	51.0	31.0	65.0	58.0	80.0	69.0	78.0
0.569	53.0	32.0	66.0	60.0	80.0	70.0	77.5
0.598	55.0	35.0	68.0	62.5	80.5	70.0	79.0
0.630	56.0	36.0	70.0	65.0	81.0	75.0	79.5
0.6[illegible]	58.0	40.0	74.0	65.0	81.0	75.0	79.0
0.700	62.0	40.0	77.0	67.0	82.0	78.0	80.0
0.738	67.0	42.0	78.5	70.0	82.0	78.0	81.5
0.781	62.0	43.0	80.0	70.0	82.0	78.0	82.0
0.828	65.0	47.0	80.0	73.0	82.0	78.0	82.0
0.880	66.0	50.0	80.0	75.0	81.0	79.0	82.0
0.940	67.0	53.5	82.0	75.0	81.0	80.0	82.0
1.011	69.0	56.5	81.5	78.0	81.0	80.0	81.0
1.096	70.0	59.5	83.0	81.0	81.5	80.0	80.5
1.200	70.0	60.0	82.5	80.0	81.0	79.5	80.[illegible]
1.341	70.0	66.0	83.0	80.0	81.0	77.5	78.0
1.536	73.0	67.5	80.0	78.0	80.0	76.5	78.0
1.854	67.0	63.0	72.0	76.0	77.5	70.0	76.0
2.690	55.0	55.5	52.5	72.0	70.0	56.0	66.0

*Surveyor sample 909 - tests in vacuum (5×10^{-5} Torr)
**Sample of Surveyor white inorganic paint exposed to ultraviolet at 5X for 65 hours in 1965 - tests in vacuum (5×10^{-5} Torr) and air.
***Samples of Surveyor white inorganic paint exposed to ultraviolet at 1X for 96 hours in 1965 - tests in air.

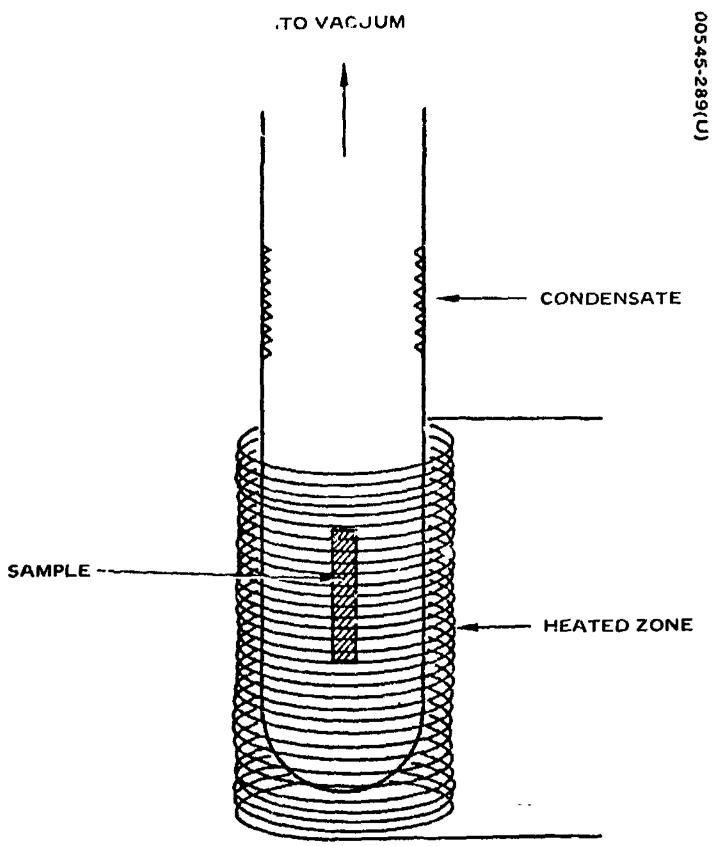

Figure J-26. Experimental Configuration for Thermal-Vacuum Exposure of Surveyor III Sample 909

The Surveyor III sample 909 outgassed a heavy but clear condensate during its thermal-vacuum exposure. This condensate appeared on the glass tube above the heated zone where the glass was at room temperature. The experimental configuration is shown in Figure J-26. No condensate was found on the glass tube where it had been heated. No condensate was found on the tube used to vacuum-thermal anneal the non-flight Surveyor inorganic white paint. The outgassing of sample 909 was due to the black organic paint. This paint has a history of high outgassing and is not used on current designs where outgassing limits are imposed.

A second, laboratory-tested sample of the Surveyor inorganic white paint was selected for similar testing. The sample was exposed for 18 hours at 450°F in air, not vacuum. Results of the spectral reflectance measurements before and after exposure are also shown in Table J-7. This sample was from the same paint lot as the vacuum-tested sample above. The only difference between the two was that this second sample had been exposed to ultraviolet at 1X for 96 hours. Temperature during exposure and storage conditions since 1965 are the same.

An additional test was then conducted on the sample of white paint previously exposed to ultraviolet in the laboratory and then thermally annealed in vacuum. The sample was placed in the air-thermal anneal test chamber and was exposed for 18 hours at 450°F. The spectral reflectance was remeasured, and results are shown in Table J-7.

J.5 MATHEMATICAL ANALYSIS OF LUNAR DUST CONTRIBUTION TO REFLECTANCE

Early in the evaluation, it was clearly established that physical separation of the lunar material from the paint surface without removal of at least a small amount of the degraded coating was impossible. Thus, it became necessary to achieve such separation analytically using measured spectral reflectance values and a knowledge of the Surveyor III orientation.

Energy reflected from the camera surfaces is affected by discoloration of the paint, possibly by discolored contaminants on the surface and by the amount of lunar dust present. In the first order of analysis (direct comparison of reflectance data), it is impossible to separate the effects of contaminants other than dust, degradation of the paint, and the effect of lunar dust. However, separation of dust effects can be accomplished with some degree of success by analyzing the near-infrared spectra. The reduction of the reflectance of the paint at 1.5 microns is due entirely to the lunar dust. The reflectance of the painted surfaces is affected in the visible portion of the spectrum by all the possible discoloration mechanisms: radiation damage to the paint, contaminants, and lunar dust.

This section summarizes results of the effort to derive an equation that could be used to separate the effect of the lunar dust on the reflectance spectrum of the paint. The resultant radiation damage reflectance spectrum could then be compared to the well-established characteristics of the ultraviolet damage in the paint. Any deviation from this curve may then be attributed to radiation damage in contaminants found on the paint surface.

There were several possible effects of a dust layer on the reflectance spectrum of the paint. Dust deposited during the Surveyor III landing would reduce the effect of solar ultraviolet radiation, partially shielding the paint. The dust would also interact with the actual measurement of reflectance in the following manner:

1) **Partially absorb incident energy**

2) **Partially absorb energy reflected from paint surface**

3) **Back scatter incident energy**

4) **Forward scatter incident energy**

5) **Reduce by absorption incident energy transmitted through dust particles**

Measured reflectance of bulk lunar fine samples from Apollo XI, reported in Reference 113, as well as examination of the Surveyor surfaces, indicated a non-gray behavior of the lunar dust (i.e., the effect was not the same at all wavelengths). The dust behaved as a broadband selective filter either by absorption or by scattering, with the greatest effect at the short wavelengths.

The following expression could be derived by considering the energy balance of monochromatic illumination on the contaminated, degraded surface, and the mechanism of light interaction with the surface, discussed above:

$$I_m = I_o \rho_d K_i A_d + I_o \rho_p \left[(1-K_2 A_d)(1-K_3 A_d)\right]$$

or

$$\rho_m = \rho_d K_i A_d + \rho_p (1-K_2 A_d)(1-K_3 A_d) \tag{1}$$

I_m = measured radiant flux (reflected from surface)

I_o = radiant flux incident on surface

ρ_m = (reflectance) = $\frac{I_m}{I_o}$

ρ_d = reflectance of lunar dust

ρ_p = reflectance of paint surface

A_d = fraction of surface area covered by dust

K_i, K_2, K_3 = constants

Note that ρ_p is the reflectance of the paint, including degradation due to radiation and possible contaminants. K_2 and K_3 are unknown spectral constants associated with transmission, forward scattering, and geometry of the dust for the incident and leaving beam. (K_1 is discussed below.) It was not practical within the scope of this program to determine the various parameters which are part of K_2 and K_3. It was similarly impossible to directly measure the dust area on the painted surface. Since K_2 and K_3 are related and approximately equal, it is possible to rewrite Equation 1 as follows:

$$\rho_m = \rho_d K_1 A_d + \rho_p (1-K_4 A_d)^2 \tag{2}$$

where K_4 is an effective average for the incident and reflected beam and K_4A_d can be determined experimentally.

Further defining a term D as the ratio of the reflectance of the degraded paint (ρ_p) to the initial reflectance of the paint (ρ_o), Equation 2 becomes:

$$\rho_m = \rho_d K_1 A_d + \rho_o D(1-K_4A_d)^2 \tag{3}$$

The quantity D includes both the radiation damage and the effects of contaminants other than lunar dust. The term $\rho_d K_1 A_d$ in Equations 1 through 3, the back reflection from the first surface of the dust, is the product of three factors: reflectance of the dust, a proportionality constant, and an effective area of the dust. The reflectance of the dust ranged between 0.04 and 0.10. The proportionality constant for the back reflection is related to the particle shape and was less than 1.0. The effective area of the dust, expressed as a fraction of surface coverage, was on the order of 0.05 to 0.30 for the returned Surveyor surfaces. The first term $\rho_d K_1 A_d$ above was small compared to the other quantities. In view of the uncertainties associated with the analysis, the errors introduced by disregarding it were negligible. Although inclusion of this term would be possible, it was neglected in the analysis. Equation 3 now becomes:

$$\rho_m = \rho_o D(1-K_4A_d)^2 \tag{4}$$

Laboratory data on the damage to the Surveyor coatings by ultraviolet radiation and solar wind protons indicated a yellow or brown degradation, with the primary effect in the short wavelengths and little or no effect in the near-infrared. Assumption that this condition existed on the surfaces returned from the moon permitted the determination of the effective dust area (K_4A_d) in the longer wavelengths. Using the spectral character of the dust, as derived from the data shown in Figure J-27, the effect of the dust could be determined over the entire wavelength range measured.

The radiation effects on the reflectance of the paint measured in laboratory were primarily seen at the shorter wavelengths, less than 1.0 micron. The paint reflectance in the near-infrared (1.0 to 2.5 microns) was a function of thickness and possibly of surface finish and porosity. It was also a function of the amount of chemically absorbed water, as shown in Section J.4.5. In view of the above discussion, it was necessary to use some judgment in the selection of wavelengths at which the effective area was determined.

Figure J-27 shows the results of measurements by D. Nash (JPL), discussed in Reference 114, using Apollo XI fines on control samples of Surveyor coatings. The curves are plotted as a ratio of reflectance of surfaces covered with lunar dust, ρ_m, to reflectance of clean surfaces, ρ_0. From

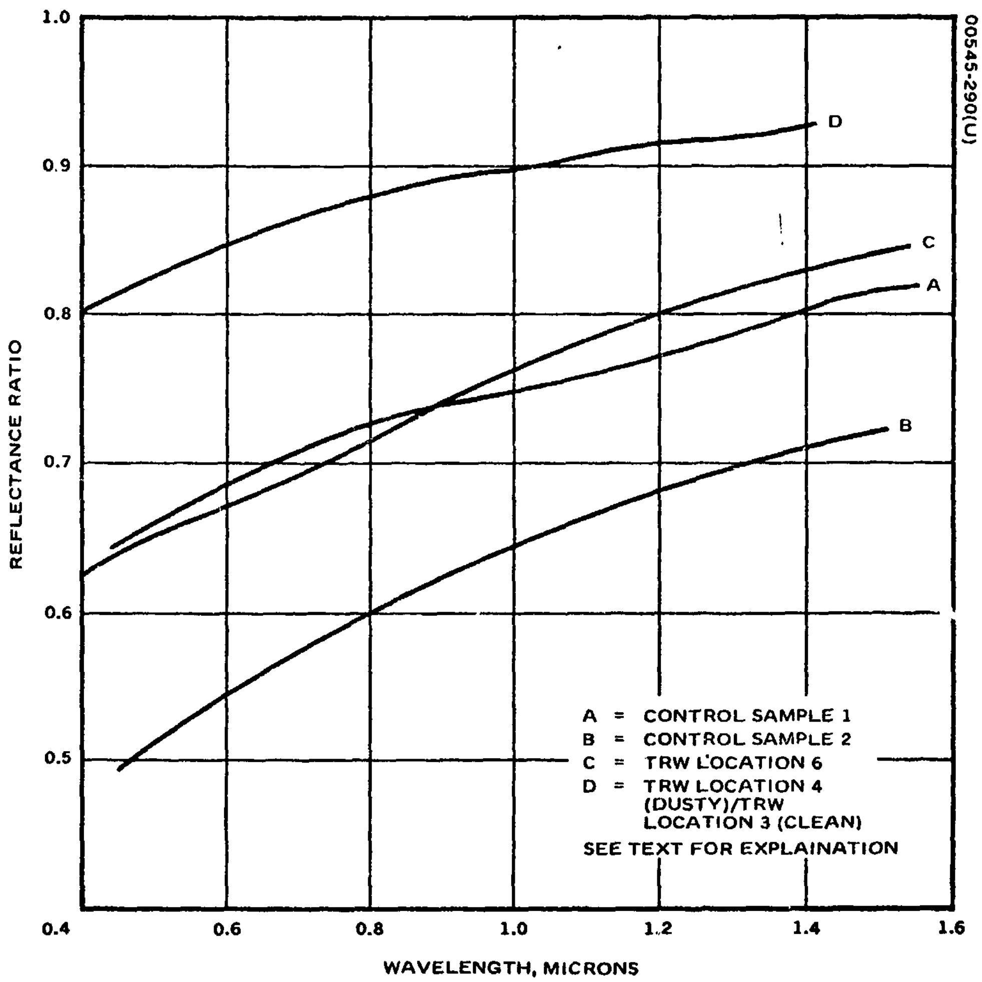

Figure J-27. Ratio of Reflectance of Painted Surfaces Covered With Lunar Dust to the Reflectance of Clean Surfaces (White Inorganic Paint)

this ratio ρ_m/ρ_0, the factor K_4A_d can be computed as a function of wavelength using Equation 4 since there was no degradation (D=1).

Also shown for comparison are results of measurements of samples from Surveyor III surfaces. The ratio ρ_m/ρ_0 is plotted for the sample from TRW position 6,* using the clean undegraded reflectance of TRW position 1 under the connector bracket as ρ_0. Position 6 showed very little or no radiation effect; the discoloration was clearly due to dust. The difference between control sample 1 (curve A in Figure J-27) and TRW sample 6 (curve C) in the near-infrared was probably due to the differences in the reflectance of the paint, discussed above.

In addition $\rho_m/(\rho_0 D)$ for position 4, using $(\rho_0 D)$ from position 3, showed similar agreement on the effects of dust. Positions 3 and 4 were both on the southeast side of the camera and would be expected to have the same degradation; position 3 appeared to be free of dust, as indicated by no decrease in reflectance in the near infrared.

*Shown in Figure J-9.

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