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INVESTIGATION OF SPACECRAFT COATINGS

Prepared under Contract No. NAS 8-30504 by
R. A. Mayer, M. L. Zaring, and H. T. Kemp

BATTELLE MEMORIAL INSTITUTE

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

FOREWORD

This compilation of data was prepared at Battelle Memorial Institute, Columbus Laboratories, under National Aeronautics and Space Administration Contract NAS8-30504. The program was administered by the Materials Engineering Division at the George C. Marshall Space Flight Center. Mr. Frederick J. Beyerle, Manufacturing Engineering Laboratory, Manufacturing Research and Technical Division, served as the contracting officer's Technical Representative.

Principal investigator was Miss Ramona Mayer, Research Chemist, Organic and Polymer Chemistry, with assistance from Miss Mary Zaring. The work was directed by Mr. H. T. Kemp, Battelle Senior Microbiologist, Microbiology and Environmental Biology Division. Mr. C. William Cooper and Mr. R. E. Pattee served in an advisory capacity.

ABSTRACT

This collection contains data primarily concerning chemical, physical, and related properties of inorganic, organic, and semiorganic coating materials for external application on space vehicles. It also includes information such as manufacturer's designations, composition, methods of application, etc. Special attention was given to obtaining pertinent absorption-reflectance data and appropriate curves were included when available.

SPECIFIC COATINGS TESTED ON SPACECRAFT
IDENTIFIED IN THE LITERATURE REVIEWED AS OF
DECEMBER 12, 1968

Agena-D/SNAP-10A

Lithafrax, Sodium Silicate (Lockheed)

Ultrox, Silicate (Lockheed)

Lanthanum Oxide, Sodium Silicate

Titanium Oxide, Sodium Silicate

Zinc Sulfide, Sodium Silicate

Zinc Oxide, Sodium Silicate

Skyspar Enamel A423/SA9185 Epoxy (Andrew Brown Co.)

Aluminum Silicone 172-A-1 (Fuller)

Silicone-Alkyd 517-W-1 (Fuller)

Aluminum-Acrylic (Lockheed)

Kemacryl Lacquer M49BC12 Acrylic (Sherwin-Williams)

Kemacryl Lacquer M49WC17 Acrylic (Sherwin-Williams)

ATS-I

Thermatrol-A100 Silicone (Lockheed)

S-13 Silicone (IITRI)

Silicate White Paint

Multilayer - Al_2O_3, Al, SiO

Multilayer - SiO_x, Al, SiO

ATS-II

S-13 Silicone (IITRI)

Thermatrol-A100 Silicone (Lockheed)

Explorer I, II, and IV

Rokide A Alumina (Norton Co.)

Explorer XI

Multilayer - SiO, Ge, SiO

Explorer XVII

Silicon Oxide on Aluminum

Gemeni

Lockpaint, Lithium Aluminum Silicate (Lockheed)

BZr Silicon-Bonded Zircon Paint (McConnell)

PV-100 Silicone (Vita-Var Corp.)

Lunar Orbiter-I and -II

S-13G Silicone (IITRI)

Mariner-IV

Z93 White Silicate (IITRI)

Aluminum Silicone 172-A-1 (Fuller)

OSO-I

Miltilayer - Ge, SiO, Al

Multilayer - Si, Ge, SiO, Al

White Porcelain Enamel

Skyspar Enamel A423/SA9185 Epoxy (Andrew Brown Co.)

Aluminum Silicone 172-A-1 (Fuller)

Thermatrol-A100 Silicone (Lockheed)

OSO-II

S-8 ZnO-Silicone (IITRI)

Z62 Silicate (IITRI)

LP 10A Potassium Silicate (Lockheed)

Zirconium Silicate

SnO_2 Silicate

Spodumene-Sodium Silicate

Antimony Oxide-Potassium Silicate

TiO_2-Silicone

ZnO-Silicone

OSO-III

Z93 Silicate (IITRI)

Ow-III 650 Methyl Silicate

MgF_2 on Molybdenum

Cobalt Oxide

Aluminum Reflector

S-13 Silicone (IITRI)

S-13G Silicone (IITRI)

Polyvinyl Chloride Terpolymer

OV1-10

TiO-Potassium Silicate

$ZnO-TiO_2-Al_2O_3$-Potassium Silicate

Al_2O_3-Potassium Silicate

$SrMoO_4$-Potassium Silicate

MgF_2 or FeO_x

Sil cone-Alkyd 517-W-1 (Fuller)

Thermatrol-A100 Silicone (Lockheed)

Acrylic

Pegasus I

TiO_2-Silicate

Alodine 401-45

S-13 Silicone (IITRI)

Pegasus-II

Z93 Silicate (IITRI)

Alodine 401-45

S-13 Silicone (IITRI)

Pegasus-III

Z93 Silicate (IITRI)

Alodine 401-45

S-13 Silicone (IITRI)

Ranger-Mariner

Lube-Lok 2396 Sodium Silicate/MoS_2 and 4306 Phenolic/MoS_2 (Electrofilm Corp.)

Tuf-On 747-S (Brooklyn Paint & Varnish)

Corlar 585/586 (Du Pont)

Pyre-ML Varnish RK 692 (Du Pont)

Uralane 241/973 (Furane Plastics)

Alkenex Varnish 9522 (General Electric)

6SR 290 (General Electric)

Eccocoat EC 200 A/B Epoxy (Emerson Cuming)

Eccocoat VE A/B Epoxy (Emerson Cuming)

Eccosil No 33 Silicone (Emerson Cuming)

Eccocoat 1C 2 (Emerson Cuming)

Cat-A-Lac 463-1-8 Epoxy (Finch Paint and Chemical)

Cat-A-Lac 463-1 Epoxy (Finch Paint and Chemical

Cat-A-Lac 443-1 Epoxy (Finch Paint and Chemical)

Silicone-Alkyd No 7576-515 (Fuller)

Silicone-Aluminum 171-A-28 (Fuller)

U86 Melamine-Alkyd (Insl-X Products)

12412 Phenolic-Butyrate (Interchemical Corp.)

Laminar X500 Polyurethane (Magna Coatings)

UC 11659 Silicone-Aluminum (Pittsburgh Plate Glass Co.)

PR 1902 Silicone (Products Research Co.)

D25W2 Speedprint Ink Alkyd (Sherwin-Williams)

445 Silicone (Sinclair)

B-224-2 Tuffernell Varnish Alkyd (Westinghouse)

B-276 Epoxy Varnish (Westinghouse)

Fungicidal Varnish 220 F, Alkyd-Salicylanilide (Westinghouse)

Perma-Fri Ink 177 (Acme Marking Co.)

73-X Ink (Independent Ink Co.)

Agena-D/SNAP-10A

Lithafrax, Sodium Silicate (Lockheed)

Ultrox, Silicate (Lockheed)

Lanthanum Oxide, Sodium Silicate

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TiO_2-Silicone

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$ZnO-TiO_2-Al_2O_3$-Potassium Silicate

Al_2O_3-Potassium Silicate

$SrMoO_4$-Potassium Silicate

MgF_2 on FeO_x

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Acrylic

Pegasus I

TiO_2-Silicate

Alodine 401-45

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Z93 Silicate (IITRI)

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Corlar 585/586 (Du Pont)

Pyre-ML Varnish RK 692 (Du Pont)

Uralane 241/973 (Furane Plastics)

Alkenex Varnish 9522 (General Electric)

6SR 290 (General Electric)

Eccocoat EC 200 A/B Epoxy (Emerson Cuming)

Eccocoat VE A/B Epoxy (Emerson Cuming)

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U86 Melamine-Alkyd (Insl-X Products)

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Laminar X500 Polyurethane (Magna Coatings)

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D25W2 Speedprint Ink Alkyd (Sherwin-Williams)

445 Silicone (Sinclair)

B-224-2 Tuffernell Varnish Alkyd (Westinghouse)

B-276 Epoxy Varnish (Westinghouse)

Fungicidal Varnish 220 F, Alkyd-Salicylanilide (Westinghouse)

Perma-Fri Ink 177 (Acme Marking Co.)

73-X Ink (Independent Ink Co.)

PARTIAL LIST OF COATINGS USED ON SPECIFIC SPACECRAFT
OBTAINED FROM THE LITERATURE

Spacecraft \ Coating	Inorganic								Organic							
	Alumina	Cobalt Oxide	MgF_2 on Mo or FeO_x	Multilayer	Porcelain	Silicate	SiO on Al	Zirconia	Acrylic	Alkyd	Epoxy	Phenolic	Polyurethane	Polyvinyl Chloride	Silicone
Agena-D/SNAP-10A						x			x	x	x				x
ATS-I				x											x
ATS-II															x
Explorer-I, -II, and -III	x														
Explorer-XI				x											
Explorer-XVII							x								
Gemini						x		x							x
Lunar Orbiter-I and -II															x
Mariner-IV						x									x
OSO-I				x	x						x				x
OSO-II						x									x
OSO-III		x	x			x								x	x
OV1-10			x			x			x	x					x
Pegasus-I, -II, and -III						x									x
Ranger-Mariner						x				x	x	x	x		x

DATA SHEETS

Coating: Acrylic Paint

Trade Name:

Source: General Electric, Reentry Systems Dept.

Chemical Nature of Formula: 300 parts Acryloid A-21 (Rohm and Haas),
360 parts zinc oxide (Eagle-Picher #428),
130 parts xylol

Solar Absorptance, Initial (α_s):	0.25
After Heat Flux	0.26
After Combined Heat Flux and Ultraviolet Exposure	0.28
Hemispherical Emittance, Initial (ϵ_H):	0.80
After Heat Flux	0.77
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.31

Ref. 15

Coating: Acrylic White Paint

Trade Name:

Source:

Chemical Nature of Formula: $SrMoO_2$ pigment and acrylic vehicle

Substrate: Aluminum alloy

Comments: Tested on OV1-10

Ref. 11

Coating: Alkyd

Trade Name: B-224-2 Tuffernell Varnish

Source: Westinghouse

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, >10.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 9.3
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 6.81×10^{14}
- Surface Resistivity, ohms
  - Control, 4.25×10^{15}
- Dielectric Strength, v/mil
  - Control, 1550
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1810

Surface Condition After Thermal Cycling:
Darkening of color; blisters on electrical samples.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Alkyd

Trade Name: D 25 W2 Speedprint Ink

Source: Sherwin-Williams

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 1.2
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Failed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 8.00×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.32×10^{15}
- Surface Resistivity, ohms
  - Control, 6.65×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.19×10^{14}
- Dielectric Strength, v/mil
  - Control, 715
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 345

Surface Condition After Thermal Cycling:
Darkening of color; gets brittle.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Alkyd Polyester

Trade Name: Alkenex Varnish 9522

Source: General Electric, Reentry Systems Dept.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 6.8
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 9.0
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Dielectric Strength, v/mil
  - Control, 585
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 640

Surface Condition After Thermal Cycling:
Darkening of color; blisters which prevented resistivity measurement.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Alkyd-Salicylanilide Fungicide

Trade Name: Fungicidal Varnish 220F

Source: Westinghouse

Mechanical Properties:

- Scrape Adhesion, kgm
  - Control, 2.3
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.3
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:

- Volume Resistivity, ohm-cm
  - Control, 1.41×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.13×10^{15}
- Surface Resistivity, ohms
  - Control, 6.65×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.74×10^{14}
- Dielectric Strength, v/mil
  - Control, 446
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 693

Surface Condition After Thermal Cycling:

Darkening of color.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating:

Trade Name: Alodine 401-45

Source:

Chemical Nature of Formula: $CrPO_4$, $AlPO_4$, and HF reacted with an aluminum surface

Substrate: Aluminum

Comments: Tested on Pegasus I, II, and III

Ref. 11

Coating: Alumina

Trade Name: Rokide A

Source: The Norton Co.[a]

Chemical Nature of Formula: 98.6% Al_2O_3

Substrate: Aluminum alloy, AISI 410[b], AISI 430 Steel[b], and epoxy-fiberglass laminate[b]

Density, lbs./in.^{3}: 0.115

Thickness, in.: 0.005-0.100

Porosity, %: 8-12

Thermal Drop Through 0.030 in. at Steady-State Melting Temperature: 6 F per 0.001 in.

Maximum Service Temperature: 3000 F

Thermal Conductivity, B.T.U. per hr. per sq. ft. per in. per ^oF: 19, at 1000 to 2000 F

Thermal Expansion Coefficient, 70 to 2550 F: 43×10^{-7} per ^oF

Emissivity at 1000 to 2000 F: 0.3-0.4

Thermal Shock Resistance: Excellent

Resistance to Vibration and Flexing: Very good

Hardness and Abrasion Resistance: Very high

Solar Absorptance (α_s): 0.26 [a]

Hemispherical Emittance at 600 ^oR (ϵ_H): 0.73[a]

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.36[a]

Comments: Tested on Explorer-I[b], -II[b], -IV[b].

Ref. 8, [a]20, [b]17

Coating: Aluminum

Trade Name: 2024 Aluminum Alloy

Source:

Solar Absorptance at 535 ^{o}R (α_s):	0.20
Hemispherical Emittance at 535 ^{o}R (ϵ_H):	0.06
Absorptance-Emittance Ratio (α_s/ϵ_H):	3.33

Comments: Solar absorber. Prelaunch - aluminum is susceptible to increases in α_s and ϵ_H caused by contamination. Protection with LAC-1002 is required. Postlaunch - no restrictions other than structural.

Ref. 6

Coating: Aluminum

Trade Name: 6061 Aluminum Alloy

Source:

	Nonclad Sheet	Sheet Sanded	Agena Fuel Tank, Sanded
Solar Absorptance at 530 ^{o}R (α_s)	0.16	0.19	0.18
Hemispherical Emittance at 530 ^{o}R (ϵ_H)	0.06	-	0.08
Absorptance-Emittance Ratio (α_s/ϵ_H)	2.67	-	2.25

Comments: Solar absorber. Prelaunch - aluminum is susceptible to increases in α_s and ϵ_H caused by contamination. Protection with LAC-1002 is required. Postlaunch - no restrictions other than structural.

Ref. 6

Coating: Aluminum Adhesive-Backed Foil

Trade Name: Fasson Foil

Source:

Solar Absorptance at 530 ^{o}R (α_s):	0.12
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.04
Absorptance-Emittance Ratio (α_s/ϵ_H):	3

Comments: Solar absorber. Prelaunch - aluminum is susceptible to increases in α_s and ϵ_H caused by contamination. Protection with LAC-1002 is required. Postlaunch - material should be used only in areas where peak ascent temperatures are not expected to exceed 375 F; it must not be external during ascent.

Ref. 6

Coating: Aluminum Alloy

Trade Name: 6061

Source:

Chemical Nature of Formula: 6061 aluminum sheet (nonclad)

Substrate: Not applicable

Solar Absorptance at 530°R (α_s): 0.16

Hemispherical Emittance at 530°R (ϵ_H): 0.06

Absorptance-Emittance Ratio (α_s/ϵ_H): 2.67

Comments: Solar absorber. Prelaunch- aluminum surface is very susceptible to increases in α_s and ϵ_H caused by contamination. The surface must be protected from physical abuse, atmospheric exposure, and caustic contaminants; cleanliness must be assured. Postlaunch- no known restrictions other than structural requirements.

Ref. 18

Coating: Aluminum Coated, Fused Silica, Second Surface Mirror

Trade Name:

Source:

Chemical Nature of Formula:

Substrate: Aluminum alloys per surface preparation
LAC 3013, primer LAC 30-4325 and adhesive RTV-615 per LAC 30-4324

Solar Absorptance at 325-530 ^{o}R (α_s):	0.100
Hemispherical Emittance at 460 ^{o}R (ϵ_H):	0.807
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.124

Comments: Optical solar reflector. Prelaunch - fragile and should be protected from mechanical damage during storage and shipping. Surface contamination due to fingerprints, oil. dust, and atmospheric weathering does not cause permanent degradation. Temporary contaminants must be removed prior to launch per LAC 3801. Postlaunch - the surface requires a minimum of 14 days of room-temperature curing to minimize outgassing of adhesive during ascent. Orbital - no measurable change in α_s due to near-ultraviolet radiation. Coating is stable in all combined space environments.

Ref. 6

Coating: Aluminum Foil (MIL-A-148C)

Trade Name:

Source:

Solar Absorptance at 530 ^{o}R (α_s):	0.12
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.04
Absorptance-Emittance Ratio (α_s/ϵ_H):	3

Comments: Solar absorber. Prelaunch - foil surface is susceptible to increases in α_s and ϵ_H caused by contamination. Protection with LAC-1002 after degreasing with LAC 0170. Postlaunch - no restrictions other than structural.

Ref. 6

Coating: Aluminum Foil With Silicone Adhesive

Trade Name: Mystik 7402

Source:

Solar Absorptance at 530 ^{o}R (α_s):	0.12
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.04
Absorptance-Emittance Ratio (α_s/ϵ_H):	3

Comments: Solar absorber. Prelaunch - aluminum surface is susceptible to increases in α_s and ϵ_H caused by contamination. Protection with LAC-1002 is required. Postlaunch - if applied externally the tape should have mechanical fastening to prevent pulloff during ascent. It may be used internally where peak temperatures of up to 900 F are anticipated and externally for temperatures up to 750 F.

Ref. 6

Coating: Aluminum Oxide

Trade Name:

Source:

Solar Absorptance (α_s): 0.30

Hemispherical Emittance at 546°R (ϵ_H): 0.90

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.33

Comments:

Ref. 14

Coating: Aluminum Oxide

Trade Name:

Source:

Substrate: Reflectal aluminum alloy

Solar Absorptance (α_s): 0.2

Hemispherical Emittance at 670°R (ϵ_H): ≥ 0.8

Absorptance-Emittance (α_s/ϵ_H): 0.25

Ref. 14

Coating: Al_2O_3 Reflector

Trade Name:

Source:

Substrate: Aluminum alloy

Comments: Tested on OV1-10

Ref. 11

Coating: Aluminum Phosphate Paint

Trade Name:

Source: Atomics International

Chemical Nature of Formula: SnO pigment and $AlPO_4$ vehicle

Substrate: Subcoat of Cr-Co-Ni spinel bonded with aluminum phosphate; 1100-0 aluminum

Thickness, mils: 2

Solar Absorptance, Initial (α_s): 0.40

Hemispherical Emittance, Initial (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.47

Thermal Stability:

At 390 °K Good

At 530 °K Good

Adhesion: Good

Substrate Compatibility: With 1100-0 aluminum only

Reliability and Reproducibility: Poor

Predicted Ultraviolet and Nuclear Radiation Stability: Good

Ref. 16

Coating: Aluminum Reflector

Trade Name:

Source:

Chemical Nature of Formula: Aluminum, 2000 Å

Substrate: Stainless steel

Comments: Tested on OSO-III

Ref. 11

Coating: Aluminum-Silicone-Alkyd Paint

Trade Name: D4D

Source: General Electric, Missiles and Space Div.

Chemical Nature of Formula:

Substrate: Aluminum, aluminized Mylar, and polyester-impregnated fiberglass mat

		Irradiated	
	Initial	After 10^{14}-10^{15} ergs/g	After 2×10^{13} ergs/g
Solar Absorptance (α_s):	0.27-0.27	0.33	0.29
Hemispherical Emittance (ϵ_H):	0.27-0.28	0.27	0.27
Absorptance-Emittance Ratio (α_s/ϵ_H)	0.96-0.97	1.23	1.07

Ref. 12

Coating: Aluminum Silicone Paint

Trade Name: Aluminum Silicone 172-A-1

Source: Fuller Paint Co.

Chemical Nature of Formula: Leafing aluminum pigment in silicone vehicle, baked on at 465 F

Substrate: HM21A-T8 magnesium, annealed (-0) magnesium and aluminum, titanium, stainless steels, and super alloys, and any other rigid substrate capable of withstanding cure cycle

Thickness, mils: 3.0 (minimum for opacity)

Solar Absorptance at 530 °R (α_s): 0.25

$\Delta\alpha_s$ After Irradiation to 5×10^7 R(C): 0.01 (a)

$\Delta\alpha_s$ After Irradiation to 2×10^8 R(C): 0.02 (a)

Hemispherical Emittance at 530 °R (ϵ_H): 0.28

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.90

Maximum Service Temperature, °F: 800*

Continueous Service Temperature, °F: 300*

Comments: Flat reflector. Prelaunch - handle and protect per LAC-1002. Post-launch - no change was observed in α_s and ϵ_H as a result of ascent heating with peak temperatures $\leq$ 885 F. Orbital - primary source of degradation appears to be the near-ultraviolet portion of incident solar and albedo radiation. α_s increases by $\Delta\alpha_s = 0.09 \pm 0.04$ after 600 "sunhours"; ϵ_H is unaffected. Tested on an Agena-D/SNAP-10A spacecraft vehicle (a), OSO-I (b), and Mariner IV (b).

Ref. 6, (a)2, (b)11, *Supplier's Data

Coating: Aluminum Silicone Paint

Trade Name: Aluminum Silicone 171-A-152

Source: Fuller Paint Co.

Chemical Nature of Formula: Leafing aluminum pigment in silicone vehicle; baked on at 465 F.

Substrate: HM21A-T8 magnesium, annealed (-0) magnesium and aluminum, titanium, stainless steels, and super alloys, and any other rigid substrate capable of withstanding the cure cycle

Thickness, mil: 3.0 (minimum for opacity)

Solar Absorptance at 530 °R (α_s): 0.22

Hemispherical Emittance at 530 °R (ϵ_H): 0.24

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.92

Maximum Service Temperature, °F: 1200*

Continuous Service Temperature, °F: 800*

Comments: Flat reflector. Prelaunch - handle and protect per LAC-1002. Postlaunch - ascent heating histories with peak temperatures ≤ 880 F cause an increase in α_s of 0.01 or less; ϵ_H is unaffected. Orbital - primary source of degradation appears to be near-ultraviolet portion of incident solar and albedo radiation. α_s increases by $\Delta\alpha_s$=0.09±0.04 after 600 "sunhours"; ϵ_H is unaffected.

Ref. 6, *Supplier's Data

Coating:

Trade Name: Alzak

Source:

Substrate: Aluminum Alloy

Solar Absorptance (α_s): 0.19

Hemispherical Emittance at 600°R (ϵ_H): 0.71

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.27

Ref. 20

Coating: Anodized Aluminum, Black

Trade Name: RCA 1980039

Source: Radio Corporation of America

Chemical Nature of Formula:

Solar Absorptance (α_s): 0.65

Hemispherical Emittance (e_H): 0.87

Ref. 23

Coating: Anodized Magnesium

Trade Name: Dow-17

Source: Dow Chemical Co.

Chemical Nature of Formula: Proprietary

Substrate: HM21A-T8 Magnesium Alloy Sheet

Solar Absorptance at 530 ^{o}R (α_s):	0.78
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.70
Absorptance-Emittance Ratio (α_s/ϵ_H):	1.11

Comments: Flat absorber. Prelaunch- the surface is porous and requires the necessary protection per LAC-1002 if used as a thermal control surface. Postlaunch - no restrictions other than structural requirements. Thermal stability above 500 F is doubtful.

Ref. 6

Coating: Bi_2S_3 Dyed Anodized Aluminum

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 26.4

Solar Absorptance (α_s):

Initial, 0.728

After Space Simulation Environment and 10^{15} e/cm^2, 0.760

After Micrometeroid Impact, 0.743

Hemispherical Emittance (ϵ_H):

Initial, 0.909

After Space Simulation Environment and 10^{15} e/cm^2, 0.890

After Micrometeroid Impact, 0.917

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.80

Abrasive Resistance, g/μm: 13.37

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: Black Nickel Plate

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 2.8

Solar Absorptance (α_s/ϵ_H):

Initial, 0.959

After Space Simulation Environment and 10^{15} e/cm^2, 0.953

After Micrometeroid Impact, 0.956

Hemispherical Emittance (ϵ_H):

Initial, 0.686

After Space Simulation Environment and 10^{15} e/cm^2, 0.598

After Micrometeroid Impact, 0.828

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.140

Abrasive Resistance, g/μm: 2.20

Flexibility (Bend) Test: Slight spalling at edges

Ref. 11

Coating: Black Paint

Trade Name:

Source: Lowe Brothers

Chemical Nature of Formula: Commercially produced paint, constituents proprietary

Substrate: Aluminum

Comments: Tested on Pegasus I, II, and III

Ref. 11

Coating: Black Silicone Paint

Trade Name: Fuller 517-B-2

Source: Fuller Paint Co.

Chemical Nature of Formula:

Lamp black pigment in silicone vehicle

Substrate: HM21A-T8 magnesium, annealed (-0) magnesium and aluminum, titanium, stainless steels, and superalloys, and any other rigid substrate capable of withstanding the cure cycle

Thickness, mils: 1.0 (minimum for opacity)

Solar Absorptance at 530 ^{o}R (α_s):	0.89
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.88
Absorptance-Emittance Ratio (α_s/ϵ_H):	1.01
Maximum Service Temperature, °F:	800*
Continuous Service Temperature, °F:	570*

Comments: Flat absorber. Prelaunch - hardle and protect per LAC-1002. Postlaunch - adhesion, α_s, and ϵ_H are unaffected by ascent-heating histories with peak temperatures $\lesssim$ 1070 F. Material has not been evaluated at higher temperatures. Orbital - in tests simulating exposure to extraterrestrial solar near-ultraviolet energy in vacuum, changes in α_s of 0.05 or less were observed after 600 "sunhours".

Ref. 6, *Supplier's Data

Coating: Boron Nitride

Trade Name:

Source:

Thickness, mils: 253

Solar Absorptance (α_s): 0.21

Hemispherical Emittance at 1860°R (ϵ_H): 0.79

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.27

Comments: Large thickness required because of infrared transparency.

Ref. 14

Coating: Butyral Paint

Trade Name:

Source: American Cyanamid Company

Chemical Nature of Formula: TiO_2 pigment and polyvinyl butyral resin vehicle

Substrate: 6061-T6 aluminum

Solar Absorptance, Initial (α_s): 0.19

Hemispherical Emittance, Initial (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.22

Thermal Stability:

At 390 ^{o}K Good

At 530 ^{o}K Poor

Adhesion: Fair

Substrate Compatibility: Good

Reliability and Reproducibility: Good

Predicted Ultraviolet and Nuclear Radiation Stability: Poor

Ref. 16

Coating: Cermet

Trade Name:

Source: Magna Coatings and Chemical Corp.

Chemical Nature of Formula: Ceramic vehicle containing sintered metal

Solar Absorptance at 500°R (α_S): 0.65

Hemispherical Emittance at 500°R (ϵ_H): 0.58

Absorptance-Emittance Ratio (α_S/ϵ_H): 1.1

Ref. 20

Coating: Chemically Polished Beryllium

Trade Name: QMV

Source: Brush Co.

Solar Absorptance at 530 ^{o}R (α_s):	0.50
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.10
Absorptance-Emittance Ratio (α_s/ϵ_H):	5

Comments: Solar absorber. Prelaunch - requires precautions to prevent surface corrosion which results in increased α_s and ϵ_H. Postlaunch - normal ascent temperatures do not affect the optical properties of this material. Oxidation rates below 1400 F are negligible. Heating to 1600 F within 3 min. followed by normal cooling increases ϵ_H by 0.04; heating to 1700 F within 5 min. increases ϵ_H by 0.01.

Ref. 6

Coating: Chromic Oxide

Trade Name: Rokide C

Source: Norton Abrasive Co.

Chemical Nature of Formula: 85% Cr_2O_3, flame-sprayed

Substrate: René 41 with a 2-mil coating of nichrome

Solar Absorptance at 530 ^{o}R (α_s): 0.90

Hemispherical Emittance at 400-800 ^{o}R (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 1.06

Comments: Flat absorber. Prelaunch - coating is extremely hard and very inert chemically. No problems are anticipated with the prelaunch environment. Postlaunch - no degradation of optical properties resulting from ultraviolet exposure. No coating failures were noted on heating complex shapes to 2100 ^{o}R within 5 min. followed by a 5-min. cooling period.

Ref. 6

Coating: Cr-Ti-Si for Columbium Alloys

Source: TRW Equipment Labs

Preparation: Vacuum pack deposition in two steps using halide activators

Weight Gain in Coating, %: 25.2

Substrate Loss in Coating, %: 28

Substrate Hardness Change; Nil

Ultimate Tensile Strength, ksi: 81

Yield Strength (0.2%), ksi: 79

Elongation, %: 1.3
Type of Fracture: Ductile

Oxidation Resistance, Hrs. to Failure:
1800°F 100+
2350°F 100+
2500°F 47 to 49

Oxidation Resistance After Prestrain at Room Temperature:
2000°F 75+
2500°F 75+

Diffusion Rate at 2500°F, Mil/Hr: 0.05

Bend Transition Temperature, °F:
As Received -210
After 8 Hrs. at 2000°F -210
After 8 Hrs. at 2350°F -180

Fatigue Life at Room Temperature
Maximum Stress at 10^6 Cycles, ksi: 30

Creep Test (Stress to Produce 1% Creep in 1 Hr), ksi:
2000°F 16 to 18
2500°F 2.2 to 3.7

Elongation to Failure in Creep, %:
2000°F 10+
2500°F 10+

Continued

Coating: Cr-Ti-Si For Columbium Alloys (Continued)

Comments: Applications include the following:

a. Thin gage (10-12 mil) heat shield face sheets for multi-mission life reentry applications.
b. Refractory metal fasteners.
c. Thin wall tubes for heat exchanger or regenerative cooled propulsion system applications.
d. Spun or welded sheet rocket engine nozzle extension or skirts.
e. Complete chamber and nozzle, for radiatively cooled attitude control or small thrust vector control rocket engine.

Ref. - 19

Coating: Cobalt Oxide Solar Absorber

Trade Name:

Source:

Chemical Nature of Formula:

Substrate: Aluminum Alloy

Comments: Tested on OSO-III

Ref. 11

Coating: CoS Dyed Anodized Aluminum

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 26.2

Solar Absorptance (α_s):

Initial, 0.957

After Space Simulation Environment and 10^{15} e/cm^2, 0.963

After Micrometeroid Impact, 0.962

Hemispherical Emittance (ϵ_H):

Initial, 0.930

After Space Simulation Environment and 10^{15} e/cm^2, 0.924

After Micrometeroid Impact, 0.936

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.103

Abrasive Resistance, g/μm: 14.15

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating:

Trade Name: Du-lite 3-0

Source: Du-lite Chemical Corporation

Chemical Nature of Formula:

Substrate: Type 304 stainless-steel grit blasted

Thickness, μm: 3.8

Solar Absorptance (α_s):

Initial, 0.952

After Space Simulation Environment and 10^{15} e/cm^2, 0.945

After Micrometeroid Impact, 0.944

Hemispherical Emittance (ϵ_H):

Initial, 0.653

After Space Simulation Environment and 10^{15} e/cm^2, 0.626

After Micrometeroid Impact, 0.639

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.146

Abrasive Resistance, g/μm: 0.51

Flexibility (Bend) Test: No specimens available

Ref. 13

Coating: Dyed Anodized Aluminum

Trade Name: Sandoz Black BK

Source: Sandoz

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 22.6

Solar Absorptance (α_s):

Initial, 0.757

After Space Simulation Environment and 10^{15} e/cm^2, 0.786

After Micrometeroid Impact, 0.796

Hemispherical Emittance (ϵ_H):

Initial, 0.926

After Space Simulation Environment and 10^{15} e/cm^2, 0.929

After Micrometeroid Impact, 0.929

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.817

Abrasive Resistance, g/μm: 10.35

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: Dyed Anodized Aluminum

Trade Name: Sandoz Black OA

Source: Sandoz

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 20.1

Solar Absorptance (α_s):

Initial, 0.647

After Space Simulation Environment and 10^{15} e/cm^2, 0.684

After Micrometeroid Impact, 0.681

Hemispherical Emittance (ϵ_H):

Initial, 0.927

After Space Simulation Environment and 10^{15} e/cm^2, 0.913

After Micrometeroid Impact, 0.915

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.07

Abrasive Resistance, g/μm: 12.72

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: Elastomeric Silicone Paint

Trade Name:

Source: General Electric, Reentry Systems Dept.

Chemical Nature of Formula: 300.0 parts G. E. SR-126 silicone, 72.0 parts Titanox RA, 4.0 parts zinc oxide, 7.0 parts aluminum silicate, 3.0 aluminum octoate, 172.0 parts toluol, 0.8 parts G. E. catalyst SRC-05

Ref. 15

Coating: Epoxy

Trade Name: B-276 Clear Air Drying Varnish

Source: Westinghouse

Surface Condition After Thermal Cycling:
Yellowed; softens and runs during preliminary thermal exposure.

Comments: Used on Ranger and Mariner spacecrafts .

Ref. 4

Coating: Epoxy

Trade Name: Eccocoat VE A/B

Source: Emerson Cuming

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 6.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 5.3
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 5.85×10^{12}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.29×10^{16}
- Surface Resistivity, ohms
  - Control, 2.73×10^{11}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.07×10^{14}
- Dielectric Strength, v/mil
  - Control, 711
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1136

Surface Condition After Thermal Cycling:
- Darkening of color.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

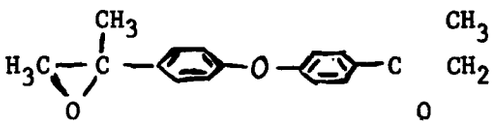
Coating: Epoxy

Trade Name: NApoxy-1

Source: North American, Los Angeles Division

Chemical Nature of Formula:

4,4'-Bis(1 methyl-1,2-epoxyethyl)phenyl ether



Property Data	Varnish	White, TiO_2 Pigment (Titanox AMO)	Yellow, $SrCrO_4$ Pigment (Harshaw 2821)	Black, Graphite (Dixon MIL-G-6711)
Adhesion	Good	Good	Good	Good
Liquid Oxygen Impact	40/40 Passed	40/40 Passed	39/40* Passed	40/40 Passed
Fluid Contact	Passed	Passed	Passed	Passed
Accelerated Weathering	O.K., 80 hrs	Severe chalking, 100 hrs	Light chalking, 600 hrs	O.K., 600 hrs
Conical Bend	Failed	O.K., 7/8" radius	O.K., 5/8" radius	O.K., 5/8" radius
NTO Immersion	-	Passed	Passed	Passed
Elevated Temperature				
500 F	96.6% loss, 142 hrs	14.6% loss, 175 hrs (adhesion loss)	26.5% loss, 142 hrs	32.2% loss, 142 hrs
450 F	45.4% loss, 500 hrs	12.03% loss, 500 hrs	13.83% loss 500 hrs	10.57% loss, 150 hrs

Continued

Coating: Epoxy NApoxy-1 (Continued)

Property Data	Varnish	White, TiO_2 Pigment (Titanox AMO)	Yellow, $SrCrO_4$ Pigment (Harshaw 2821)	Black, Graphite (Dixon MIL-G-6711)
Salt Spray	-	Moderate corrosion, 50 hrs	Light corrosion at scribe marks, 150 hrs	Severe corrosion, 50 hrs
Abrasion	Poor	Poor	Poor	Poor

*An additional set of specimens showed two successive failures and further tests were stopped. Since the varnish was insensitive, the pigment mixture alone was tested and passed 20/20.

Comments: **Experimental coatings for large structural components in contact with N_2O_4 oxidizer.**

Ref. 1

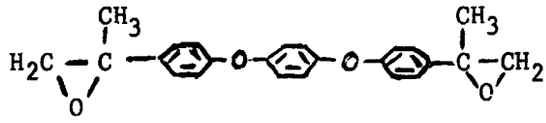
Coating: Epoxy

Trade Name: NApoxy-2

Source: North American, Los Angeles Division

Chemical Nature of Formula:

1,4-Bis[4(1-methyl-1,2-epoxyethyl)phenoxy]benzene



Property Data:	White, TiO_2 pigment (Titanox AMO)
Adhesion	Good
Liquid Oxygen Impact	20/20 Passed
Fluid Contact	Passed
Accelerated Weathering	Severe chalking, 200 hrs
Conical Bend	OK, 1/4 inch radius
NTO Immersion	Passed
Elevated Temperature, 450 F	10.57% loss, 150 hrs

Comments: Experimental coating for large structural components in contact with N_2O_4 oxidizer.

Ref. 1

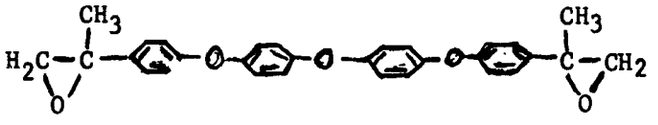
Coating: Epoxy

Trade Name: NApoxy-3

Source: North American, Los Angeles Division

Chemical Nature of Formula:

4,4'Bis [4(1-methyl-1,2-epoxyethyl)phenyoxy] phenyl ether



Comments: Experimental coating for large structural components in contact with N_2O_4 oxidizer. Not recommended for improved coating properties because of lower solubility and higher melting point.

Ref. 1

Coating: Epoxy/Amine

Trade Name: Cat-A-Lac 443-1 Gloss White

Source: Finch Paint & Chemical Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 5.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 8.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Failed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 1.2×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.0×10^{14}
- Surface Resistivity, ohms
  - Control, 1.1×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.43×10^{14}
- Dielectric Strength, v/mil
  - Control, 1463
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1125

Surface Condition After Thermal Cycling:
White changes to cream color; gets brittle after thermal exposure.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Epoxy/Amine

Trade Name: Cat-A-Lac 463-1 Flat White

Source: Finch Paint & Chemical Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 5.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, >10.0
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Failed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 9.98×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.58×10^{14}
- Surface Resistivity, ohms
  - Control, 9.78×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.41×10^{14}
- Dielectric Strength, v/mil
  - Control, 1106
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1113

Solar Absorptance (α_s): $0.248^{(a)}$

Hemispherical Emittance at 1000 ^{o}R (ϵ_H): $0.912^{(a)}$

Absorptance-Emittance Ratio (α_s/ϵ_H): $0.27^{(a)}$

Surface Condition After Thermal Cycling:
White changes to dark cream; gets brittle.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4, (a) 14

Coating: Epoxy/Amine

Trade Name: Cat-A-Lac 463-1-8 Flat Black

Source: Finch Paint & Chemical Co.

Mechanical Properties
- Scrape Adhesion, kgm
  - Control, >10.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, >10.0
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Failed

Electrical Properties
- Volume Resistivity, ohm-cm
  - Control, 5.68×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.0×10^{13}
- Surface Resistivity, ohms
  - Control, 2.83×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.33×10^{10}
- Dielectric Strength, v/mil
  - Control, 930
  - After thermal ex posure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 526

Surface Condition After Thermal Cycling:
No change in color; gets brittle.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Epoxy/Amine

Trade Name: Corlar 585/586

Source: Du Pont

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 2.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 2.3
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 9.90×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 9.10×10^{14}
- Surface Resistivity, ohms
  - Control, 5.52×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.09×10^{14}
- Dielectric Strength, v/mil
  - Control, 373
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 300

Surface Condition After Thermal Cycling:
- No change observed.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Epoxy-Base Paint

Trade Name: White Skyspar A-423/Federal 17875

Source: Andrew Brown Co.

Chemical Nature of Formula:

Solar Absorptance at 500°R (α_s): 0.27

Hemispherical Emittance at 500°R (ϵ_H): 0.87

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.31

Ref. 20

Coating: Epoxy-Base Paint

Trade Name: White Skyspar A-423/SA8818

Source: Andrew Brown Co.

Chemical Nature of Formula:

Solar Absorptance at 500°R (α_s): 0.22

Hemispherical Emittance at 500°R (ϵ_H): 0.83

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.27

Ref. 20

Coating: Epoxy-Base Paint

Trade Name: White Skyspar Enamel A423/SA9185

Source: Andrew Brown Co.

Chemical Nature of Formula:

TiO_2 pigmented epoxy-base paint

Substrate: Any rigid substrate

Thickness, mils: 4 (minimum for opacity)

Solar Absorptance at 530 ^{o}R (α_s):	0.22
$\Delta\alpha_s$ After Irradiation to 5 x 10^7 R(C):	0.07[a]
$\Delta\alpha_s$ After Irradiation to 2 x 10^8 R(C):	0.12[a]
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.91
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.24

Comments: Solar reflector. Prelaunch - resistance to ultraviolet energy, including fluorescent lamps, is low. LAC-1002 protection from contamination is required. Postlaunch - paint is not recommended for general use in locations reaching temperatures above 450 F during ascent. Orbital - primary source of degradation appears to be near-ultraviolet portion of incident solar and albedo radiation. Tested for thermal control on Agena-D/SNAP-10A spacecraft vehicle[a] and on OSO-I[b].

Ref. 6,[a] 2,[b] 11

Coating: Epoxy Paint, Black

Trade Name: RCA 1985090

Source: Radio Corporation of America

Chemical Nature of Formula:

Solar Absorptance (α_s): 0.894

Hemispherical Emittance (ϵ_H): 0.883

Ref. 23

Coating: Gloss White Silicone-Modified Alkyd Paint

Trade Name: Gloss White 517-W-1

Source: Fuller Paint Co.

Chemical Nature of Formula:

TiO_2 pigment in silicone-modified alkyd vehicle

Substrate: HM 21A-T8 magnesium annealed (-0) magnesium and aluminum, titanium, stainless steels, and super alloys, and any other rigid substrate capable of withstanding the cure cycle

Thickness, mils: 5.0 (minimum for opacity)

Solar Absorptance at 530 °R (α_s):	0.25
$\Delta\alpha_s$ After Irradiation to 5×10^7 R(C):	0[a]
$\Delta\alpha_s$ After Irradiation to 2×10^8 R(C):	0[a]
Hemispherical Emittance at 530 °R (α_s):	0.90
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.28
Maximum Service Temperature, °F:	570*
Continuous Service Temperature, °F:	500*

Comments: Solar reflector. Prelaunch - surface must be protected per LAC-1002. Postlaunch - paint is not recommended for general use in locations reaching temperatures above 650 F during ascent. Paint cracks at 960 to 775 F. Orbital - primary source of degradation appears to be the near-ultraviolet portion of incident solar and albedo rediation.[a] Tested for thermal control on an Agena-D/SNAP-10A spacecraft vehicle[a] and on OVI-10[b].

Ref. 6,[a] 2, [b]11, *Supplier's Data

Coating: Iridite, Chemical Treatment

Trade Name: RCA 1980135

Source: Radio Corporation of America

Chemical Nature of Formula:

Solar Absorptance (α_s): 0.33

Hemispherical Emittance (ϵ_H): 0.092

Ref. 23

Coating:

Trade Name: Korotherm H1 Protective Coating

Source: De Soto Chemical Coatings, Inc.

Chemical Nature of Formula:

Solar Absorptance at 400°R (α_s): 0.34

Hemispherical Emittance at 400°R (ϵ_H): 0.71

Absorptance-Emittance (α_s/ϵ_H): 0.48

Ref. 20

Coating: PbS Dyed Anodized Aluminum

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 17.3

Solar Absorptance (α_s):

Initial, 0.861

After Space Simulation Environment and 10^{15} e/cm^2, 0.891

After Micrometeroid Impact, 0.881

Hemispherical Emittance (ϵ_H):

Initial, 0.912

After Space Simulation Environment and 10^{15} e/cm^2, 0.908

After Micrometeroid Impact, 0.908

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.944

Abrasive Resistance, g/μm: 12.77

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: Lithium-Aluminum Silicate

Trade Name: "Lockpaint"

Source: Lockheed Missile and Space Co.

Vibration Test: Passed

Comments: Gemini space radiator coating.

Ref. 10

Coating: Magnesium and Aluminum Composite

Trade Name: Rokide MA

Source: The Norton Co.

Chemical Nature of Formula: 98% $MgO-Al_2O_3$ (a)

Substrate: Aluminum

Thickness, mils: 10

Solar Abosrptance (α_s): 0.34

Hemispherical Emittance at 600 ^oR (ϵ_H): 0.76

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.45

Melting Temperature, ^oF: 3500 (a)

Mean Specific Heat, BTU/lb/^oF
At 70-1832 F: 0.25 (a)

Coefficient of Expansion, in/in/^oF
At 70-2000 F: 4.5×10^{-6} (a)

Thermal Conductivity, BTU/hr/ft^2-in/^oF: 18 (a)

Comments:

Ref. 20, (a) 9

Coating: MgF_2 Solar Absorber

Trade Name;

Source:

Chemical Nature of Formula: MgF_2 on molybdenum

Substrate: Molybdenum

Comments: Tested on OSO-III

Ref. 11

Coating: Melamine-Alkyd Modified

Trade Name: Insl-X U86

Source: Insl-X Products

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 1.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 1.83×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 9.19×10^{14}
- Surface Resistivity, ohms
  - Control, 2.44×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.44×10^{14}
- Dielectric Strength, v/mil
  - Control, 1297
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1722

Surface Condition After Thermal Cycling:
Severe darkening of color.

Comments: Used on Ranger and Mariner spacecrafts. Insl-x U86F contains Cunilate 2137, a copper-type fungicide supplied by Scientific Chem. Co.; Insl-x U-86T contains Steritize OL-30, a mercury-type fungicide supplied by Steritized Inc.*

Ref. 4, *Supplier's Data

Coating: Methyl Silicate (Ow-III 650) Clear Film

Trade Name:

Source:

Chemical Nature of Formula:

Substrate: Aluminum Alloy

Comments: Tested on OSO-III

Ref. 11

Coating: Mixing White Acrylic Lacquer

Trade Name:

Source: Pittsburgh Plate Glass Co., Ditzler Finishes Div.

Chemical Nature of Formula:

Thickness: 0.006 inch

Solar Absorptance at 500°R (α_s): 0.21

Hemispherical Emittance at 500°R (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.25

Ref. 20

Coating: Multilayer

Trade Name:

Source:

Chemical Nature of Formula: Al_2O_3 (1.1 microns, top), Al (opaque), and SiO

Substrate: Aluminum alloy

Comments: Tested on ATS-1 and ATS-II

Ref. 11

Coating: Multilayer

Trade Name;

Source:

Chemical Nature of Formula: Ge (110 Å, top), SiO (1.1 microns), Al (opaque)

Substrate: Stainless steel

Comments: Tested on OSO-I

Ref. 11

Coating: Multilayer

Trade Name:

Source:

Chemical Nature of Formula: SiO (500 Å, top), Ge (200 Å), SiO (1.1 microns), and Al (opaque)

Substrate: Stainless steel

Comments: Tested on OSO-I

Ref. 11

Coating: Multilayer

Trade Name:

Source:

Chemical Nature of Formula: SiO (1500 Å, top), Ge (200 Å), and SiO (9000 Å)

Substrate: Aluminum Alloy

Comments: Tested on Explorer XI

Ref. 11

Coating: Multilayer

Trade Name:

Source:

Chemical Nature of Formula: SiO_x (1.5 microns, top), Al (opaque), snd SiO

Substrate: Aluminum Alloy

Comments: Tested on ATS-1 and ATS-II

Ref. 11

Coating: Nickel-Chrome Alloy Foil

Trade Name: Inconel TPS-0101B

Source: H. I. Thompson Co.

Solar Absorptance at 530 ^{o}R (α_s):	0.38
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.12
Absorptance-Emittance Ratio (α_s/ϵ_H):	3.17

Comments: Solar absorber. Prelaunch - highly polished foil is susceptible to increases in α_s and ϵ_H by fingerprinting and oxidation of the surface. Coating with LAC-1002 is required. Postlaunch - ascent heating increases α_s and ϵ_H.

Ref. 6

Coating: Nickel-Chromium Alloy Foil

Trade Name: Inconel X

Source: H. I. Thompson Co.

Solar Absorptance at 530 ^{o}R (α_s):	0.66
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.15
Absorptance-Emittance Ratio (α_s/ϵ_H):	4.44

Comments: Solar absorber. Prelaunch - highly polished foil is susceptible to increases in α_s and ϵ_H. Coating with LAC-1002 is required. Postlaunch - ascent heating is likely to increase α_s and ϵ_H by 100% or more.

Ref. 6

Coating: Nonleafing Aluminum Flat Acrylic-Based Paint

Trade Name:

Source: Mixed at Lockheed Missile and Space Co.

Chemical Nature of Formula:

Base is Kemacryl Clear Acrylic Vehicle (Sherwin-Williams); pigment is aluminum paste

Substrate: Any clean substrate; primer required

Thickness, mils: 3.0 (minimum for opacity)

Solar Absorptance at 530 ^{o}R (α_s):	0.38-0.55
$\Delta\alpha_s$ After Irradiation to 5 x 10^7 R(C):	0.01 [a]
$\Delta\alpha_s$ After Irradiation to 2 x 10^8 R(C):	Moderate to severe mechanical damage, temperature dependent [a]
Hemispherical Emittance at 530 ^{o}R (ϵ_H):	0.36-0.58
Absorptance-Emittance Ratio (α_s/ϵ_H):	1.06-0.95

Comments: Flat reflector. Prelaunch - surface is porous and requires protection from contamination per LAC-1002. Postlaunch - requires a minimum of 14 days at room-temperature curing to remove volatiles sufficiently to minimize blistering during ascent heating. At peak temperatures < 650 F the most serious problem is caused by outgassing or bubbling of the surface. Bubble height ≤ 0.015 in.; bubble diameter < 0.04 in. Bubbling begins at 245 F. May be used in locations where maximum ascent temperatures are < 650 F providing surface changes can be tolerated. Tested on an Agena-D/SNAP-10A spacecraft vehicle [a].

Ref. 6, [a] 2

Coating: Not Revealed

Trade Name: Number 73-X Ink

Source: Independent Ink Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, < 0.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 1.16×10^{10}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.70×10^{9}
- Surface Resistivity, ohms
  - Control, 8.77×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.90×10^{14}
- Dielectric Strength, v/mil
  - Control, 24
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 21

Surface Condition After Thermal Cycling:
No change observable; low adhesion.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Not Revealed

Trade Name: Perma-Dri Ink 177

Source: Acme Marking Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, <0.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.3
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 7.2×10^9
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.18×10^9
- Surface Resistivity, ohms
  - Control, 9.23×10^6
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.90×10^6
- Dielectric Strength, v/mil
  - Control, 0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 0

Surface Condition After Thermal Cycling:
No change observable; low resistivities; not for electrical insulation.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Optical Thin Films by Vapor Deposition

Trade Name:

Source:

Chemical Nature of Formula:

Metal films (silver, aluminum, gold) with dielectric overlay (silicon dioxide, aluminum dioxide)

Thickness of Dielectric Overlay: $< 60{,}000$ Å

Solar Absorptance at 530 °R (α_2):	0.05 (silver)
(Dependent on metal film, substrate finish, and deposition parameters)	0.14 (aluminum)
	0.20 (gold)
Hemispherical Emittance at 530 °R (ϵ_H):	0.03 (500 Å dielectric overlay)
(Varies with dielectric thickness)	to 0.66 (60,000 Å dielectric)

Comments: Prelaunch - surfaces are hard and abrasion-resistant; may be cleaned by conventional techniques. Postlaunch - coatings do not require cure treatment, will not blister, and are capable of repeated thermal cycling between 30-500 F, if substrates and coatings are compatible. Ascent - no deterioration noted due to vacuum or thermal effects up to 500 F for silver or aluminum films. Gold films on aluminum substrates fail at these temperatures. Thermal diffusion barriers between coating and substrate should provide stability up to 2000 F. Orbital - no significant degradation was observed for these systems due to simulated solar ultraviolet irradiation at 70-500 F for periods equivalent to 2000 "sunhours", with the exception of aluminum alloy/gold/silica and aluminum alloy/silver/alumina systems at 500 F.

Ref. 6

Coating: p-Phenyl Phenol-Aldehyde

Trade Name: Tuf-On 747-S

Source: Brooklyn Paint & Varnish

Chemical Nature of Formula: Contains 7% salicylanilide fungicide*

Surface Condition After Thermal Cycling:
Fails adhesion and flexibility tests; preliminary thermal exposure

Comments: **Used on Ranger and Mariner spacecrafts.** Resists fungus growth*.

Ref. 4, *Supplier's Data

Coating:

Trade Name: Parsonloid Optical Black Paint

Source: Eppley Laboratory

Chemical Nature of Formula:

Solar Absorptance at 500°R (α_s): 0.99

Hemispherical Emittance at 500°R (ϵ_H): 0.97

Absorptance-Emittance Ratio (α_s/ϵ_H); 1.0

Ref. 20

Coating: Phenolic-Butyrate

Trade Name: Interchemical 12412

Source: Interchemical Corp.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 5.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 9.9
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 2.05×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Shorted
- Surface Resistivity, ohms
  - Control, 7.74×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Shorted
- Dielectric Strength, v/mil
  - Control, 283
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 125

Surface Condition After Thermal Cycling:
- No change observable; not for electrical insulation.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Phenolic/MoS_2

Trade Name: Electrofilm Lube-Lok 4306

Source: Electrofilm Corp.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 6.3
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.8
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 4.81×10^{16}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.05×10^{16}
- Surface Resistivity, ohms
  - Control, 2.24×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.02×10^{14}
- Dielectric Strength, v/mil
  - Control, 805
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 716

Maximum Temperature, 450°F*

Surface Condition After Thermal Cycling:
No change.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4, *Supplier's Data

Coating: Platinum Black

Trade Name:

Source:

Chemical Nature of Formula:

Finely divided platinum deposited on beryllium from a solution of chloroplatinic acid (H_2PtCl_2)

Substrate: QMV Beryllium

Solar Absorptance at 530 ^{o}R (α_s):	0.94
Hemispherical Emittance at 360-500 ^{o}R (ϵ_H):	0.80
Absorptance-Emittance Ratio (α_s/ϵ_H):	$\sim$ 1.17

Comments: Flat absorber. Prelaunch - no corrosive effects resulting from normal storage and/or atmospheric exposure. The surface is porous and must be protected from contamination per LAC-1002. Postlaunch - ascent heating (short-duration) temperatures of < 1200 F will not change the optical properties of the surface. Sintering occurs above 390 F.

Ref. 6

Coating: Polyimide

Trade Name: Pyre-ML Varnish RK692

Source: Du Pont

Chemical Nature of Formula: Polyimide resin in N-methylpyrrolidone and xylene solvent*

Mechanical Properties:

Scrape Adhesion, kgm

Control, 3.1

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.3

Flexibility (FTMS Nr 141, Method 6223)

Control, Passed

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:

Volume Resistivity, ohm-cm

Control, 6.83×10^{11}

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 8.46×10^{14}

Surface Resistivity, ohms

Control, 5.26×10^{14}

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 5.13×10^{11}

Dielectric Strength, v/mil

Control, 800

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 590

Radiation Resistance: Good (Exposure to 3000 megarads (electrons) caused only minor changes in electrical and physical properties)*

Thermal Conductivity, $Cal/sec/cm^2/°C/cm$ 72×10^{-5}*

Linear Coefficient of Thermal Expansion, per °C 4×10^{-5}*

Coefficient of Kinetic Friction, 0.17*

Solvent and Oil Resistance, Excellent*

Flame Resistance, Excellent*

Surface Condition After Thermal Cycling:

No change observable.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4, *Supplier's Data

Coating: Polyurethane

Trade Name: Ecccoat 1C 2

Source: Emerson Cuming

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 6.8
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 7.6
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 8.47×10^{11}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.89×10^{12}
- Surface Resistivity, ohms
  - Control, 5.31×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.10×10^{13}
- Dielectric Strength, v/mil
  - Control, 463
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 873

Surface Condition After Thermal Cycling:
Yellowing.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Polyurethane

Trade Name: Uralane 241/973

Source: Furane Plastics

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 0.75
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.6
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 9.20×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen 7.09×10^{14}
- Surface Resistivity, ohms
  - Control, 3.50×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.70×10^{14}
- Dielectric Strength, v/mil
  - Control, 2293
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3275

Non-nutrient in contact with fungus cultures including:*
- Chaetomium globosum
- Aspergillus niger
- Aspergillus flavus
- Penicillium brevi-compactum

Surface Condition After Thermal Cycling:
Yellowing.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4, *Supplier's Data

Coating: Polyvinyl Chloride (VMCH) Research Film

Trade Name:

Source:

Chemical Nature of Formula: Polyvinyl chloride terpolymer

Comments: Tested on OSO-III

Ref. 11

ing: Porcelain Enamel

.rade Name: PEMCO Nr R 46460

Source:

Chemical Nature of Formula:

Soalr Absorptance at 500°R (α_s): 0.22

Hemispherical Emittance at 500°R (ϵ_H): 0.78

Absorptance-Emittance Ratio (α_s/ϵ_H):).23

Ref. 20

Coating: Porcelain Enamel

Trade Name: PEMCO No R 46460

Source:

Substrate: Steel

Solar Absorptance (α_s): 0.22

Hemispherical Emittance (ϵ_H): 0.79

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.23

Ref. 20

Coating: Potassium Silicate Paint

Trade Name:

Source:

Chemical Nature of Formula: La_2O_3 pigment and K_2SiO_2 vehicle (4.3 pigment-vehicle ratio by weight)

Solar Absorptance (α_s):
Control, 0.091
After 250 "sun-hours", 0.142

Ref. 17

Coating: Potassium Silicate Paint

Trade Name:

Source: Lockheed Missile and Space Co.

Chemical Nature of Formula: Li-Al-SiO_4 pigment and K_2SiO_4 vehicle

Substrate: 6061-T6 aluminum

Solar Absorptance, Initial (α_s): 0.11

Hemispherical Emittance, Initial (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.13

Thermal Stability:

At 390 ^oK	Good
At 530 ^oK	Good

Adhesion: Good

Substrate Compatibility: Good

Reliability and Reproducibility: Fair

Predicted Ultraviolet and Nuclear Radiation Stability: Poor

Ref. 16

Coating: Potassium Silicate Paint

Trade Name:

Source;

Chemical Nature of Formula: Y_2O_3 pigment in K_2SiO_2 vehicle (4.3 pigment-vehicle ratio by weight)

Solar Absorptance (α_s):
Control, 0.072
After 250 "sun-hours", 0.132

Ref. 17

Coating: Potassium Silicate Paint

Trade Name:

Source:

Chemical Nature of Formula: $ZnTiO_3$ pigment and K_2SiO_2 vehicle, (4.3 pigment-vehicle ratio by weight)

Solar Absorptance (α_s):
Control, 0.117
After 570 "sun-hours", 0.138

Ref. 17

Coating: Potassium Silicate Paint

Trade Name:

Source:

Chemical Nature of Formula: ZrO_2 pigment and K_2SiO_2 vehicle (6.45 pigment-vehicle ratio by weight)

Solar Absorptance (α_s):

Control, 0.099
After 6000 "sun-hours", 0.333
Pigment calcined at 300C for 4 hours,
Control, 0.075
After 1600 "sun-hours", 0.140

Ref. 17

Coating: Potassium Silicate Paint

Trade Name: LP 10A

Source: Lockheed Missiles and Space Co.

Chemical Nature of Formula: $ZrSiO_4$ pigment (1000 N ·ox, Metals and Thermit Corp.) and K_2SiO_4 vehicles

Substrate: Aluminum alloy

Thickness, mils: 3.0 to 5.0

Solar Absorptance (α_s)
At Room Temperature in Air: 0.12; 0.11 [a]

Hemispherical Emittance (ϵ_H)
At Room Temperature in Air: 0.90; 0.85 [a]

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.13; 0.13 [a]

Thermal Stability:

At 390 °K Good [a]

At 530 °K Good [a]

Adhesion: Good [a]

Substrate Compatibility: Good [a]

Reliability and Reproducibility: Fair [a]

Predicted Ultraviolet and Nuclear Radiation Stability: Good [a]

Comments: Experimental. Tested on OSO-II [b].

Ref. 6, [a]16, [b]11

Coating:

Trade Name: Pyrochrome Paint

Source:

Chemical Nature of Formula: Cr_2O_3 pigment

Solar Absorptance at 500°R (α_s): 0.73

Hemispherical Emittance at 500°R (ϵ_H): 0.79

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.92

Ref. 20

Coating:

Trade Name: Pyromark Black

Source:

Chemical Nature of Formula:

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 32.8

Solar Absorptance (α_s):

Initial, 0.902

After Space Simulation Environment and 10^{15} e/cm^2, 0.903

After Micrometeroid Impact, 0.923

Hemispherical Emittance (ϵ_H):

Initial, 0.830

After Space Simulation Environment and 10^{15} e/cm^2, 0.820

After Micrometeroid Impact, 0.873

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.109

Abrasive Resistance, g/μm: 1.26

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating:

Trade Name: Pyromark Black

Source:

Chemical Nature of Formula:

Substrate: Inconel

Thickness, μm: 32.3

Solar Absorptance (α_s):

Initial, 0.906

After Space Simulation Environment and 10^{15} e/cm^2, 0.906

After Micrometeroid Impact, 0.921

Hemispherical Emittance (ϵ_H):

Initial, 0.842

After Space Simulation Environment and 10^{15} e/cm^2, 0.845

After Micrometeroid Impact, 0.866

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.108

Abrasive Resistance, g/μm: 1.26

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: Ribbon Glass

Trade Name:

Source:

Substrate: Aluminum

Thickness, mils: 6

Solar Absorptance (α_s): 0.20

Hemispherical Emittance at 546°R (ϵ_H): 0.77

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.26

Ref. 14

Coating: Rutile Silicone Alkyd Enamel

Trade Name:

Source:

Thickness, mils: 5

Solar Absorptance (α_s): 0.22

Hemispherical Emittance at 546°R (ϵ_H): 0.94

Absorptance-Emittance (α_s/ϵ_H): 0.23

Ref. 14

Coating: Silica

Trade Name:

Source: Brunswick-Balke-Collendor Co.

Chemical Nature of Formula: Five mils of silica on HM21A magnesium

Solar Absorptance at 500°R (α_s): 0.21

Hemispherical Emittance at 500°R (ϵ_H): 0.83

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.25

Ref. 20

Coating: Silica-Base Ceramic Paint

Trade Name: PT-209

Source: Paint Techniques, Inc.

Chemical Nature of Formula: Five mils on René 41 foil

Solar Absorptance at 500°R (α_s): 0.38

Hemispherical Emittance at 500°R (ϵ_H): 0.80

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.48

Ref. 20

Coating: Silicate

Trade Name:

Source:

Chemical Nature of Formula: La_2O_3 pigment and $Na_2O.SiO_2$ vehicle

Solar Absorptance (α_s):

Control	0.08
$\Delta\alpha_s$ After Irradiation to 5×10^7 R (C),	0.02
$\Delta\alpha_s$ After Irradiation to 2×10^8 R (C),	0.06

Hemispherical Emissivity at 500°R (ϵ_H): 0.89

Absorptivity-Emissivity Ratio (α_s/ϵ_H): 0.09

Comments: Solar reflector: tested for thermal control on an Agena-D/ SNAP-10A spacecraft vehicle.

Ref. 2

Coating: Silicate

Trade Name:

Source: Lockheed Missiles and Space Co.

Chemical Nature of Formula: Ultrox pigment and $K_2O.SiO_2$ vehicle

Solar Absorptance (α_s):
Control, 0.11
$\Delta\alpha_s$ After Irradiation to 5×10^7 R (C), 0.01
$\Delta\alpha_s$ After Irradiation to 2×10^8 R (C), 0.02

Hemispherical Emissivity at 500°R (ϵ_H): 0.89

Absorptivity-Emissivity Ratio (α_s/ϵ_H): 0.12

Comments: Solar reflector: tested for thermal control on an Agena-D/ SNAP-10A spacecraft vehicle.

Ref. 2

Coating: Silicate

Trade Name:

Source:

Chemical Nature of Formula: TiO_2 pigment and $Na_2O.SiO_2$ vehicle

Solar Absorptance (α_s):
Control, 0.15
$\Delta\alpha_s$ After Irradiation to 5×10^7 R (C), 0.02
$\Delta\alpha_s$ After Irradiation to 2×10^8 R (C), 0.06

Hemispherical Emissivity at 500°R (ϵ_H): 0.85

Absorptivity-Emissivity Ratio (α_s/ϵ_H): 0.18

Comments: Solar reflector: tested for thermal control on an Agena-D/ SNAP-10A spacecraft vehicle.

Ref. 2

Coating: Silicate

Trade Name: (Experimental)

Source: Lockheed, Missiles and Space Division

Chemical Nature of Formula: $ZrSiO_4$-K_2SiO_3

Adherence: Excellent on aluminum and Dow-17-coated magnesium-alloy substrates; somewhat less on aluminum alloy substrates

Solar Absorptivity for Coating 20-23 microns thick (α_s):

0.022 (50[illegible] hrs exposure)
0.27 (200[illegible] hrs exposure)

Absorptivity-Emissivity Ratio (α_s/ϵ_H):

0.35 (pigment-binder ratio 4.0)
0.22 (pigment-binder ratio 5.5)

Comments: Development study conducted for MIDAS reliability program.

Ref. 21

Coating: Silicate

Trade Name:

Source:

Chemical Nature of Formula: ZnO pigment and $Na_2O.SiO_2$ vehicle

Solar Absorptance (α_s):
Control, 0.15
$\Delta\alpha_s$ After Irradiation to 5×10^7 R (C), 0.02
$\Delta\alpha_s$ After Irradiation to 2×10^8 R (C), 0.05

Hemispherical Emissivity at 500°R (ϵ_H): 0.91

Absorptivity-Emissivity Ratio (α_s/ϵ_H): 0.16

Comments: Solar reflector: tested for thermal control on an Agena-D/ SNAP-10A spacecraft vehicle.

Ref. 2

Coating: Silicate

Trade Name:

Source:

Chemical Nature of Formula: ZnS pigment and $Na_2O.SiO_2$ vehicle

Solar Absorptance (α_s):
Control, 0.19
$\Delta\alpha_s$ After Irradiation to 5×10^7 R (C), 0.01
$\Delta\alpha_s$ After Irradiation to 2×10^8 R (C), 0.12

Hemispherical Emissivity at 500°R (ϵ_H); 0.88

Absorptivity-Emissivity Ratio (α_s/ϵ_H): 0.22

Comments: Solar reflector: tested for thermal control on an Agena-D/ SNAP-10A spacecraft vehicle.

Ref. 2

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: Al_2O_3 pigment and potassium silicate vehicle

Substrate: Aluminum Alloy

Comments: Tested on ATS-1

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: Sb_2O_3 pigment and potassium silicate

Substrate: Aluminum Alloy

Comments: Tested on OSO-II

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: Spodumene pigment and sodium silicate vehicle

Substrate: Aluminum Alloy

Comments: Tested on OSO-II

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: SnO_2 pigment and silicate vehicle

Substrate: Aluminum Alloy

Comments: Tested on OSO-II

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: $SrMoO_4$ pigment and potassium silicate

Substrate: Aluminum Alloy

Comments: Tested on OVI-10

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: TiO_2 (Rutile) pigment and silicate vehicle

Substrate: Aluminum

Comments: Tested on Pegasus I

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: TiO_2 pigment and potassium silicate vehicle

Substrate: Aluminum Alloy

Comments: Tested on ATS-1

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: $ZnO-TiO_2-Al_2O_3$ pigment and potassium silicate vehicle.

Substrate: Aluminum Alloy

Comments: Tested on ATS-1

Ref. 11

Coating: Silicate White Paint

Trade Name:

Source:

Chemical Nature of Formula: Zirconia pigment and potassium silicate vehicle

Substrate: Aluminum Alloy

Comments: Tested on OSO-II

Ref. 11

Coating: Silicate White Paint

Trade Name: Z52

Source: Illinois Institute of Technology Research Institute

Chemical Nature of Formula: ZnO Pigment and Potassium Silicate (Identical to Z93 except that New Jersey Zinc's SP500 is replaced by American Zinc's 55-LO zinc oxide*)

Substrate: Aluminum Alloy

Comments: Tested on OSO-II

Ref. 11, *Supplier's Data

Coating: Silicone

Trade Name: Eccosil No. 33

Source: Emerson Cuming

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 0.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.0
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 7.1×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.38×10^{15}
- Surface Resistivity, ohms
  - Control, 6.11×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.50×10^{13}
- Dielectric Strength, v/mil
  - Control, 1000
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 900

Surface Condition After Thermal Cycling:
No change; low adhesion.

Comments: Used on Ranger and Mariner spacecrafts. Primer coat.*

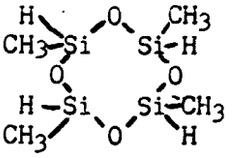
Ref. 4, *Supplier's Data

Coating: Silicone

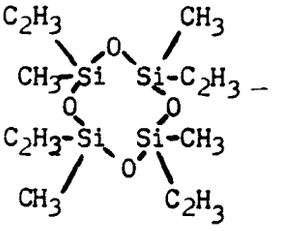
Trade Name:

Source: System developed at NASA Langley Research Center using G. E. Silicone Products

Chemical Nature of Formula: PJ113 is a condensation product of methyl hydrogen tetramer



and methyl vinyl tetramer



Solar Absorptance (α_s):

Control, 0.17 (at room temperature)

After 10^3 Thermal Cycles in Vacuum, 0.18 (at room temperature 20 hrs. after cycling)

Ref. 5

Coating: Silicone

Trade Name: SR 290

Source: General Electric, Reentry Systems Dept.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 1.0
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.0
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Failed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 6.56×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.93×10^{16}
- Surface Resistivity, ohms
  - Control, 1.00×10^{15}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.09×10^{15}
- Dielectric Strength, v/mil
  - Control, 51
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 900

Surface Condition After Thermal Cycling:
Yellowing; low adhesion; cracks easily.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Silicone

Trade Name: Number 445 Silicone Water Repellent

Source: Sinclair

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 1.8
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 0.8
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Surface Condition After Thermal Cycling:
- No change observable.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Silicone-Alkyd

Trade Name: Number 7576-#515

Source: Fuller Paint Co.

Chemical Nature of Formula: Glyceryl-Phthalate-Type Alkyd Resin, Carbon Black, Organic Derivative of Montmorillonite, Lead Drier*

Mechanical Properties:

Scrape Adhesion, kgm

Control, 3.5

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.5

Flexibility (FTMS Nr 141, Method 6223)

Control, Passed

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:

Volume Resistivity, ohm-cm

Control, 6.67×10^{13}

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 4.50×10^{13}

Surface Resistivity, ohms

Control, 1.05×10^{14}

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 2.50×10^{13}

Dielectric Strength, v/mil

Control, 266

After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 142

Surface Condition After Thermal Cycling:

No change observable; low dielectric strength; not for electrical insulation.

Comments: Used on Ranger and Mariner spacecrafts; meets military specification MIL-E-5557, Type I*

Ref. 4, *Supplier's Data

Coating: Silicone-Alkyd Aluminum Paint

Trade Name:

Source: General Electric, Reentry Systems Dept.

Chemical Nature of Formula: 173.0 parts G. E. SR-82 silicone, 173.0 parts Aroplaz #7323 alkyd, 17.3 parts Solvesso #100, 17.3 parts xylol, 375.0 parts Alcoa #1571 aluminum paste, 7.0 parts 6% Cobalt Octoate (Nuodex)

Solar Absorptance, Initial (α_s):	0.33
After Irradiation to 4×10^8 R	0.34
After Irradiation to 1.6×10^{10} R	0.34
Hemispherical Emittance, Initial (ϵ_H):	0.29
After Irradiation to 4×10^8 R	0.31
Absorptance-Emittance Ratio (α_s/ϵ_H):	1.14

Comments: Softens above 650 F but maintains adhesion when subjected to shear forces equivalent to those of powered flight.

Ref. 15

Coating: Silicone/Aluminum

Trade Name: Hi-Heat Aluminum Paint 171-A-28

Source: Fuller Paint Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 0.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 0.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Failed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Surface Condition After Thermal Cycling:
No change; conductive; low adhesion

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Silicone-Aluminum

Trade Name: UC 11659

Source: Pittsburgh Plate Glass Co.

Surface Condition After Thermal Cycling:
Fails adhesion and flexibility tests; preliminary thermal exposure.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Silicone-Acrylic Paint

Trade Name:

Source: General Electric, Reentry Systems Dept.

Chemical Nature of Formula: 60.0 parts G.E. SR-112 silicone, 16.7 parts G.E. SR-82 silicone, 200.0 parts Acryloid A-21 (Rohm and Haas), 233.8 parts Titanox RA, 1.7 parts 8% zinc octoate (Nuodex)

Solar Absorptance, Initial (α_s)	0.20
After Heat Flux	0.19
After Ultraviolet Exposure	0.26
After Combined Heat Flux and Ultraviolet Exposure	0.26
Hemispherical Emittance, Initial (ϵ_H):	0.79
After Heat Flux	0.80
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.25

Comments: Will maintain adhesion and spectral characteristics during powered flight heating to 650-675 F, during ultraviolet irradiation in high vacuum, and the thermal cycling encountered in orbit.

Ref. 15

Coating: Silicon-Bonded Zircon Paint

Trade Name: "B Zr"

Source: McConnell

Vibration Test: Passed

Comments: Gemini space radiator coating.

Ref. 10

Coating: Silicone Enamel

Trade Name: Sicon White Enamel No 7 x 1088

Source: Midland Industrial Finishes Co.

Chemical Nature of Formula:

Solar Absorptance at 500°R (α_s): 0.36

Hemispherical Emittance at 500°R (ϵ_H): 0.83

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.43

Ref. 20

Coating: Silicone Enamel

Trade Name: Sicon White Enamel No 7 x 1120

Source: Midland Industrial Finishes Co.

Solar Absorptance at 500°R (α_s): 0.30

Hemispherical Emittance at 500°R (ϵ_H): 0.82

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.37

Ref. 20

Coating: Silicone Enamel

Trade Name: Sicon White Enamel No 7 x 1153

Source: Midland Industrial Finishes Co.

Chemical Nature of Formula:

Solar Absorptance at 500°R (α_s): 0.27

Hemispherical Emittance at 500°R (ϵ_H): 0.83

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.33

Ref. 20

Coating: Silicone Paint

Trade Name:

Source:

Chemical Nature of Formula: Rutile TiO_2 pigment (30% by volume) in polydimethyl siloxane elastomer

Solar Absorptance (α_s):
Control, 0.197
After 1400 "sun-hours", 0.347

Ref. 17

Coating: Silicone Paint

Trade Name:

Source:

Chemical Nature of Formula: Rutile TiO_2 pigment (45% by volume) in phenyl-methyl silicone resin binder

Solar Absorptance (α_s):
Control, 0.296
After 1200 "sun-hours", 0.406

Ref. 17

Coating: Silicone Paint

Trade Name: S-13 *

Source: Illinois Institute of Technology Research Institute

Chemical Nature of Formula: ZnO pigment (SP-500, New Jersey Zinc Co.) and dimethyl silicone vehicle (RTV-602, General Electric Co.)

Substrate: Aluminum alloy

Thickness, mils: 3.5-5.5

Solar Absorptance (α_s)
at Room Temperature in Air: 0.19

Hemispherical Emittance (ϵ_H)
at Room Temperature in Air: 0.82

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.23

Comments: Experimental. Tested on OSO-III [(a)], Pegasus-I [(a)], -II [(a)], and III [(a)], and on ATS-1[(a)] and -II [(a)] *No longer supplied by IIT Research Institute who now discourages its use on spacecraft.

Ref. 6, [(a)] 11

Coating: Silicone Paint

Trade Name: S-33*

Source: Illinois Institute of Technology Research Center

Chemical Nature of Formula: ZnO pigment (35% by volume) in experimental polymethyl siloxane

Substrate: 6061-T6 aluminum

Solar Absorptance (α_s):

Control	0.196; 0.18 [(a)]
After 3400 "Sunhours"	0.211

Hemispherical Emittance, Initial (ϵ_H): 0.85 [(a)]

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.21 [(a)]

Thermal Stability:

At 390 °K	Good [(a)]
At 530 °K	Poor [(a)]

Adhesion: Fair [(a)]

Substrate Compatibility: Good [(a)]

Reliability and Reproducibility: Good [(a)]

Predicted Ultraviolet and Nuclear Radiation Stability: Good [(a)]

Comments: *Neither commercially available nor furnished by IITRI.

Ref. 17, [(a)]16

Coating: Silicone Paint

Trade Name: Thermatrol-A100 [a]

Source: Lockheed Missile and Space Co.

Chemical Nature of Formula: TiO_2 pigment (Titanox RA-NC, Titanium Pigment Corp.) and polymethylvinyl siloxane elastomer vehicle (Q92-009, Dow Corning) [a]

Substrate: 6061-T6 Aluminum

Thickness, mils: 3.5 to 5.0 [a]

Solar Absorptance (α_s): 0.17; 0.18 [b]

Hemispherical Emittance, (ϵ_H): 0.86; 0.85 [b]

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.20; 0.21 [b]

Thermal Stability:

At 390 ^{o}K, Good [b]

At 530 ^{o}K, Poor [b]

Adhesion: Fair [b]

Substrate Compatibility: Good [b]

Reliability and Reproducibility: Good [b]

Predicted Ultraviolet and Nuclear Radiation Stability: Good [b]

Comments: Pilot use; tested on OSO-I [c], ATS-1 [c], ATS-II [c], and OVI-10 [c]

Ref. 7, [a] 22, [b] 16, [c] 11

Coating: Silicone Paint

Trade Name: White Thermatrol 2A-100, No. 92-007

Source: Dow Corning

Chemical Nature of Formula:
TiO_2 pigment in elastomeric silicone, dimethyl siloxane, vehicle

Substrate: Any clean substrate, rigid and non-rigid; primer required; may be applied onto PBSS paints and primers and onto Mystik No 7402 aluminum tape

Thickness, mils: 3.5 to 5.0 (minimum for opacity)

Solar Absorptance at 500-700 °R (α_s): 0.16

Hemispherical Emittance at 530 °R (ϵ_H): 0.95

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.17

Comments: Solar reflector. Prelaunch - surface is soft and rubbery and should be protected from abrasion or scratches. Requires protection per LAC-1002. Postlaunch - requires a minimum of 24 hours of room-temperature cure to remove volatile materials sufficiently to avoid blistering during ascent heating. Peak temperatures $\leq$ 650 F cause an increase in α_s of 0.03 or less; ϵ_H is unaffected. Orbital - the primary source of degradation appears to be the near-ultraviolet portion of incident solar and albedo radiation.

Ref. 6

Coating: Silicone Paint

Trade Name:

Source:

Chemical Nature of Formula: ZnO Pigment (30% by volume)

Solar Absorptance (α_s):
Control, 0.204
After 1500 "sun-hours", 0.198

Ref. 17

Coating: Silicone Paint

Trade Name:

Source:

Chemical Nature of Formula: ZnO Pigment (40% by volume) in phenylmethyl silicone resin binder

Solar Absorptance (α_s):
Control, 0.221
After 1000 "sun-hours", 0.281

Ref. 17

Coating: Silicone Paint

Trade Name:

Source:

Chemical Nature of Formula: ZnS pigment (60% by volume) in phenylmethyl silicone resin binder

Solar Absorptance (α_s):
Control, 0.244
After 1000 "sun-hours", 0.314

Ref. 17

Coating: Silicone Primer

Trade Name: PR 1902

Source: Prod. Research Co.

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, <0.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, <0.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 2.76×10^{13}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.86×10^{12}
- Surface Resistivity, ohms
  - Control, 3.24×10^{14}
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 2.05×10^{14}
- Dielectric Strength, v/mil
  - Control, 426
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 480

Surface Condition After Thermal Cycling:
Lightening of color; colored outgassed material; this may affect other materials.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Silver Coated, Fused Silica, Second Surface Mirror

Trade Name:

Source:

Chemical Nature of Formula:

Substrate: Aluminum alloys per surface preparation
LAC 3013, primer LAC 30-4325 and adhesive RTV-615 per LAC 30-4324

Solar Absorptance at 325-530 ^{o}R (α_s):	0.050
Hemispherical Emittance at 460 ^{o}R (ϵ_H):	0.807
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.062

Comments: Optical solar reflector. Prelaunch - fragile and should be protected from mechanical damage during storing and shipping. Surface contamination due to fingerprints, oil, dust, and atmospheric weathering does not cause permanent degradation. Temporary contaminants must be removed per LAC 3801. Postlaunch - surface equires a minimum of 14 days of room-temperature curing to minimize outgassing of the adhesive during ascent. No significant change in α_s is noted to 500 F limit of adhesive. Orbital - no damage from ultraviolet to produce a change in α_s. Coating is stable to extended missions up to two years in all charged particle environments and combined environments of space. Tested for Agena satellite programs.

Ref. 6

Coating: Sodium Silicate/MoS_2

Trade Name: Electrofilm Lube-Lok 2396

Source: Electrofilm Corp.

Chemical Nature of Formula: MoS_2 pigment and $Na_2O.SiO_2$ vehicle

Mechanical Properties:
- Scrape Adhesion, kgm
  - Control, 1.5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 1.5
- Flexibility (FTMS Nr 141, Method 6223)
  - Control, Passed
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, Passed

Electrical Properties:
- Volume Resistivity, ohm-cm
  - Control, 7.39×10^7
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 6.71×10^7
- Surface Resistivity, ohms
  - Control, 3.06×10^5
  - After thermal exposure, 3 cycles, 40 hrs. each at 300 F, in nitrogen, 3.09×10^5

Surface Condition After Thermal Cycling:
Slight darkening of color; very low resistivities; not for insulation.

Comments: Used on Ranger and Mariner spacecrafts.

Ref. 4

Coating: Sodium Silicate Paint

Trade Name: Lithafrax, LP-30A*

Source: Lockheed Missile and Space Co.

Chemical Nature of Formula: Li-Al-SiO_4 pigment and Na_2SiO_4 vehicle

Substrate: 6061-T6 aluminum

Solar Absorptance (α_s):

Control	0.14; 0.13 [a]
$\Delta\alpha_s$ After Irradiation to 5×10^7 R(C)	0.06
$\Delta\alpha_s$ After Irradiation to 2×10^8 R(C)	0.14

Hemispherical Emittance at 500 °R (ϵ_H): 0.85; 0.85[a]

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.16; 0.15[a]

Thermal Stability:

At 390 °K	Good [a]
At 530 °K	Good [a]

Adhesion: Good [a]

Substrate Compatibility: Good [a]

Reliability and Reproducibility: Fair [a]

Predicted Ultraviolet and Nuclear Radiation Stability: Poor[a]

Comments: Solar reflector; tested for thermal control on an Agena-D-SNAP-10A spacecraft vehicle.

Ref. 2, [a]16, *Supplier's Data

Coating: $Na_2Cr_2O_7$ Blackened

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: Inconel

Thickness, μm: 9.6

Solar Absorptance (α_s):

Initial, 0.951

After Space Simulation Environment and 10^{15} e/cm^2, 0.959

After Micrometeroid Impact, 0.930

Hemispherical Emittance (ϵ_H):

Initial, 0.840

After Space Simulation Environment and 10^{15} e/cm^2, 0.817

After Micrometeroid Impact, 0.730

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.113

Abrasive Resistance, g/μm: 0.21

Flexibility (Bend) Test: Many macroscopic cracks

Ref. 13

Coating: $Na_2Cr_2O_7$ Blackened

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: Inconel X

Thickness, μm: 4.8

Solar Absorptance

Initial, 0.963

After Space Simulation Environment and 10^{15} e/cm^2, 0.960

After Micrometeroid Impact, 0.932

Hemispherical Emittance (ϵ_H):

Initial, 0.806

After Space Simulation Environment and 10^{15} e/cm^2, 0.808

After Micrometeroid Impact, 0.785

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.119

Abrasive Resistance, g/μm: 0.42

Flexibility (Bend) Test: Many macroscopic cracks

Ref. 13

Coating: $Na_2Cr_2O_7$ Blackened

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula:

Substrate: Type 347 stainless steel

Thickness, μm: 7.6

Solar Absorptance (α_s):

Initial, 0.925

After Space Simulation Environment and 10^{15} e/cm^2, 0.922

After Micrometeroid Impact, 0.904

Hemispherical Emittance (ε_H):

Initial, 0.565

After Space Simulation Environment and 10^{15} e/cm^2, 0.564

After Micrometeroid Impact, 0.603

Absorptance-Emittance Ratio (α_s/ε_H): 0.164

Abrasive Resistance, g/μm: 0.26

Flexibility (Bend) Test: Many macroscopic cracks

Ref. 13

Coating: NiS Dyed Anodized Aluminum

Trade Name:

Source: NASA Langley Research Center

Chemical Nature of Formula

Substrate: 1100 (2-S) Aluminum

Thickness, μm: 23.1

Solar Absorptance (α_s):

Initial, 0.970

After Space Simulation Environment and 10^{15} e/cm^2, 0.972

After Micrometeroid Impact, 0.965

Hemispherical Emittance (ϵ_H):

Initial, 0.929

After Space Simulation Environment and 10^{15} e/cm^2, 0.902

After Micrometeroid Impact, 0.933

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.104

Abrasive Resistance, g/μm: 10.85

Flexibility (Bend) Test: Some macroscopic cracks

Ref. 13

Coating: MgF_2 Solar Absorber

Trade Name:

Source:

Chemical Nature of Formula: MgF_2 on FeO_x

Substrate: Aluminum alloy

Comments: Tested on OV1-10

Ref. 11

Coating: Strong Black Acrylic Lacquer

Trade Name:

Source: Pittsburgh Plate Glass Co., Ditzler Finishes Div.

Chemical Nature of Formula:

Substrate: AZ31 B magnesium alloy

Thickness: 0.002 inch

Solar Absorptance at 500 (α_s): 0.92

Hemispherical Emittance at 500°R (ϵ_H): 0.74

Absorptance-Emittance Ratio (α_s/ϵ_H): 1.2

Ref. 20

Coating: Teflon-Impregnated Style 108 Glass Fabric

Trade Name: Amfab TV 20-60

Source: American Machine and Foundry Co.

Chemical Nature of Formula:

Substrate: Aluminized Mylar

		Irradiated	
	Initial	After 10^{14}-10^{15} ergs/g	After 8×10^{12} ergs/g
Solar Absorptance (α_s)	0.25-0.23	0.27	0.61
Hemispherical Emittance (ϵ_H):	0.72-0.79	0.77	0.78
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.32-0.46	0.36	0.78

Ref. 12

Coating: Titania

Trade Name: Titanox-RA

Source: Titanium Pigment Co.

Substrate: Black Paint

Solar Absorptance (α_s): 0.154

Hemispherical Emittance at 1000°R (ϵ_H): 0.905

Absorptance-Emittance (α_s/ϵ_H): 0.17

Ref. 14

Coating: TiO_2-Pigmented Epoxy

Trade Name:

Source:

Substrate: Aluminum

Solar Absorptance (α_s): 0.25

Hemispherical Emittance at 500°R (ϵ_H): 0.85

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.29

Comments: Increase in α_s noted during flight and ground simulation tests.

Ref. 14

Coating: TiO_2-Pigmented Silicone

Trade Name:

Source:

Substrate: Aluminum

Solar Absorptance (α_s): 0.28

Hemispherical Emittance at 500°R (ϵ_H): 0.74

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.38

Comments: Increase in α_s noted during flight tests and ground simulation tests.

Ref. 14

Coating: TiO_2-Pigmented Silicone White Film

Trade Name:

Source:

Chemical Nature of Formula:

Substrate: Aluminum alloy

Comments: Tested on OSO-II

Ref. 11

Coating: TiO_2-Silicone-Alkyd Paint

Trade Name: Vitavar PV-100

Source: Vitavar Paint Co.

Chemical Nature of Formula:

Substrate: Magnesium

		Irradiated	
	Initial	After 10^{14}-10^{15} ergs/g	After 2×10^{12} ergs/g
Solar Absorptance (α_s):	0.21-0.22	0.24	0.52
Hemispherical Emittance (ϵ_H):	0.86-0.88	0.87	0.89
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.24-0.25	0.28	0.58

Maximum Temperature Stability: 400 F*

Continuous Temperature Stability: 300 F*

Comments: Gemini space radiator coating[a]

Ref. 12, [a]10, *Supplier's Data

Coating: TiO_2-Silicone White Paint

Trade Name: Pyromark Standard

Source: Tempil Corp.

Chemical Nature of Formula:

Substrate: Aluminum

		Irradiated	
	Initial	After 10^{10} ergs/g	After 9×10^{11} ergs/g
Solar Absorptance (α_s):	0.19	0.22	0.27
Thermal Emittance (ϵ_H):	0.84	0.88	0.85
Absorptance-Emittance Ratio (α_s/ϵ_H)	0.24	0.25	0.32

Ref. 12.

Coating: Vinyl-phenolic

Trade Name: Dull Black Micobond (L6 x 962)

Source: Midland Industrial Finishes Co.

Chemical Nature of Formula;

Solar Absorptance at 500°R (α_s): 0.93

Hemispherical Emittance at 500°R (ϵ_H): 0.84

Absorptance-Emittance Ratio (α_s/ϵ_H): 1.1

Ref. 20

Coating:

Trade Name: Westinghouse Black

Source: Westinghouse Electric Corp.

Chemical Nature of Formula:

Substrate: Inconel

Solar Absorptance (α_s):

Initial, 0.927

After Space Simulation Environment and 10^{15} e/cm^2, 0.928

After Micrometeroid Impact, 0.924

Hemispherical Emittance (ϵ_H):

Initial, 0.822

After Space Simulation Environment and 10^{15} e/cm^2, 0.816

After Micrometeroid Impact, 0.718

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.113

Ref. 13

Coating: White Acrylic Lacquer

Trade Name:

Source: Ditzler

Substrate: Zinc chromate primer

Thickness, mils: 6

Solar Absorptance (α_s): 0.21

Hemispherical Emittance at 600°R (ϵ_H): 0.86

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.24

Ref. 20

Coating: White-Pigmented Polyurethane Lacquer

Trade Name:

Source:

Solar Absorptance (α_s): 0.25

Hemispherical Emittance at 546°R (ϵ_H): 0.88

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.28

Ref. 14

Coating: White Porcelain Enamel

Trade Name:

Source:

Chemical Nature of Formula: Alkali-titania borosilicate glass

Substrate: Aluminum alloy

Solar Absorptance (α_s): 0.30

Hemispherical Emittance at 500°R (ϵ_H): 0.75

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.40

Comments: Tested on OSO-I

Ref. 6, 11

Coating: ZnO Pigmented Silicone White Paint

Trade Name: S-8*

Source: Illinois Institute of Technology Research Institute

Chemical Nature of Formula:

Substrate: Aluminum Alloy

Comments: Tested on OSO-II. *Neither commercially available nor furnished by IIT Research Institute.

Ref. 11

Coating: ZnO Potassium Silicate White Paint

Trade Name: MSD-105

Source: General Electric, Missile and Space Div.

Chemical Nature of Formula:

Substrate: Aluminum

		Irradiated	
	Initial	After 5×10^{10} ergs/g	After 10^{12} ergs/g
Solar Absorptance (α_s):	0.15	0.26	0.49
Hemispherical Emittance (ϵ_H):	0.94	0.94	0.93
Absorptance-Emittance Ratio (α_s/ϵ_H):	0.16	0.27	0.53

Ref. 12

Coating: Zirconia

Trade Name: Rokide Z

Source: The Norton Co.

Chemical Nature of Formula: 98% ZnO_2

Density, lbs/in.^{3}:	0.187
Thickness, in.:	0.005-0.060
Porosity, %:	8-12
Thermal Drop Through 0.030 in. at Steady-State Melting Temperature:	8 F per 0.001 in.
Maximum Service Temperature:	4200 F
Thermal Conductivity, B.T.U. per hr. per sq. ft. per in. per ^oF:	8, at 1000 to 2000 F
Thermal Expansion Coefficient, 70 to 2550 F:	64 x 10^{-7} per ^oF
Thermal Shock Resistance:	Good
Resistance to Vibration and Flexing:	Good
Hardness and Abrasion Resistance:	High
Compressive Strength, psi:	21,000 [a]
Hemispherical Emittance, at 200-1000 C (ϵ_H);	0.7-0.3 [a]

Comments:

Ref. 8, [a] 9

Coating: Zirconium Silicate

Trade Name: Rokide ZS

Source: The Norton Co.

Chemical Nature of Formula: 65% ZrO_2 and 34% SiO_2 (a)

Substrate: Aluminum

Thickness, mils: 10

Solar Absorptance (α_s) 0.35

Hemispherical Emittance at 600 ^oR (ϵ_H): 0.78

Absorptance-Emittance Ratio (α_s/ϵ_H): 0.45

Melting Temperature, ^oF: 3000 (a)

Mean Specific Heat, BTU/lb/^oF: 0.15 (a)

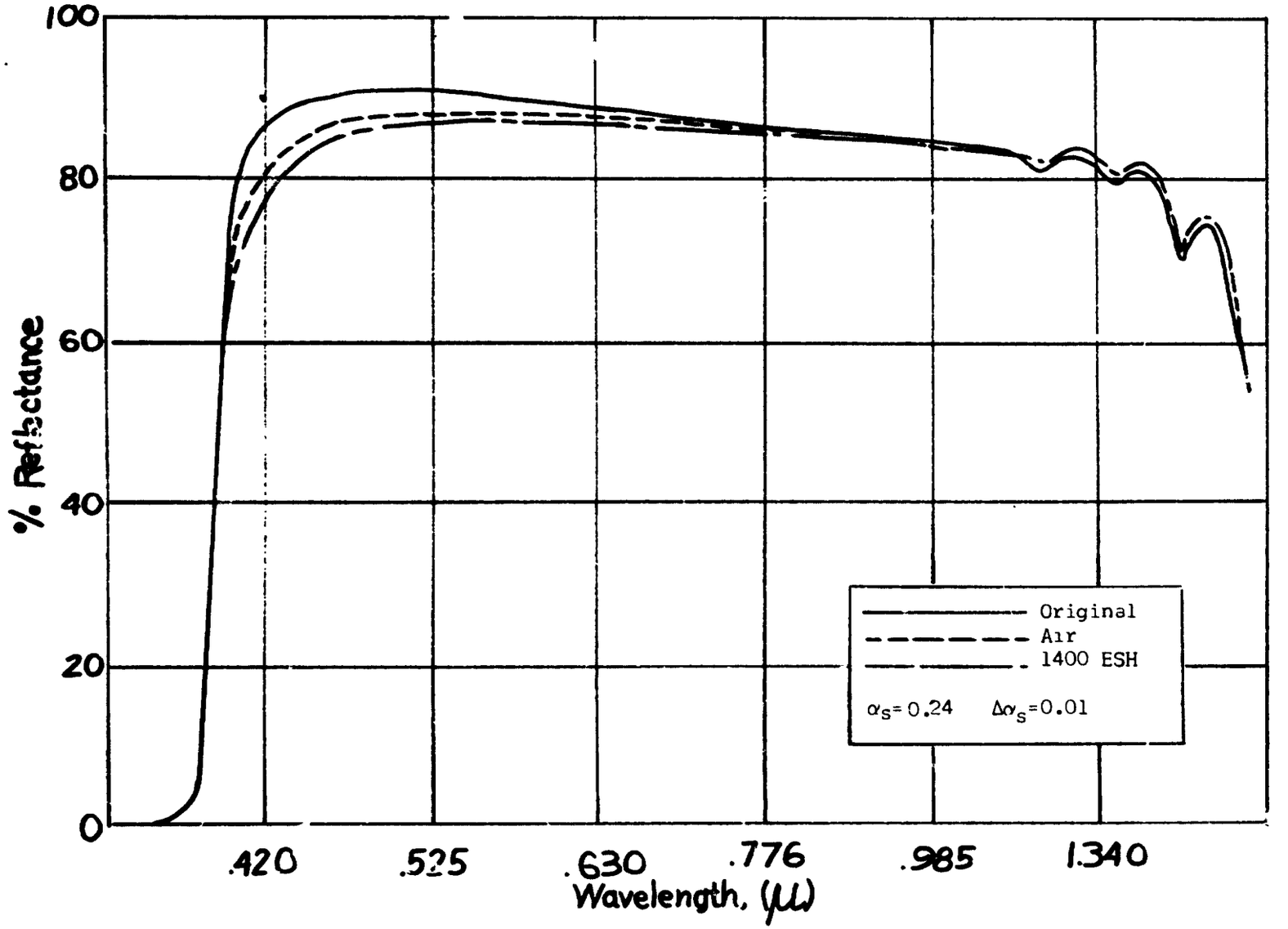
Coefficient of Expansion, in/in/^oF: 4.2×10^{-6} (a)

Thermal Conductivity, BTU/hr/ft^2-in./^oF
At 1000-2000 ^oF 15 (a)

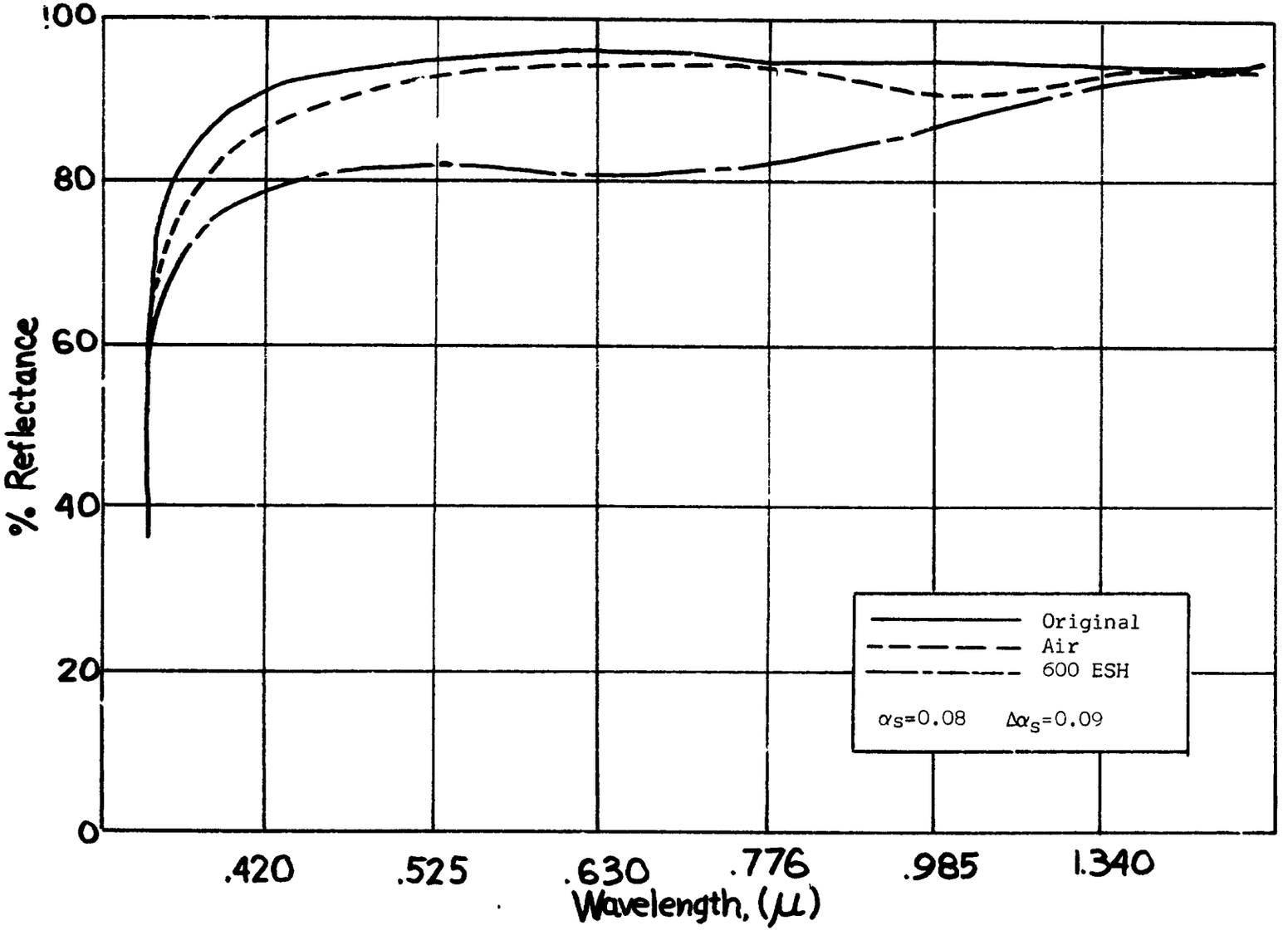
Ref. 20, (a) 9

APPENDIX IV

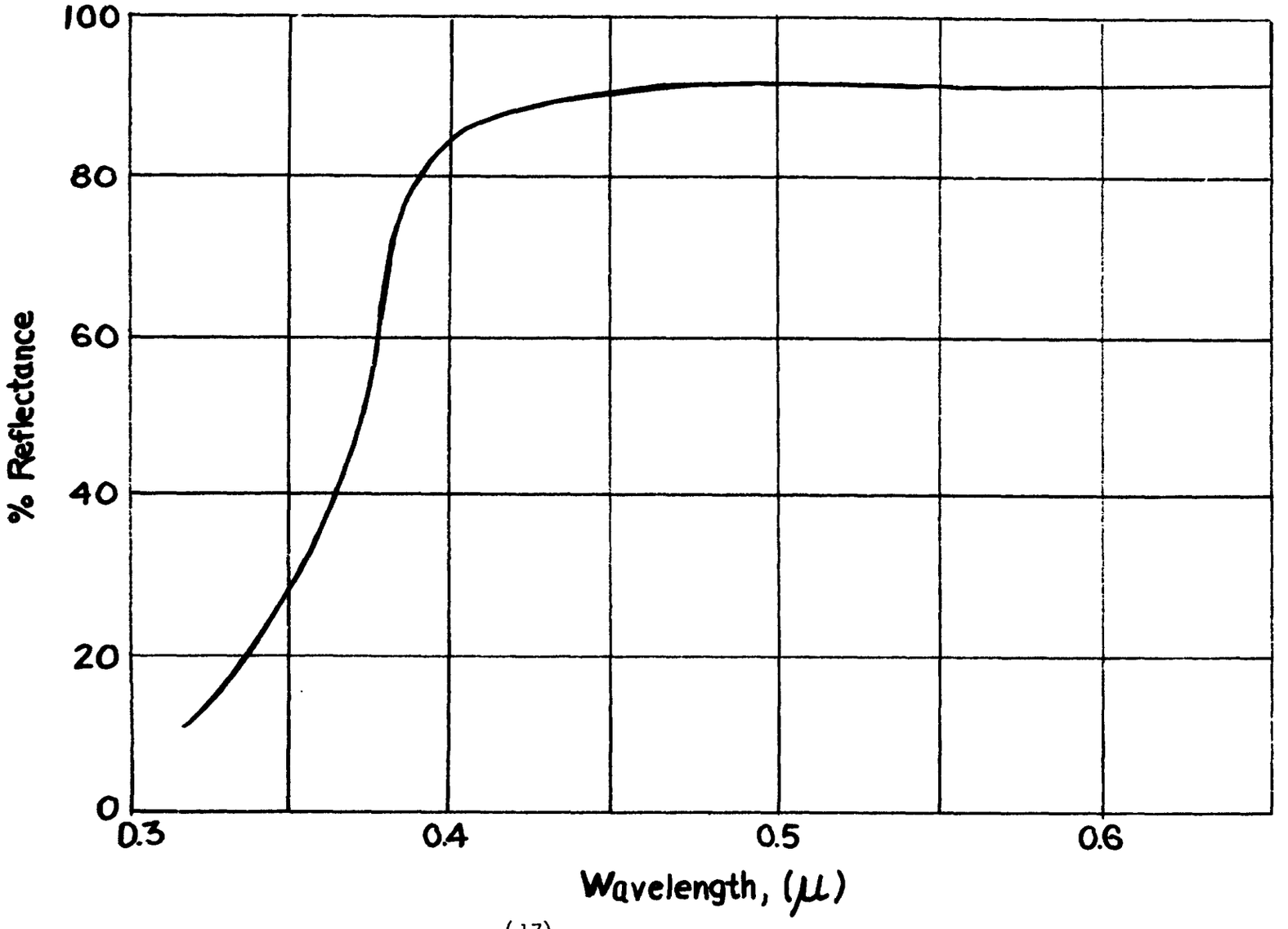
REFLECTANCE CURVES



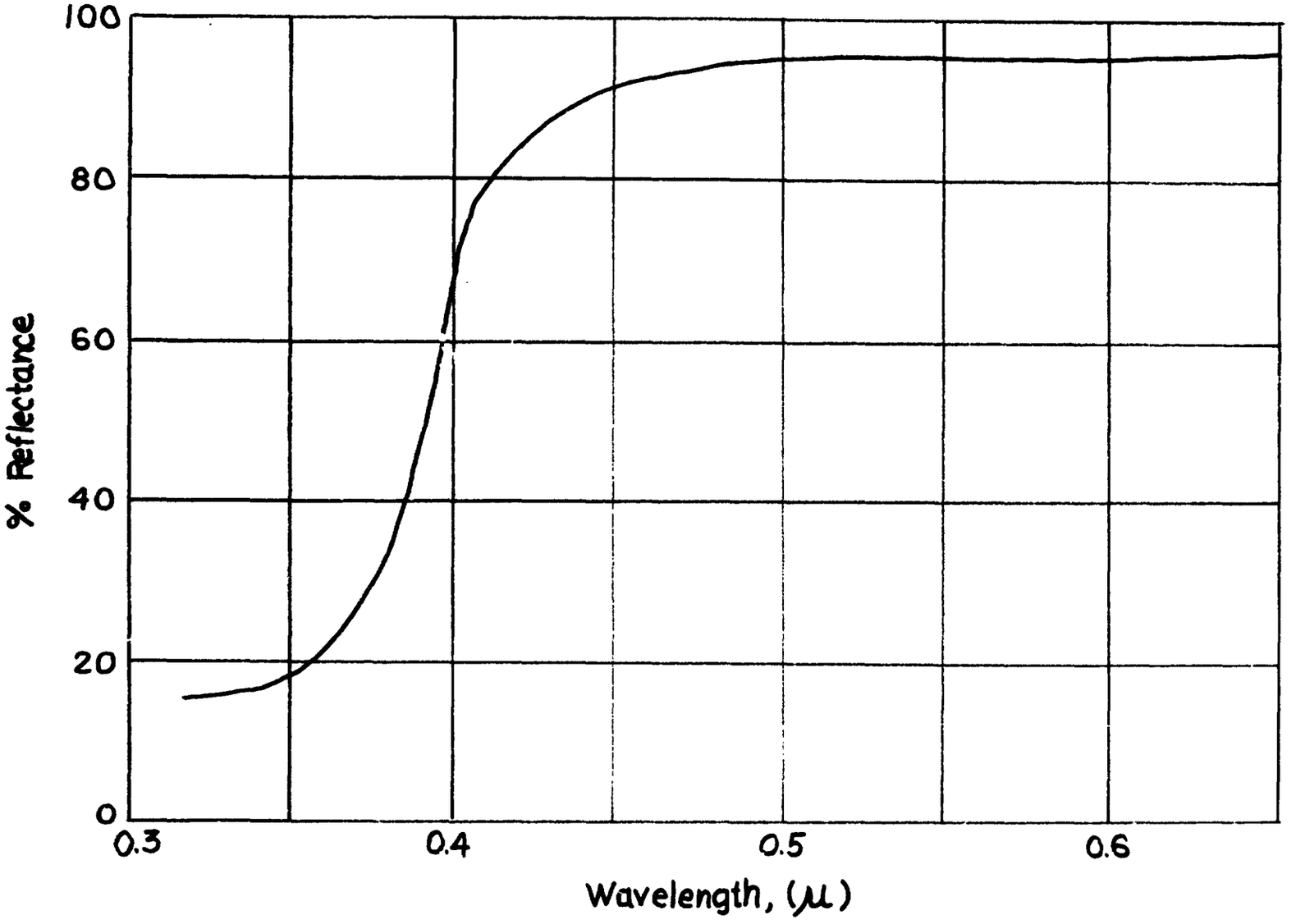
Effect of Ultraviolet Irradiation on S-13G Prepared From Sifted Pigment (Paint Grind Time=3 Hr)[17].



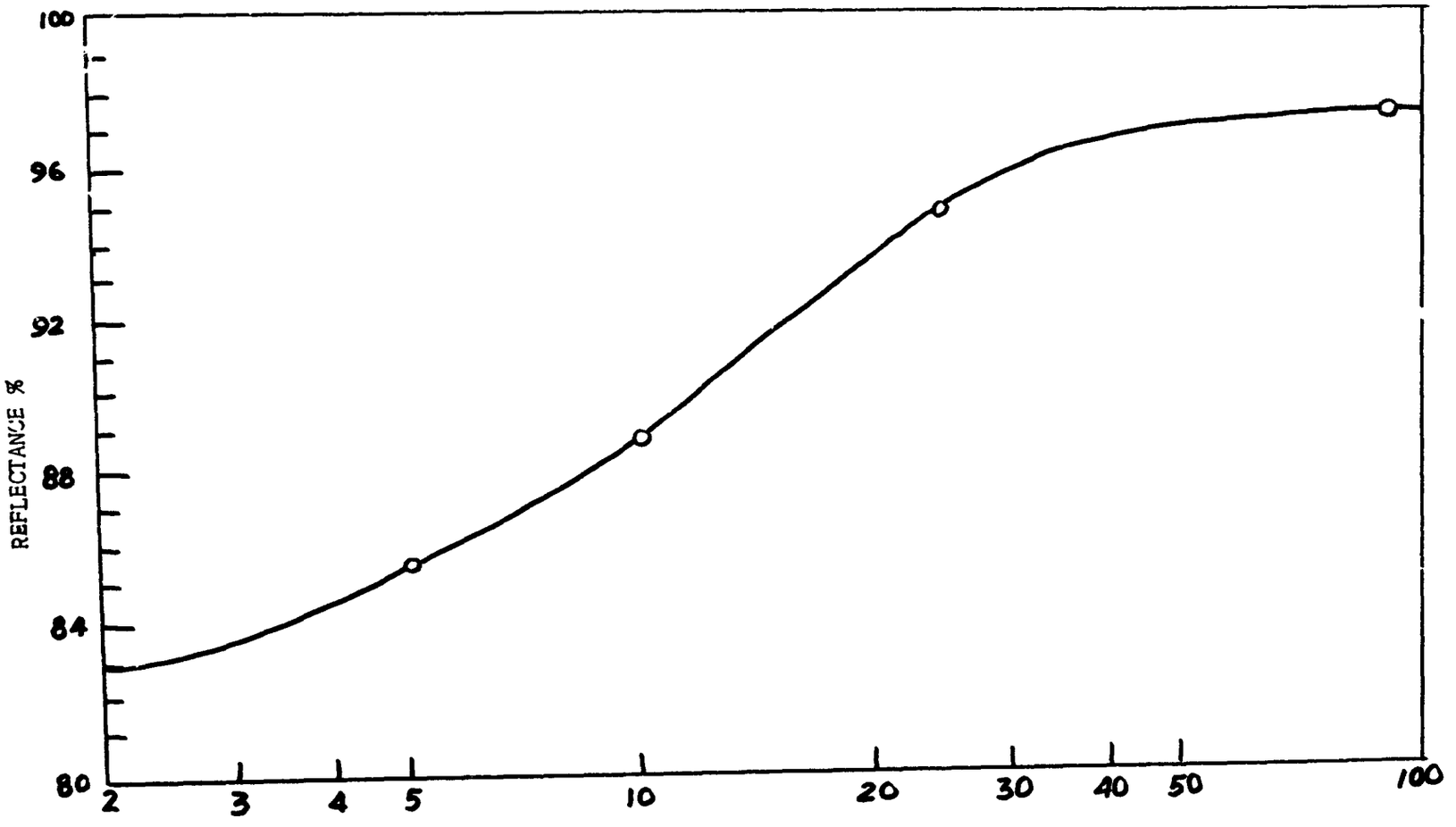
Effect of Ultraviolet Irradiation on Zn_2TiO_4[17].



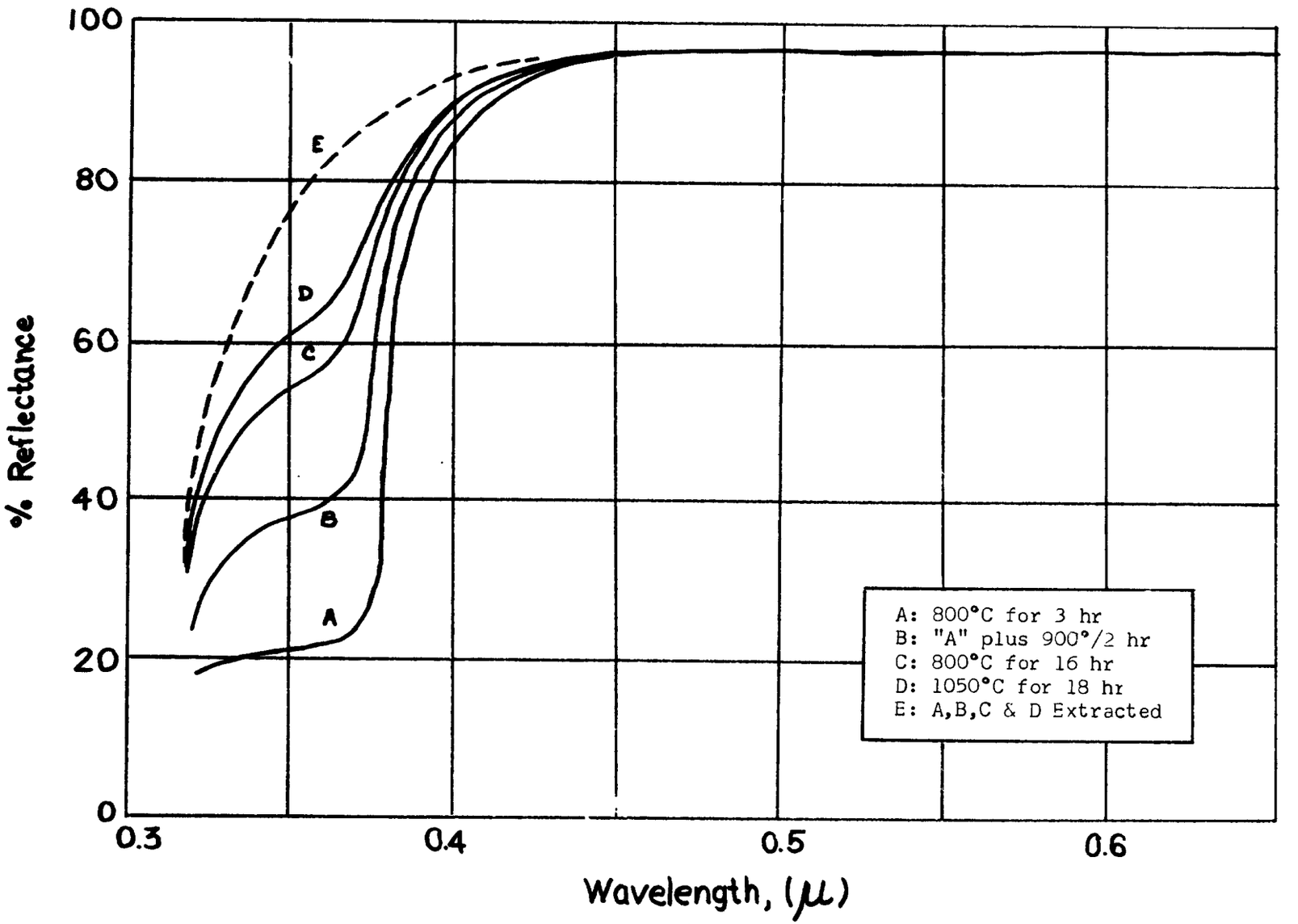
Reflectance Spectra of $Zn_2Ti_3O_8$ [17].



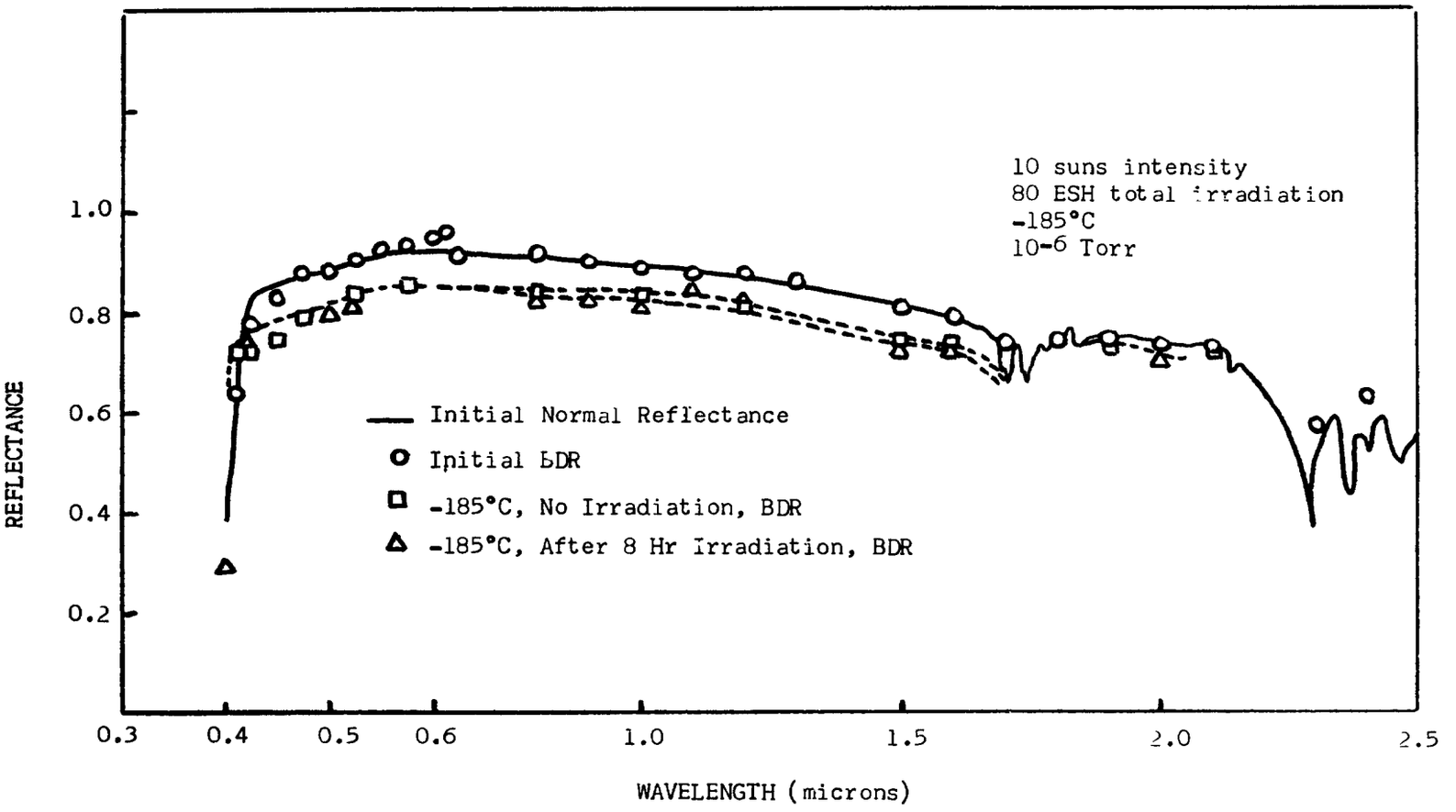
Reflectance Spectra of $ZnTiO_3$[17].



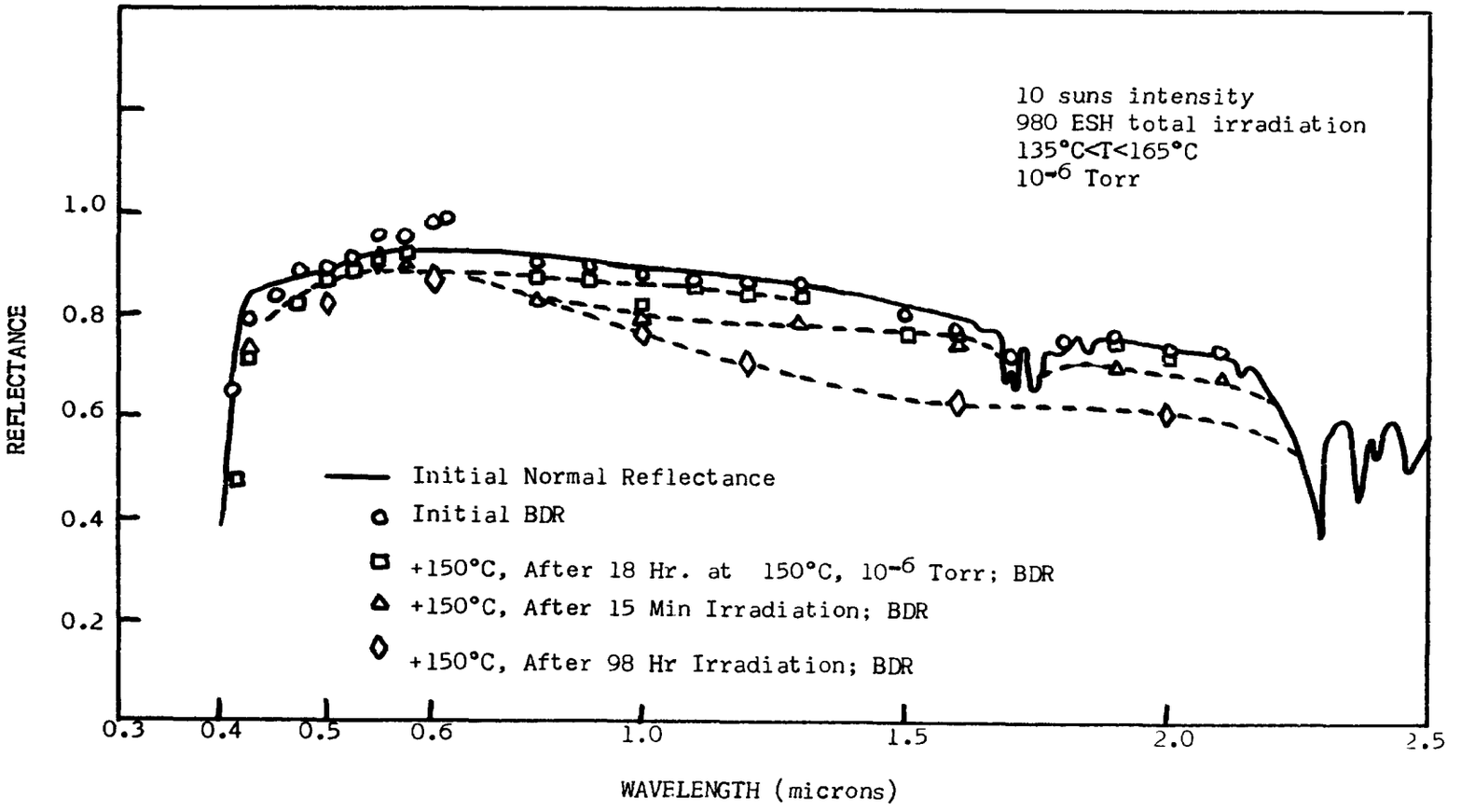
Effect of Admission of Air on the Reflectance of Zn_2TiO_4 (at 0.65μ)[17].



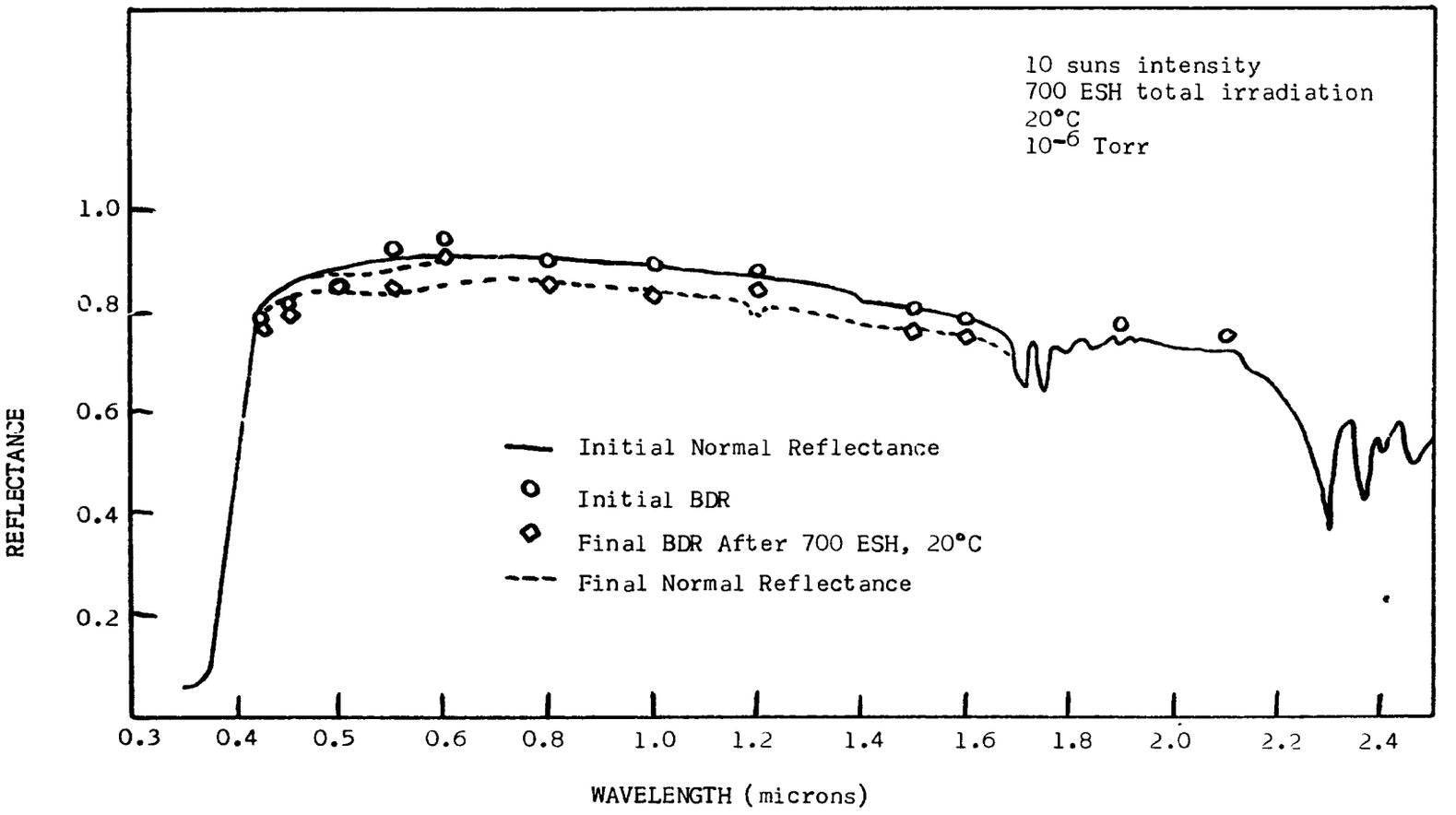
Reflectance Spectra of Several Zn_2TiO_4 Powders[17].



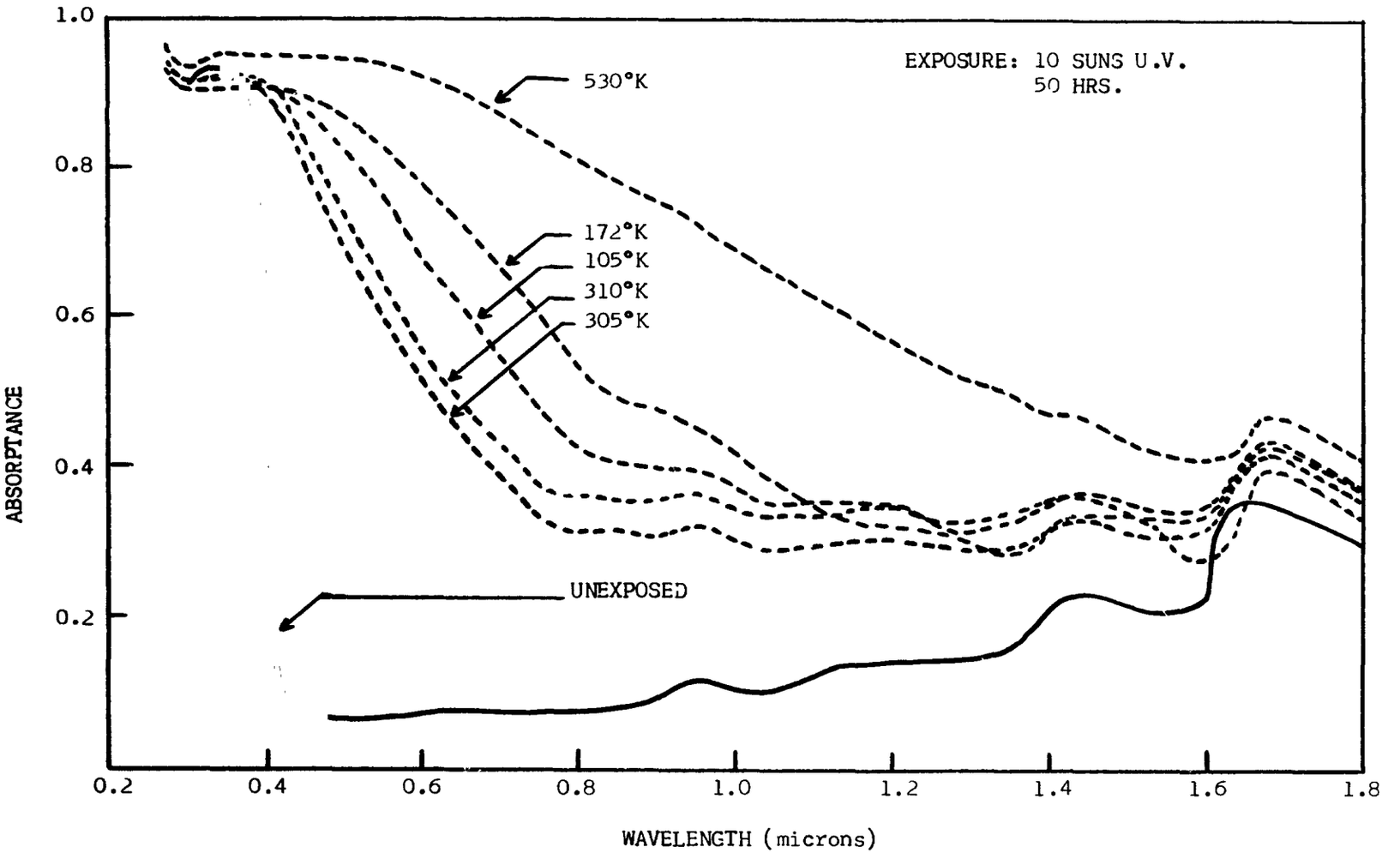
Spectral Temperature and ultraviolet Damage to TiO_2-Pigmented Silicone at -185°C[17].



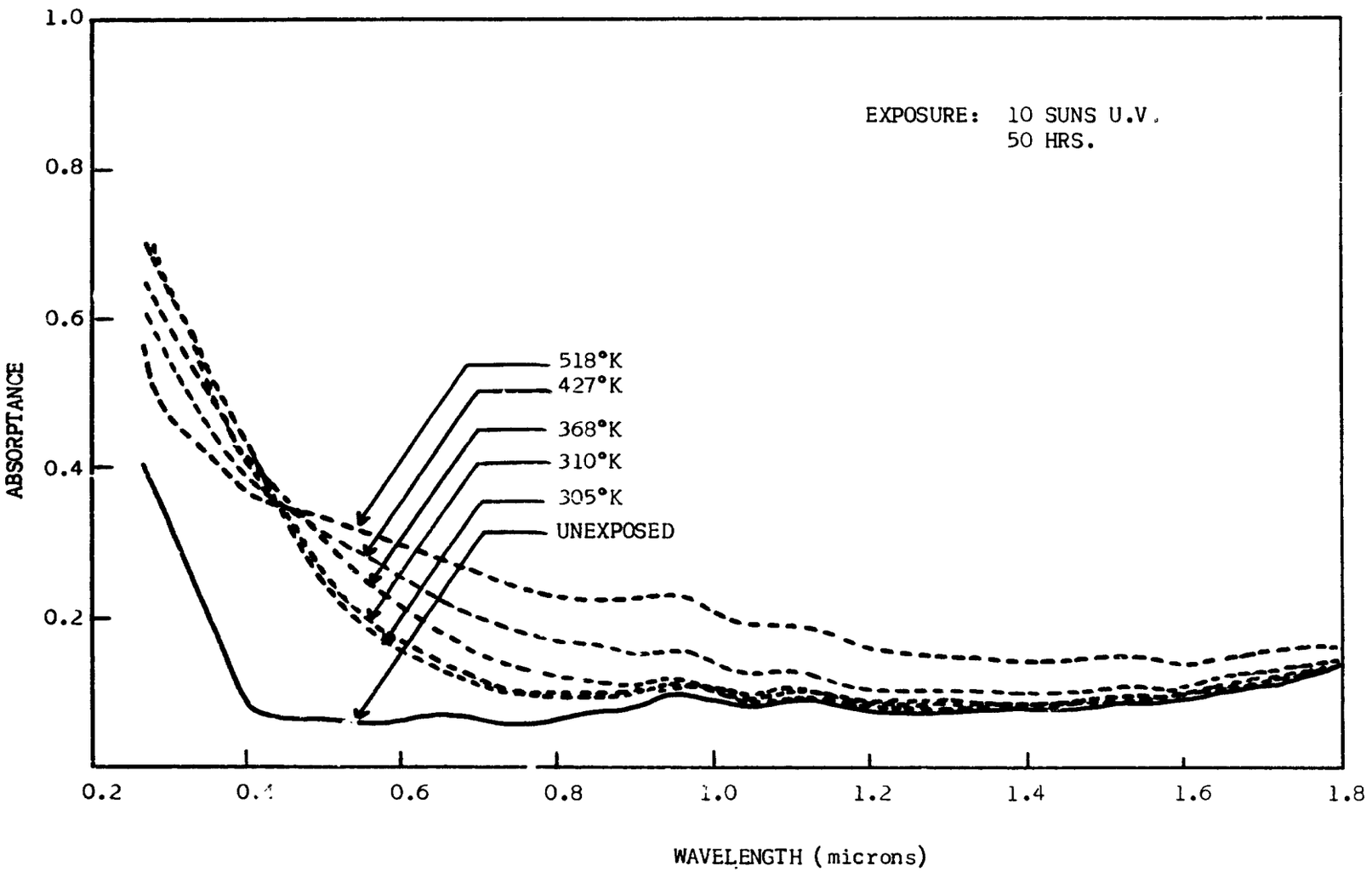
Spectral Temperature and Ultraviolet Damage to TiO_2-Pigmented Silicone at +150°C[24].



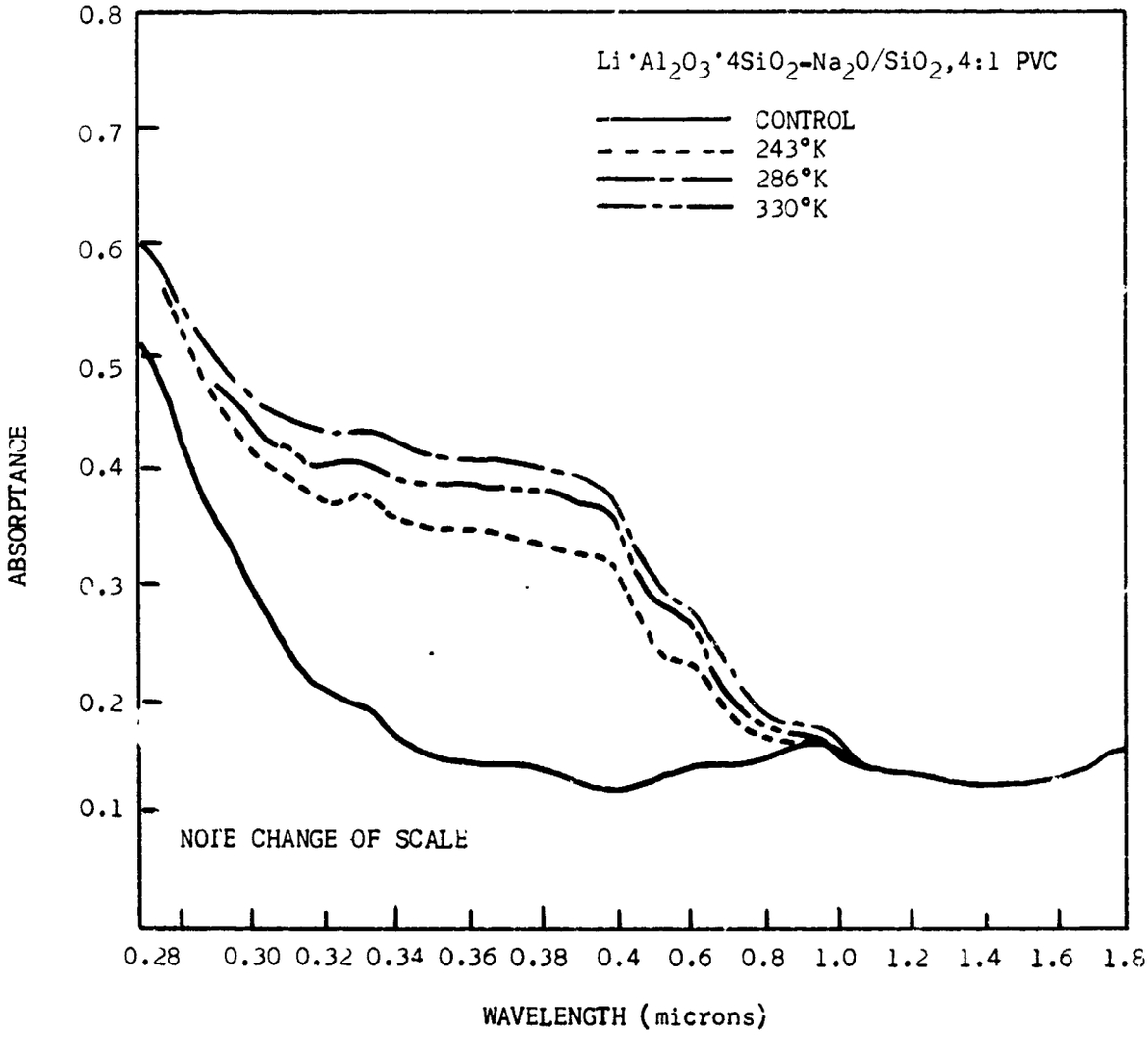
Spectral Ultraviolet Damage to TiO_2-Pigmented Silicone Paint at 20°C[24].



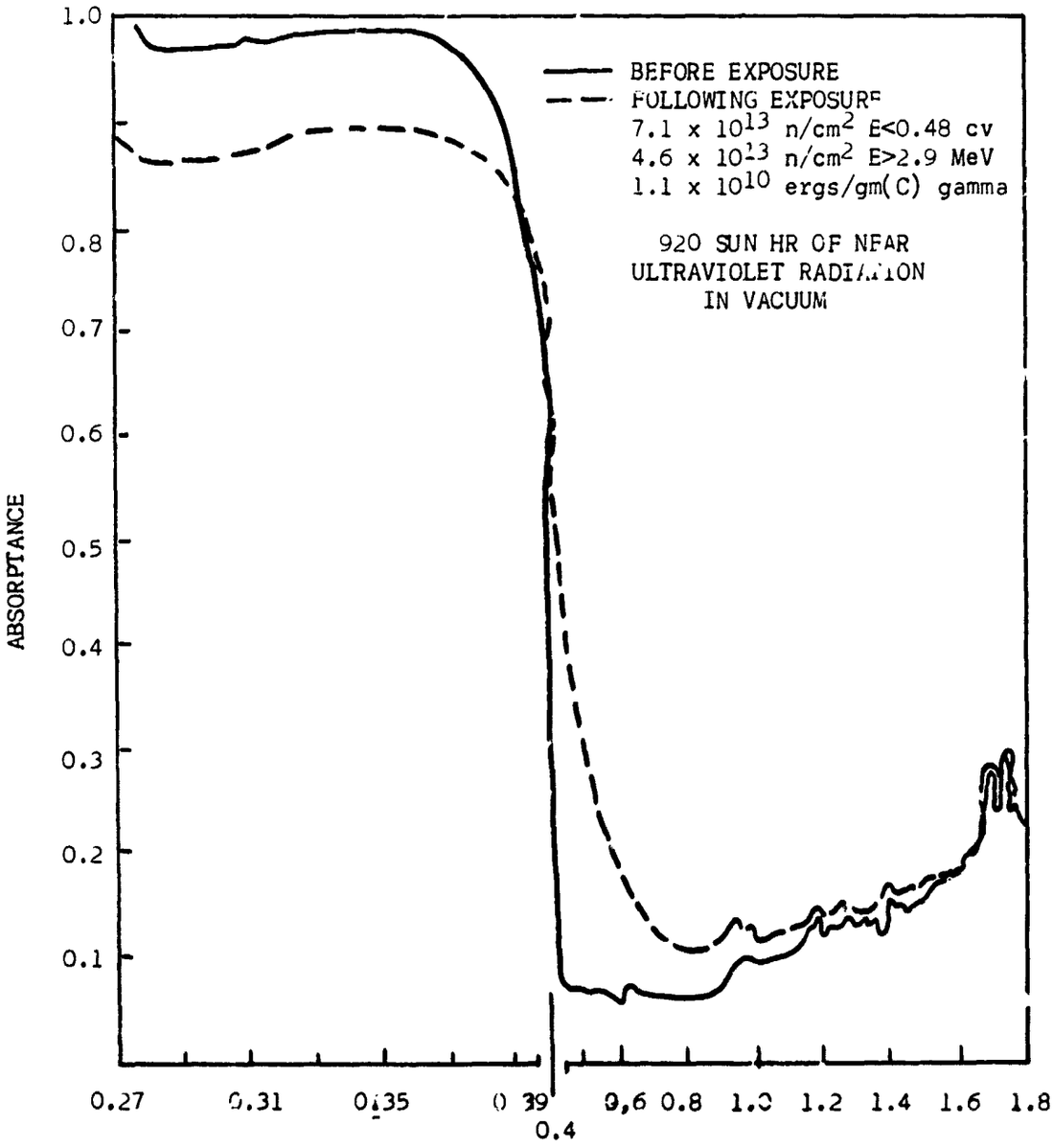
Spectral Absorptance - TiO_2/Epoxy[16]



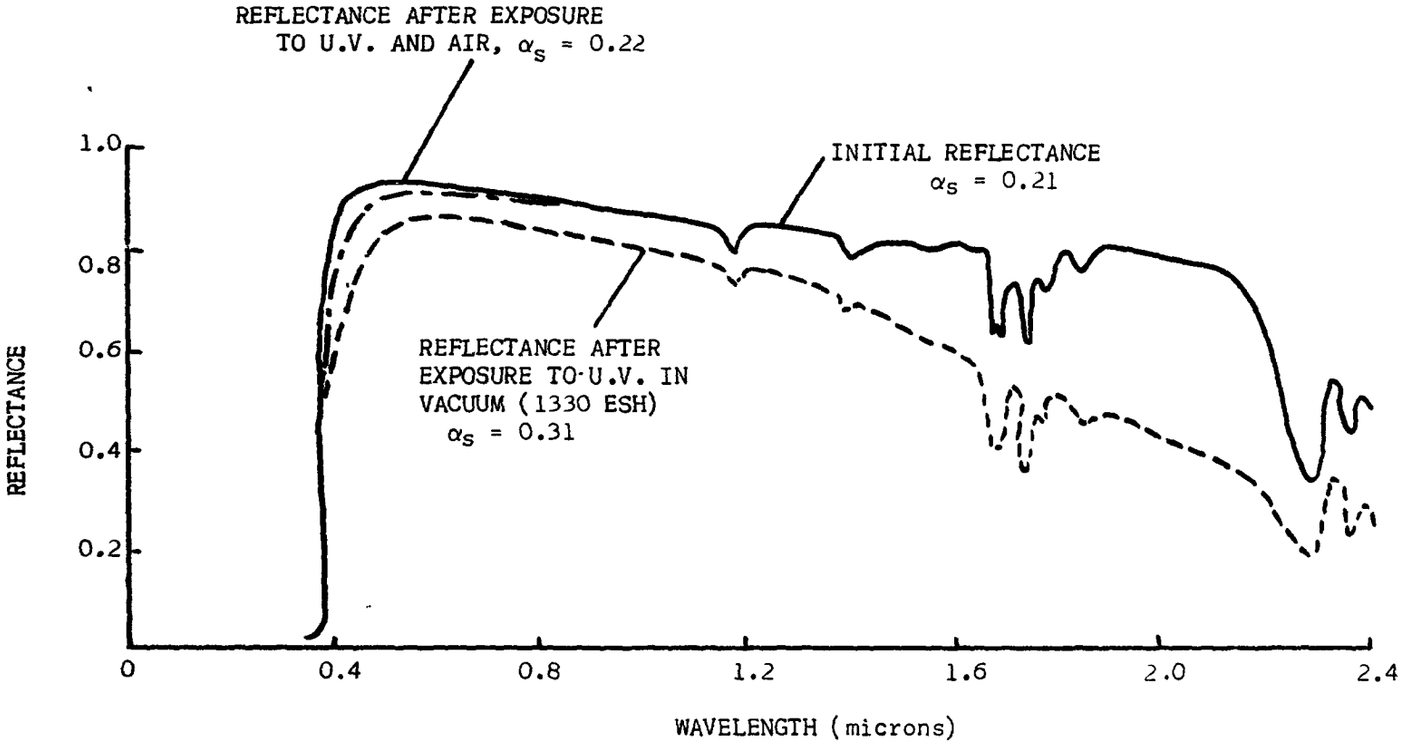
Spectral Absorptance - ZrO_2-SiO_2/K_2SiO_3[16].



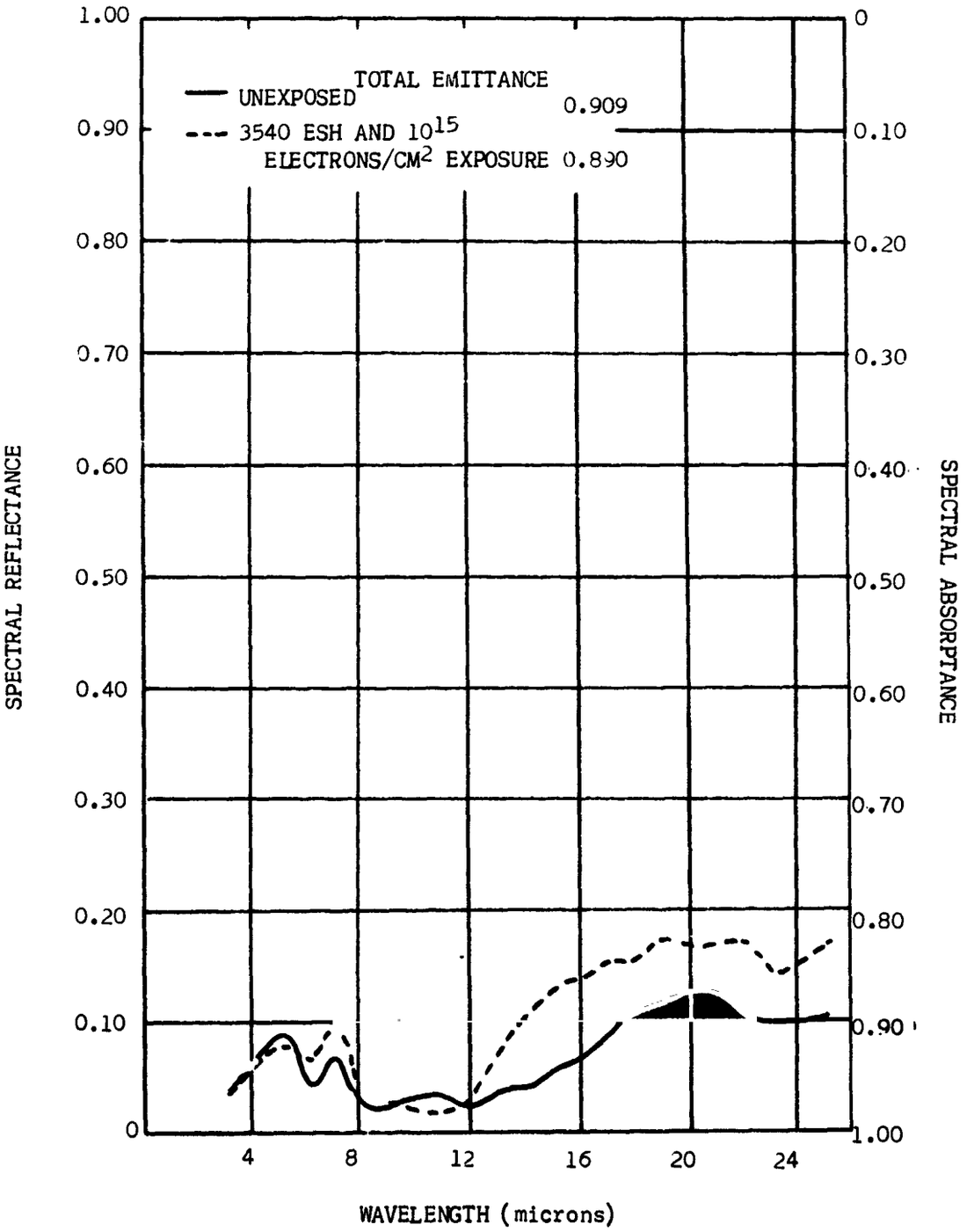
Nuclear Damage at Elevated Temperature With 10^{10} Ergs/gm (C) and 3×10^{14} Fast Neutrons/cm^2 (16).



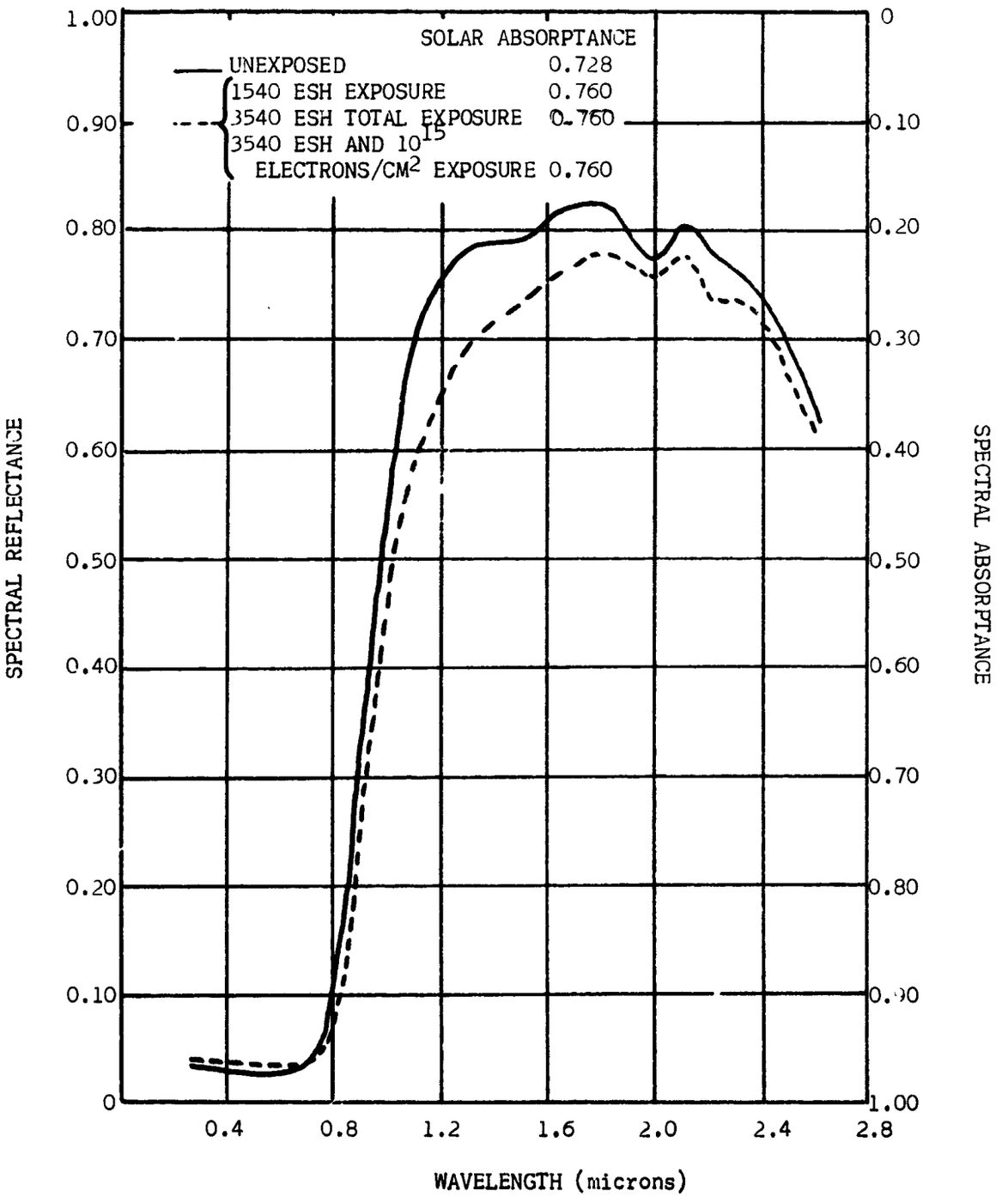
Effects of Simultaneous Nuclear and Ultraviolet Exposure on Spectral Absorptance of Thermatrol Paint 2A-100[16].



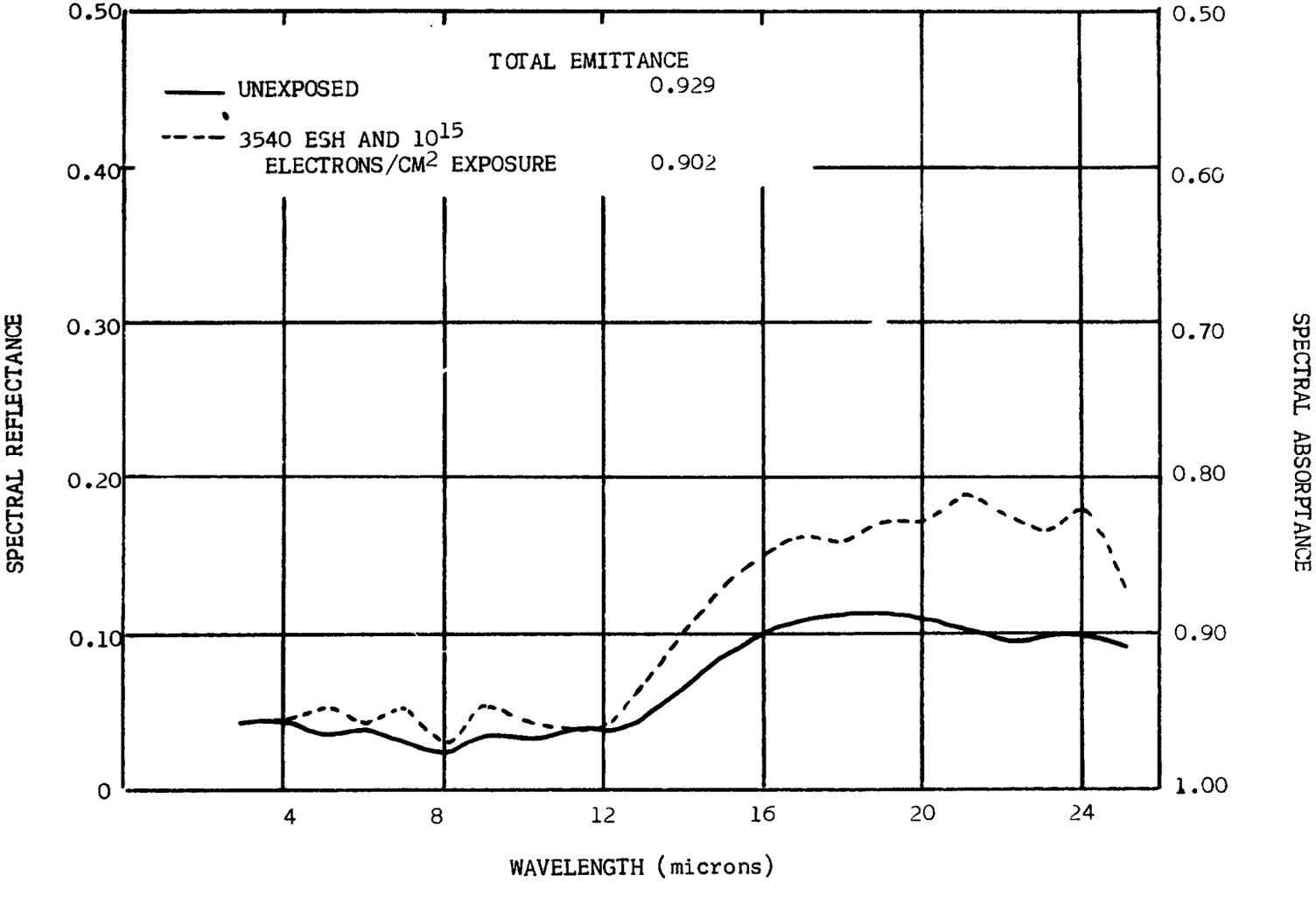
Recovery of ZnO in Silicone (S-13) After Ultraviolet Damage and Subsequent Exposure to Air[11].



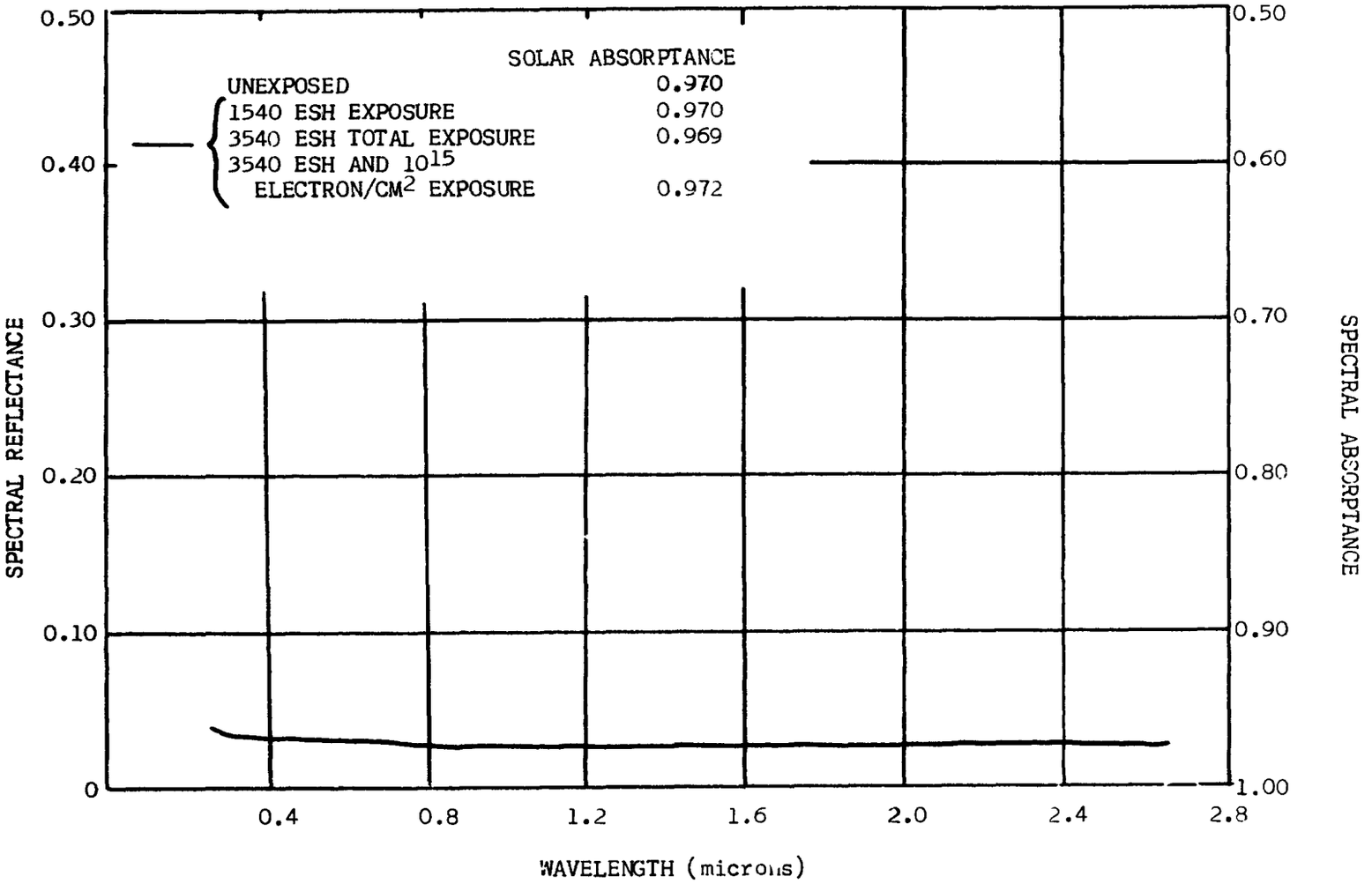
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Bi_2S_3 Dyed Anodized Aluminum (Concluded)[13].



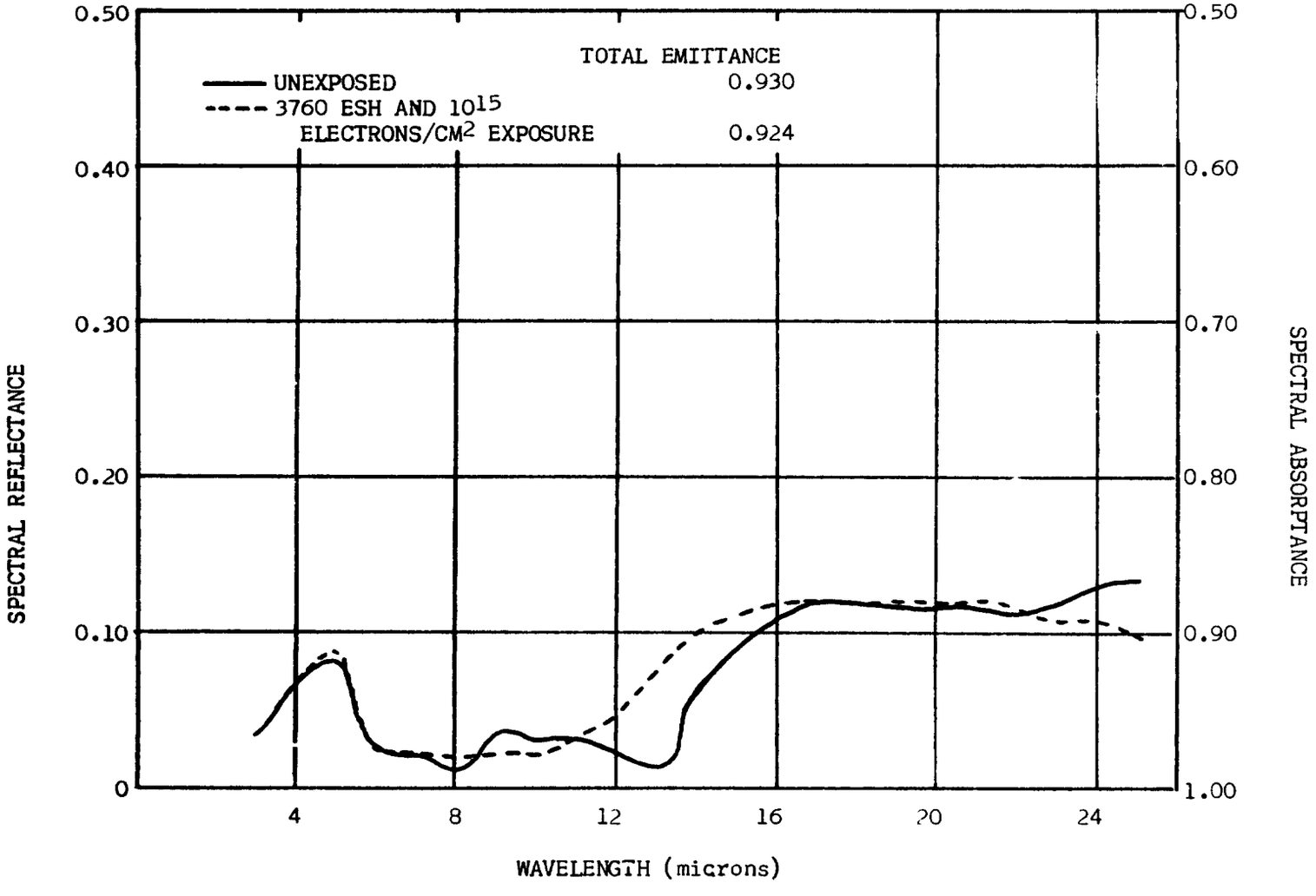
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Bi_2S_3 Dyed Anodized Aluminum (Continued)[13].



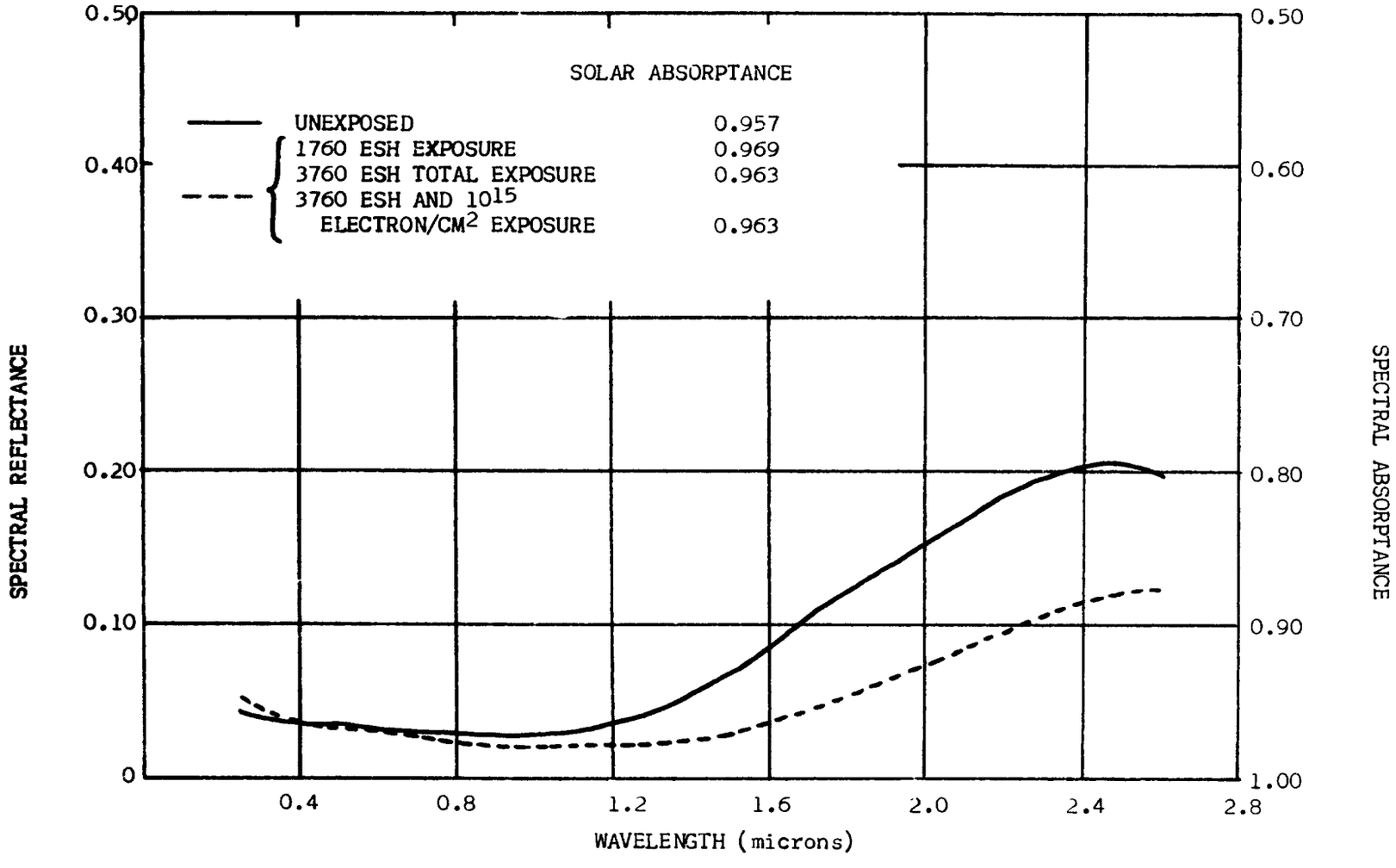
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. NiS Dyed Anodized Aluminum (Concluded)[13].



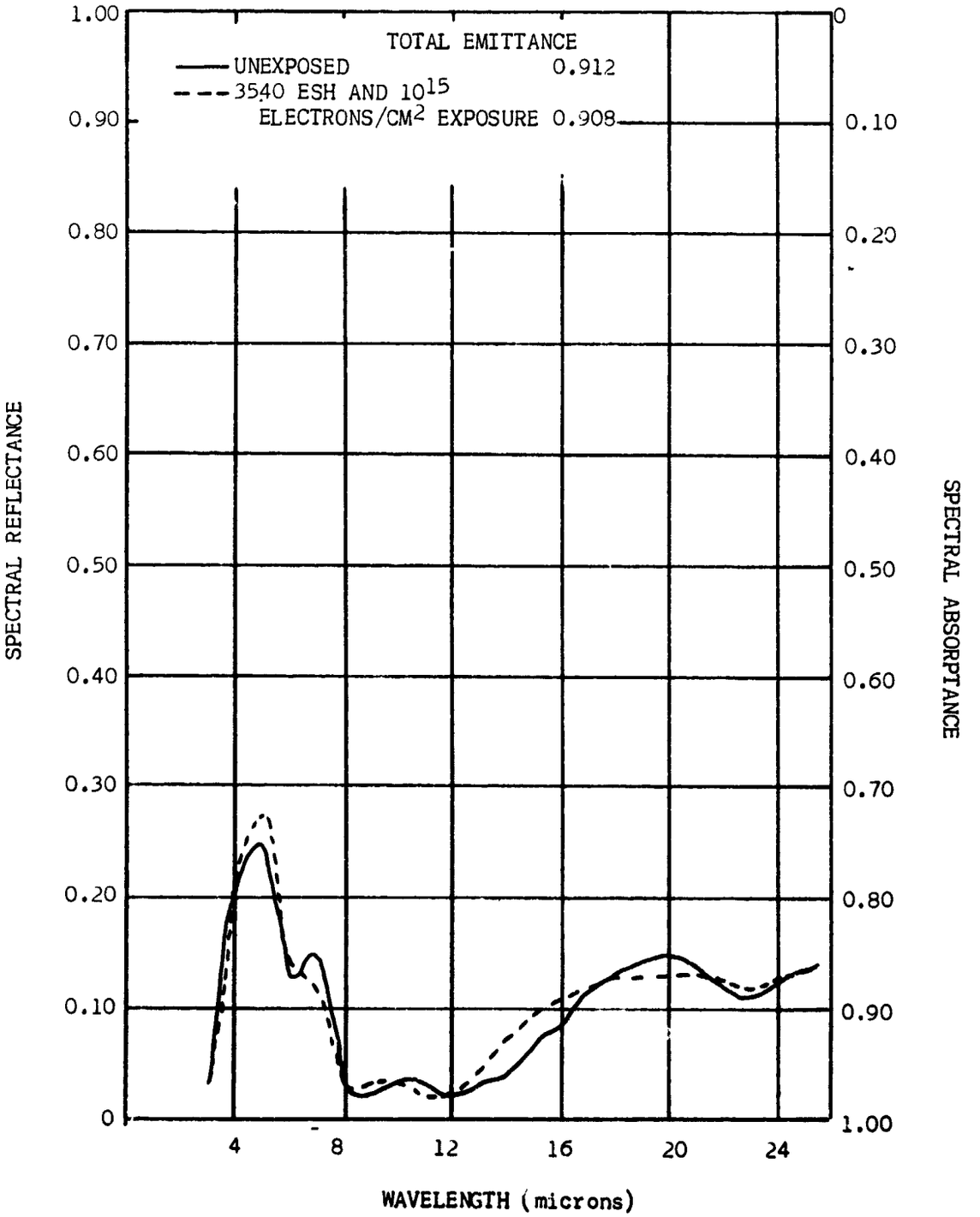
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. NiS Dyed Anodized Aluminum (Continued)[13].



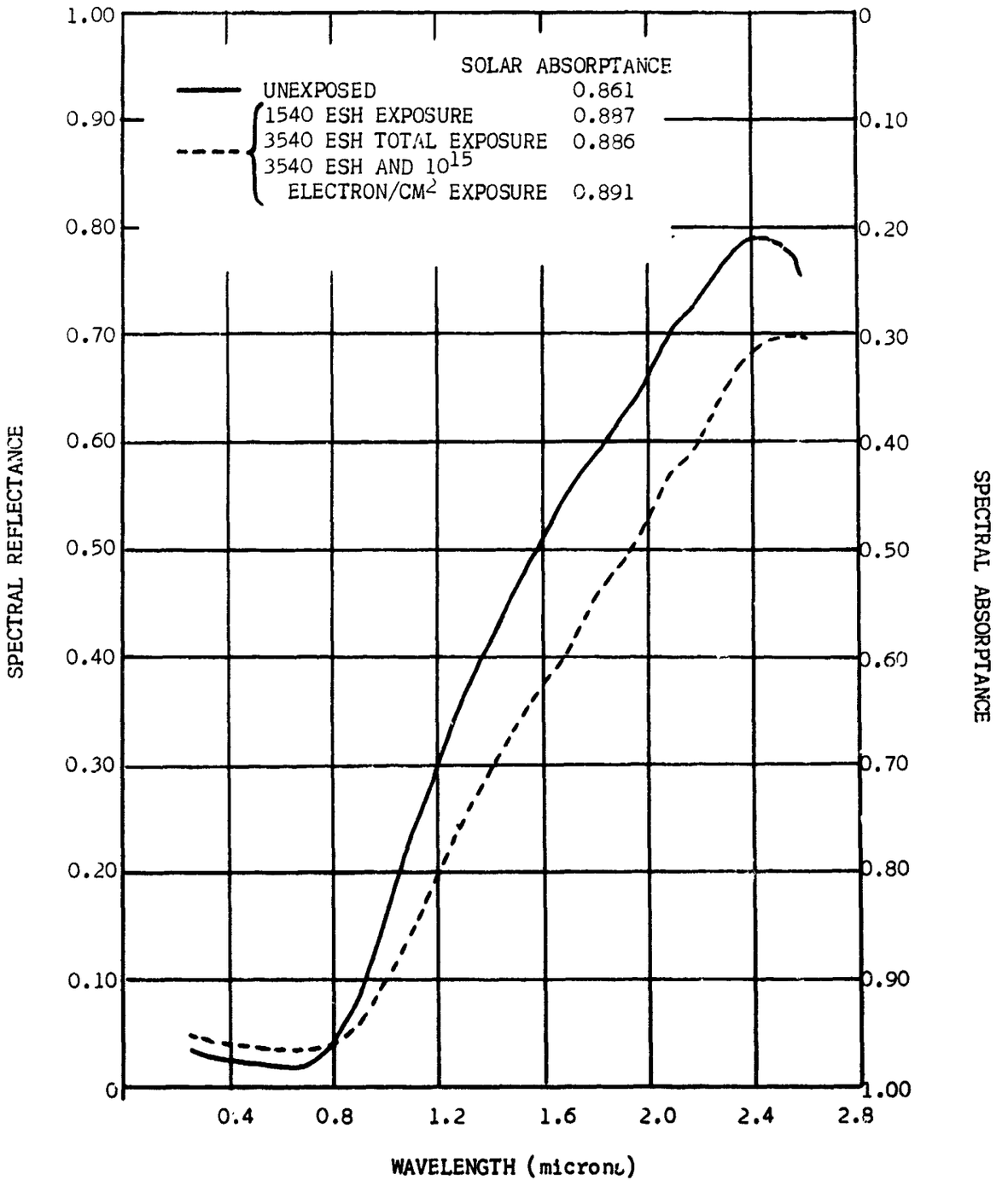
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. CoS Dyed Anodized Aluminum (Concluded)[13].



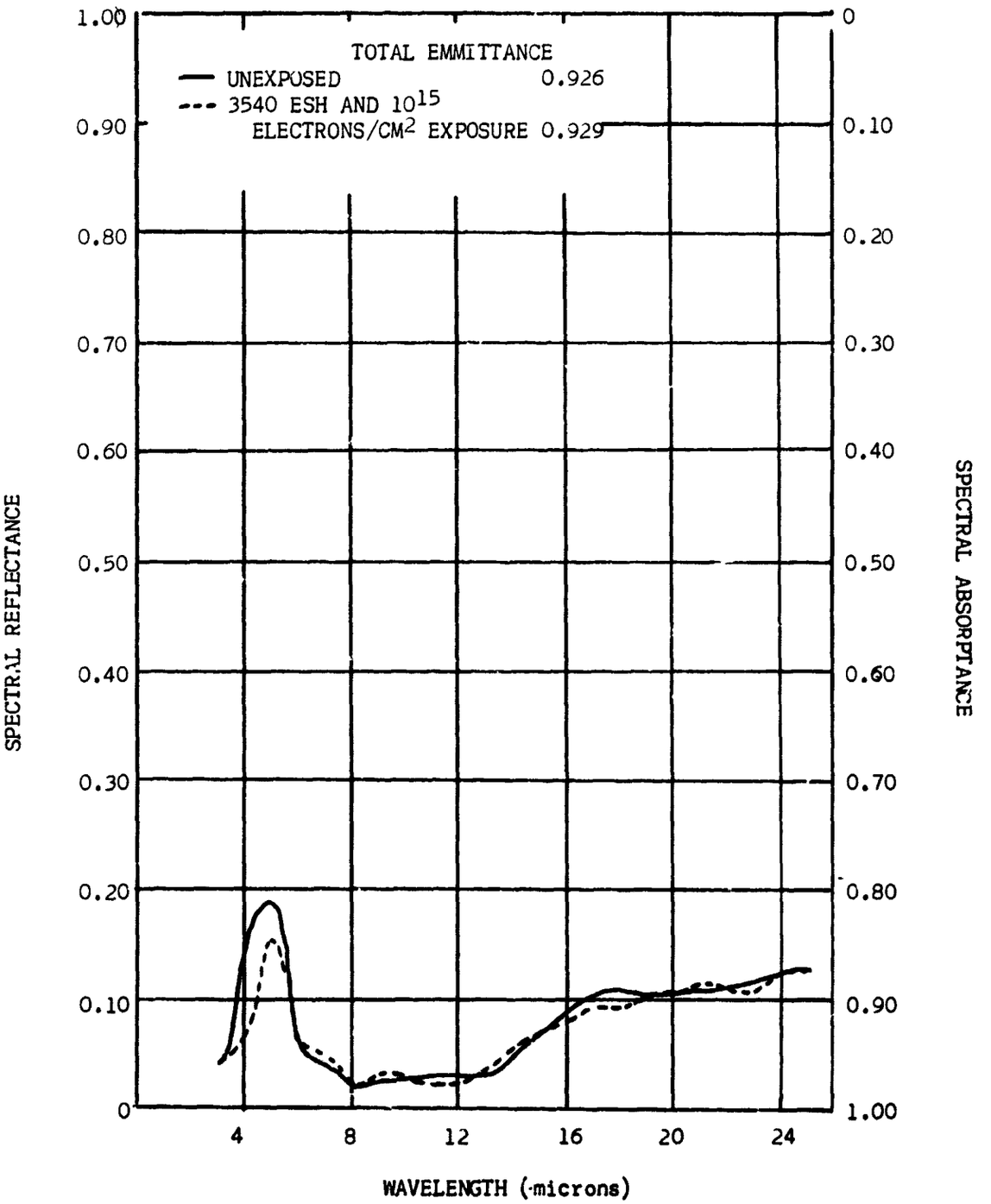
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. CoS Dyed Anodized Aluminum (Continued)[13].



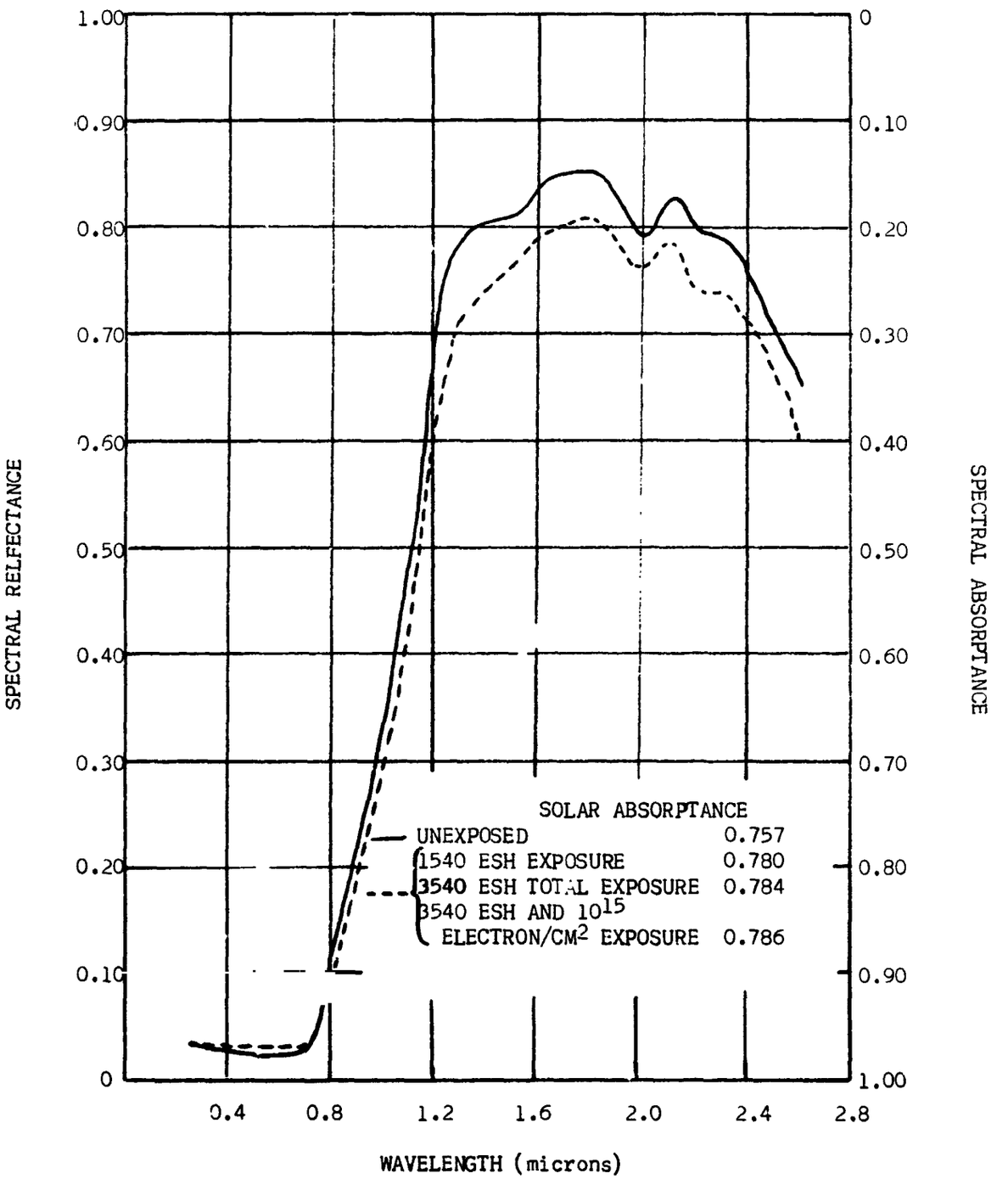
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. PbS Dyed Anodized Aluminum (Concluded)[13].



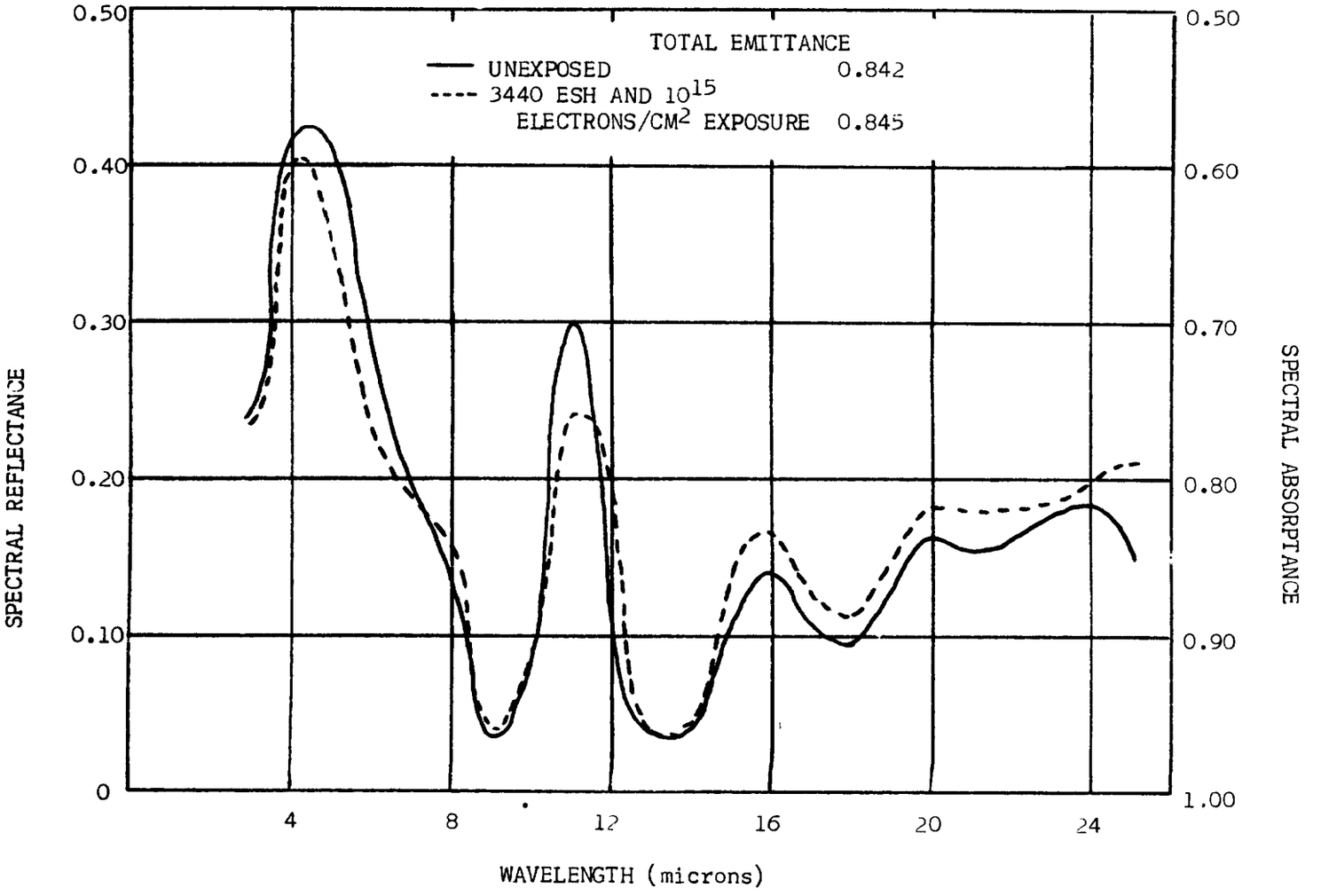
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. PbS Dyed Anodized Aluminum (Continued)[13].



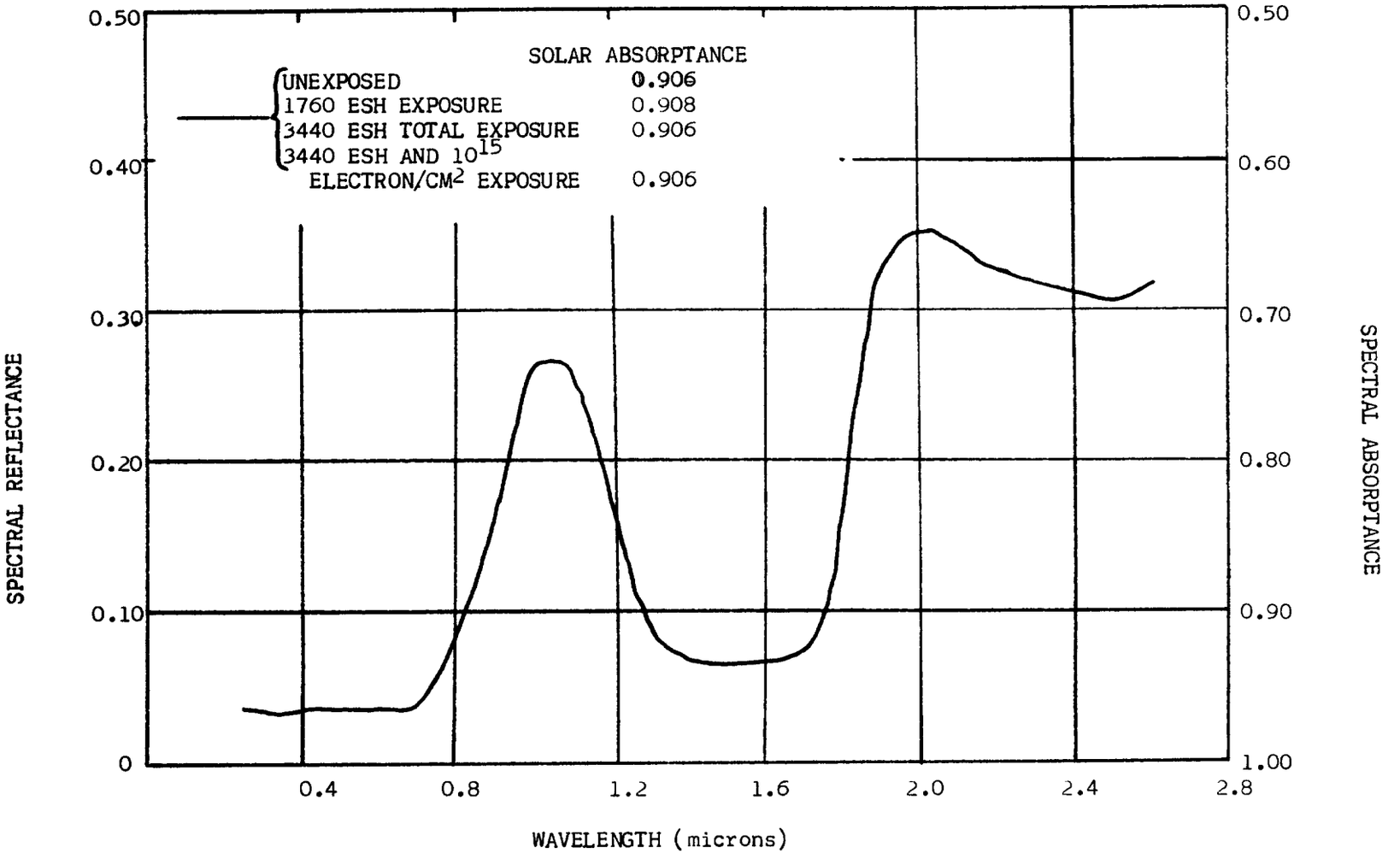
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sandoz Black BK Dyed Anodized Aluminum (Concluded)[13].



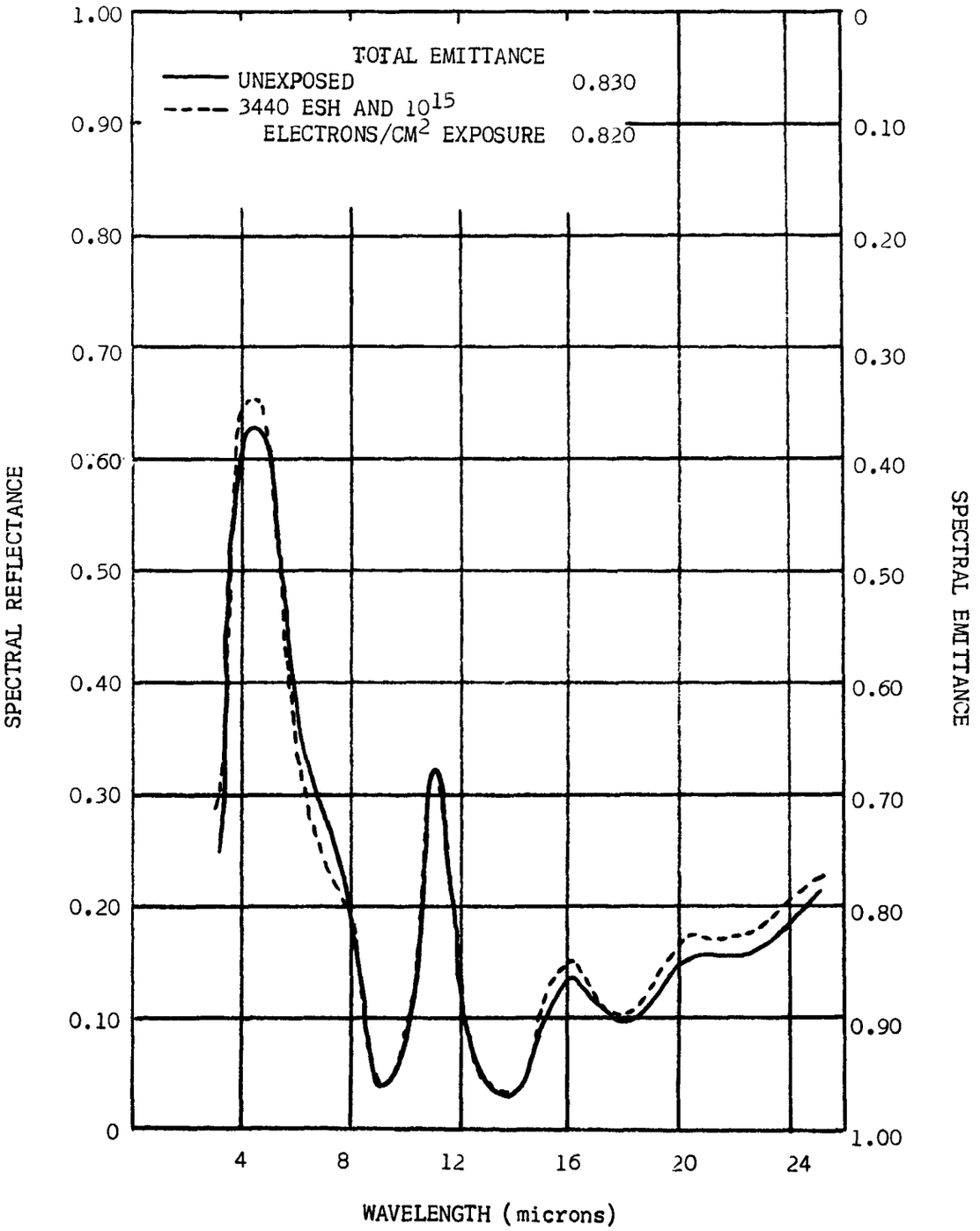
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sandoz Black BK Dyed Anodized Aluminum (Continued)[13].



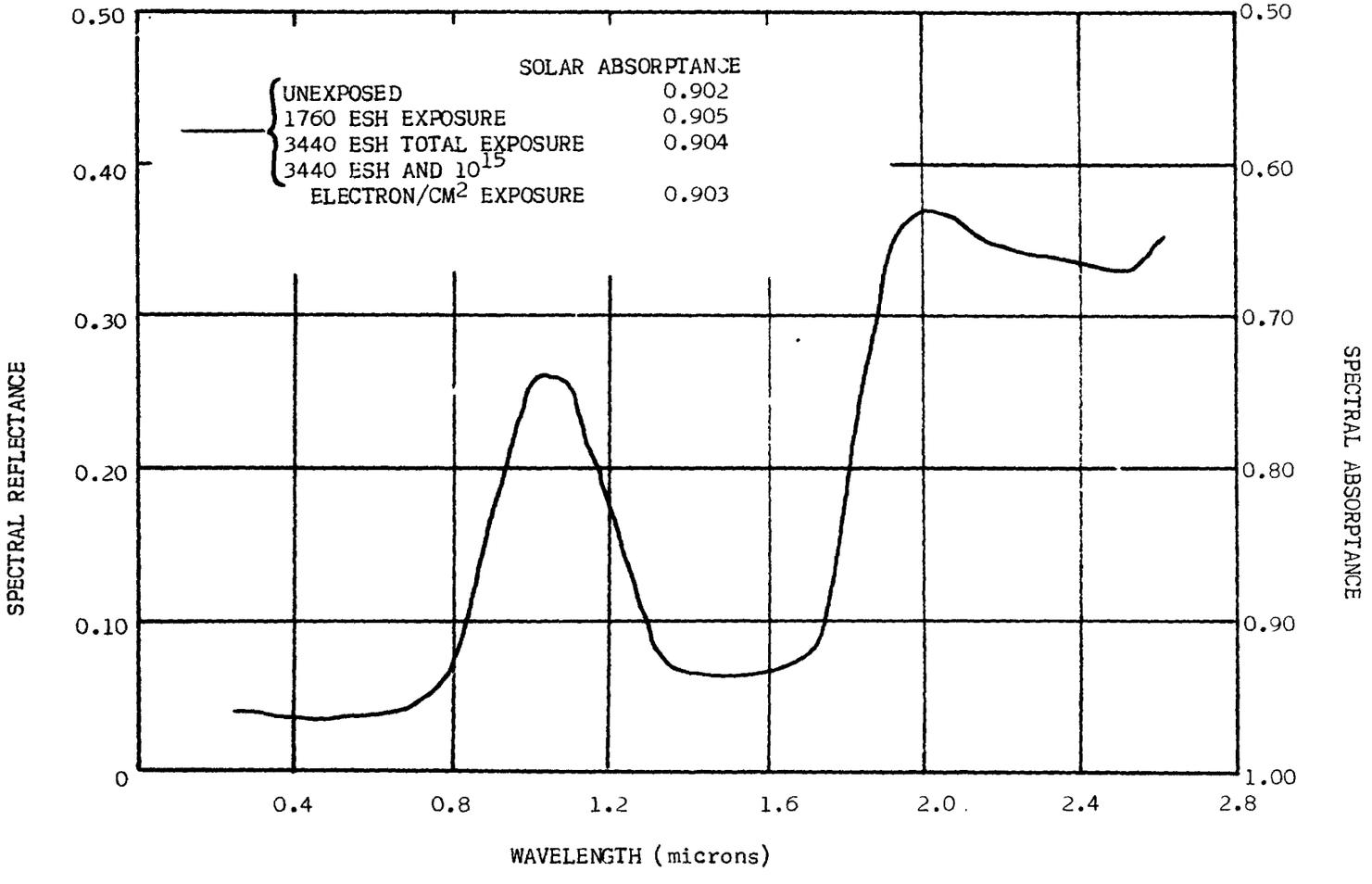
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Pyromark Black On Inconel (Concluded)[13].



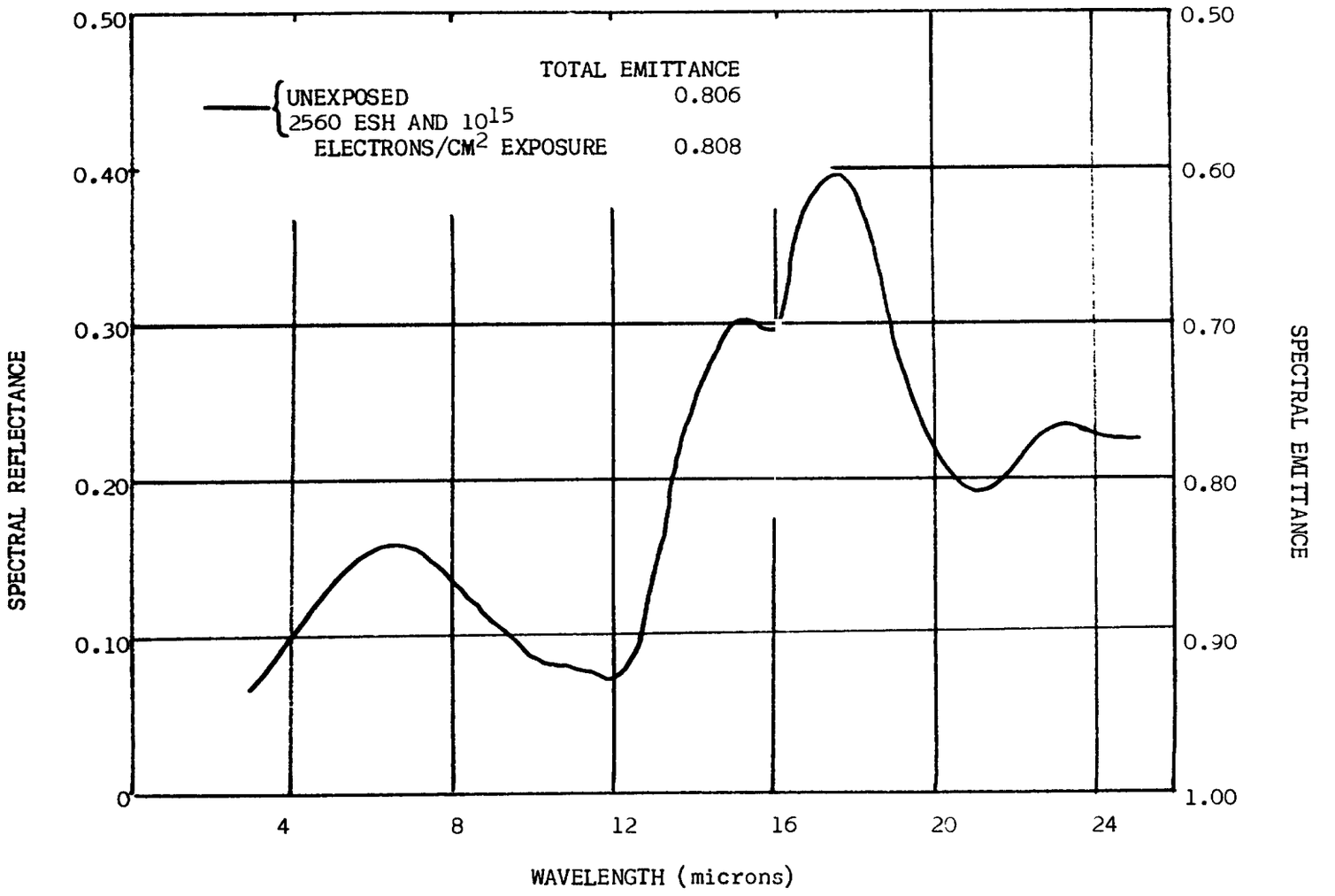
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Pyromark Black On Inconel (Continued)[13].



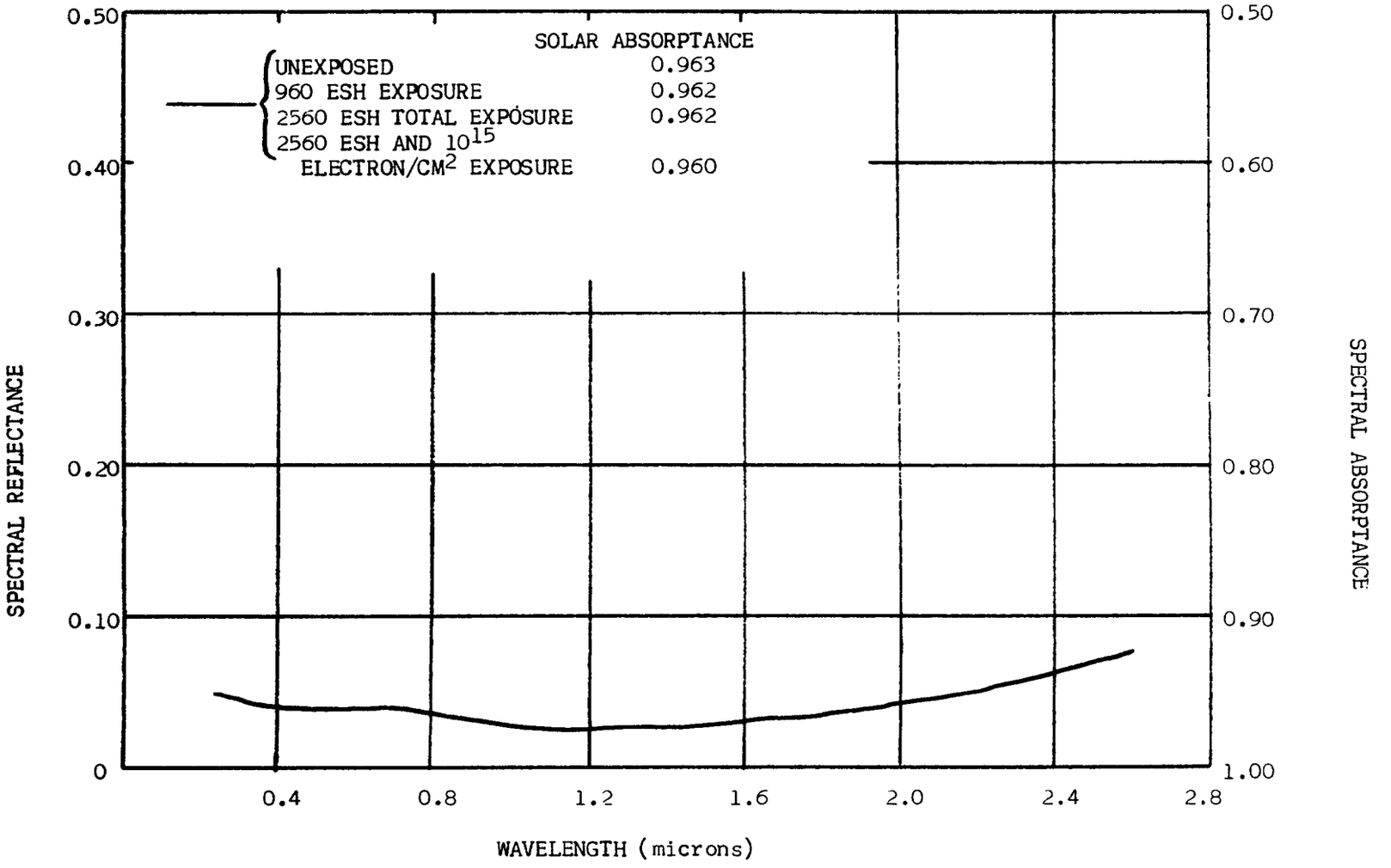
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Pyromark Black on Aluminum (Concluded)[13].



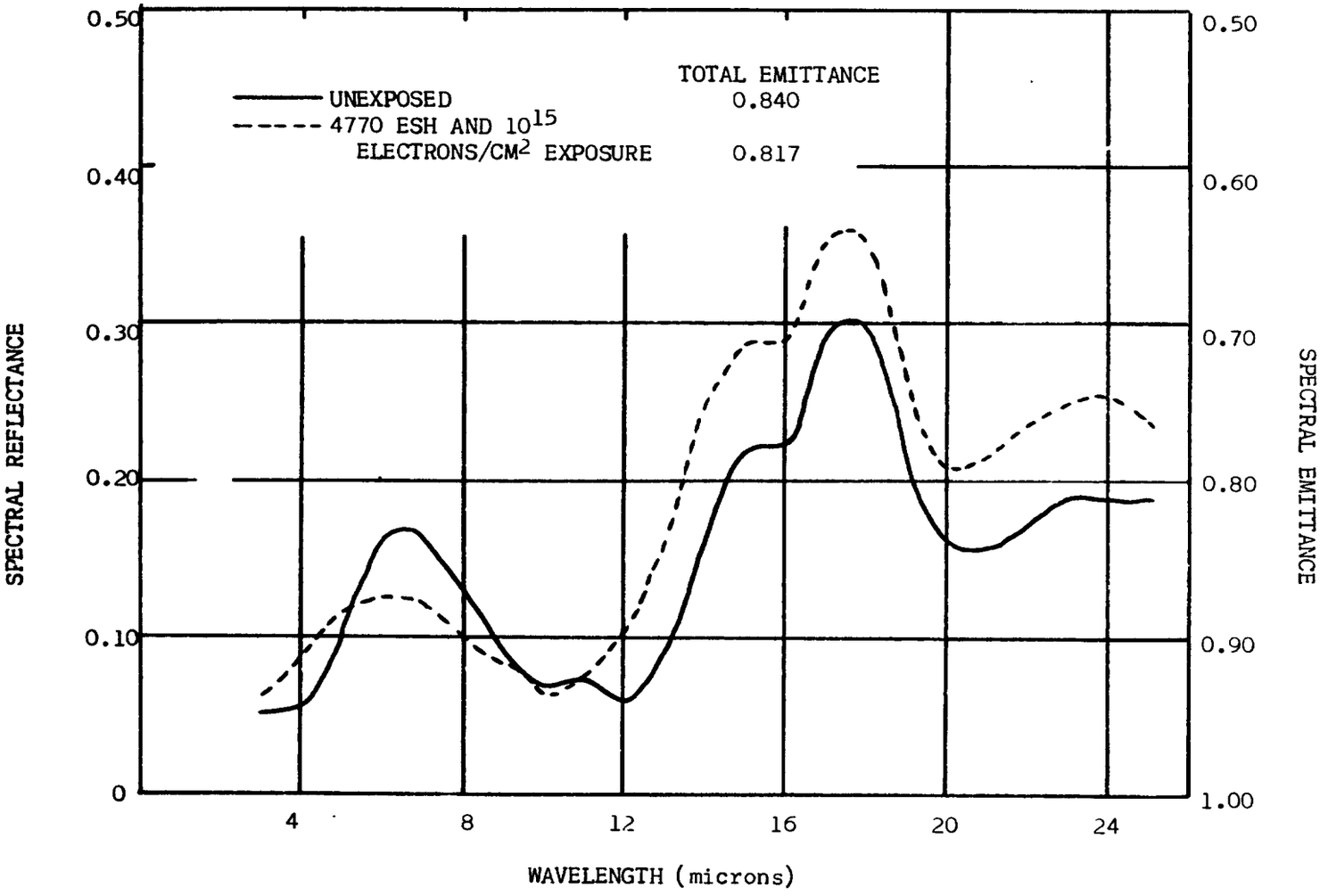
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Pyromark Black on Aluminum (Continued)[13].



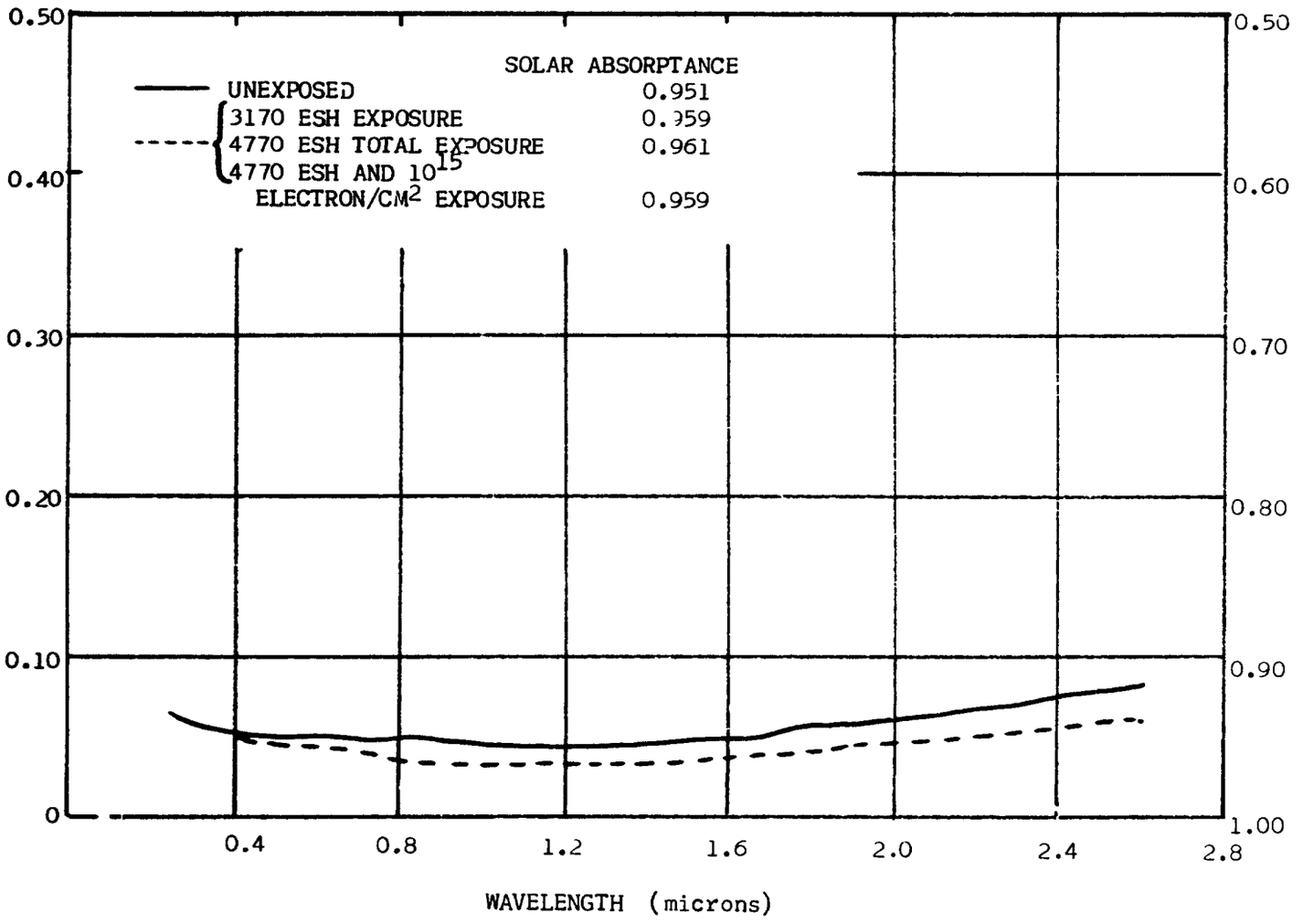
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Inconel X (Concluded)[13].



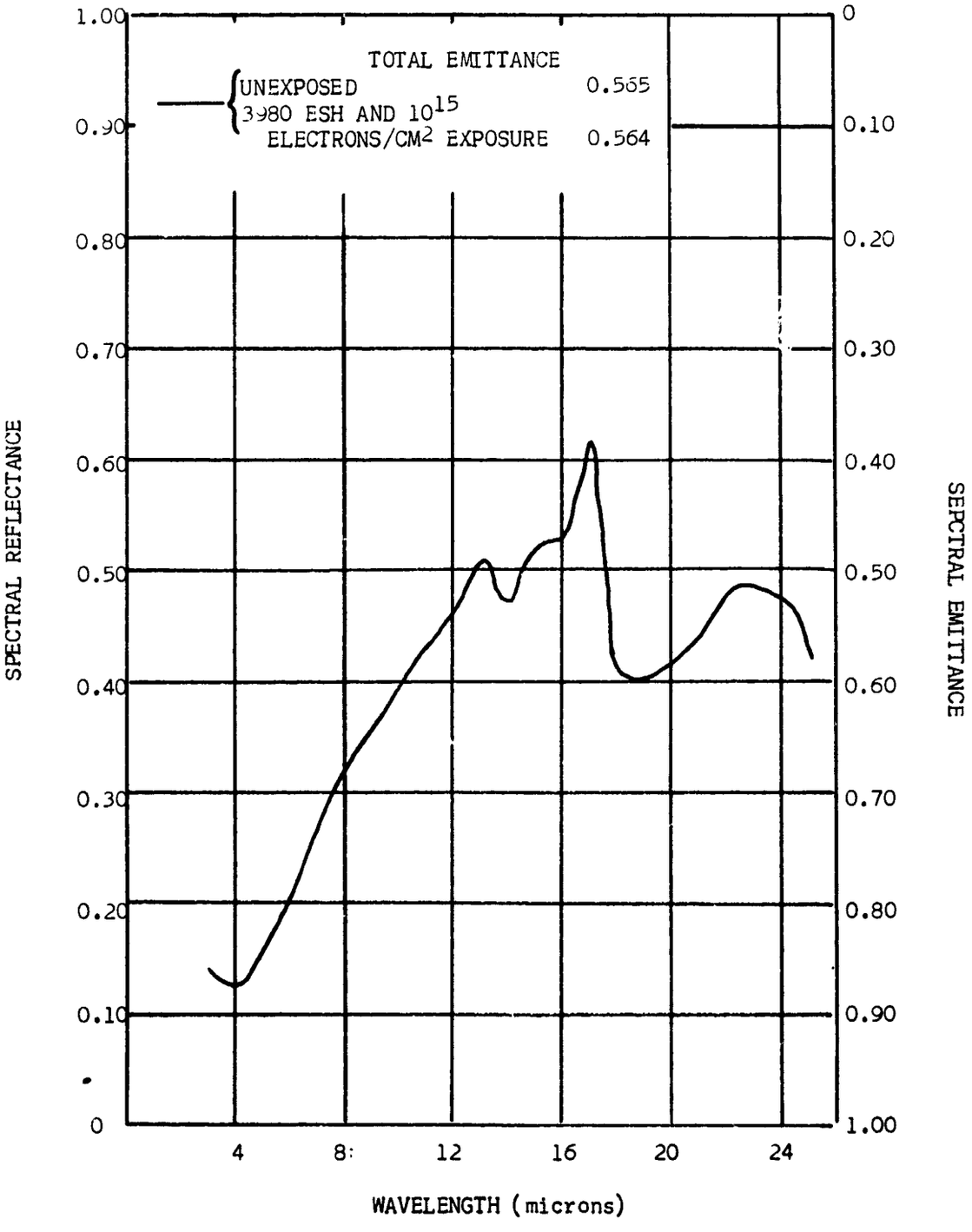
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Inconel X (Continued)[13].



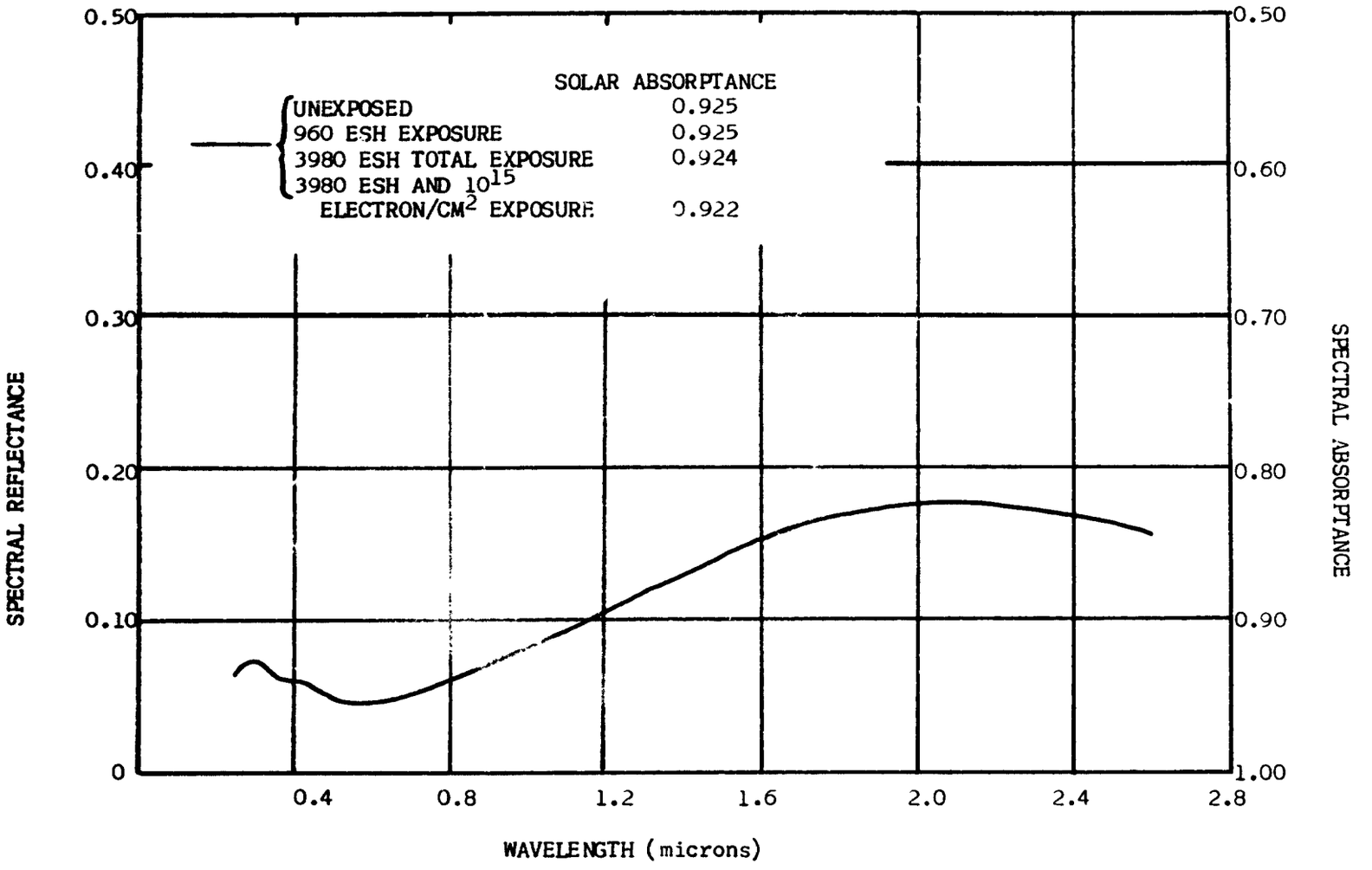
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Inconel (Concluded)[13].



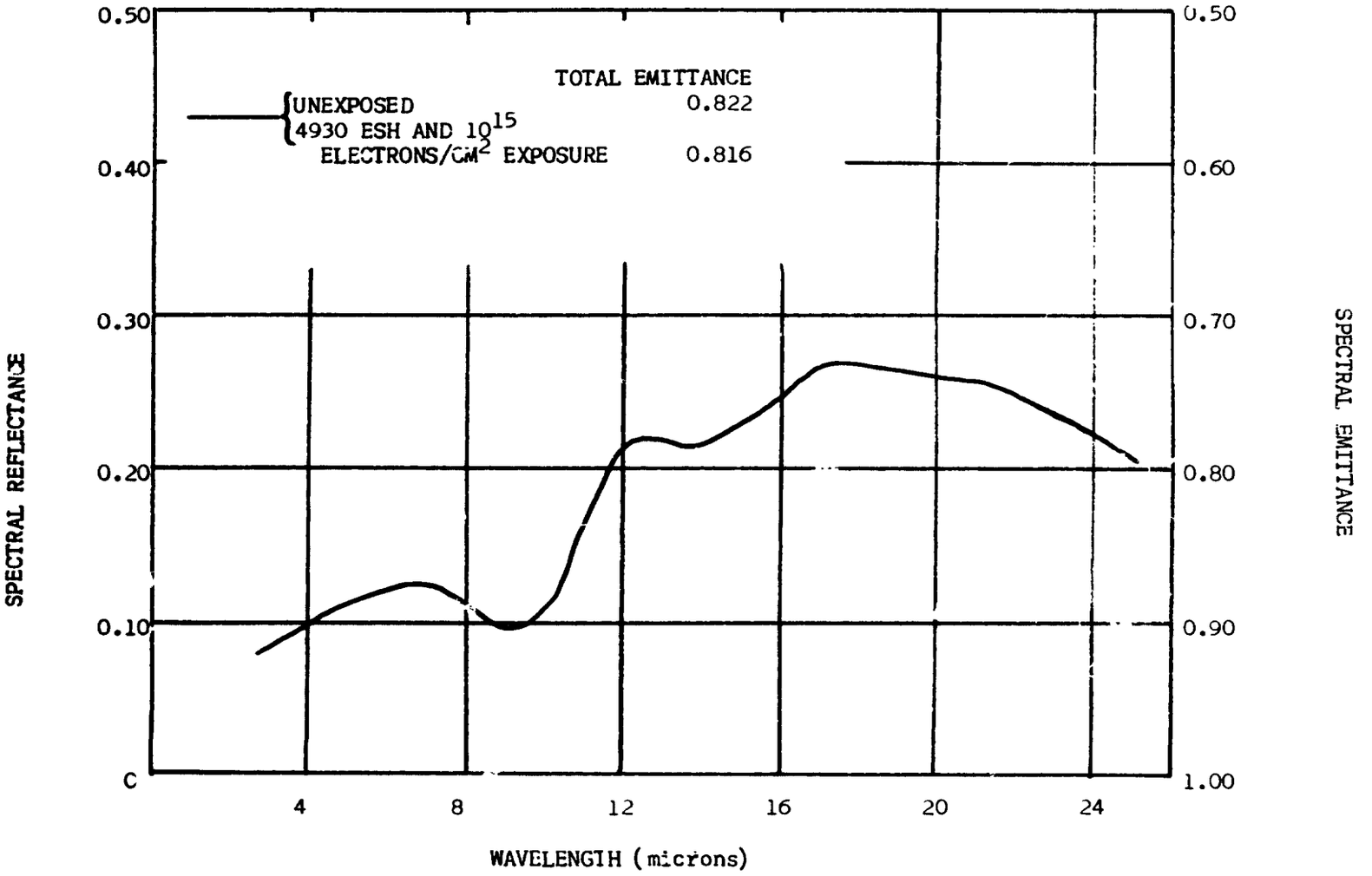
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Inconel (Continued)[13].



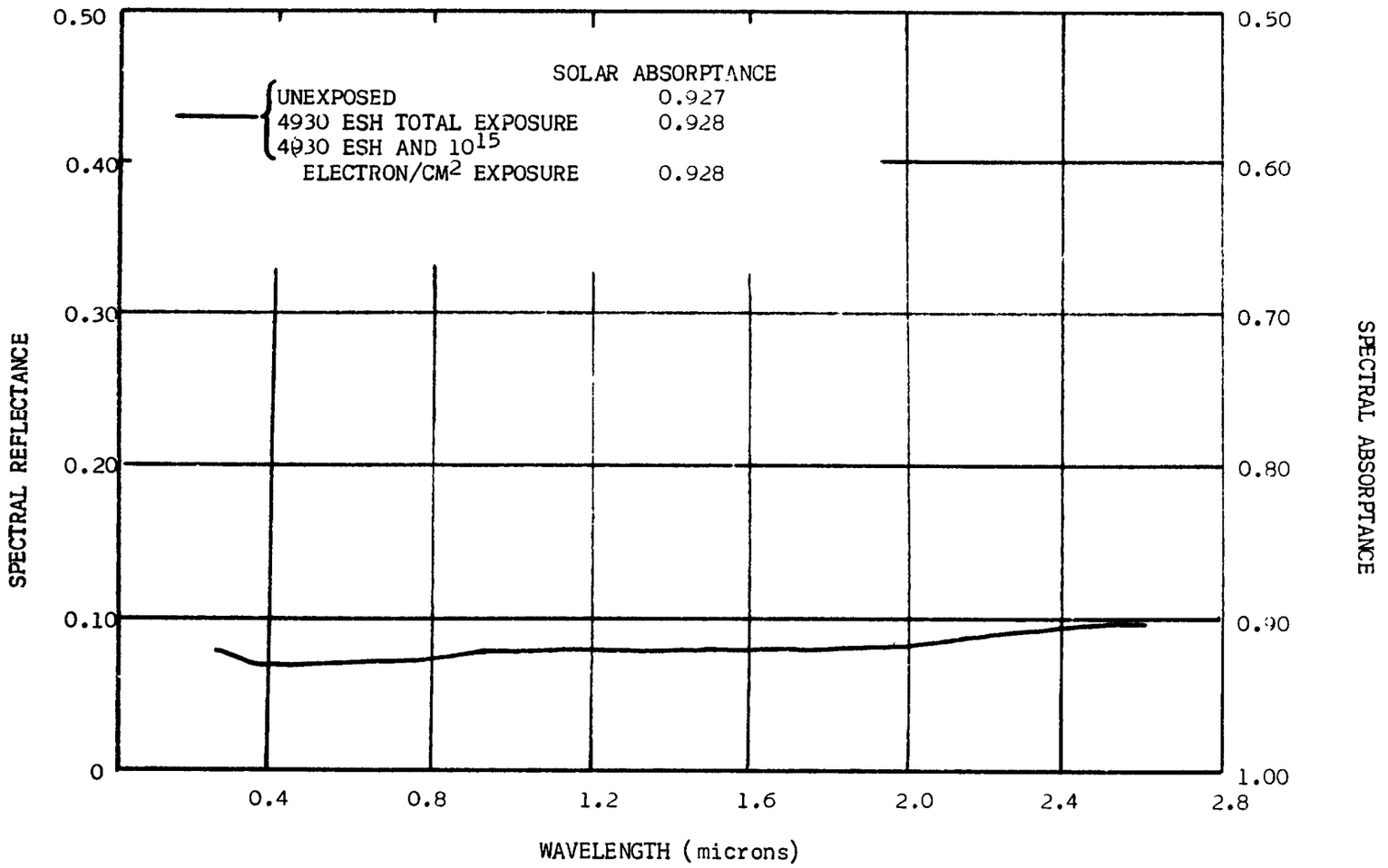
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Type 347 Stainless Steel (Concluded)[13].



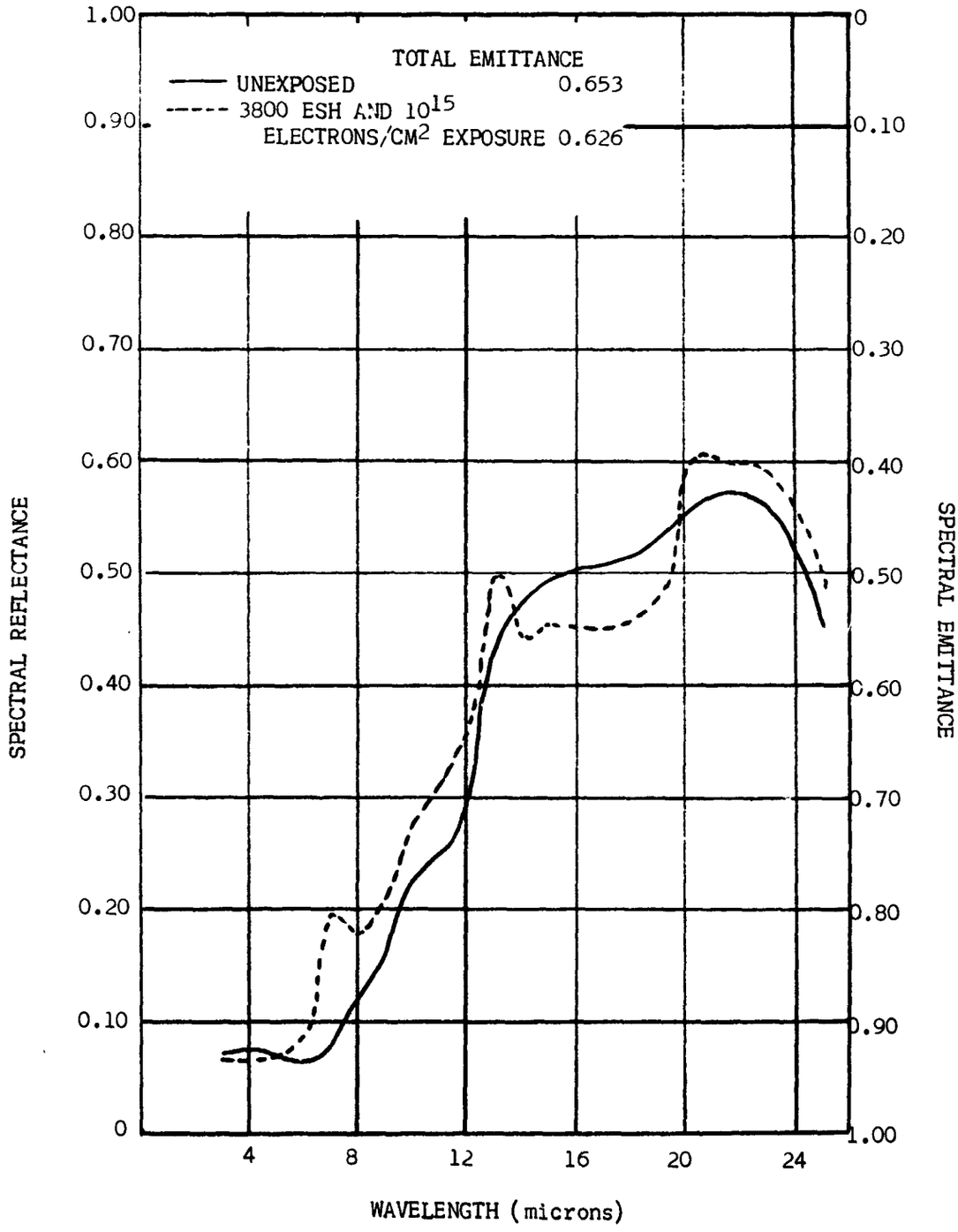
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sodium Dichromate Blackened Type 347 Stainless Steel (Continued)[13].



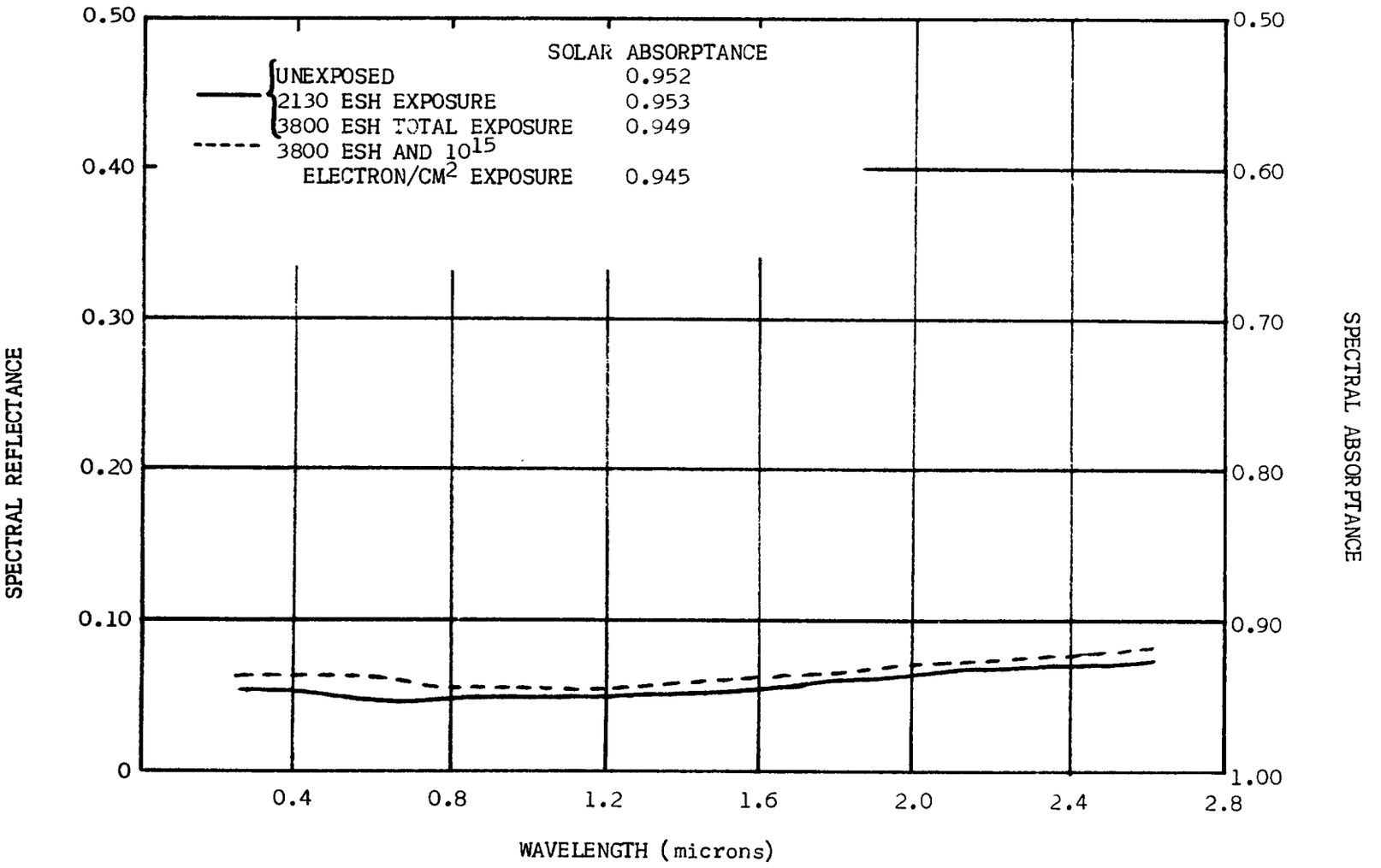
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Westinghouse Black On Inconel (Concluded)[13].



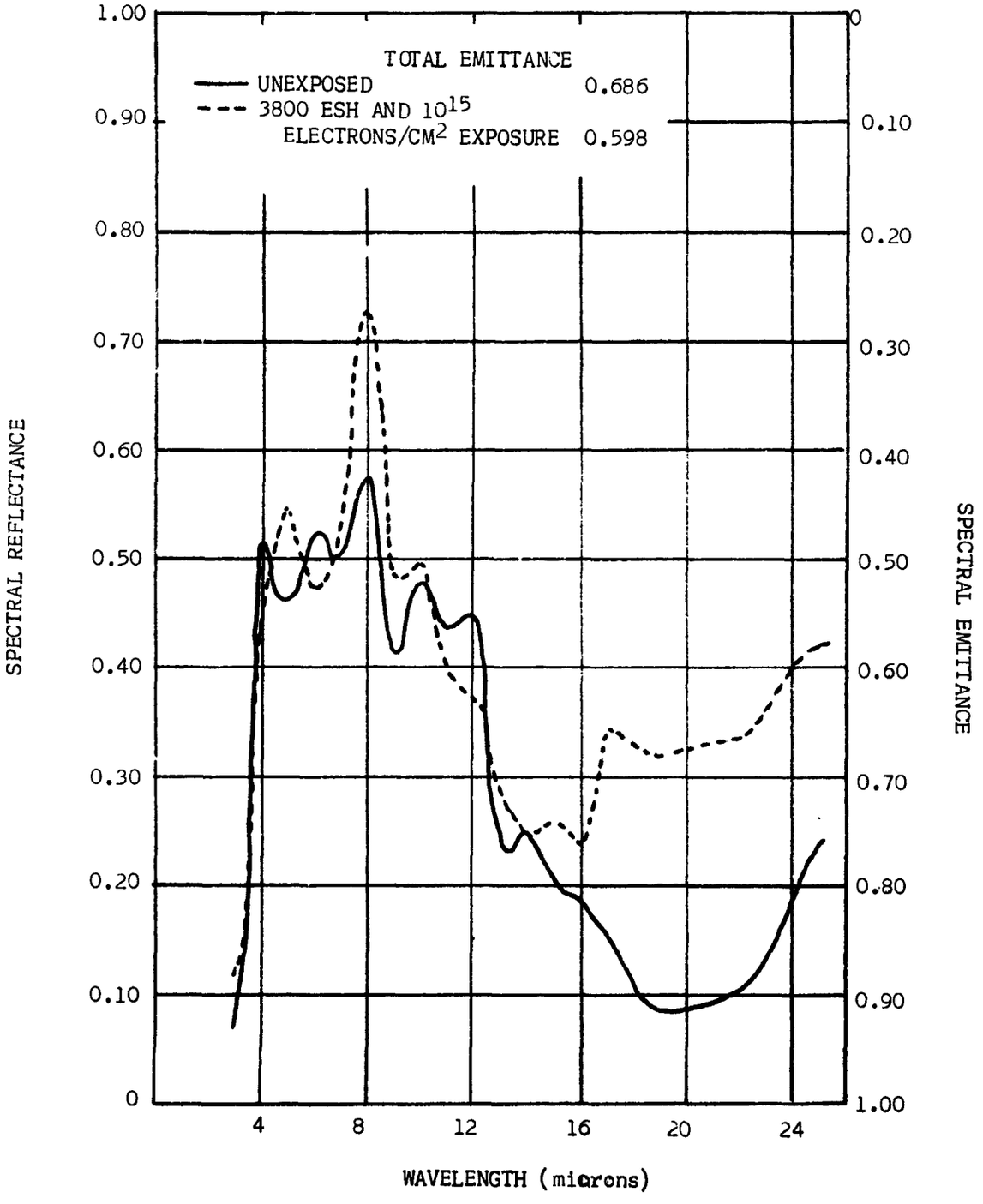
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Westinghouse Black On Inconel (Continued)[13].



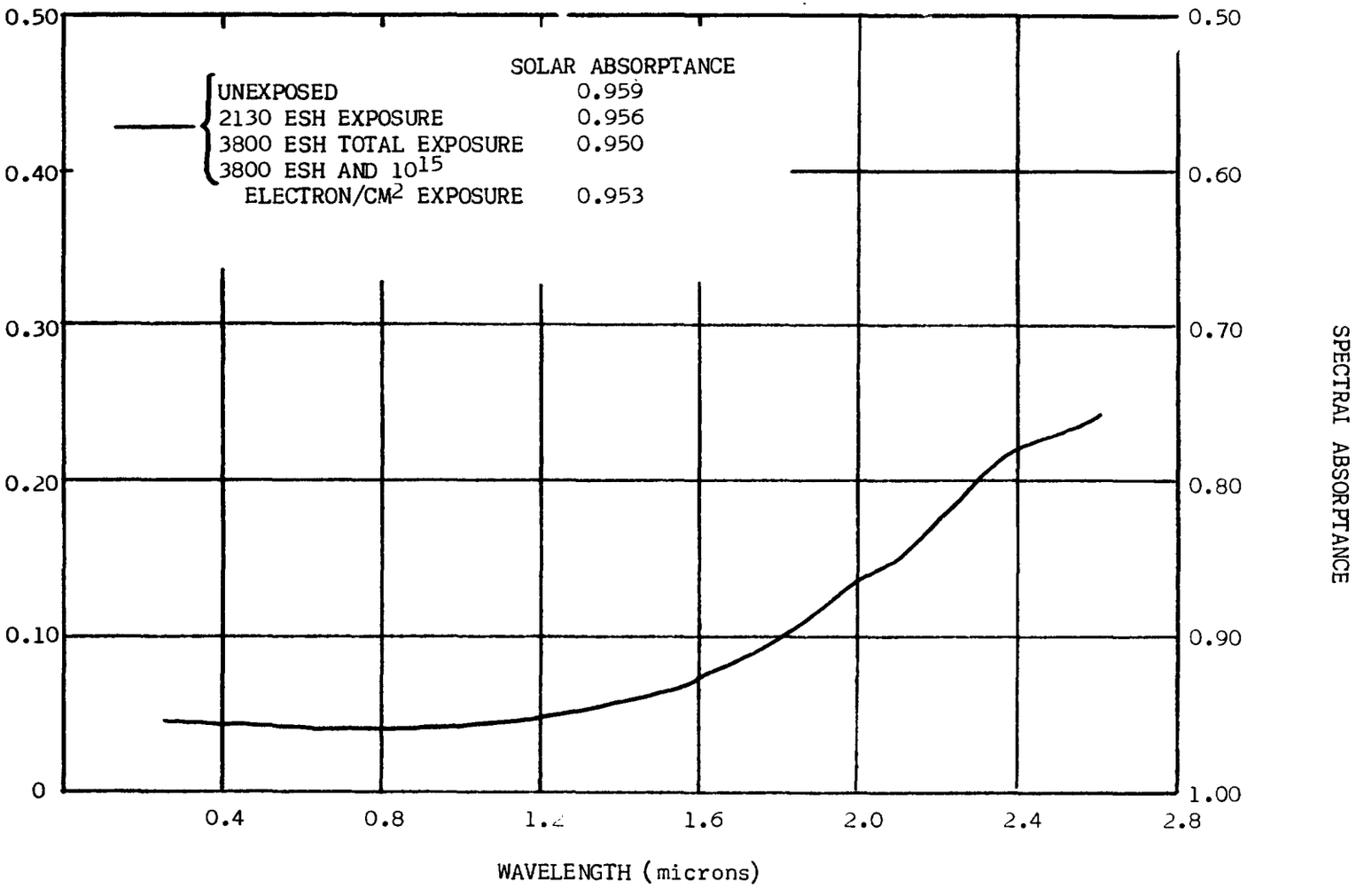
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Du-lite 3-0 On Grit-Blasted Type 3-4 Stainless Steel (Concluded)[13].



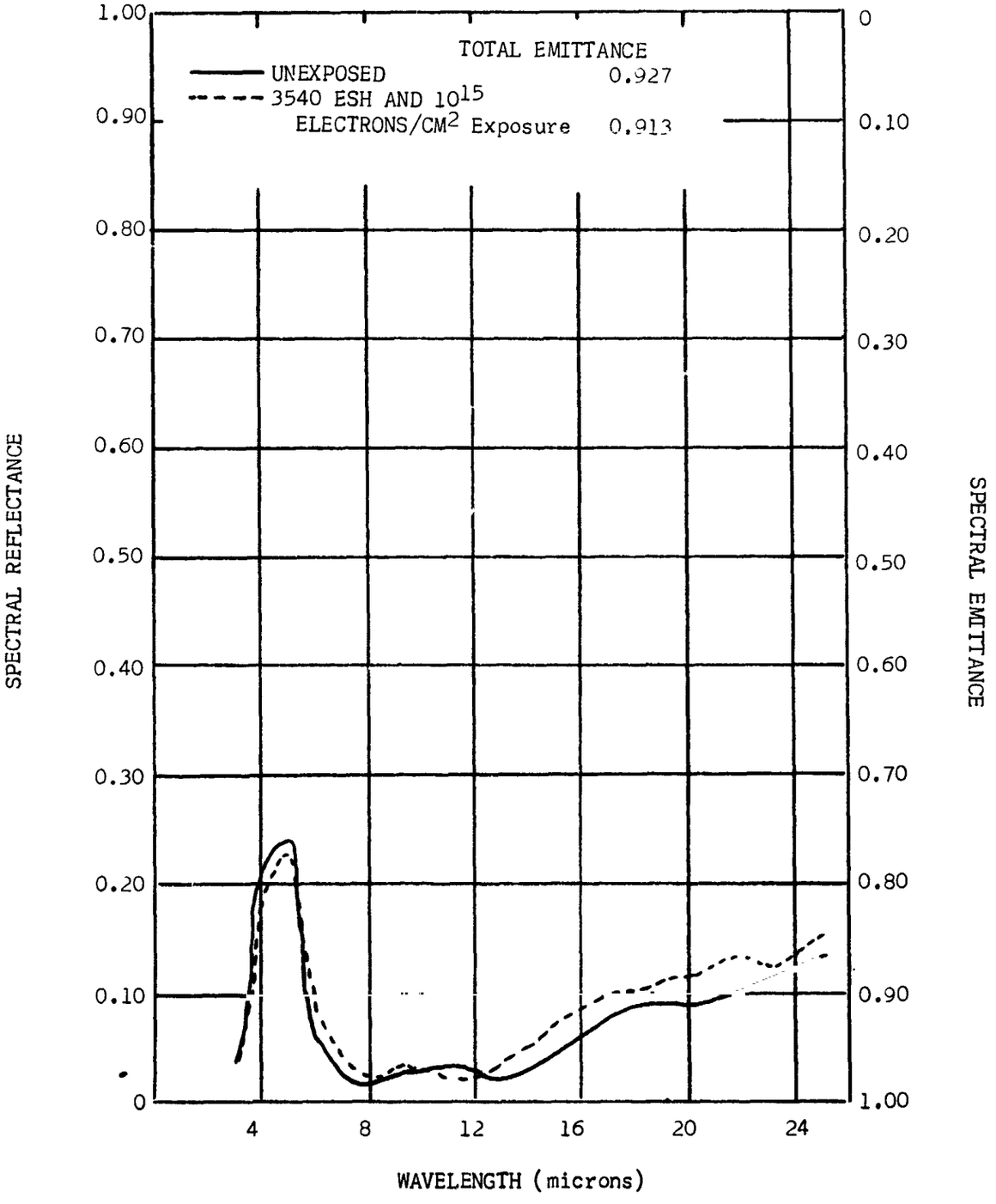
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Du-lite 3-0 On Grit-Blasted Type 3-4 Stainless Steel (Continued)[13].



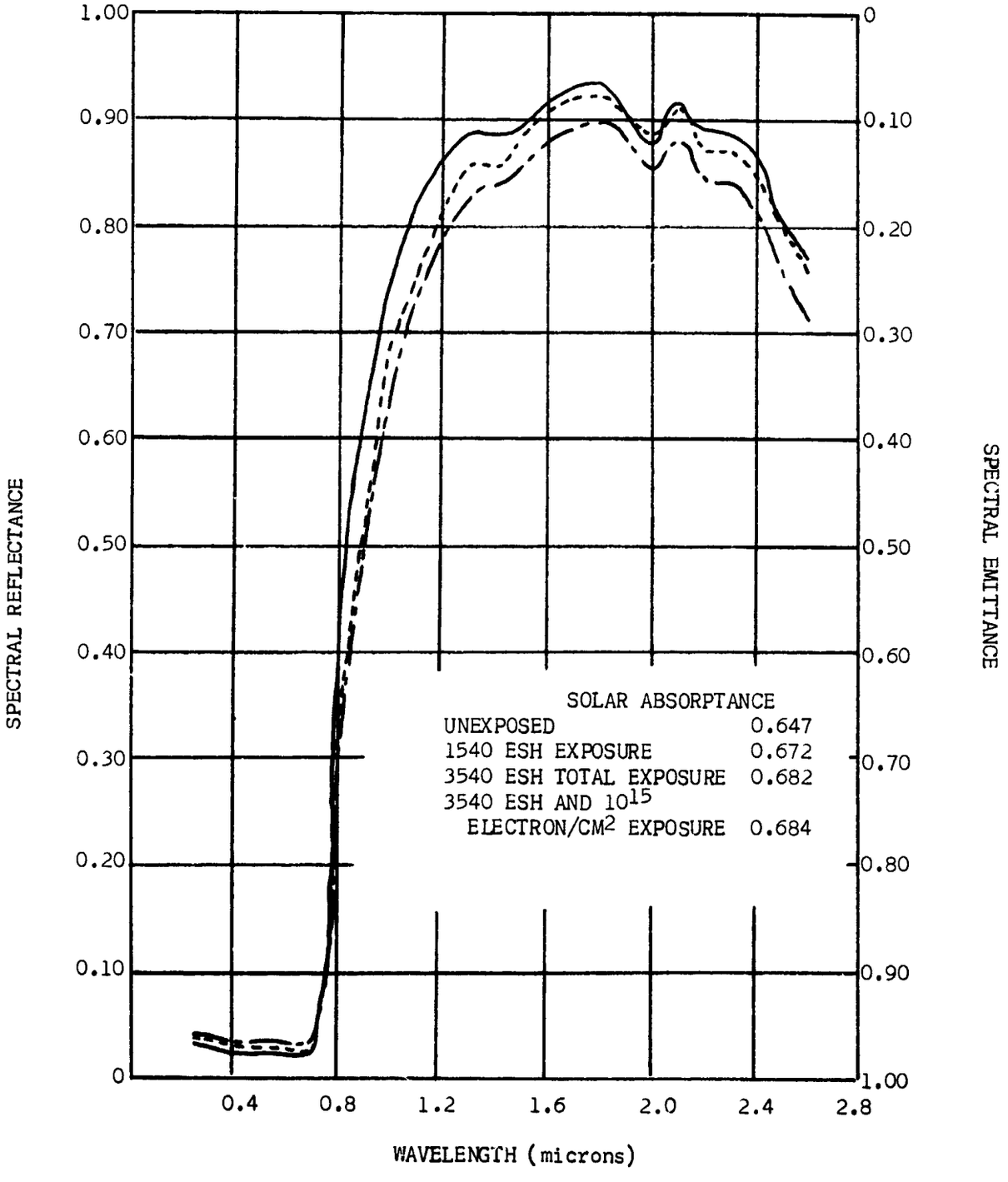
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Black Nickel Plate on Aluminum (Concluded)[13].



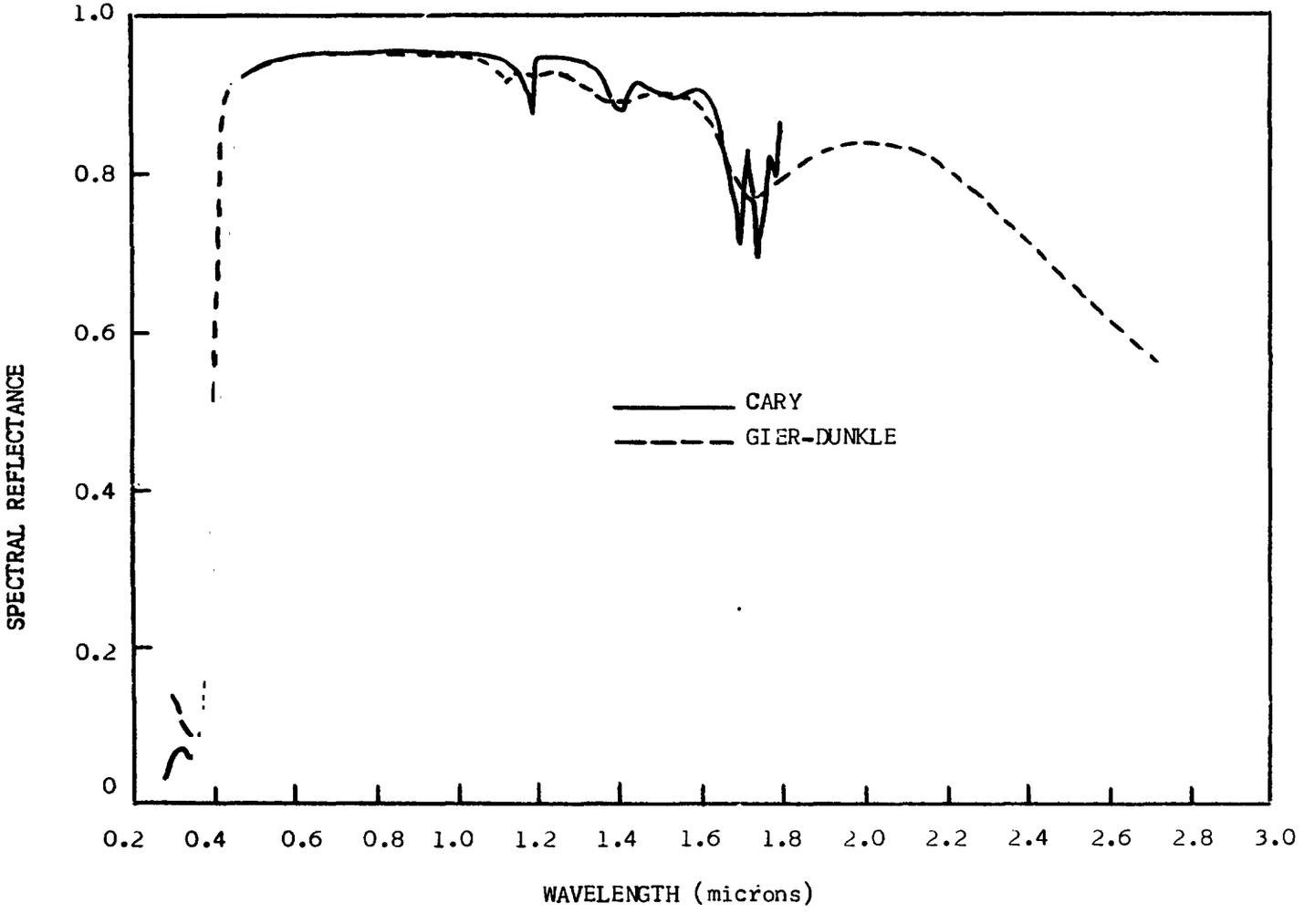
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Black Nickel Plate on Aluminum (Continued)[13].



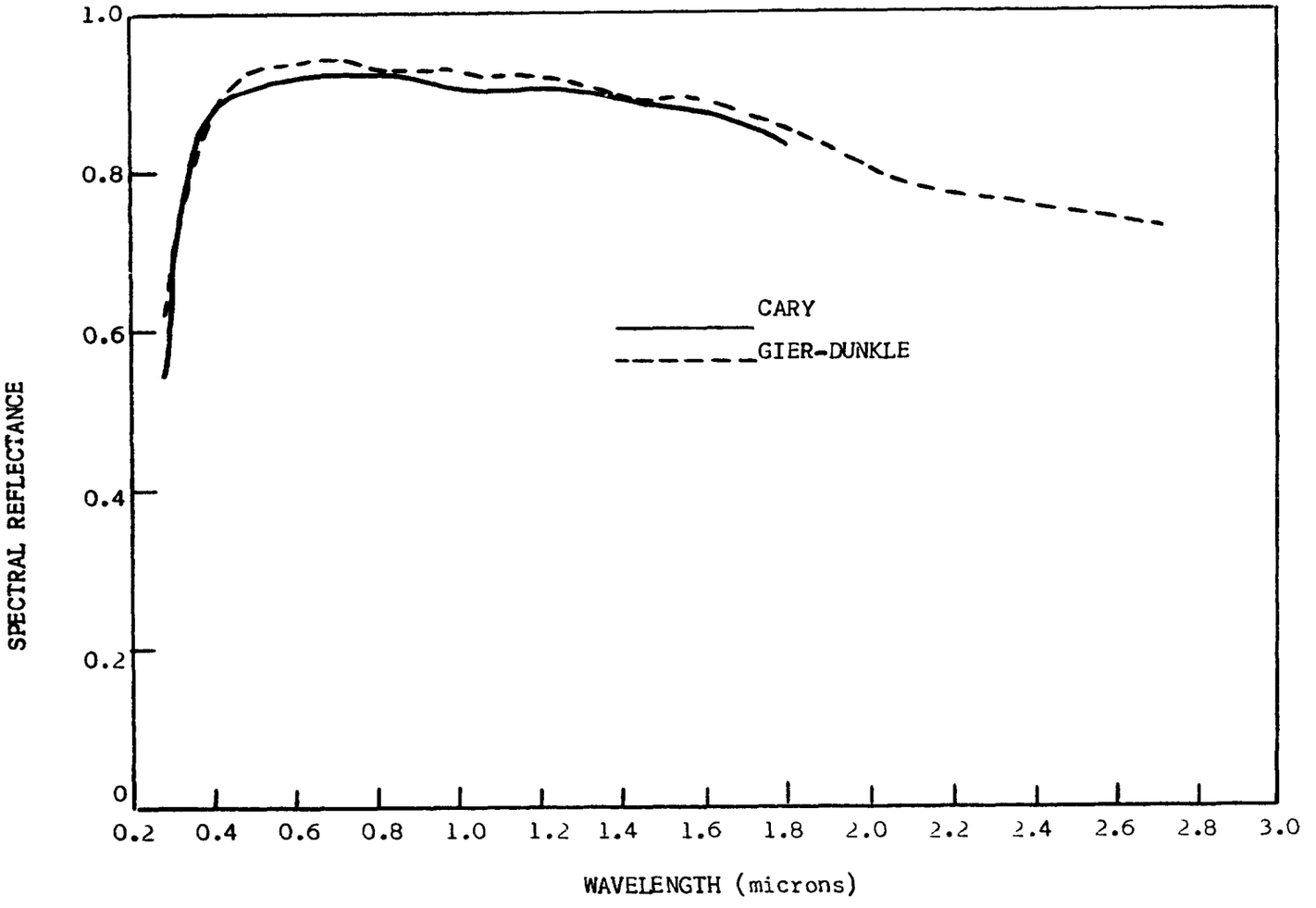
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sandoz Black OA Dyed Anodized Aluminum (Concluded)[13].



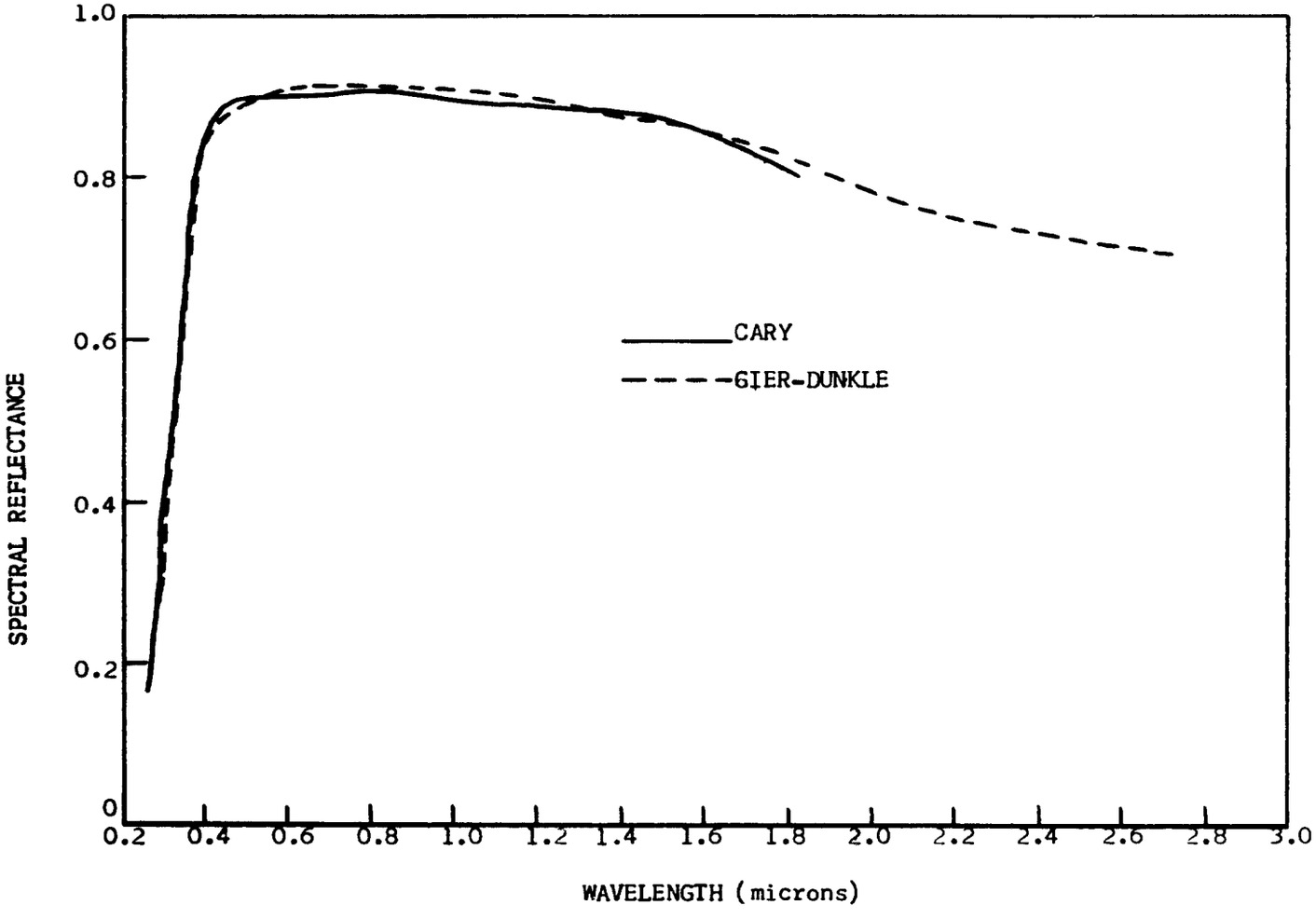
Variation of Spectral Reflectance With Wavelength Prior To and After Exposure To a Simulated Space Environment. Sandoz Black OA Dyed Anodized Aluminum (Continued)[13].



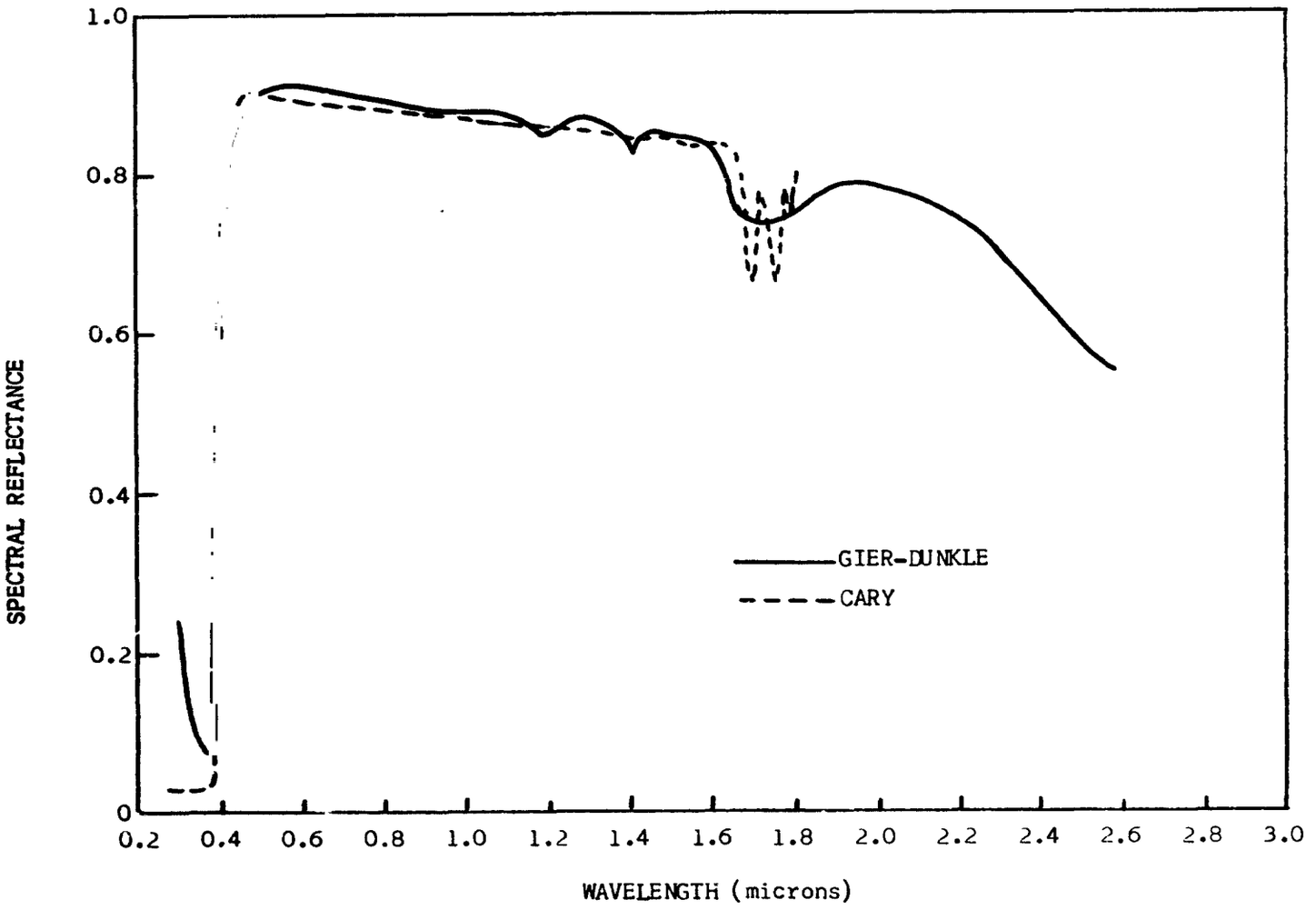
Typical Spectral Reflectance of TiO_2/Silicone Coating[22]



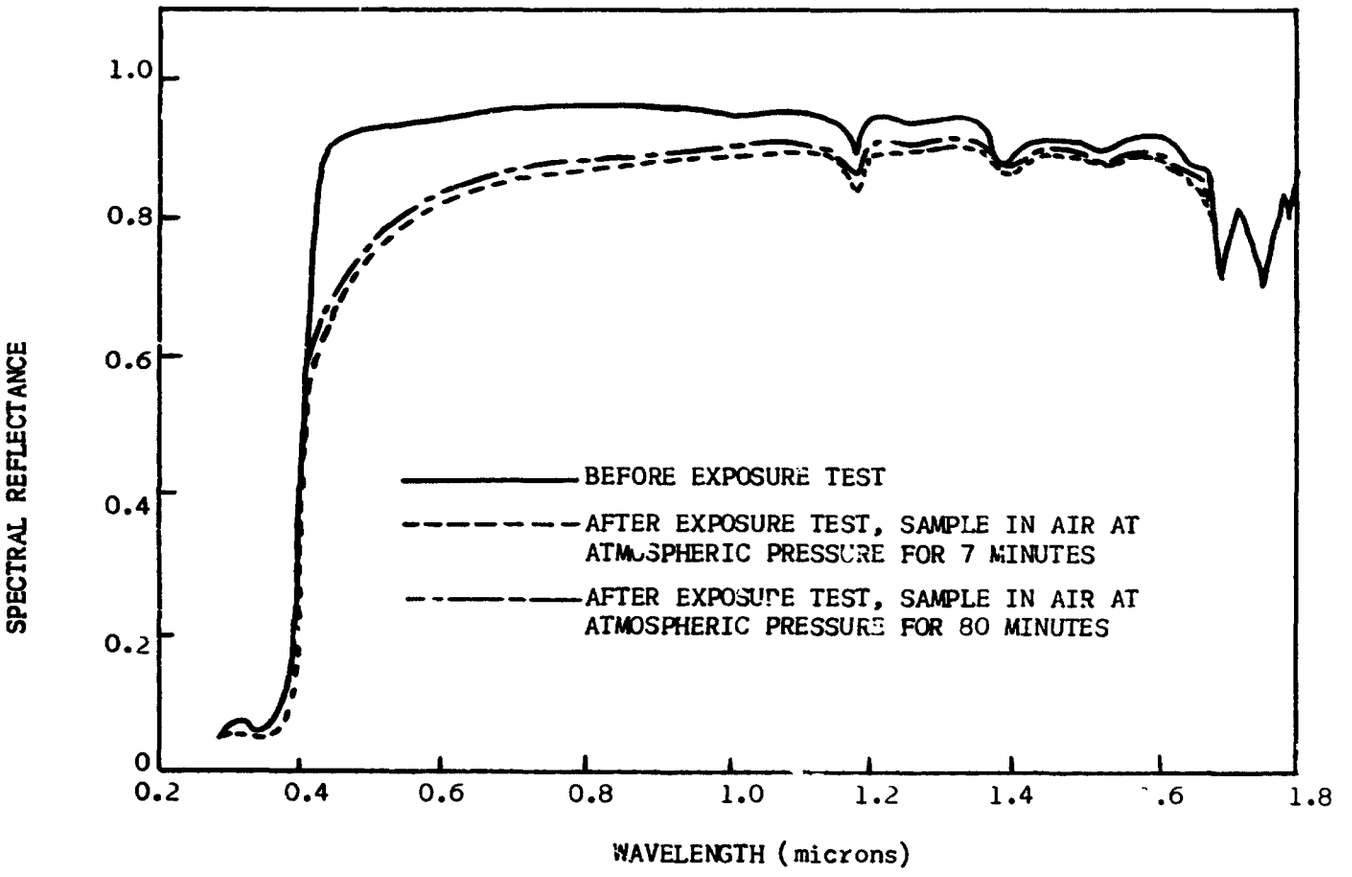
Typical Spectral Reflectance of $ZrSiO_4/K_2SiO_4$ Coating[22].



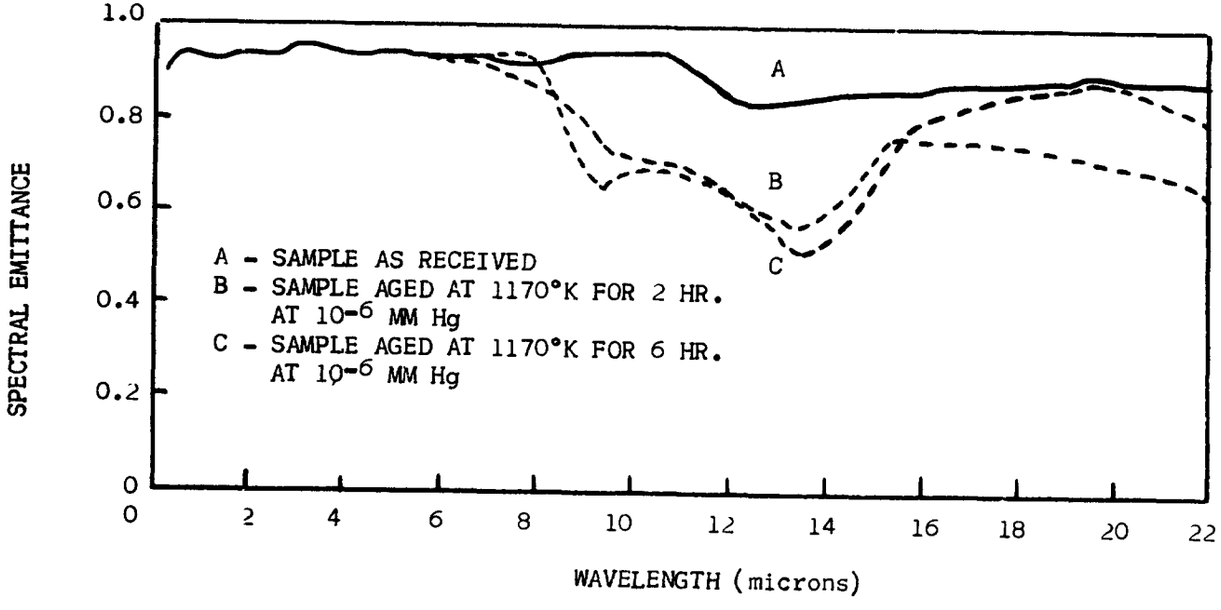
Typical Spectral Reflectance of $AlSiO_4/K_2SiO_4$ [22].



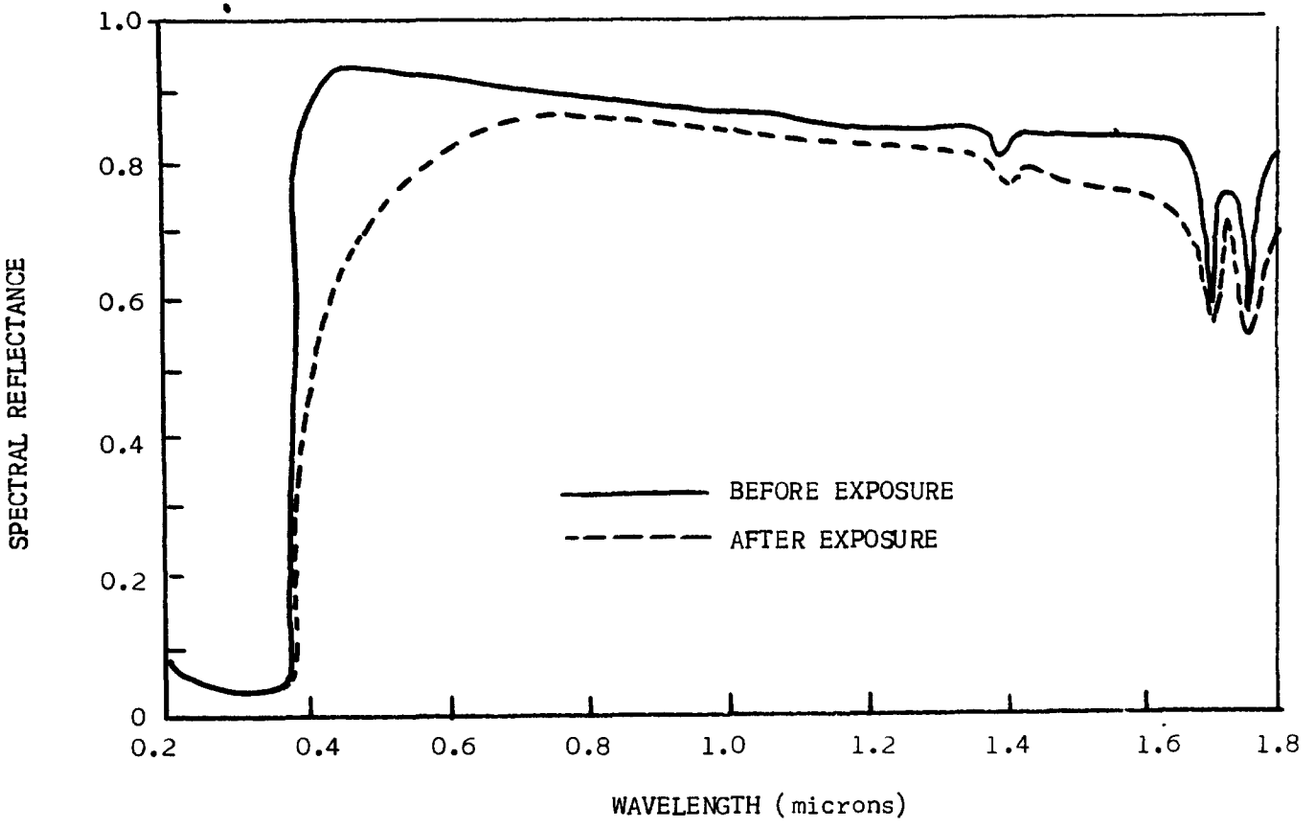
Typical Room Temperature Normal Spectral Reflectance of ZnO/Silicone (S-13G) Coating[25].



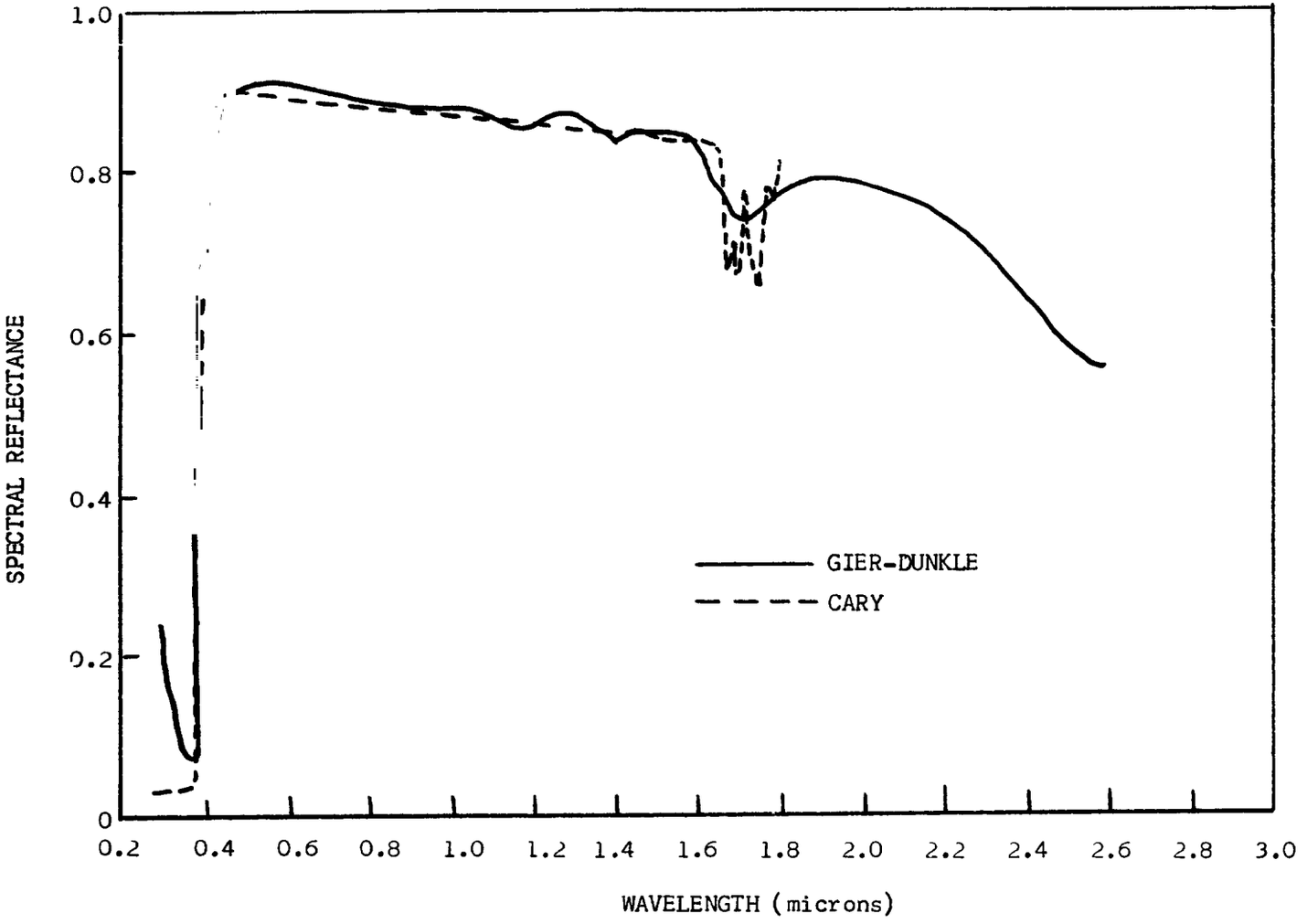
Room Temperature Normal Spectral Reflectance of TiO_2/Silicone Before and After 500-Hr Exposure Test[25].



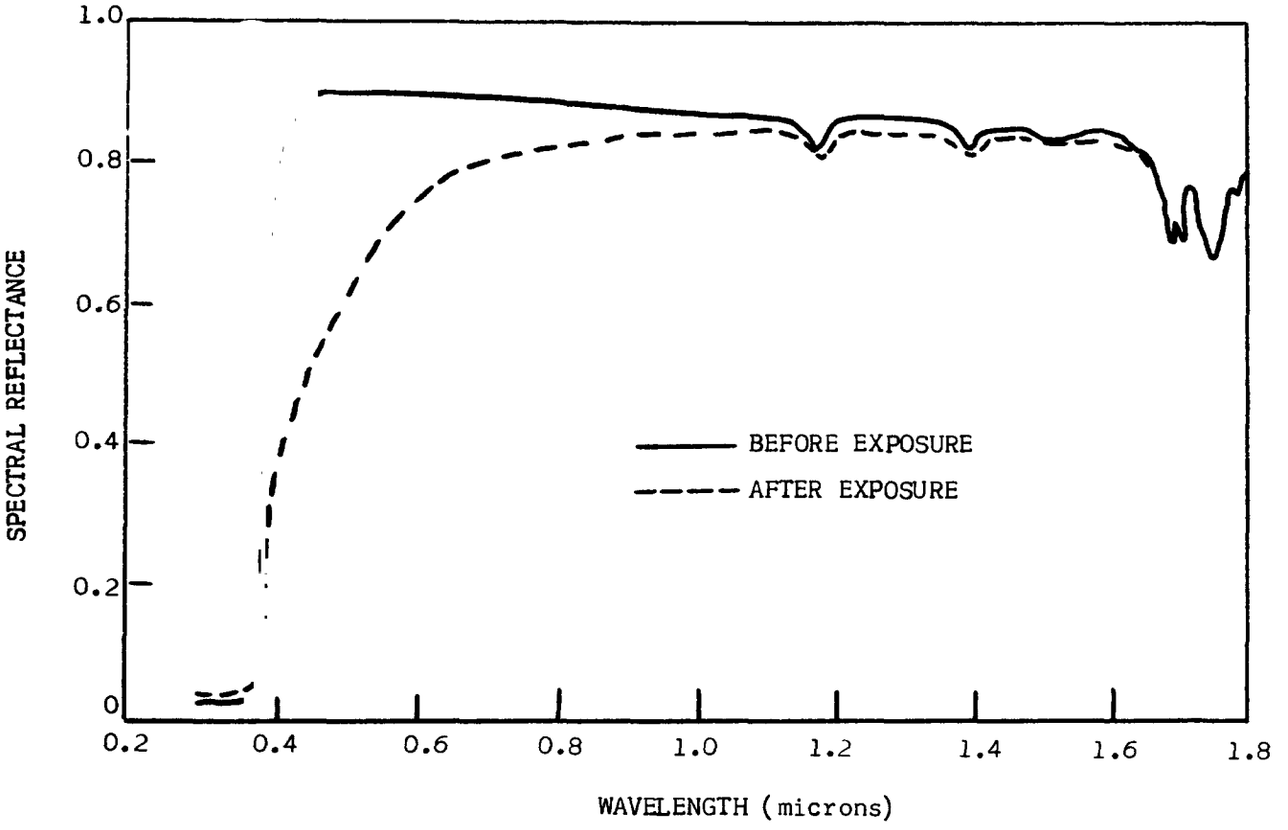
Spectral Normal Emittance of Platinum Black on Beryllium Based on Hohlraum Reflectance Data Obtained With the Sample at Room Temperature(6).



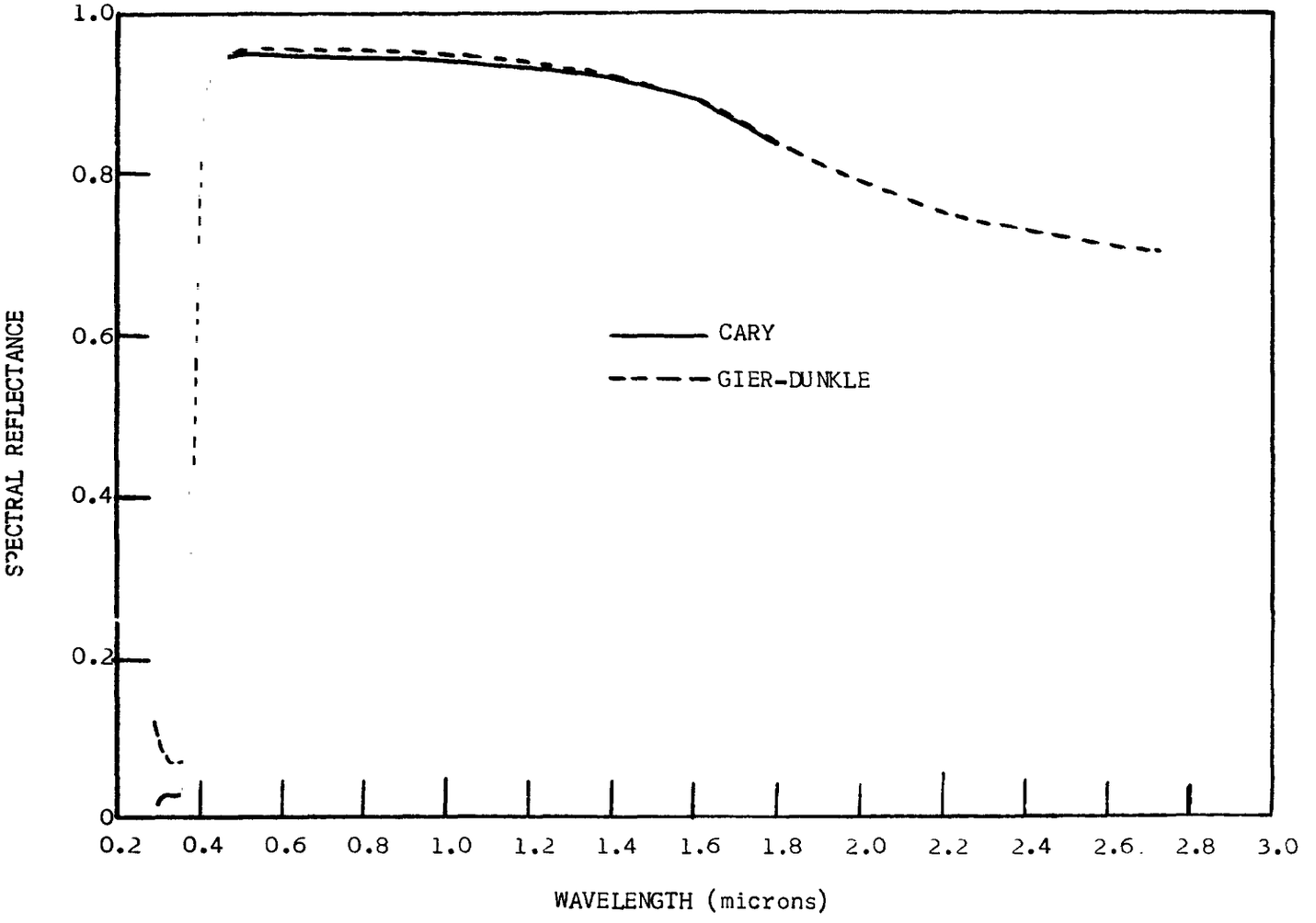
Room Temperature Spectral Reflectance of S-13 Coating[6].



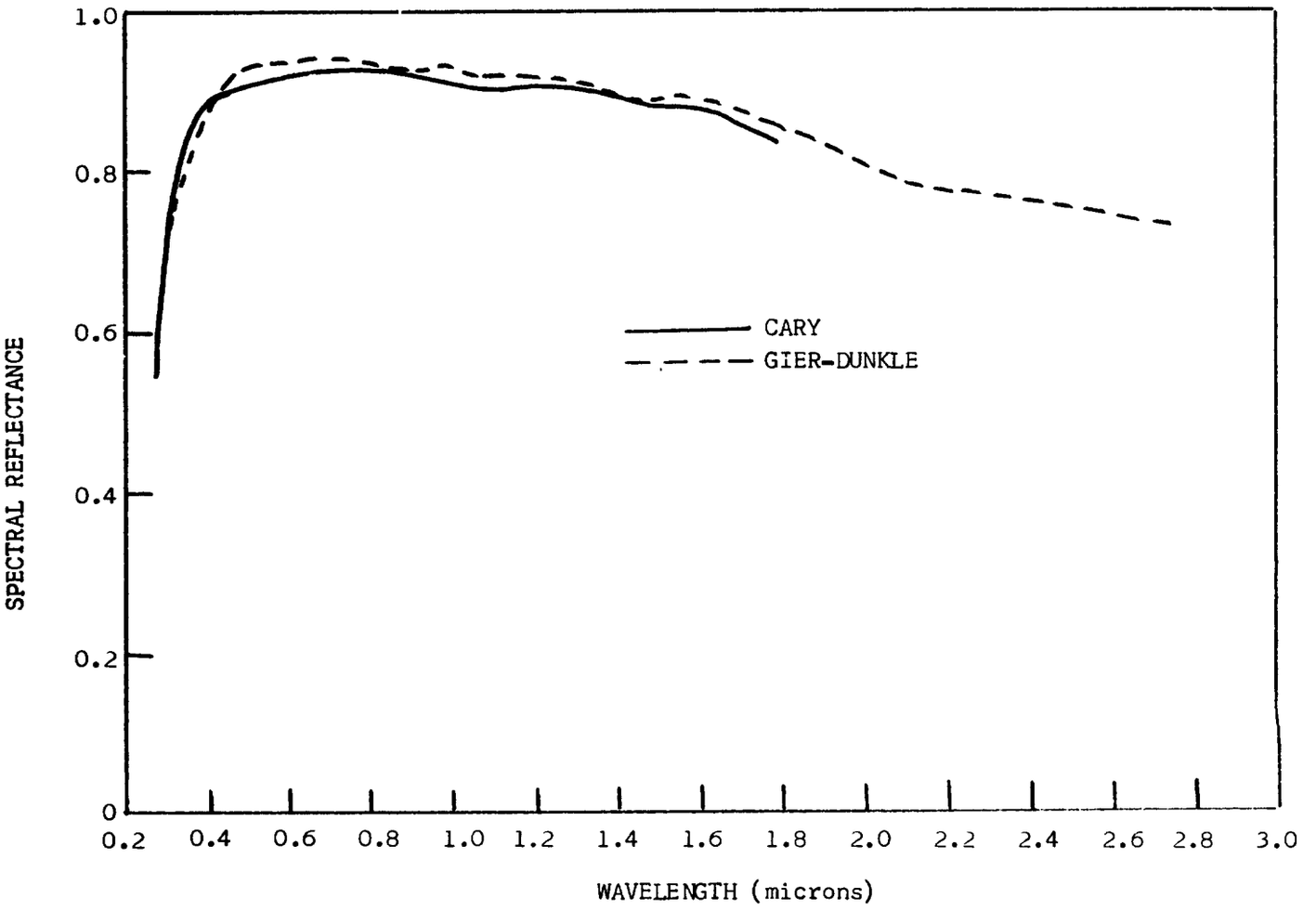
Typical Roo .emperature Normal Spectral Reflectance of ZnO/Silicone (S-13G) Coating[6].



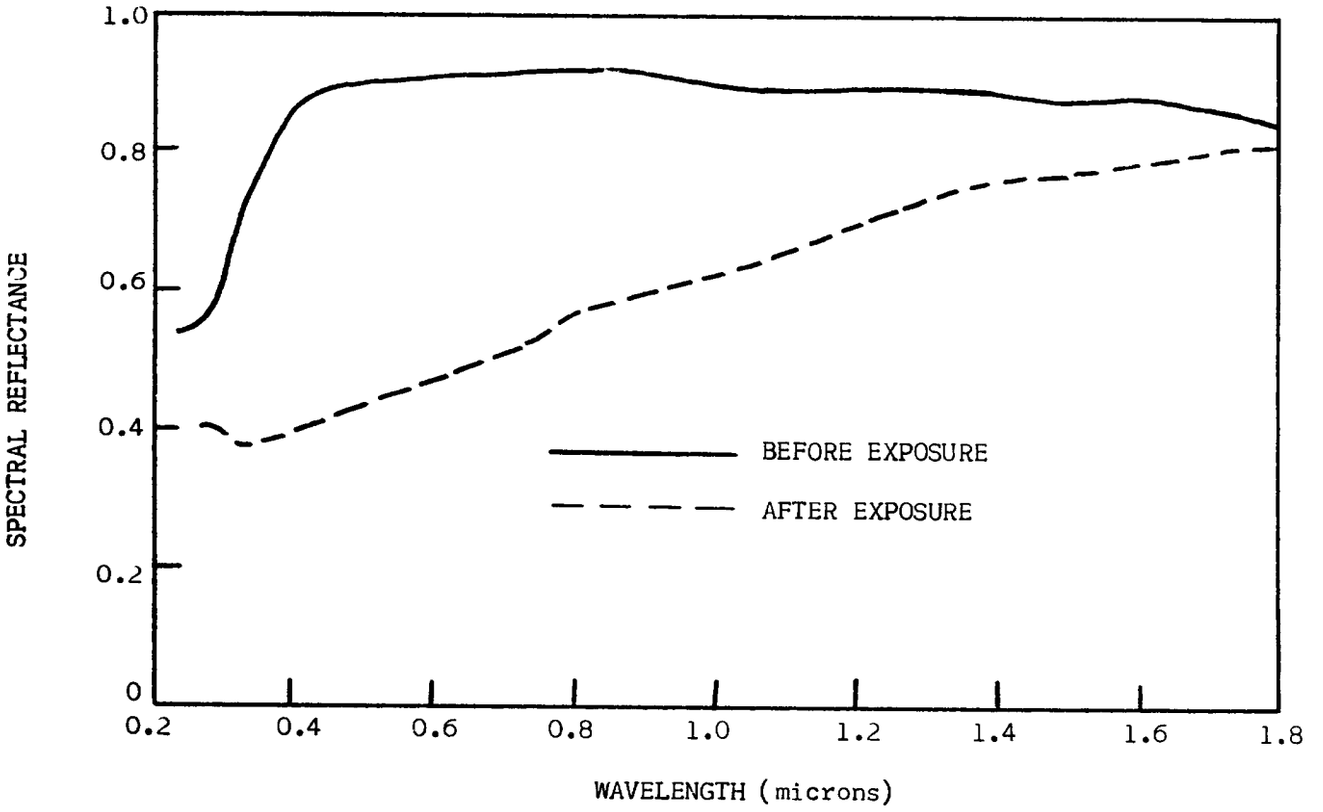
Room Temperature Spectral Reflectance of S-13G Coating(6).



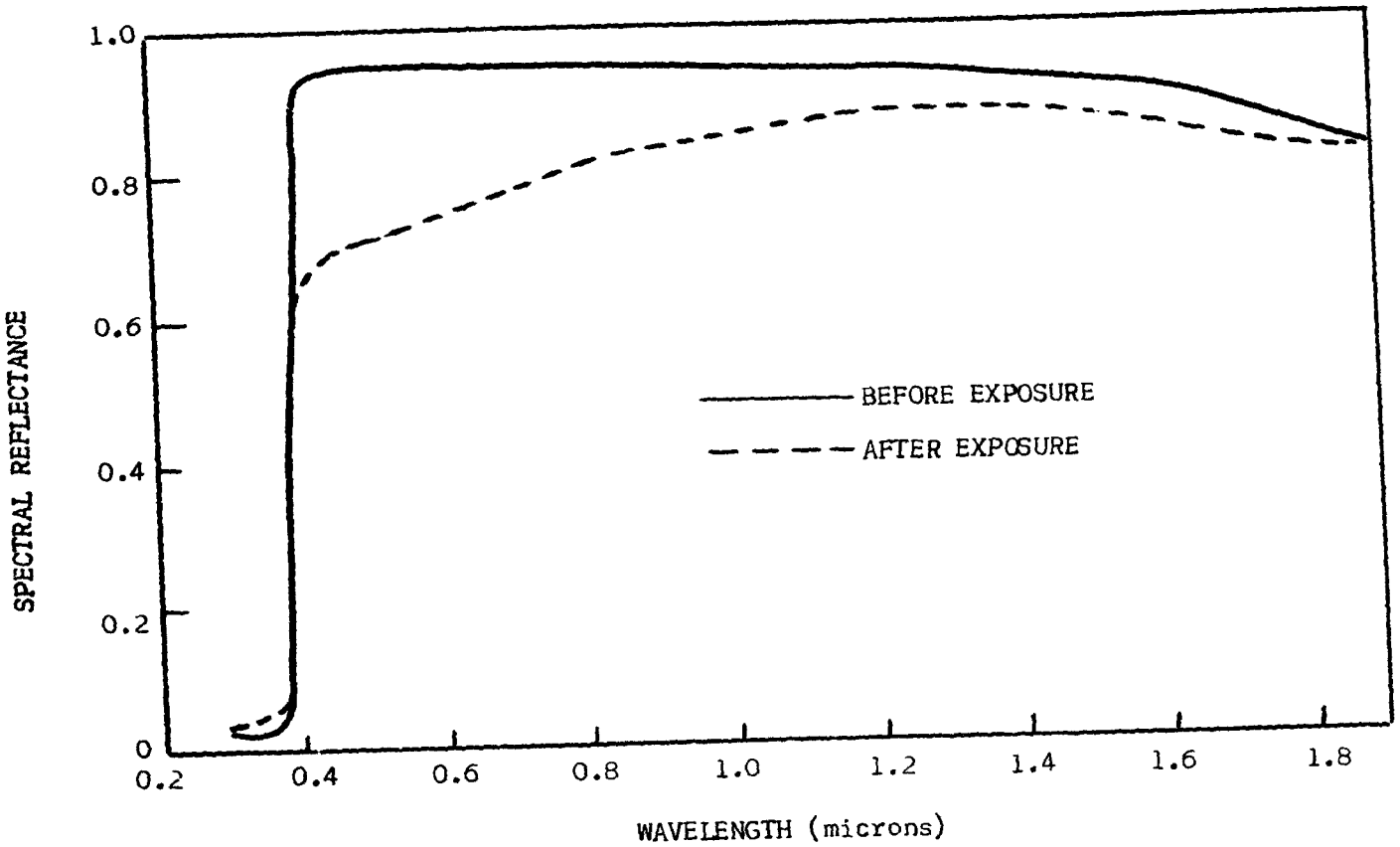
Typical Spectral Reflectance of ZnO/K_2SiO_3 Coating[6].



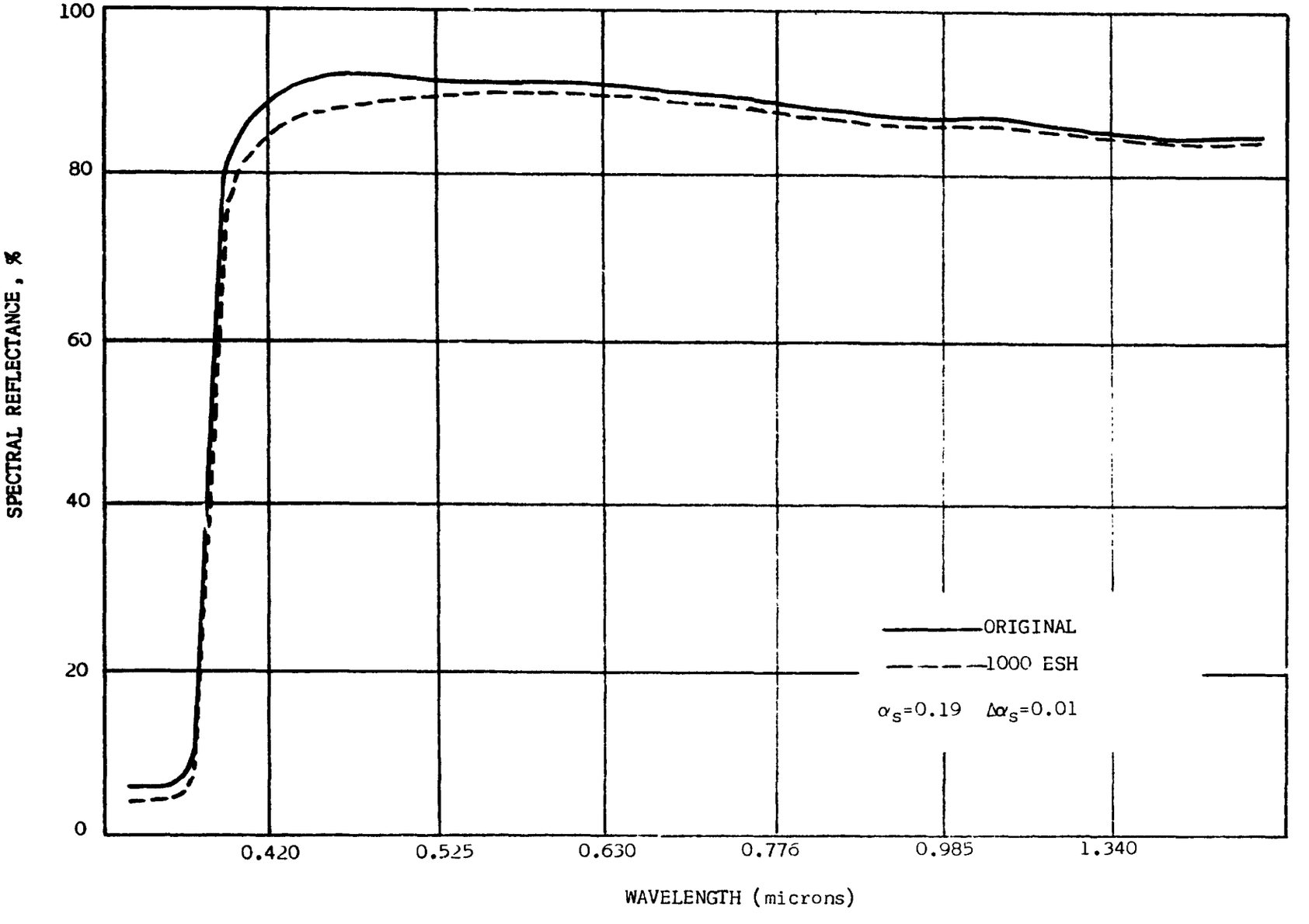
Typical Spectral Reflectance of $ZrSiO_4/K_2SiO_3$ Coating[6].



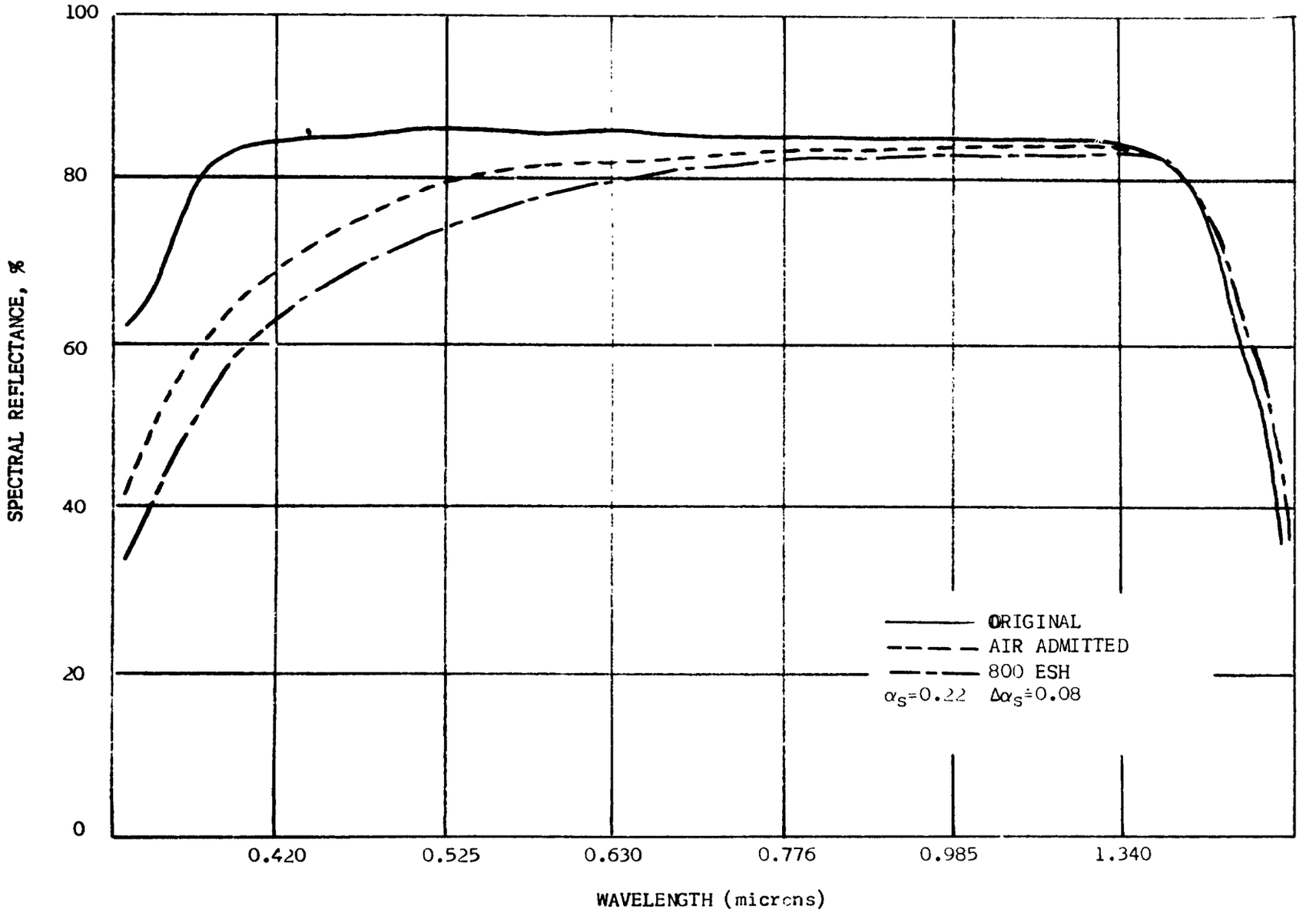
Room Temperature Spectral Reflectance of $ZrSiO_4/K_2SiO_3$ Coating[6].



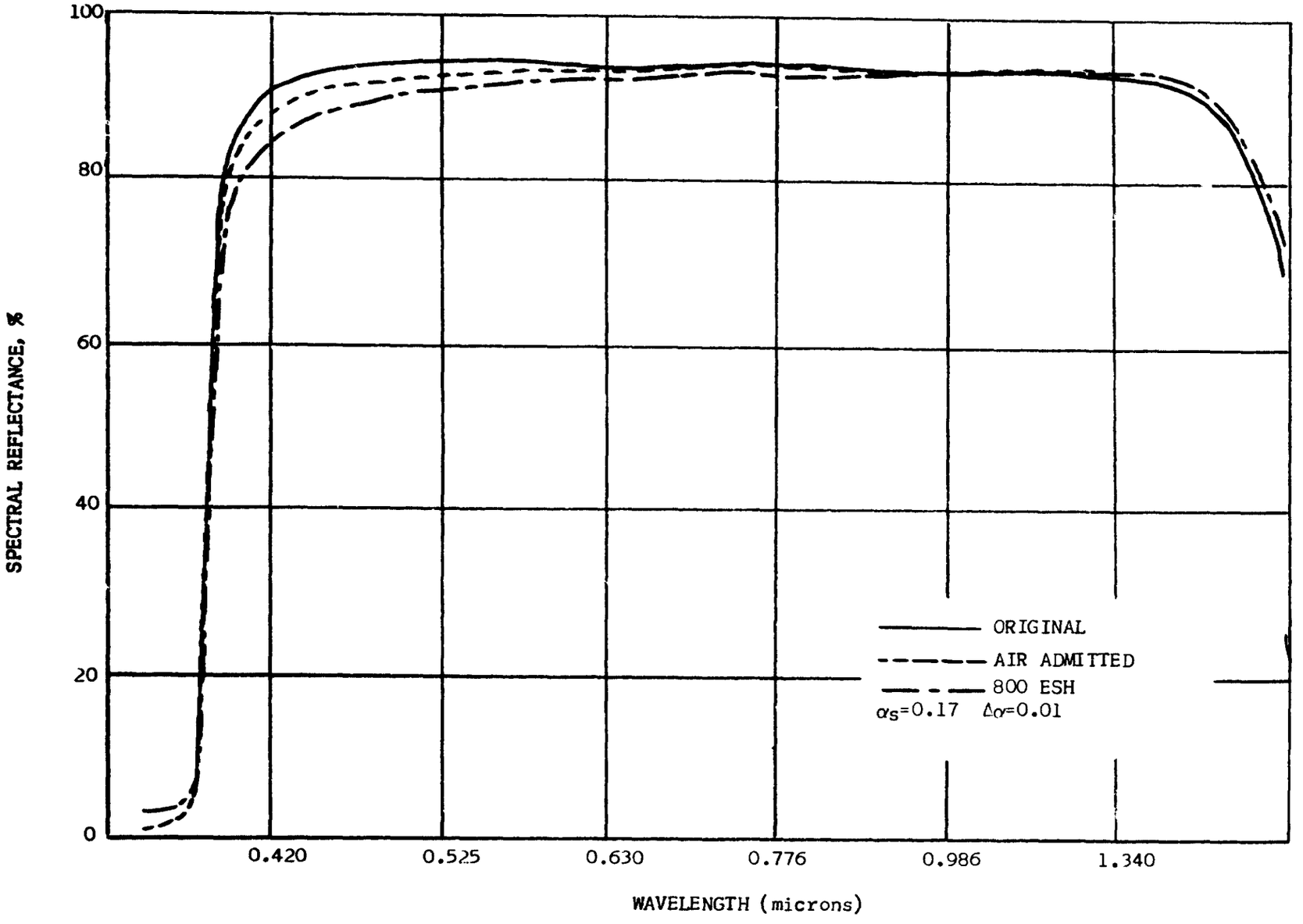
Room Temperature Spectral Reflectance of Z-93[6].



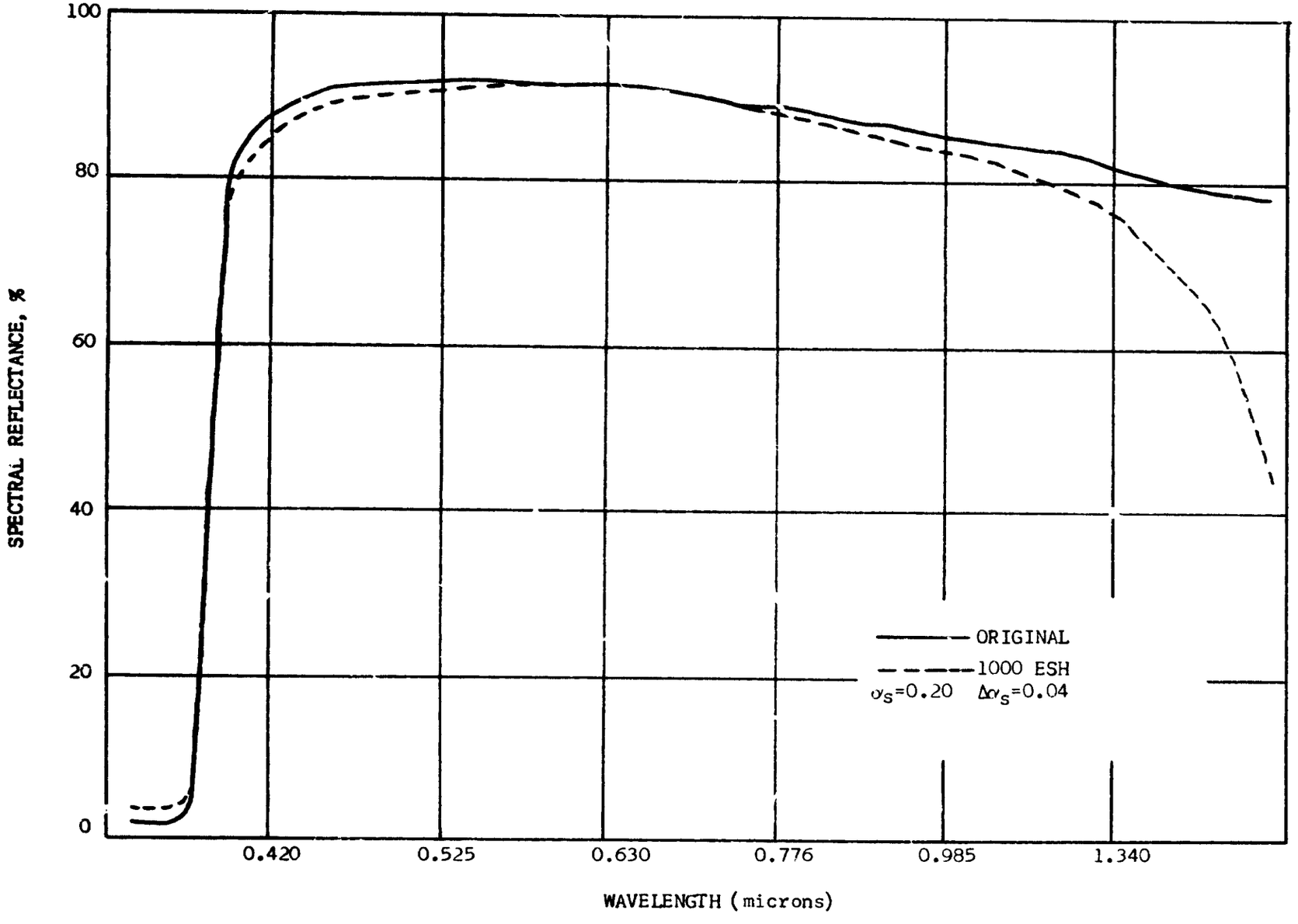
Effect of Ultraviolet in Vacuum on Silicate-Treated SP500 Zinc Oxide[26].



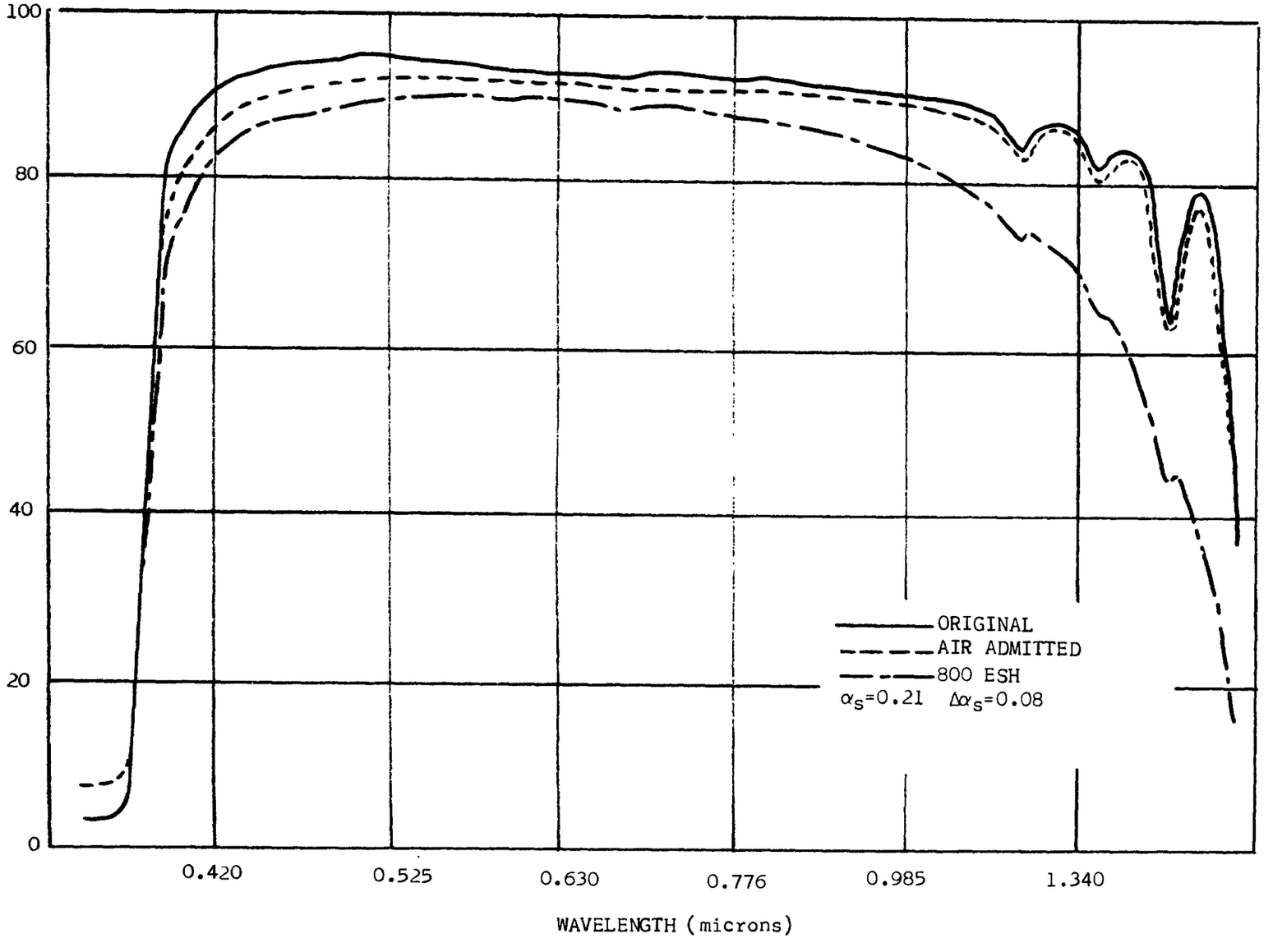
Effect of Ultraviolet in Vacuum on TAM "CP" Zirconia-Pigmented Potassium Silicate Paint[26].



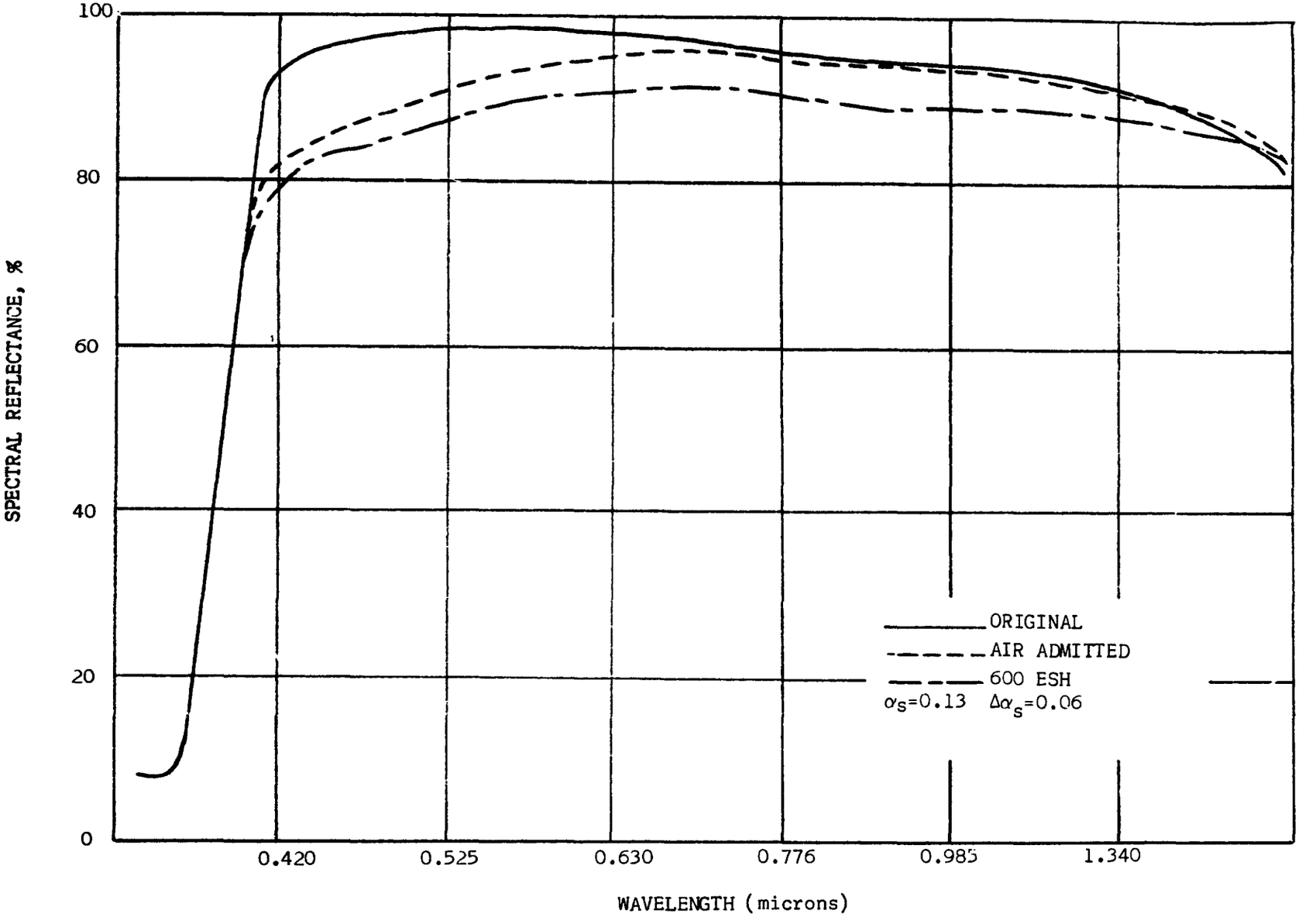
Effect of Ultraviolet in Vacuum on Z93[26].



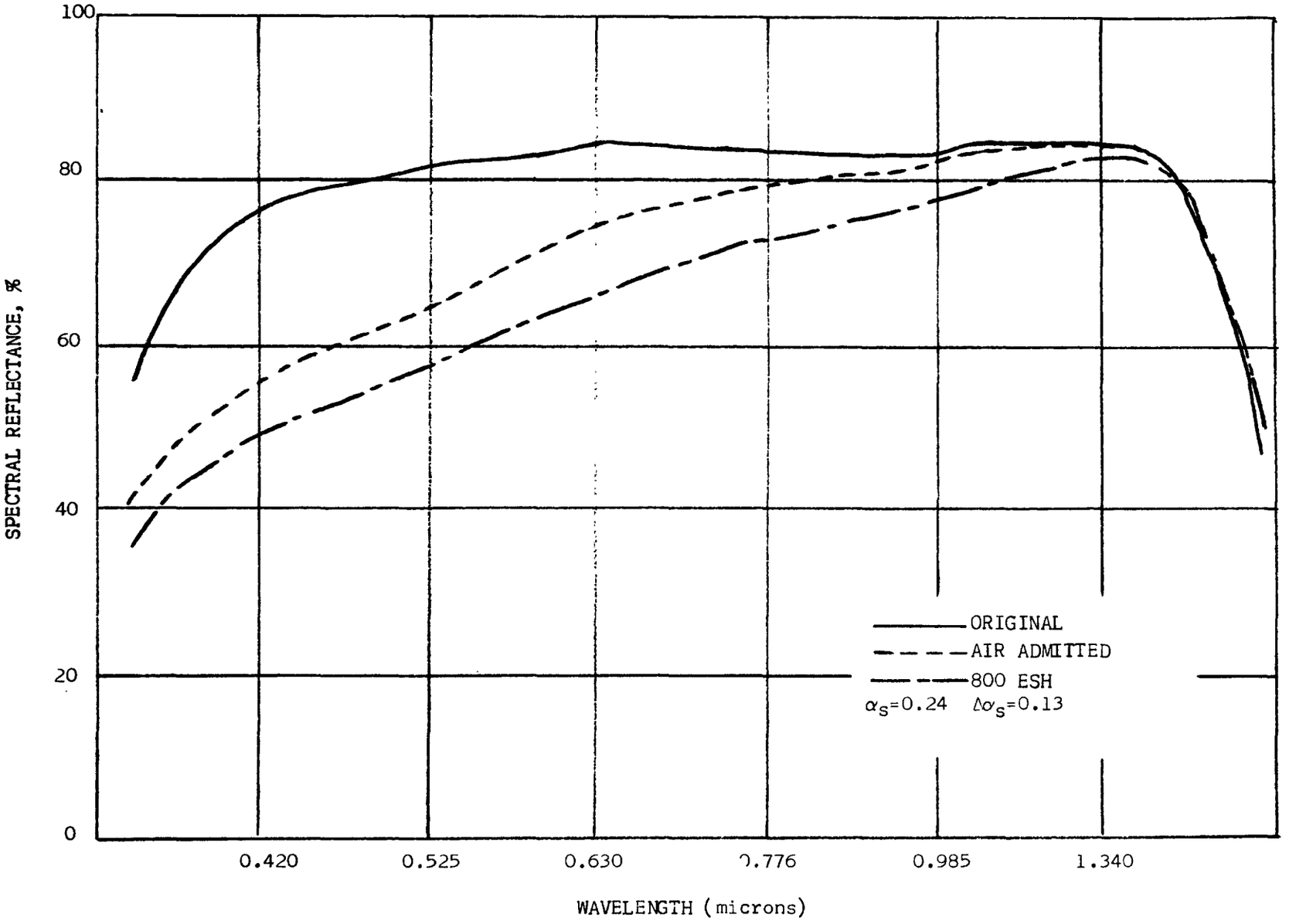
Effect of Ultraviolet in Vacuum on SP500 Zinc Oxide(26).



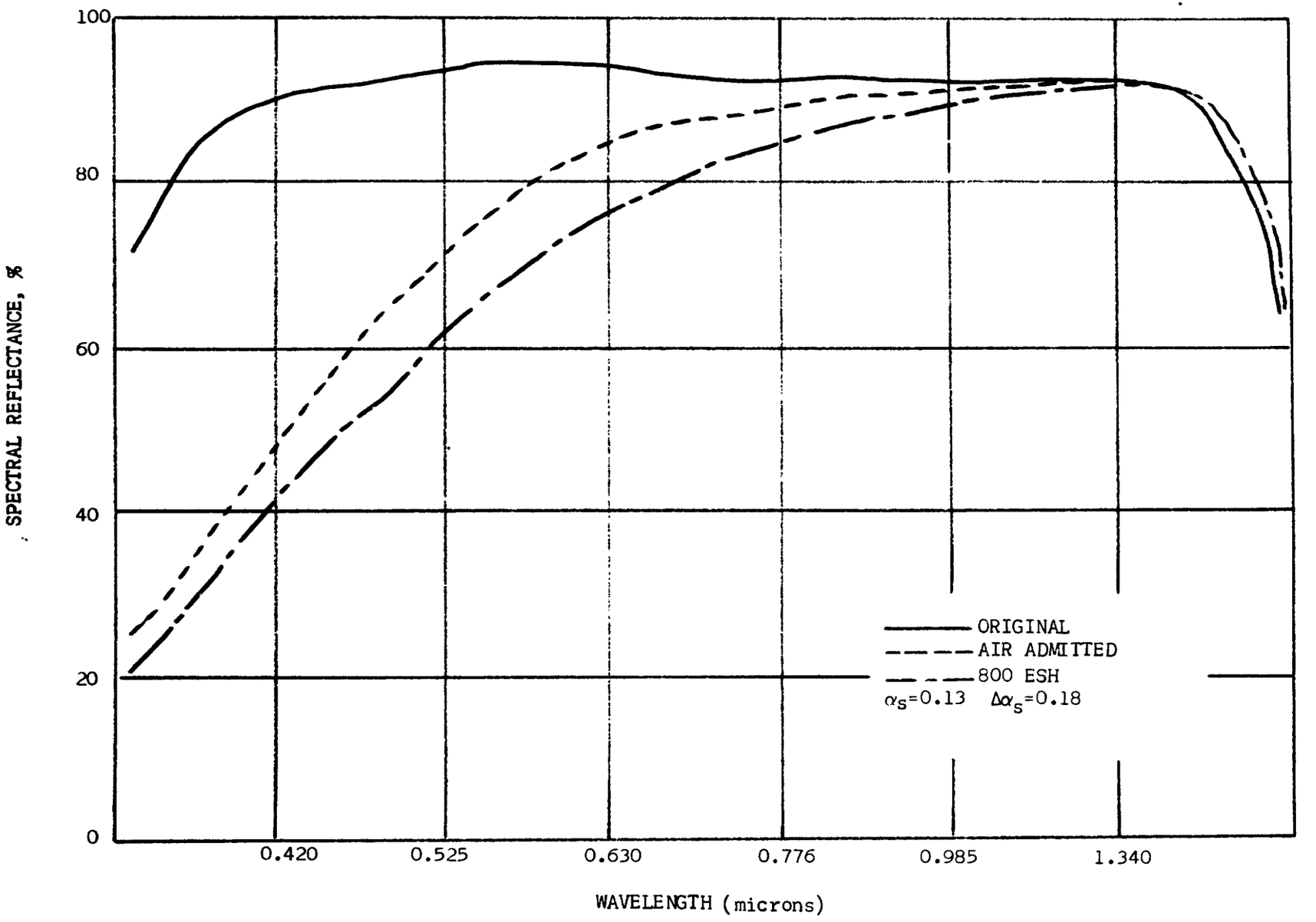
Effect of Ultraviolet In Vacuum on S-13(26).



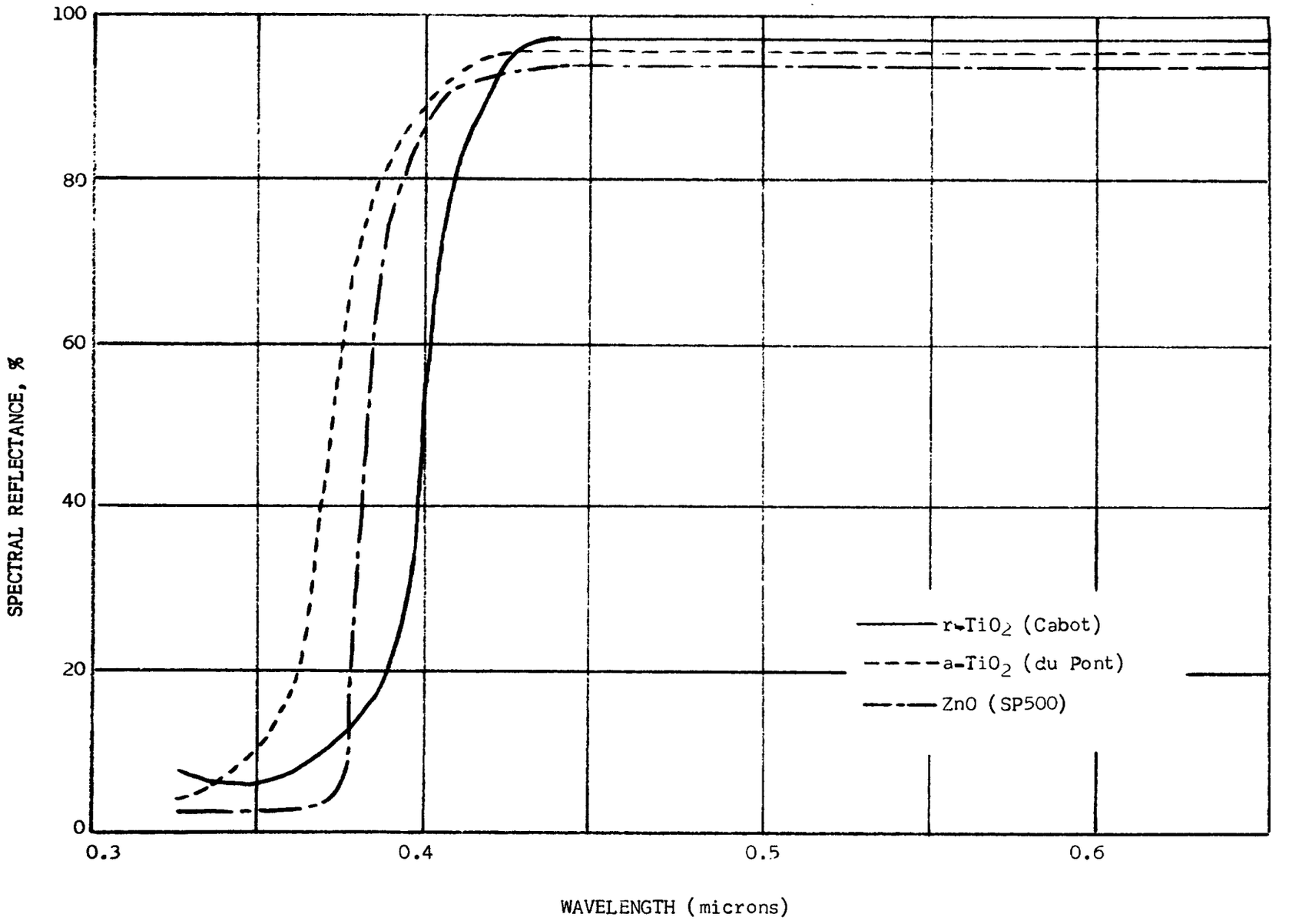
Effect of Ultraviolet in Vacuum on Cabot "RF-1" Rutile Powder[26].



Effect of Ultraviolet in Vacuum on Tantala-Pigmented Potassium Silicate Paint[26].



Effect of Ultraviolet in Vacuum on Lithium Fluoride-Pigmented Potassium Silicate Paint[26].



Reflectance Spectra of Zinc Titanates' Precursors: Zinc Oxide, Anatase and Rutile[26].

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