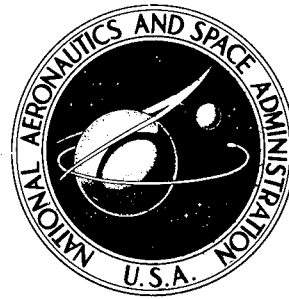


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ANALYSIS OF SURVEYOR III TELEVISION CABLE AFTER RESIDENCE ON THE MOON

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16. Abstract <p>The Apollo 12 astronauts brought the Surveyor III television camera back from the moon in November 1969. Chemical analyses of a portion of television cable revealed changes in the glass fabric sleeve and in the wire insulation as a result of exposure to the lunar environment. Loss of volatile constituents from the glass fabric and a discoloration of the glass occurred. The Teflon layer on the wire showed a slight discoloration and possibly a slight change in its infrared spectrum. Both the polyimide layer and the Teflon layer of the wire insulation showed changes in tensile strength and elongation.</p>			
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FOREWORD

It is the policy of the National Aeronautics and Space Administration to employ, in all formal publications, the international metric units known collectively as the *Système Internationale d'Unités* and designated **SI** in all languages. In certain cases, however, utility requires that other systems of units be retained in addition to the **SI** units.

This document contains data so expressed because the use of the **SI** equivalents alone would impair communication. The non-**SI** units, given in parentheses following their computed **SI** equivalents, are the basis of the measurements and calculations reported here.

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INTRODUCTION

The Apollo 12 astronauts, Charles Conrad, Jr., Richard F. Gordon, and Alan L. Bean, returned the Surveyor III television camera to earth in November 1969. Surveyor III had landed on the moon April 20, 1967, and thus had experienced 31 months of the lunar environment. The camera was delivered to the Lunar Receiving Laboratory in Houston, and it remained there in quarantine until January 7, 1970. After various tests were performed on the camera and its components at the Hughes Aircraft Company facilities in Culver City, California, the component parts were distributed to selected investigators for additional testing and evaluation.

A sample of cable described as "4 inches of TV cable, fabric wrapped" was received by the authors for tests. The cable consisted of 19 insulated wires covered by a woven glass fabric sleeve. The fabric was described as being braided glass yarn per MIL-Y-1140, with a strand diameter of 0.5 mm (0.020 in.) and a woven thickness of approximately 0.8 mm (0.030 in.). Fortunately, a similar sample approximately 10 cm (4 in.) long, described as being from the Type Approval Test (TAT) equipment vehicle, was also received. This TAT sample was reported to be an identical cable except that it had not undergone the exposure on the moon. Thus, it was possible to compare these samples and their analyses. It should be emphasized that the Surveyor sample had not been kept in vacuum but had been exposed to the earth's atmosphere for a period of time before delivery to GSFC.

PROCEDURE

Because of the value of the Surveyor cable and the admonition not to destroy the whole piece, a procedure was followed which involved dividing the cable into three parts. This allowed the investigators to perform a minimum of duplicate tests and left the third portion available to remove any doubtful results. The TAT sample was used liberally to assist in determining procedures and to work out potential problems before beginning tests on the Surveyor cable.

Each sample was considered to consist of two parts: the glass fabric outer covering, and the wires with their insulation. It was possible in some instances to use a sample for more than one test. The glass fabric could be examined in its "as received" state by attenuated total reflectance infrared (ATR-IR) spectroscopy. One portion was extracted with chloroform and filtered. The chloroform extract was evaporated and weighed and then underwent gas chromatography and infrared analysis. Then, the same fibers were extracted with hot water and filtered, the filtrate again being dried and the residue weighed; this residue underwent gas chromatography and infrared analysis. A second portion was selected for emission spectroscopy and X-ray diffraction tests. A third portion was used for pyrolysis infrared tests; of course, neither of the two pyrolysis samples could be utilized further.

The wire insulation could be stripped from the wires and examined separately. Separated portions of insulation were needed for pyrolysis gas chromatography tests, differential thermal analysis, differential scanning calorimetry tests, pyrolysis infrared tests, and the tensile tests.

THE SPECIMEN

The Surveyor cable, as was mentioned previously, consisted of a glass fabric sleeve over 19 insulated wires (Figure 1). The fabric itself appeared to be a dirty gray, darker than the TAT sample. Some small particles, presumably lunar dust, were noted on the fabric (Figure 2); these particles were neither large nor very numerous. In addition, it was noted that the TAT sample also had loose pieces of metal or dirt in its fabric sleeve. However, the Surveyor sample had more particles and was darker.

Each wire consisted of 19 braided copper strands with a thin silver plating, each copper strand being approximately 0.08 mm (0.003 in.) in diameter, and the silver plating being approximately 0.003 mm (0.0001 in.) thick. The insulation on these 19 strands was yellow; a cross section revealed that there were two layers of insulation, the outer one being much thinner than the inner one.

THE FABRIC

A number of tests were conducted on the glass fabric, as was indicated above. Comparisons between corresponding TAT and Surveyor tests were positive for some tests (i.e., there was a definite difference between the Surveyor and the TAT results), but most of the comparisons were negative (i.e., no apparent difference between the results for the two samples was recorded).

Emission Spectroscopy

The emission spectroscopy analysis of the washed fabric revealed the presence of its elemental constituents and permitted an estimate of the percentages of these constituents to be made. The composition was high in silicon, with much aluminum, magnesium, and boron (similar to a borosilicate glass).

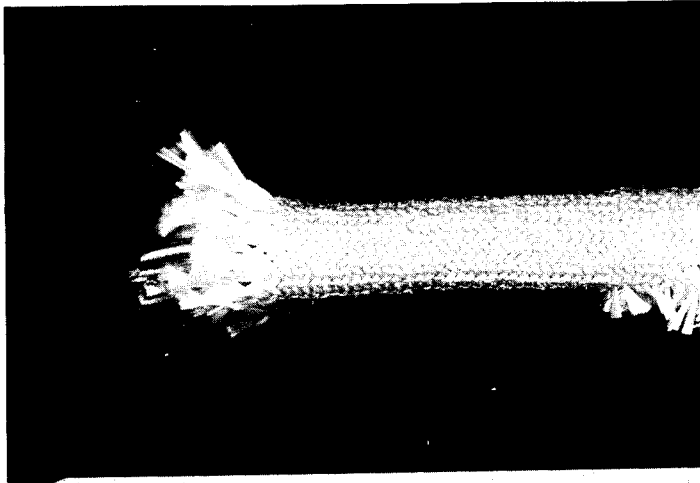


Figure 1—Surveyor cable, glass fabric covering over nineteen insulated wires. (1.5X)

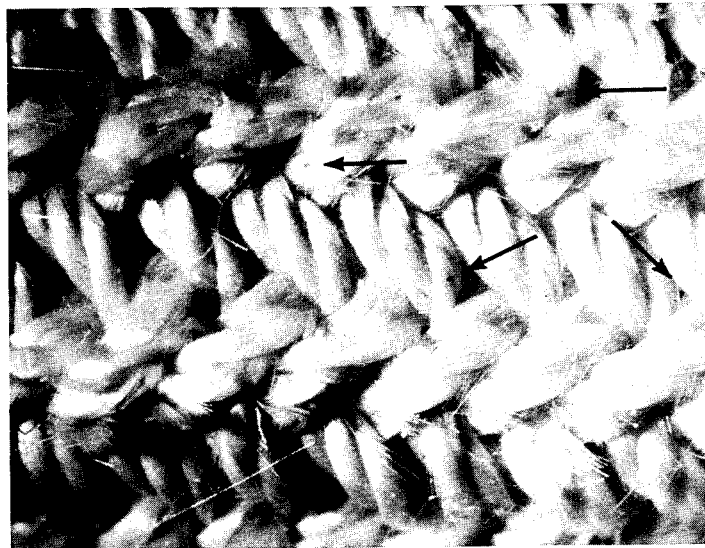


Figure 2—Enlarged view of woven glass fabric; black particles are believed to be lunar dust. (20X)

The constituents were found in the following concentrations:

Silicon	>10 percent
Aluminum, magnesium, boron	1 to 10 percent
Iron	0.1 to 1 percent
Calcium, titanium, sodium	0.01 to 0.1 percent
Zirconium	0.001 to 0.01 percent
Manganese	0.0001 to 0.001 percent

The X-ray diffraction analysis showed that the fabric was amorphous, like a glass. The comparison of the results was negative, there being no detectable difference between the Surveyor and the TAT samples.

Attenuated Total Reflectance

During examination by ATR-IR spectroscopy, the fabric was scanned in the 2.5- to 25- μm range with a spectrophotometer. The spectrum obtained was that of a noncrystalline inorganic silicate. Again, the comparison of the results was negative.

Chloroform Extraction

Samples of fabric were extracted with boiling chloroform. The chloroform was evaporated, and the weights of the extracts were determined. The comparison of these results was positive: The TAT sample had a 0.32-percent residue, and the Surveyor sample had a 0.21-percent residue. The residues were dissolved again, and their infrared spectra were obtained. The spectrum of the TAT sample [Figure 3(a)] showed mostly aliphatic esters and other carbonyl-containing compounds such as fatty acids. The spectrum of the Surveyor sample [Figure 3(b)] was a more clearly defined pattern of aliphatic esters, which indicated that some volatilization of the lower-boiling constituents might have occurred in the space vacuum.

The extracts were then examined by gas chromatography, which separates the constituents of a vaporized sample into distinct fractions. This confirmed that the extract from the Surveyor sample has less volatile components than that from the TAT sample.

The extracts were examined further by gas chromatography-mass spectrometry. This added to the evidence that volatilization of some constituents had occurred from the Surveyor fabric. The relatively low-boiling chlorinated hydrocarbons and other compounds found in the TAT extract were absent in the Surveyor sample. The higher-boiling constituents of both samples appeared to remain about the same.

Aqueous Extraction

Following the chloroform extraction, the samples were subjected to a boiling-water extraction; the extracts were used for infrared, emission spectroscopy, and X-ray diffraction analysis. This extraction yielded a positive result also, the amount of the residue being 1.75 percent for the TAT sample and 1.58 percent for the Surveyor sample. The infrared pattern indicated that the extracts

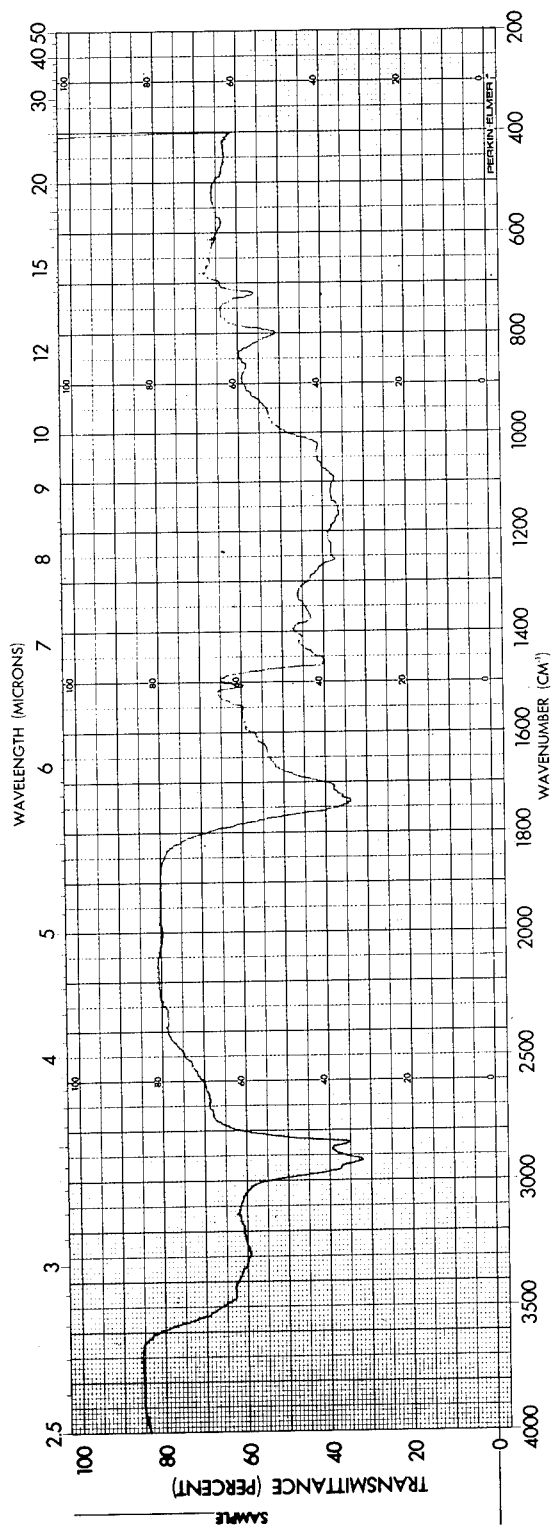


Figure 3(a)—Reproduction of spectrum of chloroform extract from TAT glass fabric. [The SI equivalent of the micron (μ) is the micrometer (μm); $1 \mu = 1 \mu\text{m}$.]

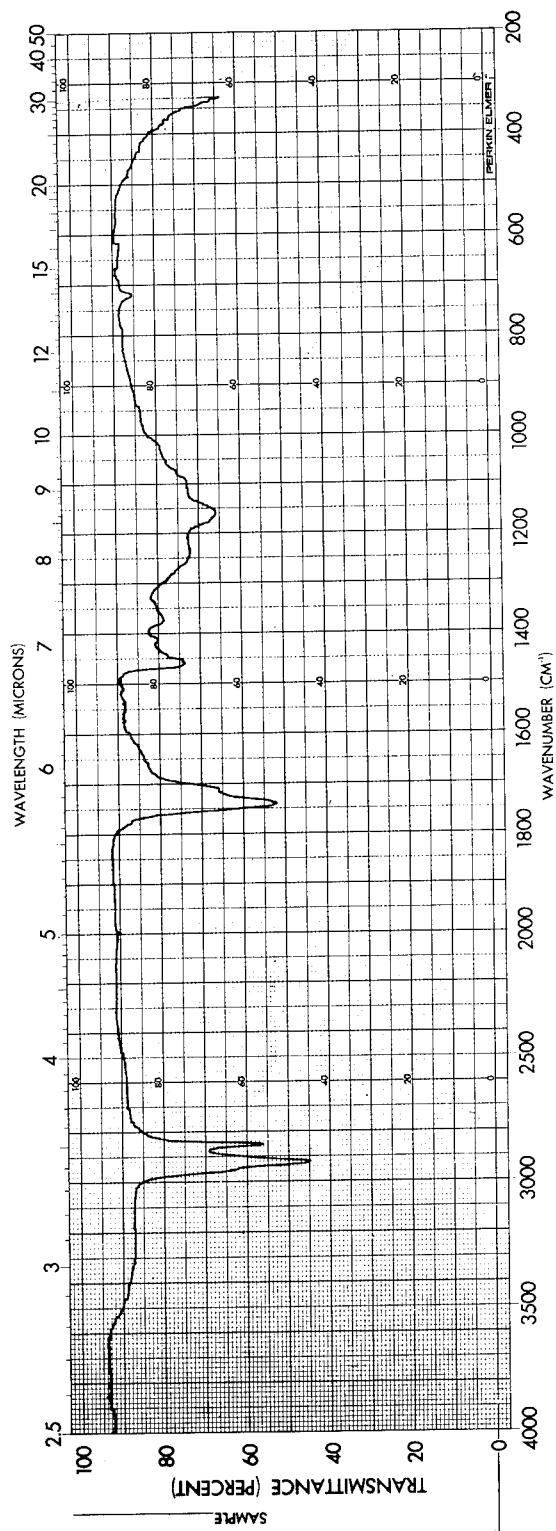


Figure 3(b)—Reproduction of spectrum of chloroform extract from Surveyor glass fabric. [The SI equivalent of the micron (μ) is the micrometer (μm); $1 \mu = 1 \mu\text{m}$.]

were an inorganic silicate; however, no significant difference could be found between the TAT and Surveyor samples. The X-ray diffraction analysis yielded only three broad weak diffraction lines. This was insufficient for positive identification. The emission spectrographic analysis also yielded a negative result, showing the presence of mainly silicon, sodium, and magnesium in the following relative amounts:

Silicon	major
Sodium, magnesium	major
Boron, aluminum, calcium	minor
Iron, copper, titanium	not detected

The extracted material was probably a form of water glass, or sodium silicate.

Pyrolysis Infrared

The infrared spectra of pyrolyzed samples of the fabric were obtained. Pyrolysis consists of burning a sample and collecting the condensable gaseous products. The spectra indicated the presence of a small amount of organic material, probably mostly hydrocarbons, but the results were negative.

Reflectance Spectroscopy

The discoloration of the Surveyor glass fiber was apparent upon visual examination. However, repeated attempts to obtain transmission and reflectance patterns in the range from the near infrared to the ultraviolet (from 25 000Å to 1900Å) from samples tested as fibers or as ground particles did not show a difference between the Surveyor or TAT samples.

THE WIRE INSULATION

The wire insulation was a yellow color. The cross-section examination revealed the existence of two layers. Subsequent tests (below) confirmed that the insulation consisted of two different polymeric materials.

Attenuated Total Reflectance of the Surface Layer

The infrared spectrum of the outer surface of the insulation indicated that it was a polyimide resin, similar to Kapton* film (H film) but probably applied as a liquid and thus referred to as "liquid H". The presence of the Kapton accounts for the yellow color. The results of the comparison were negative, there being no detectable difference in the patterns of the Surveyor insulation and the TAT insulation.

*Registered trademark, Dupont.

Pyrolysis Infrared

The spectra of the pyrolyzates indicated the presence of a fluorocarbon resin, similar to Teflon FEP. This test, though, was negative. It is interesting to note that pyrolysis of a polyimide gives no infrared pattern; therefore, the Teflon was the only constituent appearing.

Pyrolysis Gas Chromatography

The separation of the pyrolyzed constituents was carried out by heating the insulation to about 1270 K (1000°C) in a helium carrier gas. The separation gave negative results.

Differential Thermal Analysis

Small amounts of the two-layered insulation were heated to over 720 K (450°C) in air and in nitrogen. The results were negative though both samples showed an endothermic reaction starting at about 510 K (240°C), with the peak occurring at about 530 K (260°C). The differential scanning calorimeter results were also negative.

Attenuated Total Reflectance of the Subsurface Layer

Dissolution of the outer polyimide layer by a 15-percent hot potassium-hydroxide solution was carried out. The underlying Teflon layer of the Surveyor sample showed some small areas of slight discoloration. The ATR-IR patterns yielded some slight differences in the region of 800 to 500 cm^{-1} , though it would be difficult to assign positive significance to these because of the normal variations of the test [Figures 4(a) and 4(b)]. The bands in the region of 2900 cm^{-1} in Figure 4(b) are considered to be a residual contaminant on the infrared reflectance crystal.

Tensile Tests

The most obvious change in the Surveyor insulation was apparent in its tensile strength and elongation. The tensile tests were conducted on the dual-layered insulation, the wires being pulled out to leave the insulation in the tubular shape. During the tensile tests, it was observed that the outer polyimide layer separated early in the test but the Teflon inner layer remained intact for the duration of the tests. The results are listed in Table 1.

Considering the nonstandard shape of the test specimen and the likely variation in thicknesses of the two layers, the two TAT samples compared reasonably well (see Table 1). The Kapton layer was able to sustain at least a 930-g load with an elongation of 33 percent before separating; the Teflon separated at a minimum load of 920 g after an elongation of 800 percent.

Two of the insulation samples from Surveyor showed much lower strength values than did the TAT samples. These Kapton polyimide layers could sustain only a 770- to 790-g load but with an elongation of almost double the TAT Kapton, 60 and 72 percent versus 33 and 35 percent. The Surveyor Teflon layers also were considerably weaker compared to the TAT layers, having a lower ultimate load by about 200 g and an elongation reduced by about a half, as the data indicates. The third Surveyor sample, which is apparently anomalous, had ultimate load values for Kapton and Teflon very compa-

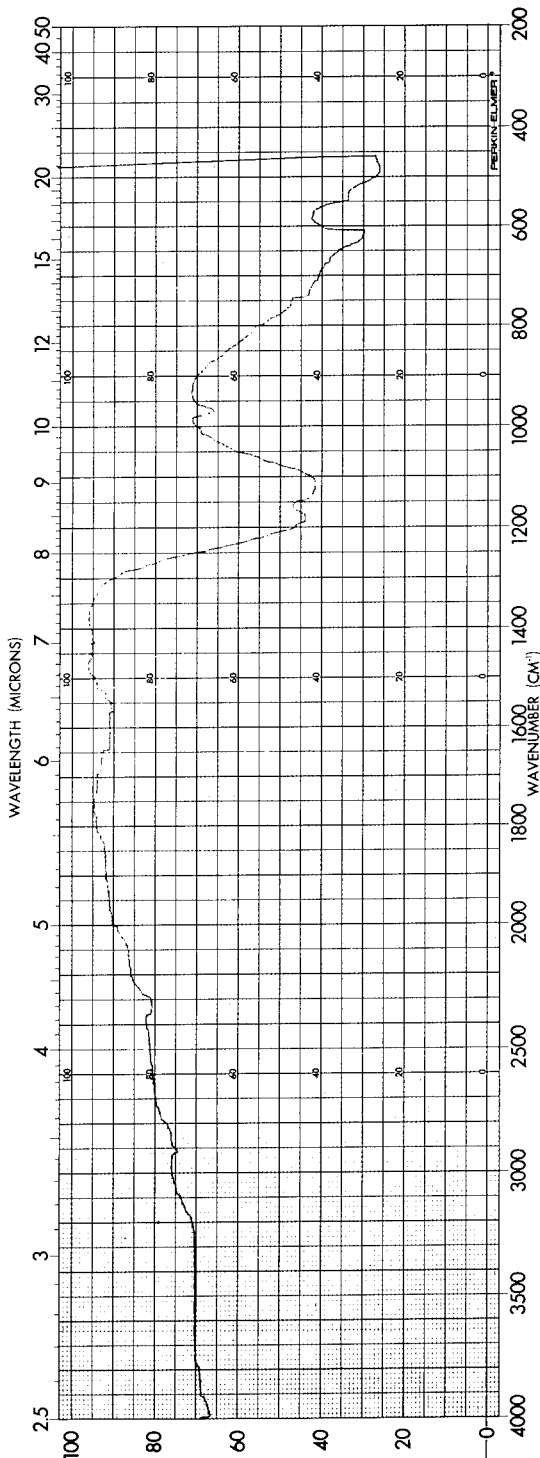


Figure 4(a)—Reproduction of ATR-IR chart of TAT Teflon insulation. [The SI equivalent of the micron (μ) is the micrometer (μm); $1 \mu = 1 \mu\text{m}$.]

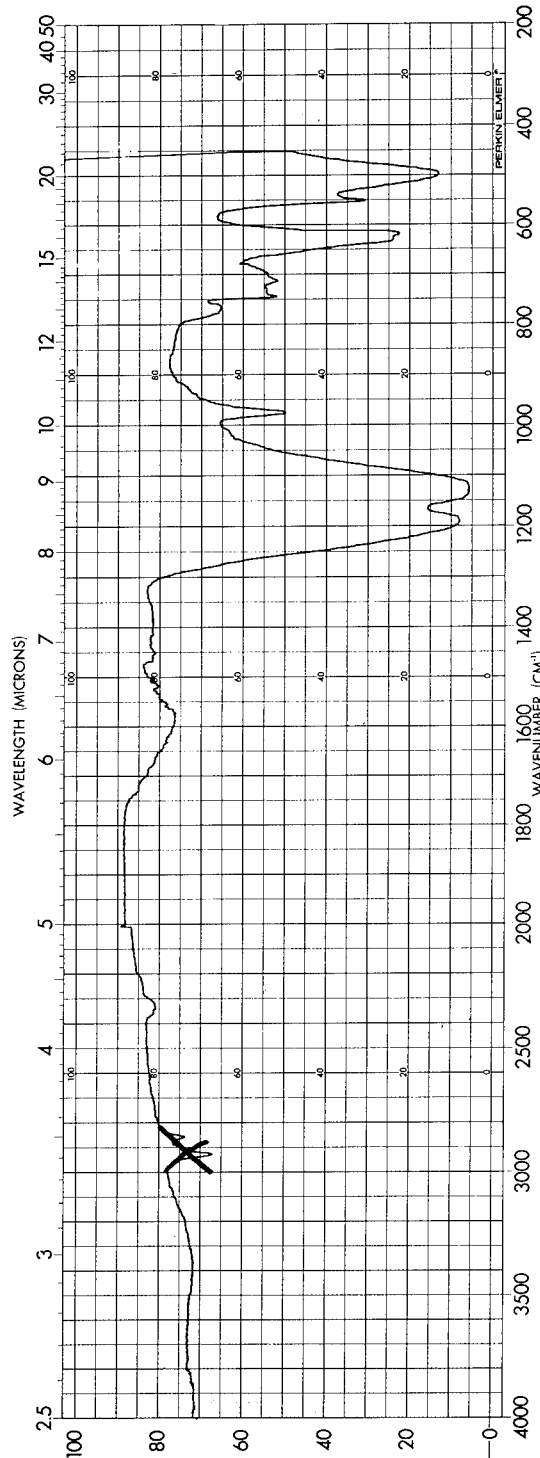


Figure 4(b)—Reproduction of ATR-IR chart of Surveyor Teflon insulation. [The SI equivalent of the micron (μ) is the micrometer (μm); $1 \mu = 1 \mu\text{m}$.]

Table 1—Results of tensile tests on the insulation.

Sample	Polyimide		Teflon	
	Ultimate Load (g)	Elongation (%)	Ultimate Load (g)	Elongation (%)
TAT	1010	35	960	990
	930	33	920	800
Surveyor	790	72	760	340
	770	60	740	400
	1000	62	920	1180

able to the TAT samples, the Teflon elongation of 1180 percent being comparable also. It is believed that this insulation was from a wire within the bundle rather than at the surface of the bundle; it was not possible to maintain with absolute certainty the location and orientation of the individual wires. However, the presence of the change in the infrared pattern, even though slight, is a clue to a change in the polymer structure. It had been pointed out by DuPont personnel that the tensile strength would probably be more obviously changed by exposure to a hostile environment. This apparently was the case. However, the increase in elongation of the polyimide layer implies a further curing of the polymer, even though the ultimate load did decrease.

OTHER OBSERVATIONS

Certain portions of at least two Surveyor wires showed black areas (Figure 6). It was determined that these areas were under the insulation rather than on the surface. These areas were examined in an electron microprobe analyzer. These results showed primarily silver and copper, but also sulfur and iron; the sulfur was associated with the silver rather than with the iron. The X-ray diffraction pattern identified the black areas as silver sulfide, Ag_2S . There were also occasional areas on the wires that were determined to be high in copper and sulfur, possibly copper sulfate, $CuSO_4$. It must be assumed that the sulfide corrosion was on the wires before the trip to the moon, though it should be pointed out that no such areas were observed on any of the TAT wires.

CONCLUSIONS

A detailed physical and chemical analysis of the Surveyor television cable was conducted. In the comparison of results of tests of the Surveyor cable with those of the TAT cable, only a few notable differences were apparent. These changes included some loss of volatile constituents from the glass fabric outer covering and the discoloration of the glass in the Surveyor cable. The insulation on the wires developed a slight change in the infrared spectrum of the Teflon layer, and a more

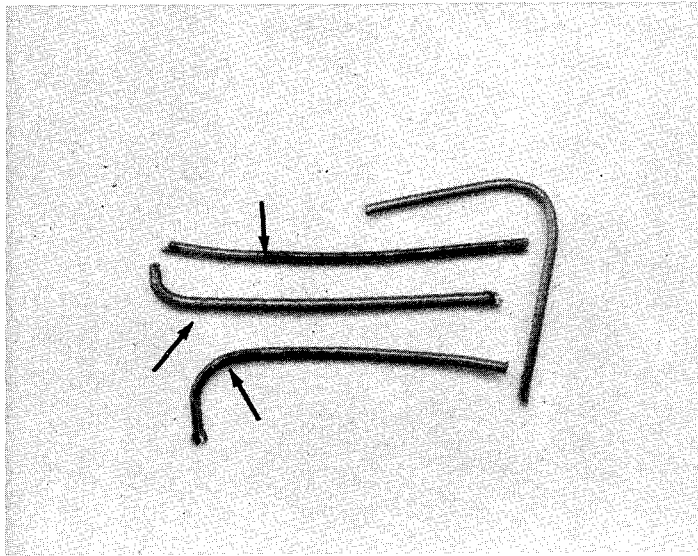


Figure 6—Surveyor wires showing corrosion on three separate wires; fourth wire with large bend is from TAT.

noticeable change occurred in the tensile strength and the elongation of both the outer polyimide layer and the inner Teflon layer. The minor change observed in the IR spectrum of the Teflon may be due to normal variations in the method of analysis. The increase in the elongation of the Kapton layer of the insulation may be explained by the possible further cure and crosslinking of the polymer due to radiation exposure in the lunar environment. The relatively minor changes exhibited by the glass fabric and the wire insulation would not affect their usefulness nor require substitution for these materials in spacecraft applications.

ACKNOWLEDGMENTS

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