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An Evaluation of Two Flat-Black Silicone Paints for Space Application

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PREFACE

Tests have been conducted on two flat-black silicone paints suggested for space applications to determine their optical, electrical, and mechanical properties for space use. These two silicone paints are the IIT Research Institute's (IITRI's) MH21S/LO, and the DSET Corporation's TB-1789. Three different types of substrate materials were chosen for the testing of these paints and the application of the paints onto the primed substrates was carried out by spray coating.

The adhesion properties were verified by thermal shock and sudden immersion into liquid nitrogen. The temperatures ranged from ambient to liquid nitrogen levels, and from higher-than-ambient to liquid nitrogen levels. A controlled thermal vacuum test was also carried out by varying the temperature of the paint from -100°C to 225°C. The measured optical properties included normal and total hemispherical emittance, and solar absorptance/reflectance. A simultaneous exposure to low-energy proton/UV irradiation in vacuum, and high-energy proton/electron irradiation was carried out. Other tests were conducted, including ultraviolet (UV) exposure for 1,000 hours, electrostatic charging using an electron gun, atomic oxygen exposure, outgassing, high-temperature exposure for 10 days in vacuum, and a particle tape-lift for surface contamination.

INTRODUCTION

The complexity of future spacecraft, their long-term missions, and flight exposure to harsh environments require identification of new materials and coatings for spacecraft use. No one coating can meet the criteria for all applications.

At present, the urethanes are the predominantly used flat-black coating materials because of their ease of application, their durability, their ease of maintenance, and their acceptable optical properties.

Silicone coatings are often considered for space applications where a low- or high-temperature condition exists, and where applications can tolerate a surface coated with a silicone having a unique combination of desirable features. Two flat-black silicone coatings have been selected for evaluation of their properties to complement and to use as an alternative to the urethane coatings. Only a few qualified silicone materials are presently available and useable for certain orbital applications.

The following sections describe and compare these two silicones and the tests which have been carried out on them.

DESCRIPTION OF MEASUREMENTS

The following tests were done to evaluate the performance of the black silicone paints, MH21S/LO, provided by the IIT Research Institute (Reference 1), and TB-1789, provided by DSET Laboratories (Reference 2). The testing included:

1. One thousand hours of equivalent-one-Sun UV exposure.
2. Simultaneous low-energy proton and UV exposure.
3. High-energy proton and electron exposure.
4. Solar absorptance/reflectance measurement.
5. Normal and hemispherical emittance.
6. Adhesion testing.
7. Atomic oxygen exposure.
8. Electrostatic charging.
9. Outgassing testing.
10. High-temperature exposure.
11. Particle tape-lift surface contamination testing.

1. Ultraviolet (UV) Degradation Test

A 1,000-hour Equivalent Sun Hours (ESH) ultraviolet degradation test was performed on both of the black silicone paints at a pressure of 10^{-6} torr with reflectance measurements being made in situ. A Spectrolab X-25 solar simulator using a Xenon lamp with an air-mass-zero filter was used to provide the one-Sun exposure.

Reflectance measurements were made in air prior to UV exposure and under vacuum. The measurements in vacuum were made after 100, 200, 500, and 1,000 hours. No changes were noted in either of the two black silicone paints.

2. Solar Wind Low-Energy Proton Particle and UV Irradiation

Samples of both paints were simultaneously exposed to low-energy, 3.5-KeV protons at a fluence level of 3.02×10^{15} p/cm^2, obtained with a flux of 2×10^9 p/cm^2/sec in conjunction with 428 ESH of UV exposure. No changes or degradations in reflectance were noted for either sample.

3. High-Energy Particle Irradiation

Both paint samples were exposed sequentially to one MeV electron and then to one MeV proton. The fluences were 7.5×10^{13} e/cm^2, obtained with a flux of 4.6×10^{10} e/cm^2/sec, and 1.5×10^{13} p/cm^2, obtained with a flux of 9.29×10^{10} p/cm^2/sec. Reflectances were obtained before and after each exposure. Figures 1 and 2 show the results of these measurements and the corresponding average absorptance (α) and emittance (ε) values. There was no change in the reflectance to either paint as a result of this exposure.

4. Optical Measurements

Optical measurements were performed with a Perkin-Elmer Lambda-9 spectrophotometer, having an accuracy of ±0.02, in accordance with ASTM-E-903. The solar absorptance/reflectance was measured as a function of wavelength and angle of incidence (20, 40, 60, 70, and 80 degrees). The absorptance was calculated from these measurements. For convenience, only the absorptance at 20° is reported in the summary sheet. Figures 3 and 4 show the measured reflectance for angles varying from 20 to 80 degrees.

The total normal emittance was measured using a Geer-Dunkel DB-100 infrared reflectometer according to ASTM-408. The emittance represents an integrated value for the 5- to 25-µm wavelengths with a ±0.02 accuracy.

The total hemispherical emittances for both silicones are shown in Figure 5, and were obtained using the vacuum calorimetric method as described in NASA Reference TND-1716 over a temperature range of -100°C to +100°C.

5. Adhesion Test--Three separate adhesion tests were conducted on the two silicone paints as applied to three different substrate materials; namely, to aluminum, Kapton*, and G-10 epoxy fiberglass. Two test samples for each of the three substrates were tested. The first adhesion test was by immersion of all three coated substrates into liquid nitrogen (LN_2) from ambient temperature. The second adhesion test was by immersion into LN_2 after the aluminum substrate

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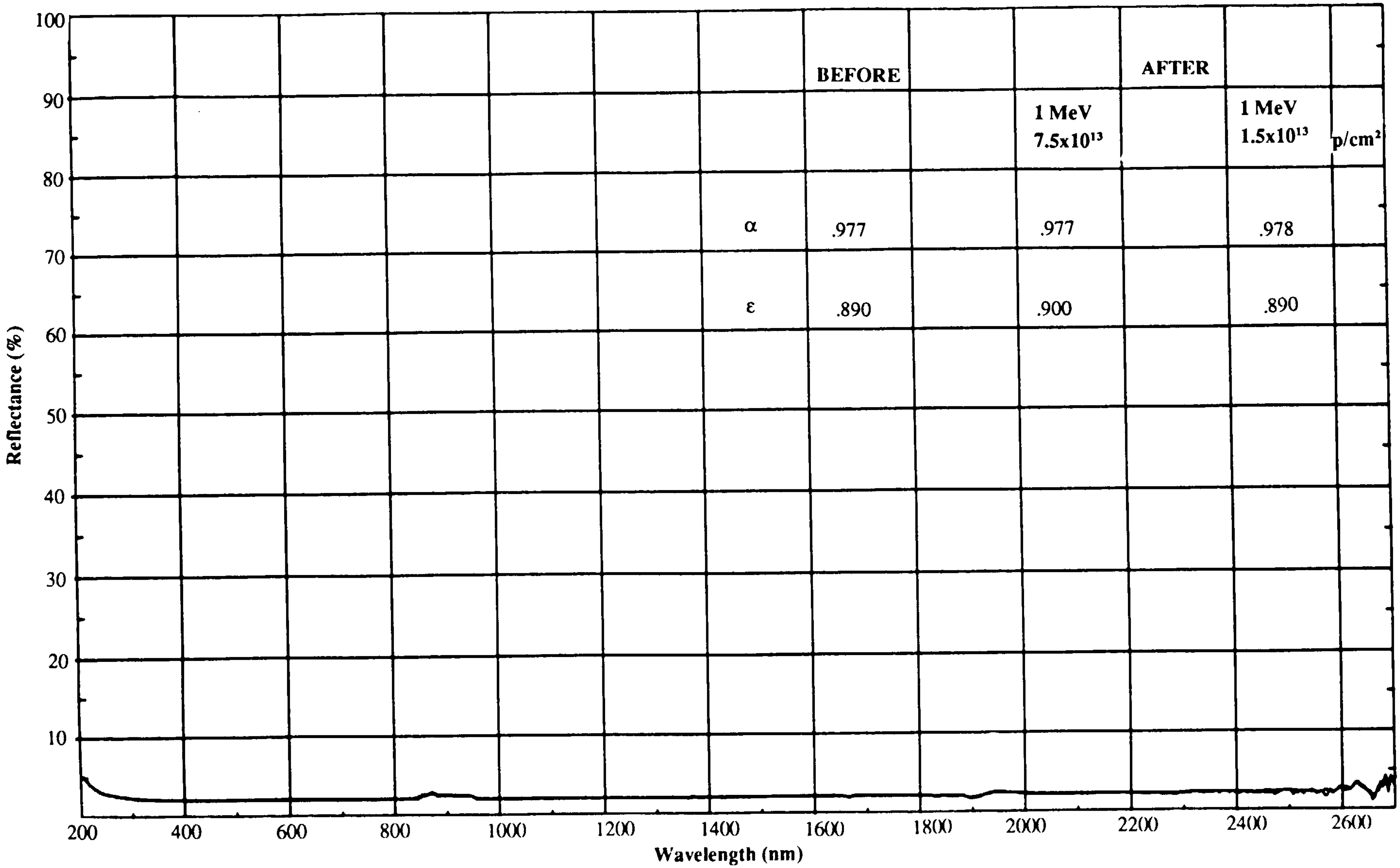
* E.I. duPont de Nemours and Co. trademark



	BEFORE	AFTER 1 MeV 7.5x10^{13}	AFTER 1 MeV 1.5x10^{13} p/cm^2
α	.977	.977	.978
ε	.890	.900	.890

Figure 1. Reflectance of IITRI's MH21S/LO black silicone paint before and after electron and proton irradiance.

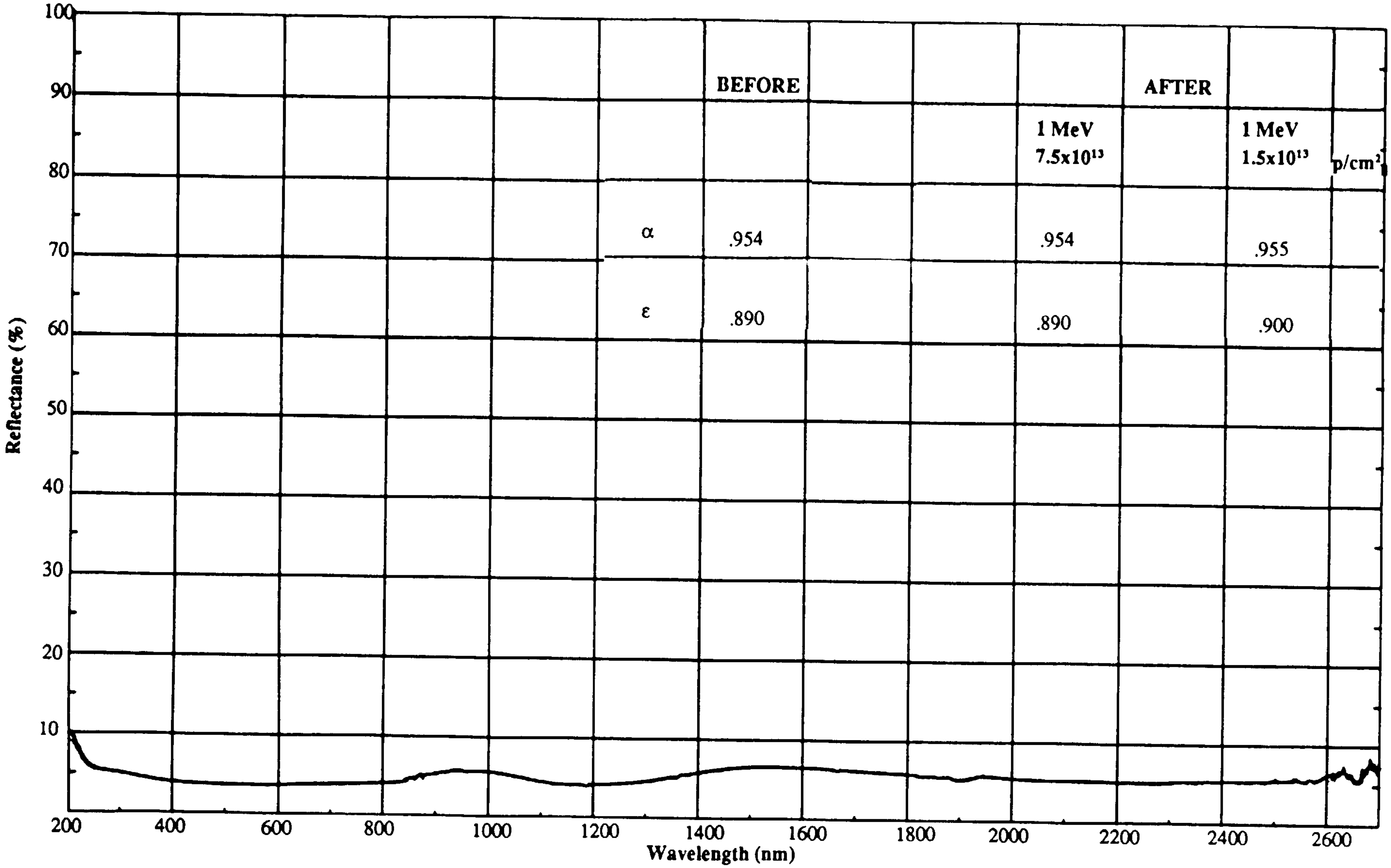
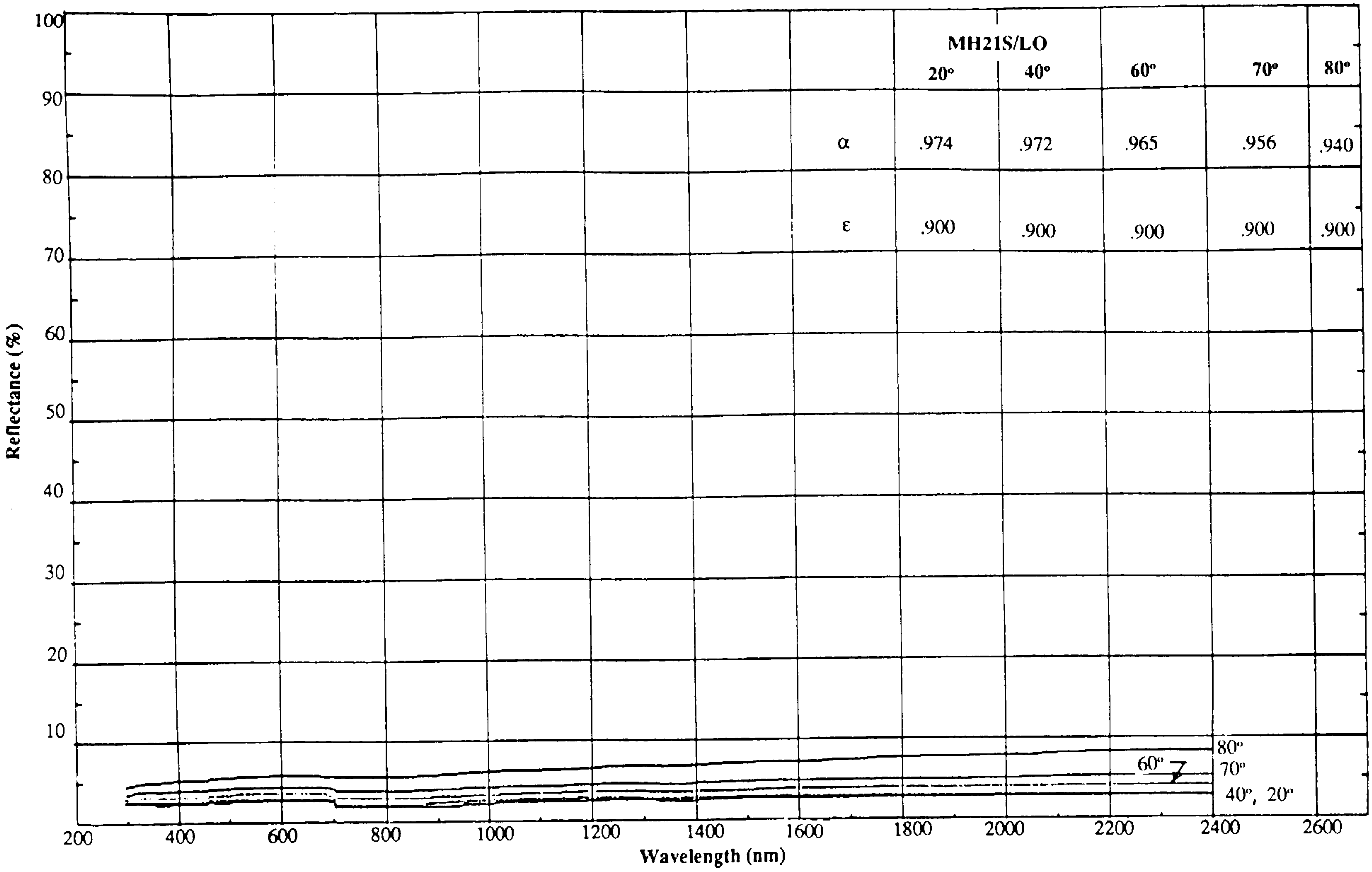


Figure 2. Reflectance of DSET's TB-1789 black silicone paint before and after electron and proton irradiation.



MH21S/LO	20°	40°	60°	70°	80°
α	.974	.972	.965	.956	.940
ε	.900	.900	.900	.900	.900

Figure 3. Reflectance Measurements of IITRI's MH21S/LO silicone paint from 20 to 80 degrees as a function of wavelength and angle of incidence.

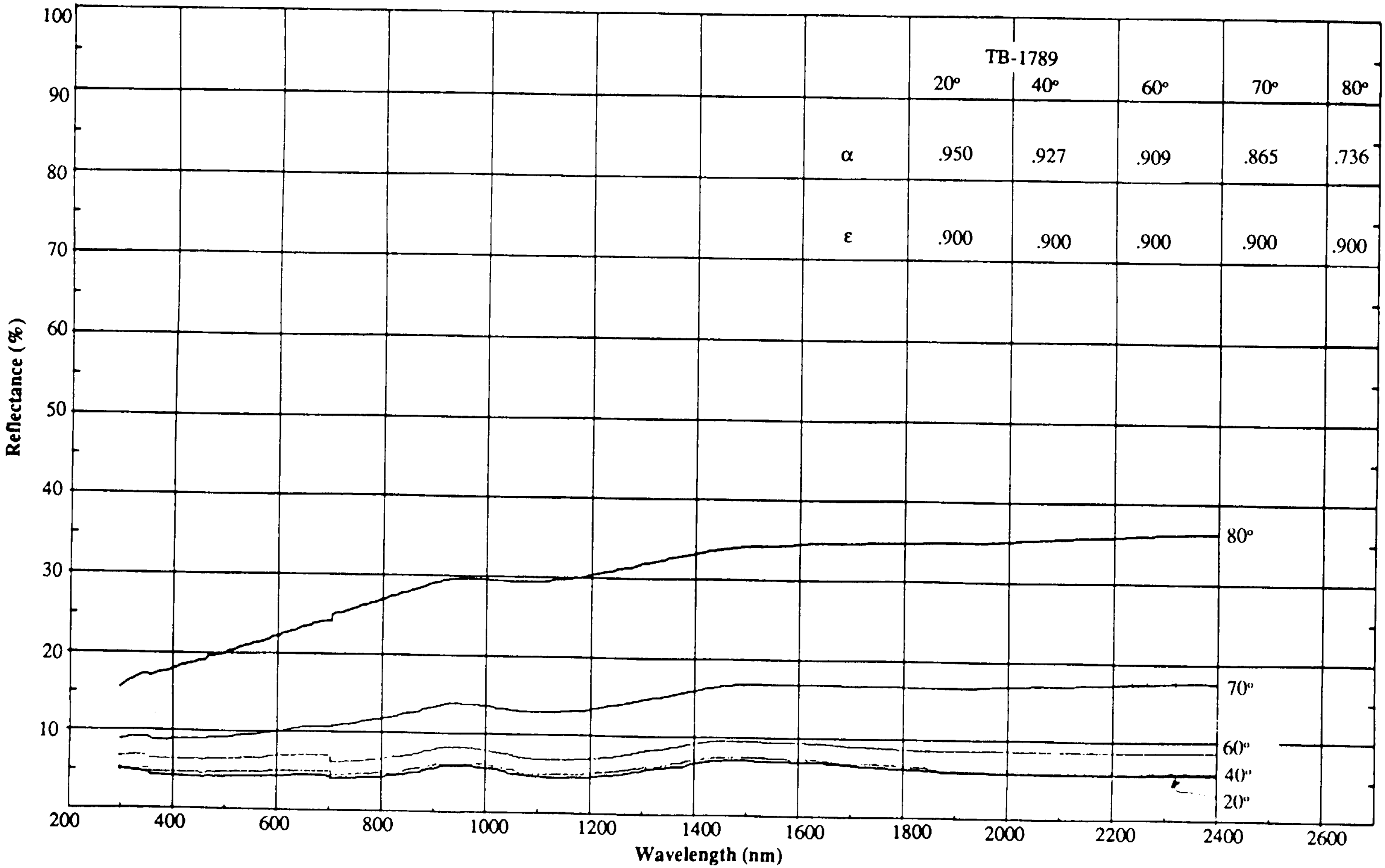


Figure 4. Reflectance Measurement of DSET's TB-1789 silicone paint from 20 to 80 degrees as a function of wavelength and angle of incidence.

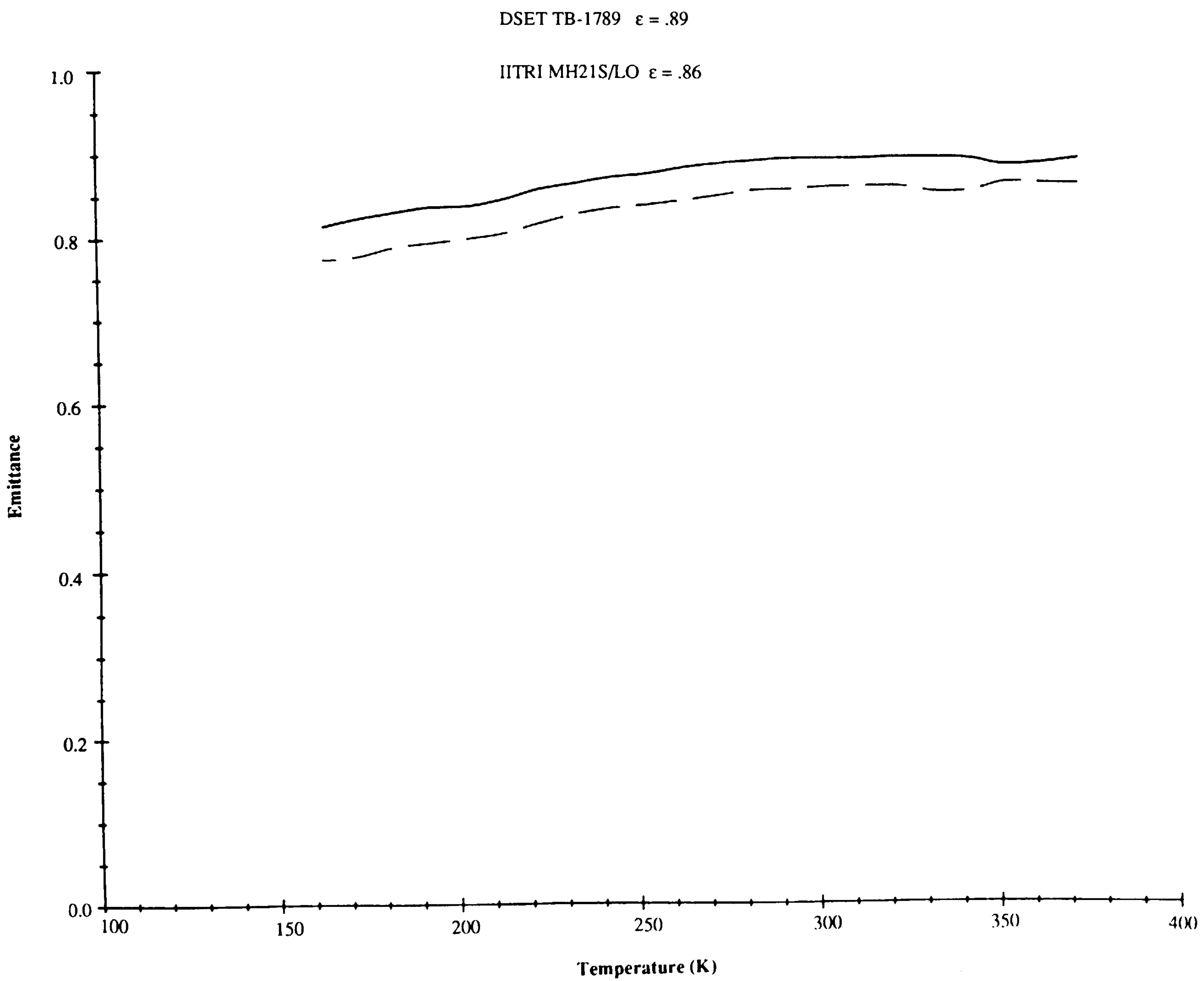


Figure 5. Total hemispherical emittance vs. temperature using a vacuum calorimetric method.

sample had been exposed to 225°C and the Kapton and G-10 epoxy fiberglass substrate samples were exposed to 150°C. The third adhesion test involved a thermal vacuum cycling test from -100°C to +150°C for the Kapton and G-10 epoxy fiberglass samples, and from -100°C to +225°C for the aluminum substrate samples. This cycling test was done at a controlled rate of 2°C per minute in a 10^{-6}-torr vacuum. None of the test samples showed any crazing or loss of adhesion after 100 cycles in any of the three adhesion tests.

6. Atomic Oxygen Exposure

An atomic oxygen test was performed on each of the two silicones by exposing them to an anisotropic oxygen plasma to estimate their stability relative to Kapton under the same environmental conditions. The testing was done in a chamber of 6.5-in. diameter and 3 3/4-in. length between parallel plates while the r.f. generator operated at 13.56 MHz. The results show that the DSET sample is 12 times less affected by the oxygen plasma than Kapton, while the IITRI sample is 19 times less affected under the same environmental conditions.

7. Electrostatic Charge

An electrostatic charge test was carried out on each silicone paint on a coated 6- by 6-in. aluminum plate. The painted plate, while in vacuum, was irradiated with 10-KeV electrons at a current density of a 10-nA/cm^2 beam from an electron flood gun. The resulting charge buildup was then measured with a contactless electrostatic probe. The MH21S/LO silicone paint charged to a high 7600 volts, while the TB-1789 charge was 300 volts. This test measurement gives a relative indication of the sample's propensity for a charge buildup in a space environment.

8. Outgassing Test

The outgassing test was done in accordance with ASTM E-595. Each silicone was spray coated onto primed, thin aluminum foils, then allowed to cure at ambient temperature for a minimum of 7 days. After the high-vacuum exposure at 125°C for 24 hours, the IITRI MH21S/LO black paint exhibited a final TML of 0.19% and a CVCM of 0.01%, while the DSET TB-1789 silicone paint had a TML of 0.36% and a CVCM of 0.02%. These results are based on an average of two test samples per each of the two paints. Both silicone paints meet the outgassing criteria for space applications with ample margin.

9. Spray Coating Applications and Handling

As previously indicated, the paints were sprayed onto three different substrates; namely, 0.062-in. aluminum 6062, 0.005-in. Kapton H film, and 0.062-in. G-10 epoxy fiberglass. Paint was applied to these primed substrates by spraying according to the manufacturers' procedures (References 3 and 4). The total thickness obtained from four successive passes, using a 90° rotation between each coat of the paint, was a nominal 0.125 mm (0.006 in.). The finished coating was allowed to fully cure by standing in air at ambient temperature for 7 days before any testing was initiated. Both paints were easily applied to all three primed substrates and they provided smooth, uniform thicknesses without paint buildup or flow from the surfaces during the application process--even in vertical positions. After testing and handling of these paints, the surfaces of both silicones were easily restored to their original condition by wiping with clean fabrics and ethyl alcohol. Table 1 indicates the characteristics of the substrates, the primers, and the silicone paints.

10. High-Temperature/Vacuum Exposure

To determine their high-temperature capabilities, both silicone paints were exposed to a temperature of 250°C for 10 days while in a vacuum of 10^{-6} torr. Both paints were applied to an aluminum substrate, and when tested, showed no signs of adhesion loss, blister, craze, or any reflectance change as shown in Figures 6 and 7. The IITRI paint had a mass loss of 2.72% while the DSET paint loss was 2.22%.

11. Surface Contamination Test

Each paint was tested for surface contamination by using the adhesive tape-lift method to determine the amount and particle size removed from the surface. Both paints exhibited clean surfaces. DSET's TM-1789 paint indicated an equivalent 150-200 cleanliness class level, while the IITRI's MH21S/LO indicated a 300-500 cleanliness class level. These class levels are described in Mil. Std. 1246B and the measuring and counting are described in ASTM F24.

CONCLUSIONS

The results of the various tests on each of the two black silicone paints have shown that these two paints have acceptable properties for application as thermal control coatings. They can be used on the interior or exterior surfaces of space instruments and spacecraft.

The samples for the various tests, with the exception of the samples for the adhesion test and electrostatic charge test, were provided by the manufacturers. The test programs were of a general nature and were not directed to a specific application. It is expected that users of these silicones will consider the results of these tests and will derive their own conclusions about applicability. Both silicones show similar performance with some minor differences.

o They performed well under three different adhesion tests and neither suffered any kind of separation from the three different substrates, nor any change from their original appearances.

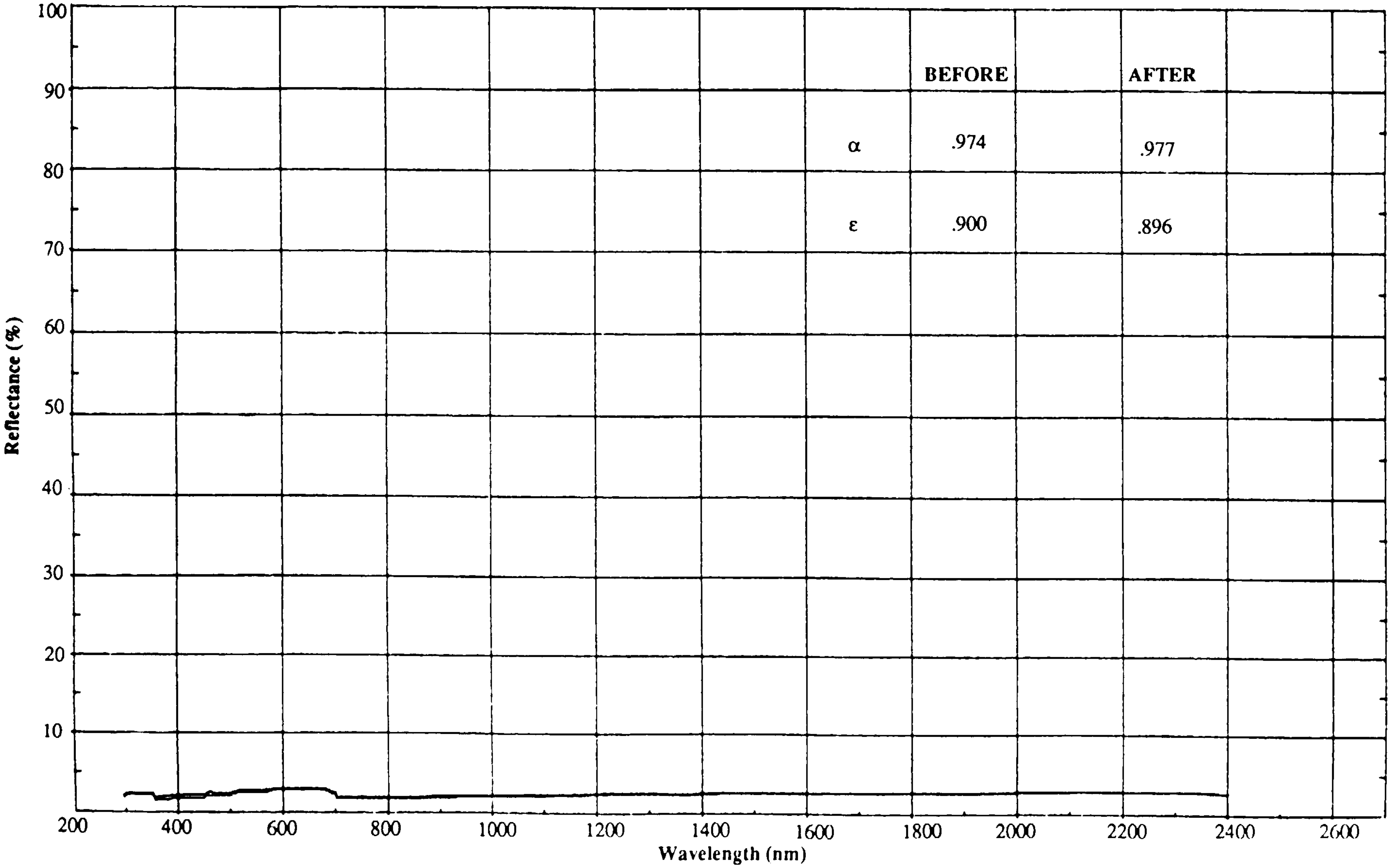
o The reflectances did not change from the initial values after exposure to low- and high-energy particles with fluence levels representing 5 years of space

Table 1. Substrate andSilicone Paint Data.

Mfr.	Silicone Paint	Substrate	Substrate Cleaning	Substrate Primer	Paint Thickness (inches)
DSET	TB-1789	Al	Abrasion	SS4044*	0.006
DSET	TB-1789	Kapton	Abrasion	A-1100**	0.006
DSET	TB-1789	Epoxy Fiber Glass	Abrasion	A-1100	0.006
IITRI	MH21S/LO	Al	Abrasion	SS4044	0.006
IITRI	MH21S/LO	Kapton	Abrasion	A-1100	0.006
IITRI	MH21S/LO Glass	Epoxy Fiber	Abrasion	A-1100	0.006

* General Electric Product

** Union Carbide Product



	BEFORE	AFTER
α	.974	.977
ε	.900	.896

Figure 6. Reflectance measurements of IITRI's MH21S/LO silicone paint before and after a high-temperature exposure to 250°C for 10 days.

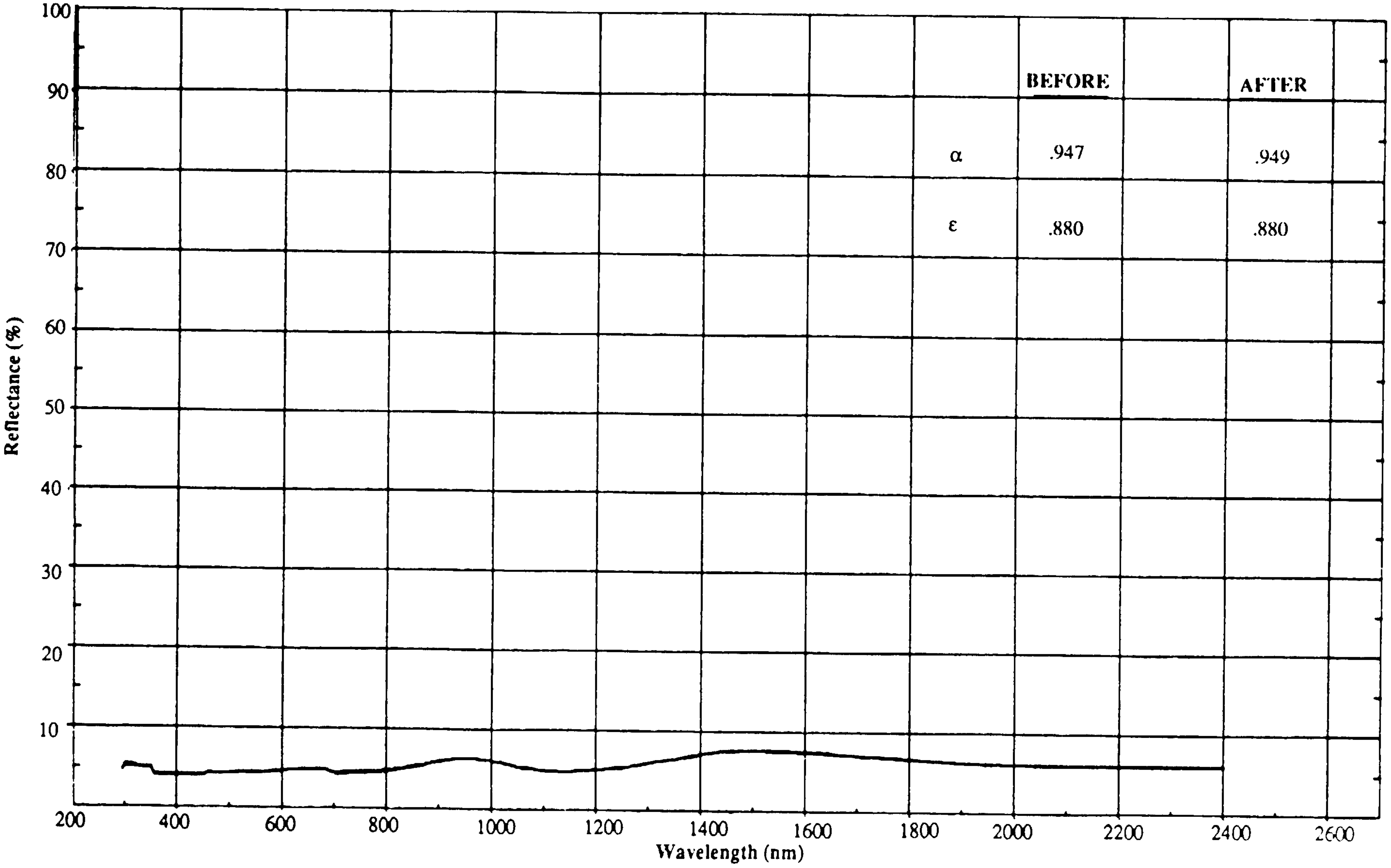


Figure 7. Reflectance measurements of DSET's TB-1789 silicone paint before and after a high-temperature exposure to 250°C for 10 days.

exposure at an altitude of approximately 350-450 miles. Reflectance measurements have shown that the DSET silicone sample suffered an approximately 20% loss of absorptance when the angle of incidence exceeded 40°, while the IITRI silicone sample, MH21S/LO,was relatively stable at all angles of incidence from 20° to 80°.

o Both silicones were measured as received and have the same normal emittance, while the IITRI sample shows a slightly lower hemispherical emittance.

o The calculated solar absorptance for the IITRI silicone is again slightly lower than the DSET. The IITRI α/ε ratio is 1.07 and that of the DSET silicone is 1.05.

o Each silicone shows low outgassing and is acceptable for space applications.

o Both silicones maintained good UV stability throughout the 1,000 ESH of testing and no change of reflectance was noted.

o When compared to the material loss experienced by Kapton exposed to an anisotropic oxygen plasma, the IITRI silicone appears to be 19 times less affected, and DSET's silicone 12 times less affected, than Kapton.

o During the electrostatic charge tests, the IITRI paint acquired an electrostatic charge of 7,600 volts, while the DSET silicone charged to 300 volts.

o Both paints survived a 250°C temperature exposure while in vacuum without any effects.

o The adhesive tape-lift test on both silicones showed that the DSET sample indicated a cleanliness class level of 150-200, while the IITRI sample showed a 300-500 level.

o For comparison, Table 2 shows a list of the optical properties (α/ε) of other black surface coatings, as reported in Reference 5. Table 3 has been included to summarize the properties of the two silicone paints described above.

Table 2. Black Coatings Properties[1].

	$\bar{\alpha}_s$	$\bar{\epsilon}_n$
Anodize Black	0.88	0.88
Carbon Black Paint NS-7	0.96	0.88
Catalac Black Paint	0.96	0.88
Chemglaze Black Paint Z306	0.96	0.91
Delrin Black Plastic	0.96	0.87
Ebanol C Black	0.97	0.73
Ebanol C Black–384 ESH* UV	0.97	0.75
GSFC Black Silicate MS-94	0.96	0.89
GSFC Black Paint 313-1	0.96	0.86
Hughson Black Paint H322	0.96	0.86
Hughson Black Paint L-300	0.95	0.84
Martin Black Paint N-150-1	0.94	0.94
Martin Black Velvet Paint	0.91	0.94
3M Black Velvet Paint	0.97	0.91
Paladin Black Lacquer	0.95	0.75
Parsons Black Paint	0.98	0.91
Polyethylene Black Plastic	0.93	0.92
Pyramil Black on Beryllium Copper	0.92	0.72
Tedlar Black Plastic	0.94	0.90
Velestat Black Plastic	0.96	0.85

*ESH = equivalent Sun hours of ultraviolet radiation.

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[1] Reproduced from Reference 6.

Table 3. Summary Sheet.

	IITRI MH21S/LO	DSET TM1789
o Solar absorptance, (α) for 20° angle of incidence	.97	.95
o Normal emittance, (ε_N) for 20° angle of incidence	.90	.90
o Hemispherical emittance, (ε_H)	.86	.89
o Adhesion after thermal cycling for aluminum, Kapton, fiberglass epoxy substrates	good	good
o UV degradation (1000 ESH)	no reflect. chg.	no reflect. chg.
o Solar wind degradation (3.5-KeV protons @ $3x10^{15}$ p/cm^2)	no reflect. chg.	no reflect. chg.
o High-energy proton degradation (1-MeV protons @ $1.5x10^{13}$ p/cm^2)	no reflect. chg.	no reflect. chg.
o High-energy electron degradation (1-MeV electrons @ $7.5x10^{13}$ e/cm^2)	no reflect. chg.	no reflect. chg.
o Charge buildup (10-KeV electrons @ 10 na/cm^2)	7600V	300V
o Outgassing test results TML% & CVCM%, ASTM E-595	0.19 (.01)	0.36(0.02)
o Percent Mass Loss at 250°C for 10 days in vacuum at 10^{-6} torr.	2.72	2.22
o Tape test surface contamination level (cleanliness class level)	300-500	150-250

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- Steve Brown and Jim Shea, NASA/GSFC, Code 311, for the high-energy particle irradiation;

- William A. Campbell, Jr., NASA/GSFC, Code 313, for the outgassing test results;

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- Jules Hirschfield, NASA/GSFC/retired, for his technical assistance with the high- and low-energy particle irradiation values.

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Chicago, IL 60616
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16. Abstract

Tests have been conducted on two flat-black silicone paints suggested for space applications to determine their optical, electrical and mechanical properties. Three different types of substrate materials were chosen for these paint tests; the application of the paints onto the primed substrates was carried out by spray coating.

The adhesion properties were verified by thermal shock and sudden immersion into liquid nitrogen. A controlled thermal vacuum test was also carried out by varying the temperature of the paint from -100°C to 225°C. The measured optical properties included normal and hemispherical emittance, and solar absorptance/reflectance. A simultaneous exposure to low-energy proton/UV irradiation in vacuum, and high-energy proton/electron irradiation was carried out. Additional tests of the paints are described.

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