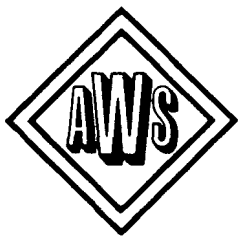


ULTRAVIOLET REFLECTANCE OF PAINT



AMERICAN WELDING SOCIETY

ULTRAVIOLET REFLECTANCE OF PAINTS

by

O. A. Ullrich and R. M. Evans

August 6, 1976

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APPENDIX

to

MONTHLY LETTER REPORT

to

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from

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INTRODUCTION

Of importance in assuring safety in the welding environment regarding ultraviolet radiations is the ultraviolet reflectance of walls and objects in the welding area. Preliminary to making recommendations concerning reflectivity or embarking on a program of measurement is the collection of data already available. Toward this end, a search has been made for data on the ultraviolet reflectance of paints, resulting in the compilation constituting this report. Although some observations and generalizations have been made, this report is not intended to be a thorough analysis of the subject.

The search for data dealing specifically with paint reflectance has yielded relatively little concerning commercial paints for interior use. Hence, data also were collected on the UV reflectance of outdoor paints and UV optical properties of materials used as ingredients in paints, i.e., pigments, binders, drying agents and other constituents. Some laboratory work was done to supplement the meager findings for indoor paints.

BACKGROUND

When radiation strikes a surface, a very small portion of it reflects without entering the surface at all, the amount being dependent on the index of refraction of the surface. Unless pigment particles protrude, the surface is made up of the binder constituent of the paint. The refractive index of these materials in the wavelength region from 200 to 800 nm generally falls in the range from 1.4 to 1.7. These indices can give rise to a single-surface reflectance of from 4 to 8 percent. Surface reflections will be "white"; that is, they are not wavelength selective, because they have not entered the paint layer and thus have not been subjected to the absorptions that give rise to the characteristic color of the pigment.

The greatest contribution to reflection for a paint, whether in the visible or the UV, arises from multiple reflections involving pigment particles within the paint layer, even though the binder may be relatively absorptive. Usually the binder layer between the paint surface and the pigment particles is so thin that the absorptivity has relatively little effect. If the pigment is not too strongly absorbing, much of the radiation which enters the pigment particles may be scattered back out of the paint layer. Colors arise because of the spectrally selective nature of the optical absorptance of the pigment particles.

A diffusely reflecting, or matte, surface will avoid shiny, specular reflections and thereby be advantageous in some cases, but does not reduce the overall reflectance of a paint which contains pigments that strongly scatter and reflect UV radiation.

SOURCES AND ORGANIZATION OF DATA

Data for this review have been collected from journal articles, books, special reports, and private communications. Seven journals specific to the paint industry were reviewed, primarily through the National Paint,

Varnish, and Lacquer Association Abstract Review back through 1945; also, an abstract service of the International Institute of Welding was searched. A total of 28 references were found to contain information of at least some relevance. Further, phone calls were made to several paint and pigment manufacturers, but these resulted in no specific information on UV reflectance of paint. One of these calls led, however, to an offer to measure a limited number of paint samples.

The UV data collected have been organized in four categories:

- (1) Reflectance of paints (Plates 1 through 49)
- (2) Reflectance of pigments (Plates 50 through 59)
- (3) Reflectance or absorbance of resins and other vehicle constituents (Plates 60 through 69)
- (4) Reflectance characteristics of other materials that might be present in the welding area. This material was not sought specifically, but was found in the course of following leads on paint reflectances. (Plates 70 through 91)

Much of the data presented here derived from work done 30 to 50 years ago; some derive from work done on satellite temperature control as part of the space program within the past 15 years.

Indexes of I - Paints, II - Pigments, III - Binders, and IV - Miscellaneous Materials are provided at the end of the report.

References

References for data included in this compilation are listed after Plate 91 and are designated throughout by the underlined letter at the right of the figures and tables.

Many of the references contain much information about various aspects of paints, pigments and vehicles but relatively little specific to UV reflectance of paint or paint constituents. For conciseness, only the most

relevant data were extracted, generally in the form of a figure or a table. When possible, the figure numbers or table numbers and captions given in the original reference have been copied to facilitate locating the information more easily. (Some of the references have hundreds of figures and tables.) The inclusion of original-source figure numbers has necessitated identifying the figures in this compilation in some other way, hence the use of plate-number designations.

Use of Data

This compilation of UV-reflectance data for paints and paint constituents is not intended to be an exhaustive study, but it should provide a broad base of data to aid the AWS Radiation Committee in deciding what further information is needed. However, it also could provide specific information for immediate use. For example, if a complaint is received about a certain painted wall reflecting erythema radiation to a dangerous degree, and the paint is known to consist primarily of zinc oxide in a Silicone binder, reference to Plate 5 would show that such a paint would be expected to reflect less than 10 percent of the incident radiation in the erythema range. Such quantitative information might quickly guide one to look for a more likely cause for the complaint.

DEFINITIONS OF TERMS

The erythema spectral region, in which radiation causes a quickly noticeable reaction on the skin and cornea of eye (ultraviolet erythema and ultraviolet keratoconjunctivitis, respectively), is considered to cover the range from 200 to 315 nanometers.

Because the original forms of the data have been preserved as they are presented in the original references, a great diversity occurs in the units included in this report. Following is a tabulation of units, with definitions, equivalents, and conversion factors:

1. Wavelength, λ :Nanometers (nm) or millimicrons (m μ)

$$1 \text{ nm} = 1 \text{ m}\mu = 10^{-9} \text{ meter (m)}$$

Angstrom ($\text{\AA}$, or A.U.)

$$1 \text{ \AA} = 10^{-10} \text{ m} = 10^{-8} \text{ cm} = 0.1 \text{ nm}$$

Micrometer (μm), or micron (μ)

Wave number: the reciprocal of the wavelength expressed in cm, giving optical vibrational cycles per cm.

2. Reflectance: the fraction of incident radiation that is reflected from a surface; e.g., if 1/2 of the radiation is reflected, the reflectance is 0.5.
3. Spectral Reflectance is a more specific term indicating that reflectance has been measured point by point through the radiation spectrum (rather than averaging it over a relatively wide spectral band, such as the entire visible range or the band from 280 to 320 nm [e.g., Plate 51]).
4. Reflectivity (loosely also called reflectance, reflection, reflection factor, or coefficient of reflection): reflected radiation in terms of per cent; e.g., if 1/2 of the radiation is reflected, the reflectivity is 50 percent.
5. Transmittance, T: the fraction of radiation transmitted through a material.
6. Transmission: transmittance expressed in percent.
7. Absorbance: the fraction of incident radiation that is absorbed. However, in Reference U, Plate 63, absorbance is defined as $A = \log_{10} \frac{1}{T}$, which is the present-day definition of optical density.
8. Absorptivity: absorbance expressed in percent.
9. Absorption Coefficient, α : a property of a substance denoting the degree to which radiation is absorbed; it is usually designated α , and is related to transmittance as follows:

$$T = \frac{I}{I_0} = e^{-\alpha t},$$

where T is the transmittance, I is the intensity of radiation transmitted, I_0 is the intensity of radiation entering (equivalent to incident radiation minus reflectance), e is the base of natural logarithm system, t is the thickness (usually in cm), and α is the absorption coefficient (usually in $\frac{1}{\text{cm}}$).

In present-day terminology, α should not be confused with other similar optical quantities such as κ (kappa) - absorption index, and k - extinction coefficient. However, Stutz (1927) called absorption coefficient K , and used 10 as the logarithm base; the form of his equation thus is $I = I_0 10^{-Kt}$, where t is in cm.

10. Extinction Coefficient, k : a means of expressing the ability of a body to absorb radiation, related to absorption coefficient by the expression:

$$\alpha = \frac{4\pi k}{\lambda_0},$$

where α is the absorption coefficient and λ_0 is the wavelength at which the absorption measurements are made. In another form:

$$I = I_0 e^{-4\pi k/\lambda_0}.$$

In reference Q (Plate 62), extinction coefficient is denoted K , and is defined as $I = I_0 10^{-Kc\ell}$, where c is the concentration of the absorbing constituent of a transparent solvent, grams/liter, ℓ is the cell length in cm, and the logarithm base is 10.

SUMMARY OF MOST-PERTINENT DATA COLLECTED

Generalizations

It appears that almost any present-day paint, white or colored, is safe to use in the welding environment from the standpoint of low reflectance of the UV. The principal reason for this is that most present-day paints contain up to 50 percent or more TiO_2 as a pigmenting agent, and TiO_2 has very

low reflectance at wavelengths shorter than 360 nm. Furthermore, with the exception of turquoise blue^{*}, all colored pigments for which data were found also have very low reflectance at wavelengths shorter than about 310 nm. This generalization covers more than 30 pigments and dyes.

Singular exceptions to this generalization about the UV safety of paints are paints containing a significant proportion of metallic particles, particularly aluminum flakes. In such cases, reflectance can be as high as 50 or even 75 percent at wavelengths through the visible and ultraviolet to 220 nm, and thus should be avoided in the welding environment.

Nonmetallic pigments identified as having reflectances greater than 50 percent in the UV, ranging from the visible to wavelengths shorter than 290 nm are listed below.

<u>Chemical Symbol</u>	<u>Common Names</u>
MgO	magnesium oxide; magnesia
CaCO ₃	calcium carbonate; whiting; precipitated chalk
Ca(OH) ₂	kalsomine; calcimine; slaked lime
Sb ₂ O ₃	antimony trioxide
BaSO ₄	barium sulfate; barytes
(See [†] below)	terra alba (any of several white mineral substances: gypsum, kaolin, magnesia)
Al ₂ O ₃ ·2SiO ₂ ·2H ₂ O	china clay
Ca/Mg Silicates	asbestine
SiO ₂	Silex; quartz
PbCO ₃ and Pb(OH) ₂	sublimed white lead, apparently also termed basic carbonate white lead when in "purer" form
BaSO ₄ - 70 percent	lithopone
ZnS - 30 percent	

^{*}Turquoise Blue - a hydrated aluminum phosphate, Al₂(OH)₃PO₄H₂O.

<u>Chemical Symbol</u>	<u>Common Names</u>
†The following, chief constituents in the material having the common name "terra alba", also have high UV reflectance:	
MgCO ₃	magnesia alba
Al ₂ Si ₂ O ₅ (OH) ₄	kaolinite
CaSO ₄ ·2H ₂ O	gypsum; alabastine; hydrated calcium sulfate; plaster of paris

This list includes materials often used as walls or wall finishes, such as plaster and calcimine, which should be avoided from the standpoint of high UV reflectance.

Various references indicate that relatively small percentages of an absorbing pigment have, because of the multiple light-scattering nature of pigment layers, a strong effect on the reflectance of the composite layer. For example, only 5 percent of zinc oxide in white lead can reduce the reflectance at about 315 nm from 70 percent to 20 percent, and a 30-percent content reduces the reflectance to about 5 percent (Plate 53). Zinc oxide is non-reflective at wavelengths shorter than about 360 nm.

In addition to UV absorption provided by the pigment component in paints, absorptive binder resins also can contribute, to some degree, to low reflectivity; among these are alkyds, urethanes, and epoxies. On the other hand, resins and binders such as acrylics, vinyls, silicones, casein and nitrocellulose, because they are not greatly absorbing in the erythema UV, would not contribute significantly to low UV reflectivity. In fact, BaSO₄ in a polyvinyl alcohol binder may have a reflectance as high as 80 percent at 230 nm, 95 percent at 290 to 340 nm (Plate 14), and even higher reflectance in the near UV and visible.

Ultraviolet radiation often has the effect of causing transparent organic materials to become yellow with extended exposure. Yellowing is the result of increased absorption in the blue and blue-green portion of the visible spectrum, and is usually (if not always) accompanied by increased UV

absorption. Thus, the generalization could be made that if paint degradation takes place as a result of welding-arc exposure, it will be accompanied by a safer UV-reflectance condition rather than a more dangerous one. Yellowing of oil-based paints also is induced by classes of materials such as (1) ammonia, ozone, and sulfur dioxide, (2) amides, amines, acid salts, peroxides in paints that contain drying oils, and (3) various driers that contain cobalt, lead or manganese, or pigments such as titanium dioxide.

A more thorough review of the data given in this report and of the references cited no doubt would reveal further inferences and generalizations pertinent to UV reflectance of paints.

Data on Paints

The principle sources of data on the UV reflectance of paints using modern binder resins were reports concerning the space program, where interest was centered on degradation of the reflecting properties of high-reflectivity paints when exposed to charged-particle bombardment. Data of value for AWS, for example, are the preirradiation curves of Plates 1 through 5.

Plates 1 through 27 present data from the literature and include the following formulations; those showing reflectances greater than 10 percent in the 240 to 320 nm spectral range are marked with an asterisk:

<u>Pigment</u>	<u>Binder</u>
ZnO	Silicone; K_2SiO_3
ZnS	Silicone; Acrylic; K_2SiO_3
TiO ₂	Silicone; Alkyd
*CaCO ₃	Silicone
*MgO	Silicone; Acrylic; Alkyd/Melamine
*PbCO ₃ /Pb(OH) ₂	Silicone; Butylacrylate; Butylated Urea formaldehyde; Nitrocellulose
*BaSO ₄	Polyvinyl alcohol; K_2SiO_4 ; K_2SO_4 ; $(NH_4)_2SO_4$; $(NH_4)_2SO_4/K_2SO_4$

<u>Pigment</u>	<u>Binder</u>
*Al ₂ O ₃	K ₂ SiO ₄
*Sb ₂ O ₃	K ₂ SiO ₄
*Al flake	Silicone
*Various	Various (Plate 23, Luckiesh and Holladay, 1931)

Also included are numerous paints identified by color but not by either specific pigment or binder, some of which show erythema-band reflectance greater than 10 percent (Plates 17 through 20, and 25 and 26).

Plates 28 through 49 are spectral reflectance curves, covering the range from 220 to 700 nm, of some paints readily available at Battelle. These paints were applied to (1) Masonite, (2) shiny aluminum, or (3) in the case of varnish and shellac, fir plywood, as indicated on the captions by the letters M, A, or W, respectively. For the paints, as many coats were applied as needed to assure no change in appearance between the last two coats applied; thus, the nature of the substrate to which the paint was applied had no effect on the reflectance of the painted surface. A minimum of 3 coats of paint were applied, except for varnish and shellac where only two coats were used.

These measurements were made, using a Beckman ACTA-M IV automatic recording spectrophotometer with an integrating sphere attachment, by Dr. Gordon Johnson of the Ferro Corporation, Independence, Ohio. Consequently, all reflected radiation was measured, whether specular or diffuse. The reflectance reference was BaSO₄ (see upper figure of Plate 22 or Plate 14 for BaSO₄ reflectance).

Following are the compositions of these paint samples:

1. Krylon; Chrome Yellow No. 1801

Pigment: 3.5 percent (Hansa Yellow, 12 percent; TiO₂, 88 percent)

Binder: 10.8 percent (Cellulose nitrate, oil-free alcohol-derived alkyd; coconut-oil modified alkyd; phthalate ester plasticizer)

Volatile: 85.7 percent (ketones; esters, alcohols; aromatic and aliphatic hydrocarbons)

2. Krylon, Brass Enamel No. 2202

Pigment: 5 percent (bronze powder)

Binder: 8.6 percent (chlorinated and acrylic-ester resins; secondary amines)

Volatile: 86.4 (aliphatic, aromatic, and halogenated hydrocarbons)
3. Krylon; Sunset Orange Enamel No. 2401

Pigment: 1.2 percent (dinitraniline orange, 58 percent; TiO_2 23 percent; iron oxide, 11 percent; Hansa Yellow, 8 percent)

Binder: 11.4 percent (as in Chrome Yellow No. 1801)

Volatile: 87.4 percent (as in Chrome Yellow No. 1801)
4. Krylon; Beige Enamel No. 2504

Pigment: 4.9 percent (TiO_2 , 83.3 percent; iron oxide yellow, 14.1 percent; iron oxide red, 2.1 percent; carbon black, 0.5 percent)

Binder: 8.9 percent (as in No. 1801)

Volatile: 86.2 percent (as in No. 1801)
5. Krylon; Baby Blue Enamel No. 1902

Pigment: 3.8 percent (TiO_2 , 97 percent; iron blue, 1.5 percent; phthalocyanine green, 1.5 percent)

Binder: 9.5 percent (as in No. 1801)

Volatile: 86.7 percent (as in No. 1801)
6. Rust-Oleum; No. 470 Ready Mixed Aluminum

Pigment: Aluminum flake

Binder: (?)

Volatile: Petroleum distillate
7. Rust-Oleum; No. 769 Damp Proof Red Primer

Pigment: 44.4 percent (red iron oxide, 30 parts; magnesium silicate, 8.3 parts; diatomaceous silica, 6.6 parts; zinc chromate, 4.6 parts)

Binder: 27.1 percent (Menhaden Alkyd Resin, 100 percent)

Volatile: 28.5 percent (Petroleum distillate)
8. Hanna; Chino-Glas Enamel No. 816, Robin Egg Blue

Pigment: 37.4 percent (titanium calcium pigment, 70.6 percent; TiO_2 , 21.7 percent; CaCO_3 , 7.8 percent; colorant ?)

Binder: 31.9 percent (soya modified alkyd resin)



8. (continued)
Volatile: 30.7 percent (mineral spirits)
9. General Electric; Glyptal No. 1201 Red Enamel
Pigment: 25.1 percent (brown ferric oxide, 32.5 percent; silica and silicates, 67.5 percent)
Binder: 32.2 percent (rosin modified soya alkyd)
Volatile: 42.7 percent (aromatic hydrocarbons, 86 percent; aliphatic hydrocarbons, 14 percent)
10. Pratt and Lambert; Aqua Satin No. 2102 (very pale green)
Pigment: 22.3 percent (TiO_2 Type III, 74 percent; silicates, 26 percent)
Binder: 34.1 percent (acrylic resin, 65 percent; propylene glycol, 35 percent)
Volatile: 43.6 percent (H_2O)
11. Dean and Barry; Dove Gray
Pigment: 58 percent (Lithopone and zinc sulfide, 41 percent; extenders, 51 percent [silicates?]; colorant, not more than 8 percent)
Binder: 8.4 percent (casein)
Volatile: 33.6 percent (H_2O)
12. Pratt and Lambert; Riviera Sand
Pigment: 52 percent (TiO_2 , $\approx$ 34 percent; CaCO_3 , 65 percent; tinting, balance)
Binder: 20 percent (soya alkyd resin)
Volatile: 28 percent (Petroleum distillate)
13. Sherwin Williams; Varnish
Pigment: 10 percent (silica, 94 percent; silicates, 6 percent)
Binder: 43 percent (rosin modified linseed alkyd)
Volatile: 47 percent (mineral spirits)
14. Orange Shellac
No components or proportions specified.
15. Sherwin Williams; Kem Glo Enamel, Yellow
Pigment: 35 percent (TiO_2 , $\approx$ 37.5 percent; CaCO_3 , $\approx$ 60.0 percent; tinting $\approx$ 2.5 percent)
Binder: 31 percent (soya alkyd resin)
Volatile: 34 percent (mineral spirits; driers)



16. Galvasheen White

Pigment: 60 percent (TiO_2 , $\approx$ 22 percent; ZnO , $\approx$ 29 percent;
 MgSiO_3 , $\approx$ 43 percent; Portland cement, $\approx$ 6 percent)

Binder: 17 percent (linseed oil)

Volatile: 23 percent (mineral spirits)

17. Sears; Acrylic Enamel, Yellow

Pigment: 13 percent (TiO_2 with < 5 percent tinting color)

Binder: 33 percent (Siliconized acrylic soya alkyd resin,
 93 percent; ester gum, 7 percent)

Volatile: 54 percent (mineral spirits and driers)

18. DuPont; Lucite Interior Enamel, White

Pigment: 24 percent (TiO_2 , 96 percent; silicates, 4 percent)

Vehicle: 76 percent (plasticized acrylic resin and H_2O)

19. Hanna; XC-800 Oil Base Primer, White

Pigment: 42 percent (TiO_2 and silicates)

Vehicle: 58 percent (alkyd-soya modified and solvent
 [petroleum distillate ?])

20. Hanna; Latex House Paint, White

Pigment: 32 percent (TiO_2 , 60 percent; ZnO , 21 percent;
 CaCO_3 , 19 percent)

Binder: 20 percent (vinyl acetate-acrylic copolymer,
 73 percent; soya alkyd, 27 percent)

Volatile: 48 percent (H_2O)

21. Fir Plywood; no finish, freshly sanded

22. Masonite, smooth surface; no finish

The presence of TiO_2 in most of these paints is evidenced by the cut-off at approximately 390 nm, unless much more strongly absorbing pigments are present. The position of the UV-side reflectance cut-off is determined by the absorption characteristic of the most strongly absorbing component, even if it is present only as one of the lesser constituents; viz., TiO_2 in Paint No. 12 (Plate 39).

The most singular curve of this group is Sample No. 6 (Plate 33)--aluminum paint--which has a reflectance of about 75 percent throughout the spectral range covered (compare with Plate 16). Brass enamel, Sample No. 2 (Plate 29), has a reflectance of about 25 percent at 300 nm.

Data on Pigments

Plates 50 through 59 show spectral-reflectance data for a wide variety of materials which are or might be used as pigments in paints. The addition of small amounts of an absorbing pigment to a highly reflecting pigment can greatly reduce reflectance of the mixture, as illustrated in Plates 53 through 56. Schatz, Reference A, discusses this point on a (dry) quantitative basis. As might be expected, the addition of small amounts of absorbing pigments to a paint with high reflectance will greatly reduce its reflectance.

The most reflective pigment in both the visible and the UV is, on the basis of the data collected here, purified BaSO_4 . Plate 59 shows MgO as having a lower reflectance than BaSO_4 ; it is taken from technical data on Eastman Kodak Company products.

Data on Binder Materials and Other Vehicle Constituents

Plates 60 through 69 present data on the absorption or extinction coefficients of various resins, fatty acids, drying oils, plasticizers, thinners and other materials used in paints. Because the paint-vehicle layers between the top of the paint film and the pigments within the film are generally very thin, the absorptivity of the vehicle generally has very little effect either on visible or UV absorption compared with the effect of the pigment. For example, linseed oil, which has an absorption coefficient of 1.6×10^{-2} inches⁻¹, will have a transmittance of 85 percent in a 0.001-inch-thick layer. Thus, if the layer were that thick, on the average, over a highly reflecting pigment such as BaSO_4 or aluminum flakes, radiation

passing through the film to the pigment and directly back out (0.002-inch-thick path) would be reduced only to nominally 73 percent. Clear vehicle layers over the pigment particles rarely are that thick; thus, the optical reflectance characteristics of paints are almost completely due to the pigment alone. Exceptions are materials such as varnish and shellac as illustrated by the lower reflectance in the blue and UV for varnish, Sample No. 13, and Shellac, Sample No. 14 (Plates 40 and 41), compared with uncoated wood, Sample No. 21 (Plate 48), where films are relatively thick.

Plate 69 is a reproduction of a page in which are discussed the effects on paint whiteness of the addition of a wide variety of materials. The relevance is that most additives cause yellowing, and yellowing is the result of blue-light absorption which generally is accompanied by UV absorption. Thus, the data in Plate 69 at least suggest that paints never increase in UV reflectance with time or exposure to most contaminating influences.

Data on Miscellaneous Materials

Some of the materials included in this section might very likely comprise wall surfaces in the welding environment, such as unpainted cement block, concrete, or brick. Some, such as sand, plywood, rusty iron, cloth, leaves, and shiny metal surfaces, might be present under temporary conditions. The others are included as a matter of casual interest.

Plates 70 through 73 show that cement block and concrete can have reflectances as high as 20 percent at around 300 nm. The same is true for white sand, light dry soil, and marble.

White cotton cloth may have a reflectance of 50 to 60 percent, and linen reflectance may be as high as 30 to 35 percent of the erythema region. Polished, specular metallic surfaces of aluminum, chromium, nickel, zinc and steel have reflectances ranging from 40 percent to 85 percent in this spectral region.

Many of the above materials probably should be avoided in the welding environment, or precautions should be taken regarding UV exposure in their presence; these include, for example, concrete, cement block, shiny metal surfaces, sand, light-colored soil, marble and some fabrics such as white cotton and linen.

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Magnesium Oxide	7, 10, 22, 23, 50, 51, 52, 58, 59, 83
Malachite Green	52
Mercuric Sulfide	52
d-Naphthylamine	52
Nickel-Aluminum	56
Ochre	51
Ochre, American	52
Ochre, French	52
Orange Mineral	52
Para Toner	52
Pigment Scarlet Toner	52
Prussian Blue	51, 52
Quartz	23, 40, 50, 51, 52, 55
Scarlet Red Chromate	52
Sienna, Burnt	52
Sienna, Raw	52
Silicates	34, 36, 37, 43
Silicon Dioxide	23, 40, 50, 51, 52, 55

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<u>Pigments, Dyes or Extenders</u>	<u>Plate Numbers</u>
Silicon Dioxide-Aluminum	56
Silicon Dioxide-Aluminum Oxide	56
Sodium Chloride	22
Tin Oxide	50
Titanium Dioxide	6, 27, 28, 30, 31, 32, 35, 37, 39, 42-47, 51, 52, 55
Titanium Dioxide (Anatase)	3
Titanium Dioxide (Rutile)	2, 12
Titanium Dioxide-Aluminum	56
Titanium Dioxide-Zirconium Dioxide	56
Turquoise	51, 52
Tuscan Red	52
Ultra Blue	52
Zinc Dust, Blue Powder	52, 55
Zinc Chromate	54
Zinc Oxide	1, 4, 5, 7, 8, 43, 47, 50-53, 55, 69
Zinc Sulfate	50
Zinc Sulfide	8, 21, 27, 51
Zirconium Dioxide	51
Zirconium Dioxide-Titanium Dioxide	56

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Binders, and other nonvolatile vehicle constituents

Plate Numbers

Acrylic	7, 10, 29, 37, 45
Acrylic Soya Alkyd, Siliconized	44
Acryloid, A-10	27
Acryloid, B-72	10
Alkyd	28, 30, 31, 32, 34, 35, 36, 39, 40, 42, 46
Alkyd Melamine, RC-7007	10
Ammonium Sulfate	22
Ammonium Sulfate-Potassium Sulfate	22
Butyl Acrylate	12
Butyl Stearate	22
Chinawood Oil	63
Casein	23, 38
Castor Oil	62
Ethyl Cellulose	22
Fatty Acids, various	62
Glue, Animal	23
Gum Arabic	23
Isobutyl Methacrylate	22
Linseed Oil	23, 43, 62, 63, 65
Methyl Methacrylate (Plexiglas)	63
Nitrocellulose	12, 23, 65
Oils, drying, various	60
Plasticizers, various	60
Potassium Silicate	7, 11, 15
Potassium Sulfate	22
Resins, various	60, 61
Silicone	12, 13, 15, 16, 21, 23, 66, 84, 89



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<u>Binders, and other nonvolatile vehicle constituents</u>	<u>Plate Numbers</u>
Silicone Alkyd	6
Silicone, DC-806A	10
Silicone, Dimethyl (RTV62)	1
Silicone, Methyl	2, 3, 4, 8
Silicone, Phenylmethyl	8, 12
Silicone, RTV-602	5, 64, 66
Sodium Silicate ($\text{Na}_2\text{O} \cdot \text{XSiO}_2$)	23
Sodium Tetraborate (Borax)	23
Soybean Oil	62
Styrene, Polymer	63
Tung Oil	62
Urea Formaldehyde, Butylated	12
Urethane, Polymer	68
Vinylacetate-Acrylic	47
Vinylalcohol, Polymer	14, 22, 63
Vinylbutyral, Polymer	63
Vinylchloride, Polymer	67

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Miscellaneous Materials

Plate Numbers

Aluminum	83, 84, 85
Aluminum, Anodized, Dyed	86
Aqueous Solutions, Various (transmittance)	90
Asphalt (blacktop)	70, 75
Basalt (gray to black rock)	72, 76
Brick	25, 70
Building Tile	70
Canvas, Gray	81
Canvas, Olive Drab	81
Cement Block	70
Chlorophyl	78
Chromium	83, 85
Cloth	80, 82, 83
Concrete	71, 72, 73
Copper	85
Fabrics	80, 82, 83
Feldspar	77
Flint	77
Glass	88
Gold	85
Granite	72, 77
Inconel, Blackened	87
Iron, Rusty	80
Leaves	78, 79
Marble	77
Masonite	49
Mylar	63
Newspaper	83
Nickel	83, 85
Organic Solutions (transmittance)	91



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INDEX IV - 2

Miscellaneous Materials

Plate Numbers

Plaster	83
Porcelain Enamel	85
Rhodium	83
Sand	74
Sandstone, Red	76
Silver	83, 85
Slag	76
Soil	74
Solutions, Aqueous (trans)	90
Solutions, Organic (trans)	91
Stainless Steel	83, 87
Stone, Dolomite, Crushed	70
Teflon	63
Wallpaper; AR, White, etc.	82
Wood	48, 70, 72, 74, 75
Zinc	85

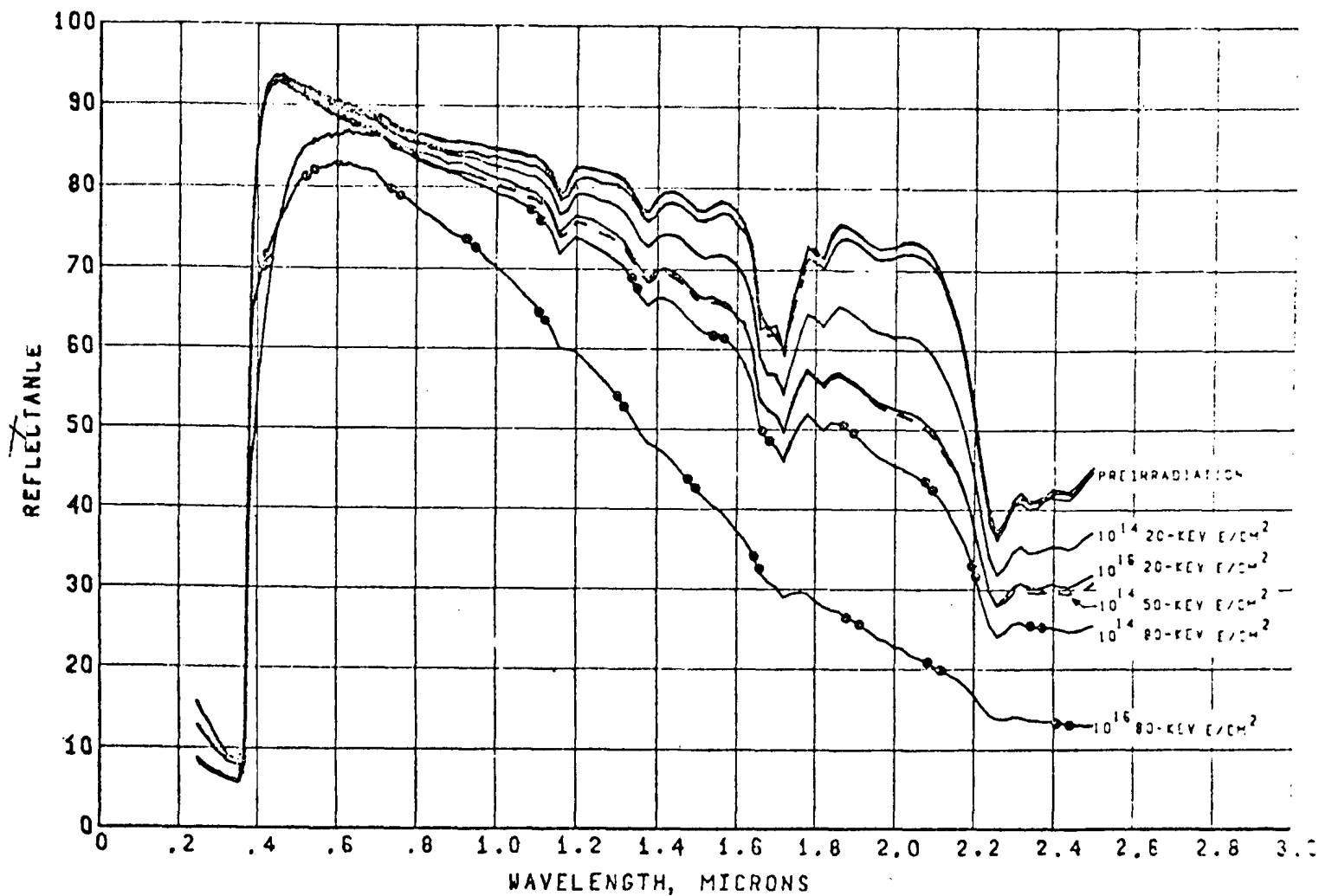


FIGURE B-28. DEPENDENCE OF REFLECTANCE DEGRADATION IN S-13 UPON ELECTRON ENERGY

Zinc Oxide/RTV-602
Dimethyl Silicone Binder (S-13)

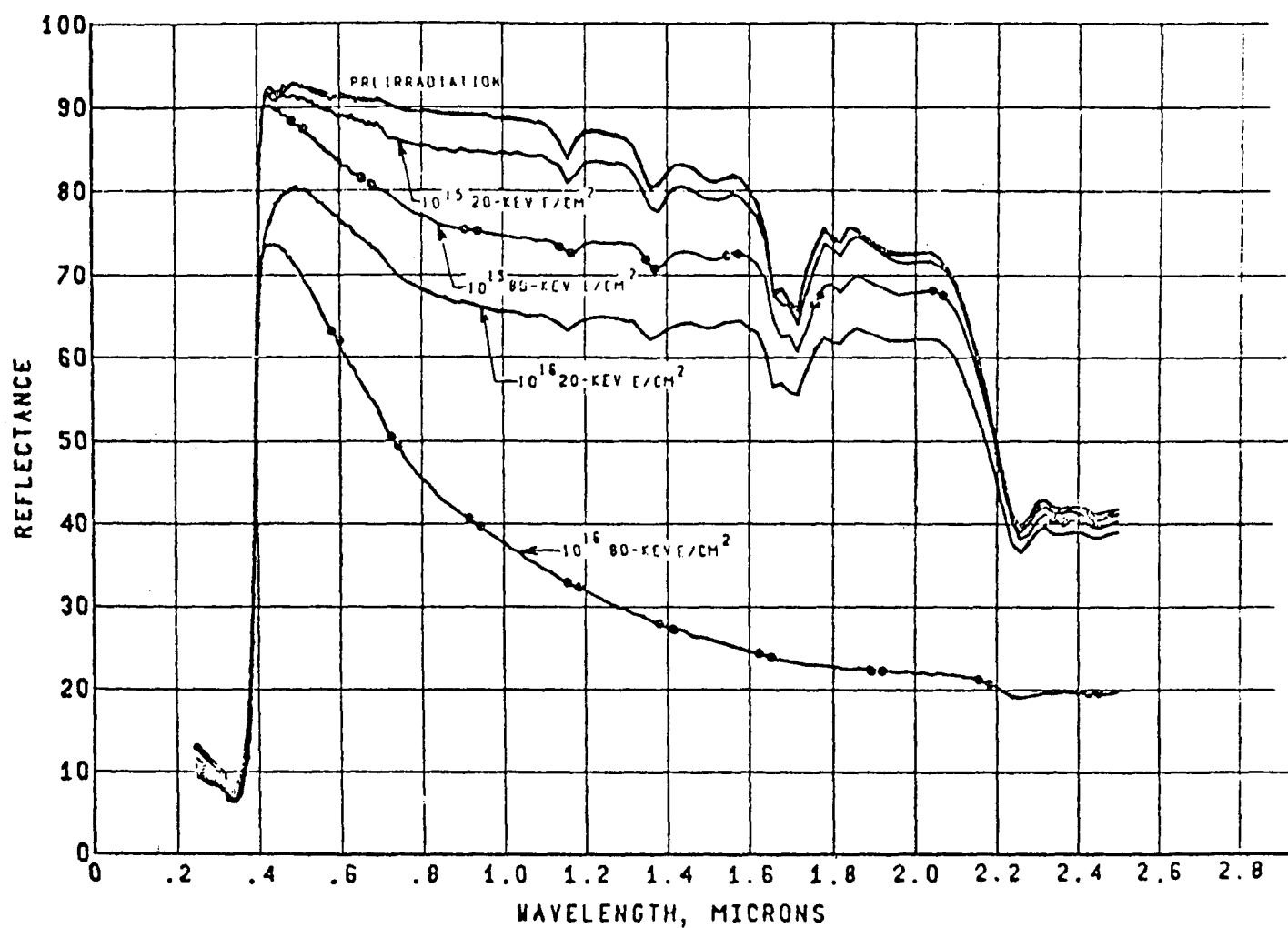


FIGURE B-37. DEPENDENCE OF REFLECTANCE DEGRADATION IN RUTILE TiO_2 -METHYL SILICONE UPON ELECTRON ENERGY

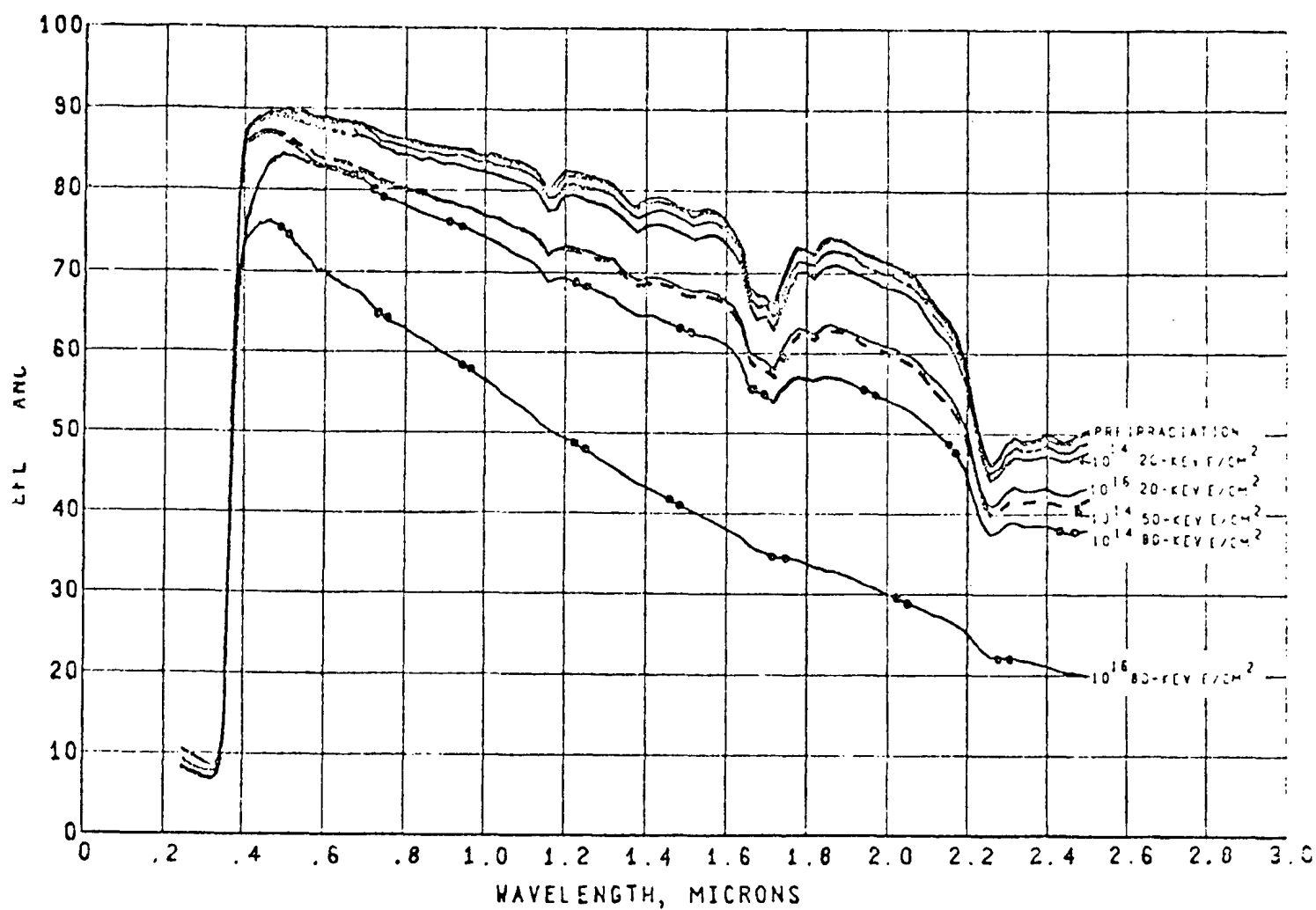


FIGURE B-3S. DEPENDENCE OF REFLECTANCE DEGRADATION IN ANATASE TiO_2 -METHYL SILICONE UPON ELECTRON ENERGY-

C

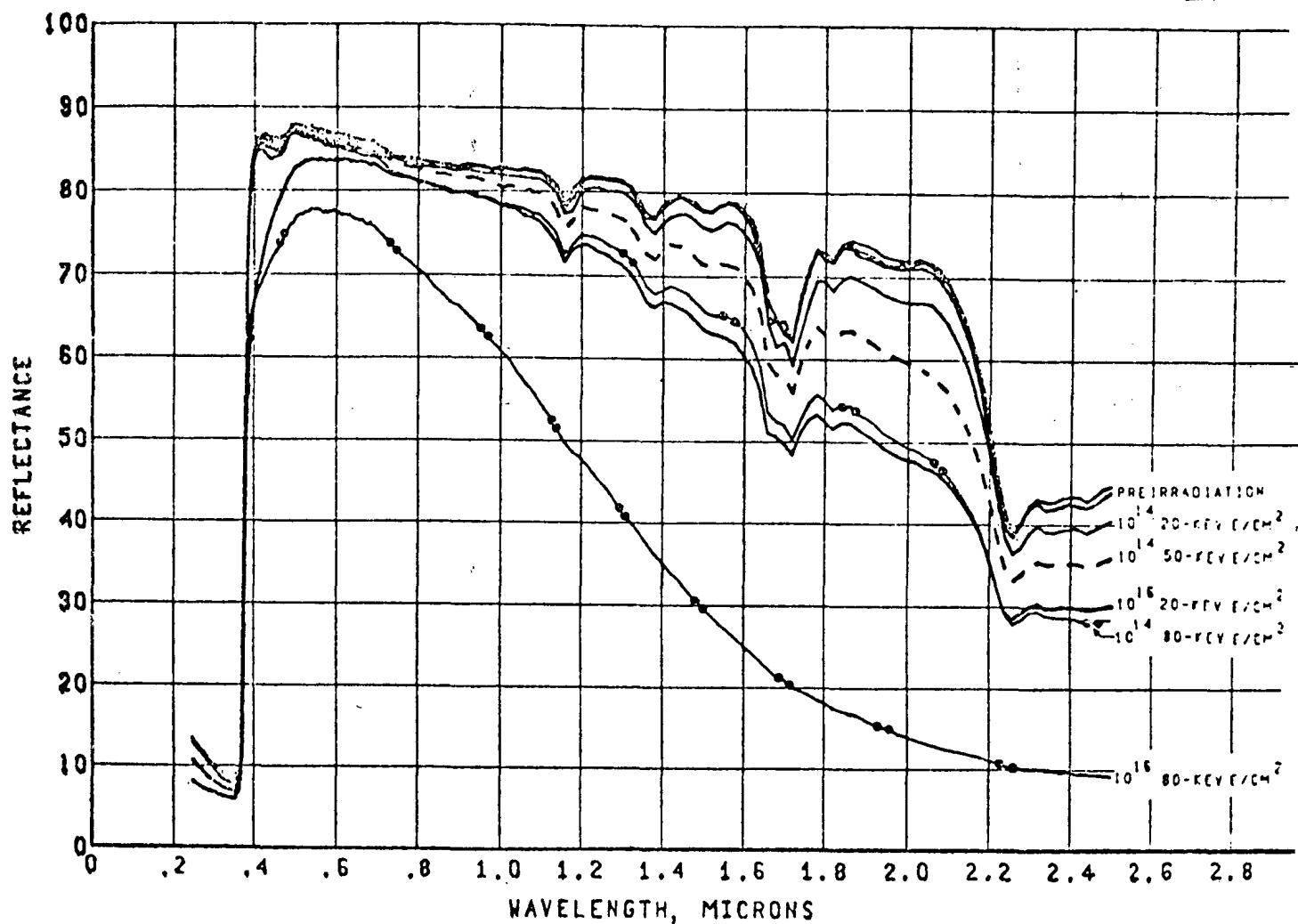


FIGURE B-30. DEPENDENCE OF REFLECTANCE DEGRADATION IN TREATED ZINC OXIDE-METHYL SILICONE (GODDARD SERIES 101-7-1) UPON ELECTRON ENERGY (28)

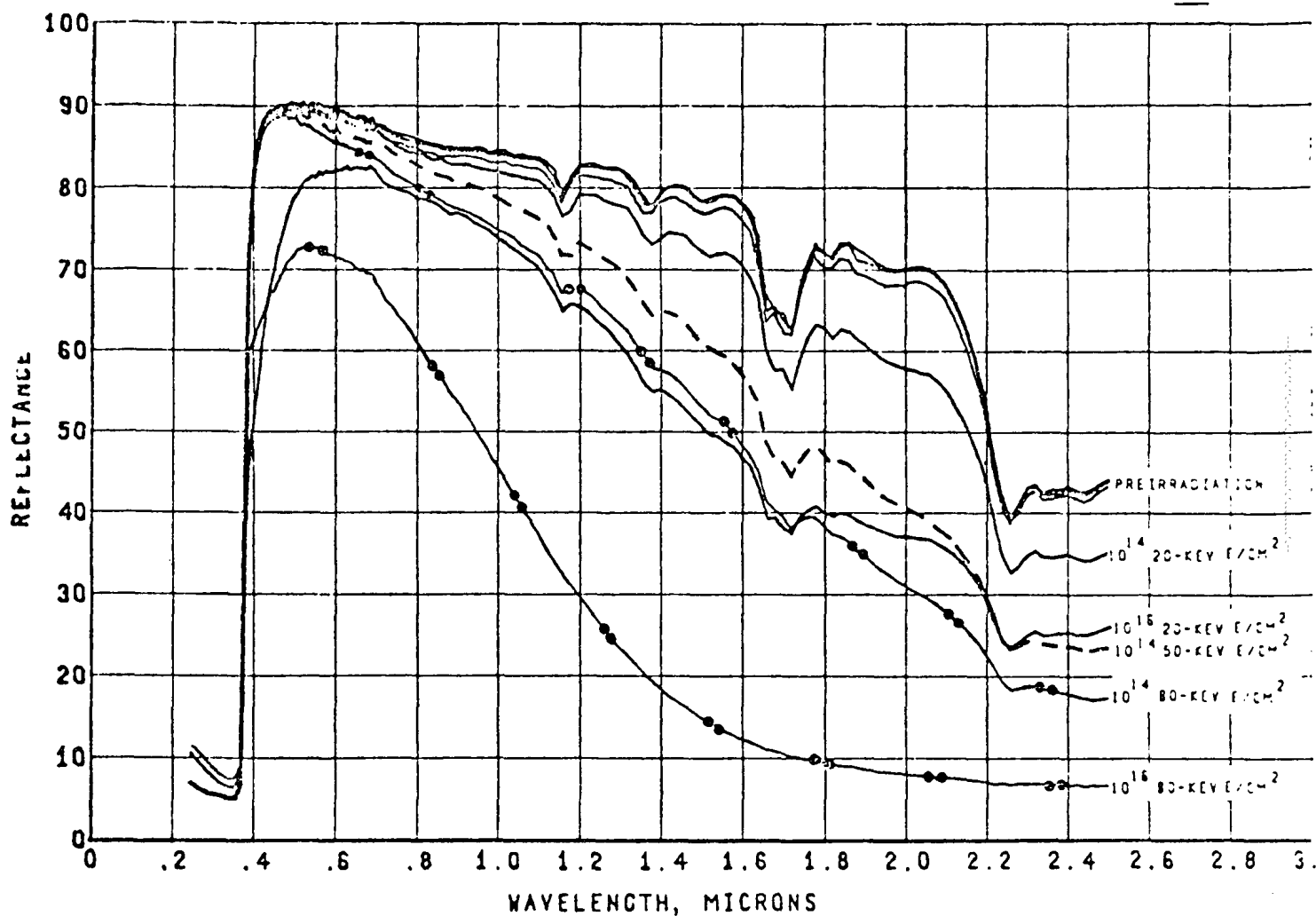


FIGURE B-29. DEPENDENCE OF REFLECTANCE DEGRADATION IN S-13G UPON ELECTRON ENERGY

Components	Weight, lbs
Silicate-treated SP500 ZnO	25
RTV-602 silicone resin (GE)	12
S-13G mixed thinner	14
(Comprising, percent)	
Toluene	40
Xylene	20
n-butanol	15
Isopropanol	20
Butyl acetate	5

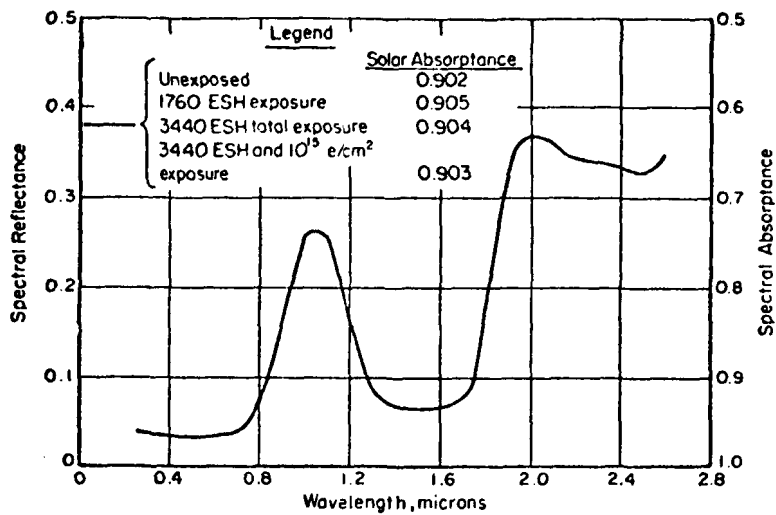


FIGURE C-71. SOLAR ABSORPTANCE OF PYROMARK BLACK ON ALUMINUM

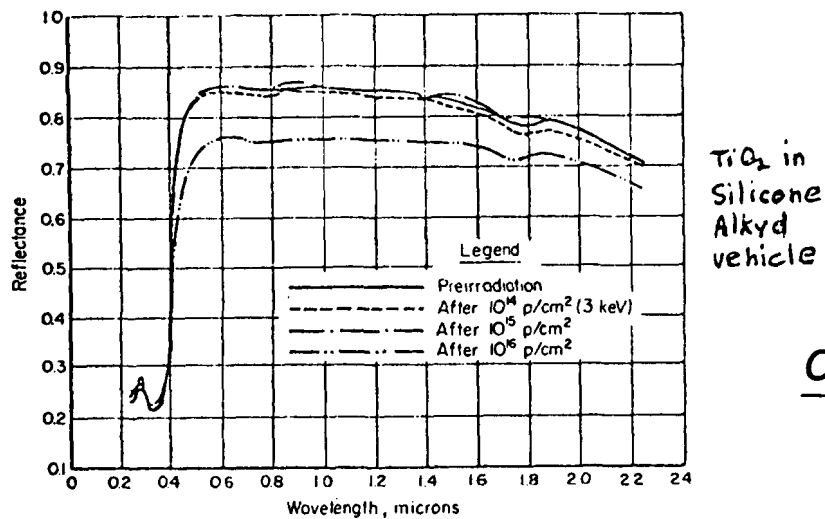


FIGURE B-19. SPECTRAL REFLECTANCE OF PV-100 (9-2) IN VACUO

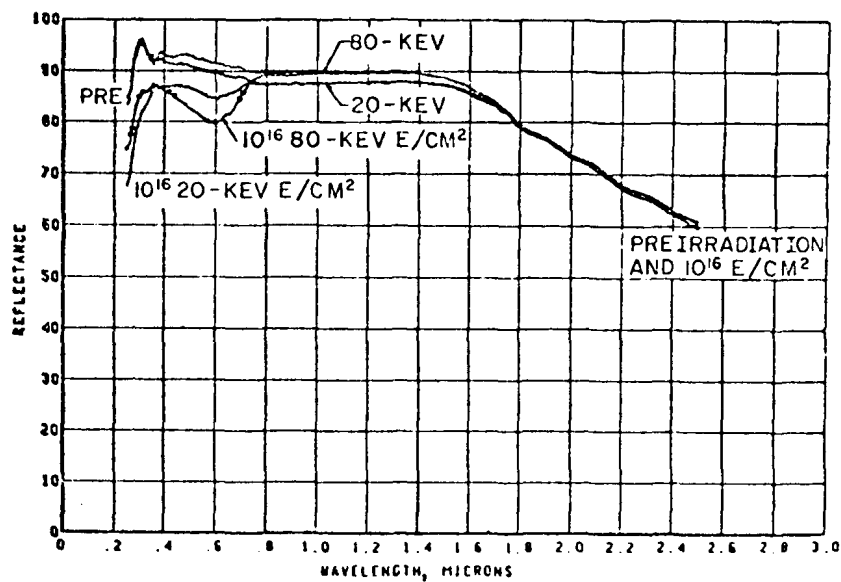


FIGURE C-3. DEPENDENCE OF REFLECTANCE DEGRADATION IN $\text{Al}_2\text{O}_3\text{-K}_2\text{SiO}_3$ UPON ELECTRON ENERGY

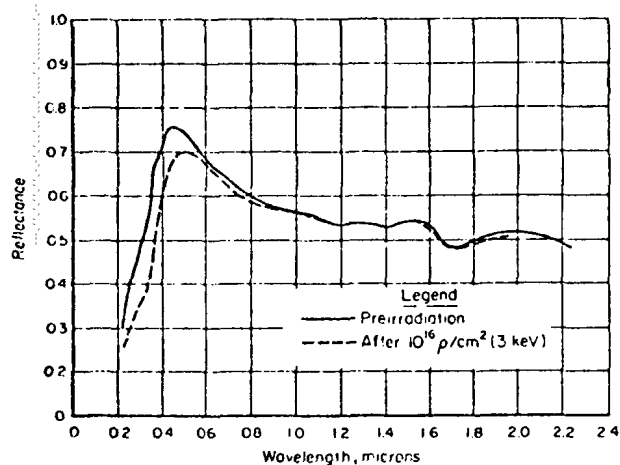


FIGURE B-53. SPECTRAL REFLECTANCE OF MgO/ACRYLIC (9-4) IN VACUUM

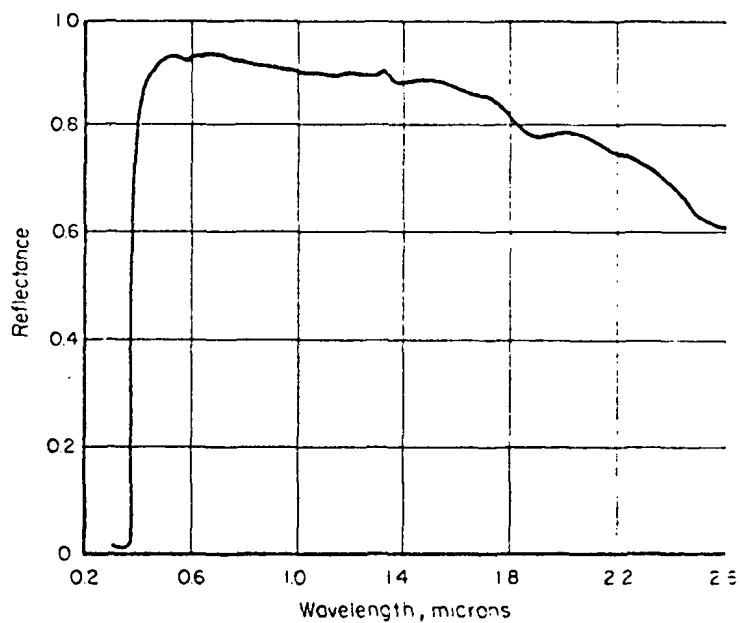
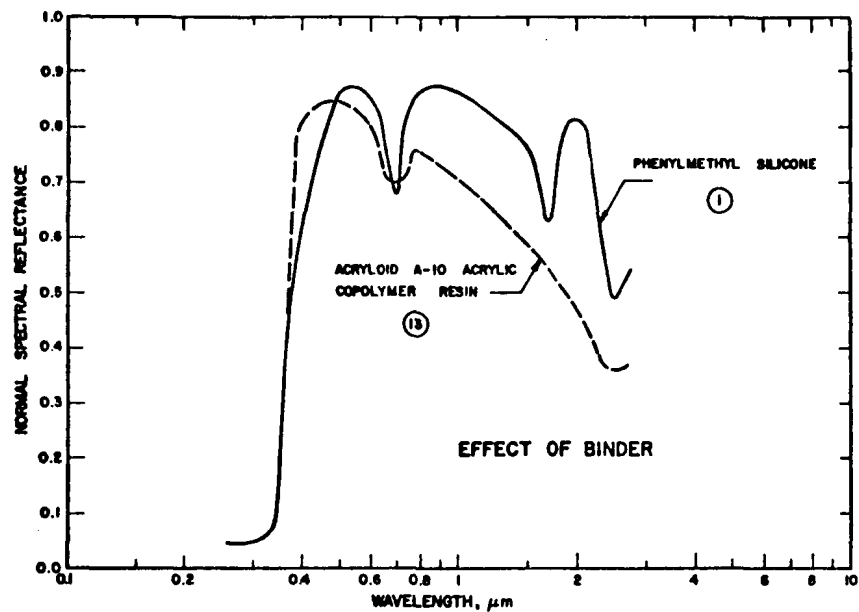
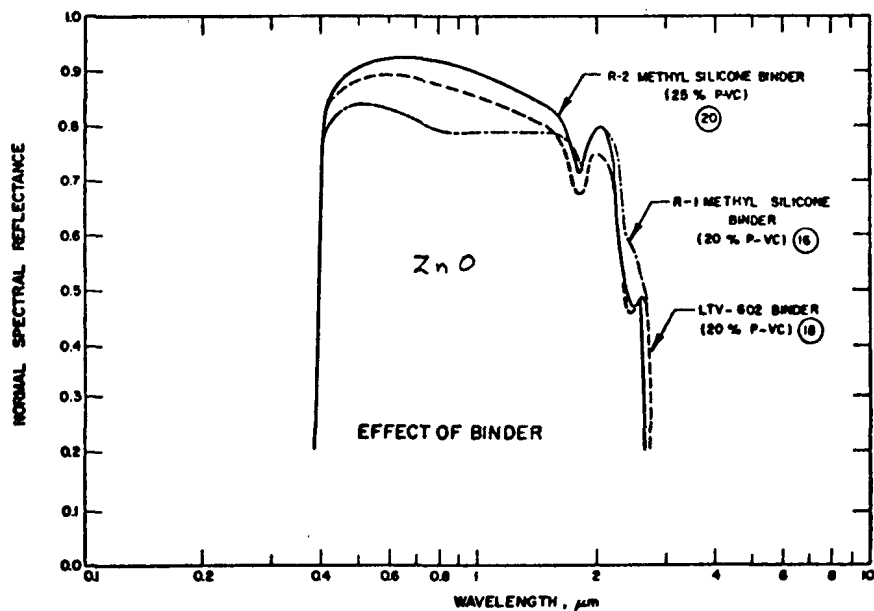


FIGURE C-12. INITIAL REFLECTANCE Z-93 USED ON LUNAR ORBITER.

ZnO in K_2SiO_3



ZINC SULFIDE



SP-500 ZnO in R-1 experimental methyl silicone binder; PBR 1.35; PVC 25%; aluminum substrate; airbrush application; data extracted from smooth curve. [Authors' designation: Sample S-4]

Above specimen and conditions except exposed in vacuum (10^{-5} mm Hg) to 1460 ESH.

SP-500 ZnO in G. E. LTV-602 binder; PBR 1.40; PVC 20%; catalyst, G. E. SRC-04; solvent, toluene; aluminum substrate; airbrush application; data extracted from smooth curve. [Authors' designation: Sample S-7]

SP-500 ZnO in R-2 experimental methyl silicone binder; Me/Si ratio 1.46; PBR 1.70; PVC 25%; aluminum substrate; airbrush application; data extracted from smooth curve. [Authors' designation: Sample S-8]

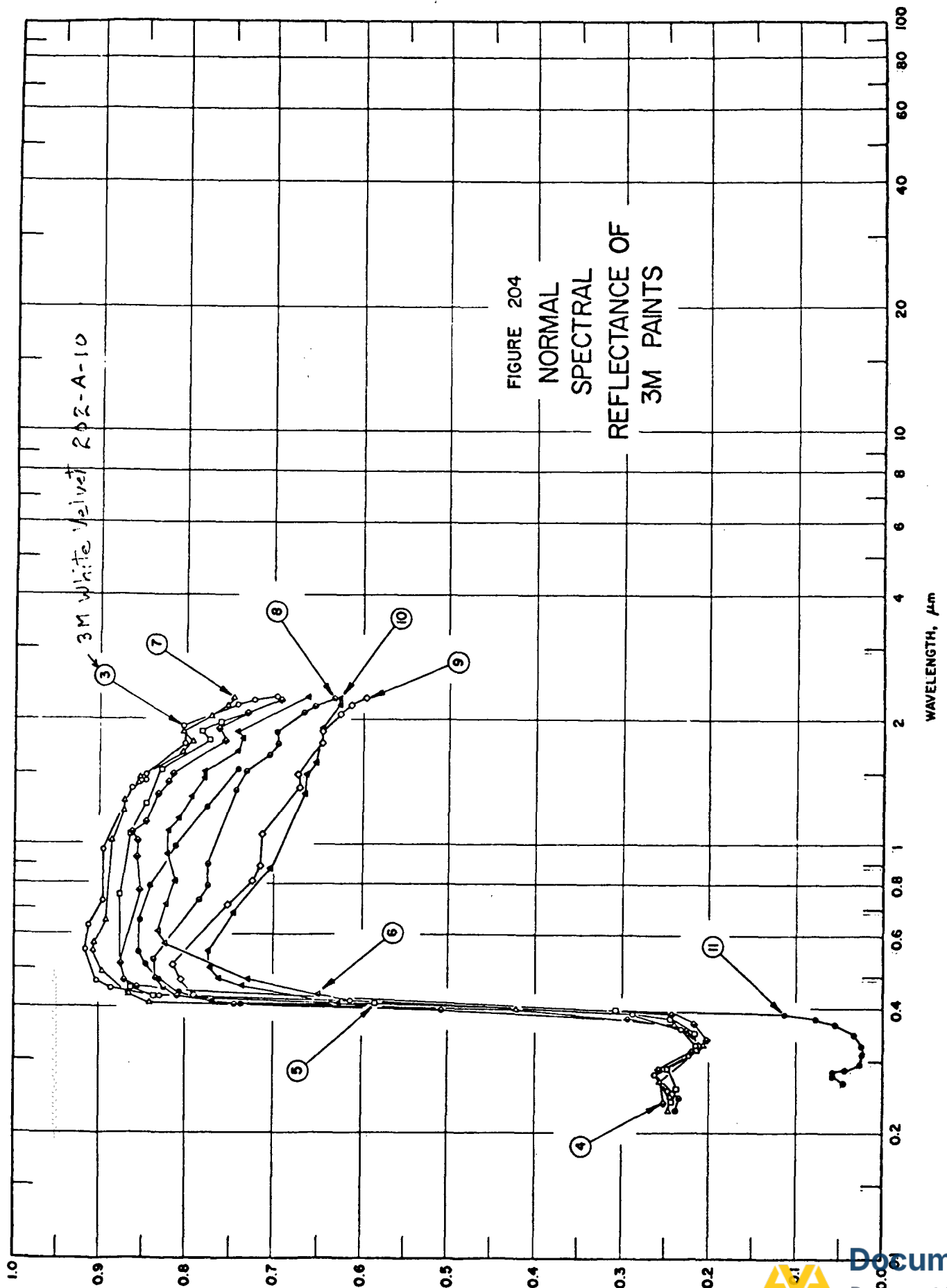


FIGURE 204
NORMAL
SPECTRAL
REFLECTANCE OF
3M PAINTS

Plate 9.

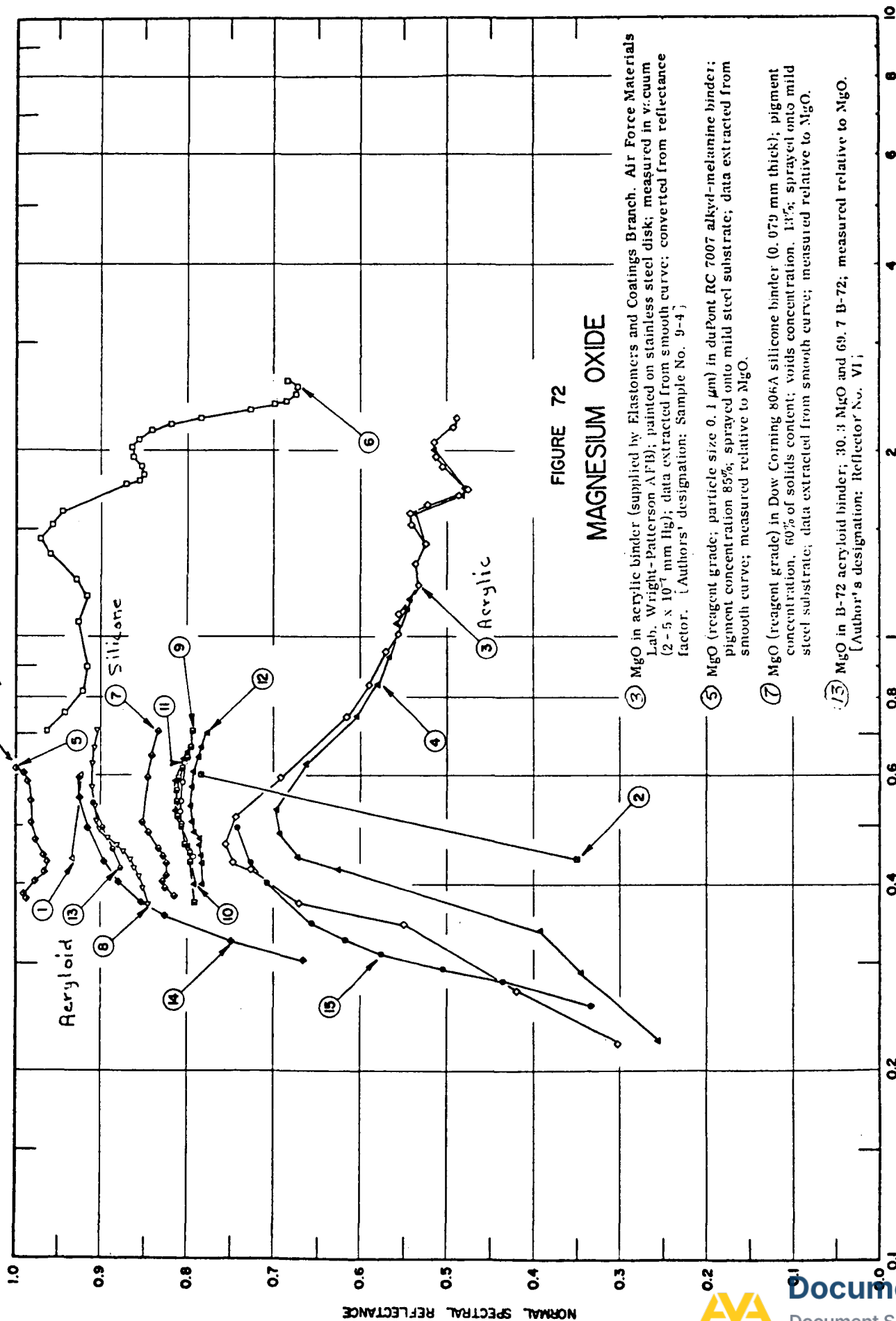
Alkyd melamine

Acryloid

Silicone

Acrylic

FIGURE 72
MAGNESIUM OXIDE



WAVELENGTH, μm

Plate 10.

- ① MgO in acrylic binder (supplied by Elastomers and Coatings Branch, Air Force Materials Lab, Wright-Patterson AFB); painted on stainless steel disk; measured in vacuum (2 - 5 x 10⁻⁷ mm Hg); data extracted from smooth curve; converted from reflectance factor. (Authors' designation: Sample No. 9-4)
- ② MgO (reagent grade; particle size 0.1 μm) in duPont RC 7007 alkyd-melamine binder; pigment concentration 85%; sprayed onto mild steel substrate; data extracted from smooth curve; measured relative to MgO.
- ③ MgO (reagent grade) in Dow Corning 806A silicone binder (0.079 mm thick); pigment concentration, 60% of solids content; voids concentration, 13%; sprayed onto mild steel substrate; data extracted from smooth curve; measured relative to MgO.
- ④ MgO in B-72 acryloid binder; 30.3 MgO and 69.7 B-72; measured relative to MgO. (Authors' designation: Reflector No. VI)
- ⑤
- ⑥
- ⑦
- ⑧
- ⑨
- ⑩
- ⑪
- ⑫
- ⑬
- ⑭
- ⑮