



BSI Standards Publication

Space Engineering — Thermal design handbook

Part 6: Thermal Control Surfaces

National foreword

This Published Document is the UK implementation of CEN/CLC/TR 17603-31-06:2021.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Published by BSI Standards Limited 2021

ISBN 978 0 539 16980 5

ICS 49.140

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2021.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

August 2021

ICS 49.140

English version

Space Engineering - Thermal design handbook - Part 6: Thermal Control Surfaces

Ingénierie spatiale - Manuel de conception thermique -
Partie 6: Revêtements de Contrôle Thermique

Raumfahrttechnik - Handbuch für thermisches Design -
Teil 6: Oberflächen zur Thermalkontrolle

This Technical Report was approved by CEN on 21 June 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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Rue de la Science 23, B-1040 Brussels

Table of contents

European Foreword	14
1 Scope	15
2 References	16
3 Terms, definitions and symbols	17
3.1 Terms and definitions	17
3.2 Abbreviated terms	17
3.3 Symbols	18
4 General introduction	21
5 Coatings	23
5.1 General	23
5.2 Solar reflectors	25
5.2.1 Titanium Dioxide-Polymethyl Vinyl Siloxane	25
5.2.2 Zinc Oxide-Potassium Silicate	32
5.2.3 Zinc Orthotitanate-Potassium Silicate	52
5.2.4 Zinc Oxide-Methylsilicone	136
5.2.5 Zinc Oxide-Potassium Silicate	163
5.2.6 Silver vacuum deposited on fused Silica	196
5.2.7 Silver vacuum deposited on fused Silica with a conductive coating	251
5.3 Total reflectors	274
5.3.1 Leafing Aluminium-Silicone	274
5.4 Total absorbers	279
5.4.1 Carbon black-Acrylic resin	279
6 Adhesive tapes	283
6.1 General	283
6.1.2 Adhesive properties	283
6.1.3 Curing of adhesive tapes	285
6.1.4 General purpose adhesive tapes	286
6.2 Application and handling	298
6.2.1 Application	298

6.2.2	Cleaning.....	298
6.2.3	Handling.....	299
6.2.4	Repairing	300
6.3	Degradation	300
6.3.1	Introduction	300
6.3.2	Terrestrial degradation	300
6.3.3	Space degradation	300
6.3.4	Blistering	304
6.4	Relevant properties of thermal control tapes.....	307
6.5	Past spatial use	331
Bibliography.....		333

Figures

Figure 4-1: Basic types of thermal control coatings. T_R [K] is the equilibrium temperature of a coated isothermal sphere at 1 AU. From Touloukian, DeWitt & Hernicz (1972) [126].	21
Figure 4-2: Range of solar absorptance, α_s , and hemispherical total emittance, ε , covered by available thermal control coatings. From Touloukian, DeWitt & Hernicz (1972) [126].	22
Figure 5-1: UV radiation effects on solar absorptance, α_s , of Thermatrol 2A-100 vs. exposure time, t . From Breuch (1967) [22].	28
Figure 5-2: Change in solar absorptance, $\Delta\alpha_s$, of Thermatrol 2A-100, under various radiation conditions, vs. exposure time, t . From McCargo et al. (1971) [82].	28
Figure 5-3: Normal-hemispherical spectral reflectance, ρ_λ' , of Thermatrol 2A-100, measured by two different methods, vs. wavelength, λ . From Cunningham, Grammer & Smith (1969) [33].	29
Figure 5-4: Effect of Ultra-Violet Radiation on spectral reflectance, ρ_λ' , of Thermatrol 2A-100 vs. wavelength, λ . Most of the data, concerning bidirectional reflectance, are from Rittenhouse & Singletary (1969) [105], while dashed line and dotted line, normal-hemispherical reflectance, are from Cunningham, Grammer & Smith (1969) [33].	30
Figure 5-5: Variation of solar absorptance, α_s , with thickness, t_c . From Stevens (1971) [120].	36
Figure 5-6: Estimated changes in the solar absorptance, α_s , of Z-93 during the total mission profile for a near-Earth orbit. From McCargo, Spradley, Greenberg & McDonald (1971) [82].	45
Figure 5-7: Normal-hemispherical spectral reflectance, ρ_λ' , of Z-93 vs. wavelength, λ . All data are from Touloukian, DeWitt & Hernicz (1972) [126] except solid and dashed lines which are from Cunningham, Grammer & Smith (1969) [33].	47
Figure 5-8: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ_λ' , of Z-93 vs. wavelength, λ . Data points are from Touloukian,	

DeWitt & Hernicz (1972) [126], while smooth curves are from Cunningham, Grammer & Smith (1969) [33].	49
Figure 5-9: Effect of Proton Radiation on normal-hemispherical spectral reflectance, ρ_{λ}' , of Z-93 vs. wavelength, λ . From Touloukian, DeWitt & Hernicz (1972) [126].	50
Figure 5-10: Hemispherical total emittance, ε , of Zinc Orthotitanate-Potassium Silicate Coatings vs. temperature, T . ○: SSR pigment, > phosphated. From Keyte (1975) [70]. ●: MOX pigment, > YB-71. From Harada & Wilkes (1979) [58]. □: YB-71. > AESC. From Ahern & Karperos (1983) [4].	60
Figure 5-11: Solar absorptance, α_s , of YB-71 vs. thickness, t_c . ○: From Harada & Wilkes (1979) [58]. ■: From measurements on 16 panels by AESC. Scatter is due to t_c variation. From Ahern & Karperos (1983) [4].	60
Figure 5-12: Solar absorptance, α_s , of Zinc Orthotitanate-Potassium Silicate coating vs. incidence angle, β . SSR pigment, phosphated. From Keyte (1975) [70].	63
Figure 5-13: Solar absorptance, α_s , of several YB-71 coatings vs. exposure time, t , as deduced from data of various spacecraft in geosynchronous orbits. Numbers corresponds to sample designations.	74
Figure 5-14: Normal-hemispherical spectral reflectance, ρ_{λ}' , of Zinc Orthotitanate-Potassium Silicate coatings vs. wavelength, λ .	76
Figure 5-15: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ_{λ}' , of Zinc Orthotitanate- Potassium Silicate coatings vs. wavelength, λ .	78
Figure 5-16: Effect of Protons Radiation on normal-hemispherical spectral reflectance, ρ_{λ}' , of Zinc Orthotitanate-Potassium Silicate coatings vs. wavelength, λ . From Gilligan & Zerlaut (1971) [46].	79
Figure 5-17: Hemispherical total emittance, ε , of S-13 G coating vs. temperature, T . 2×10^{-4} m thick coating on molybdenum substrate. From Spisz & Jack (1971) [119].	85
Figure 5-18: Hemispherical total emittance, ε , of S-13 and S-13 G coatings vs. exposure time, t , at 1-Sun level and 395 K. From Cunningham, Grammer & Smith (1969) [33]. Equal symbols correspond to the same sample. ○: > Sample 27; ●: > Sample 43; □: > Sample 28; ■: > Sample 44.	87
Figure 5-19: Variation of solar absorptance, α_s , of S-13 coating with coating thickness, t_c . ○: > Nominal composition. Sprayed on primed surface. Air dried. $T = 298$ K. (Designation in the ref.: 119 to 127). □: > ZnO in silicone binder. $T = 298$ K. (Designation in the ref.: 29, 30). From Touloukian, DeWitt & Hernicz (1972) [126].	89
Figure 5-20: Solar absorptance, α_s , of S-13 G coating vs. incidence angle, β . From Keyte (1975) [70].	90
Figure 5-21: Change in solar absorptance, $\Delta\alpha_s$, of S-13 and S-13 G coatings due to Protons and Alpha Particles Radiation vs. integrated flux, n .	94
Figure 5-22: Change in solar absorptance, $\Delta\alpha_s$, of S-13 G coating due to Electrons Radiation vs. integrated flux, n . Data taken in situ. Compiled by Bourrieau, Paillous & Romer (1976) [21].	96
Figure 5-23: Changes in solar absorptance of S-13 and S-13 G coatings. OSO III experiment. From Millard (1969) [84].	98

Figure 5-24: Change in solar absorptance, $\Delta\alpha_s$, of S-13 coatings vs. flight time in ESH as measured in orbital flight. Prepared by the compiler after Touloukian, DeWitt & Hernicz (1972) [126].	99
Figure 5-25: Change in solar absorptance, $\Delta\alpha_s$, of S-13 G coating vs. flight time in ESH as measured in orbital flight. Prepared by the compiler after Touloukian, DeWitt & Hernicz (1972) [126].	100
Figure 5-26: Position on the sample holder of the samples 1 and 2, for irradiation and measurement. From Paillous (1976) [96].	104
Figure 5-27: Solar absorptance, α_s , of S-13 G/LO coating vs. flight time,	105
Figure 5-28: Variation of absorptance to emittance ratio, α/ε , of S-13 coating vs. flight time. Prepared by the compiler after Touloukian, DeWitt & Hernicz (1972) and Triolo (1973) [126].	106
Figure 5-29: Variation of absorptance to emittance ratio, α/ε , of S-13 G coating vs. flight time. Prepared by the compiler after Touloukian, DeWitt & Hernicz (1972) [126].	107
Figure 5-30: Normal-hemispherical spectral reflectance, ρ'_λ , of S-13 coating vs. wavelength, λ , for five different values of P-VC. G.E. LTV-602 binder. From Touloukian, DeWitt & Hernicz (1972) [126].	108
Figure 5-31: Effect of Ultra-violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 coating vs. wavelength, λ . LTV-602 silicone binder. Two different pigment-binder ratios (PBR). From Touloukian, DeWitt & Hernicz (1972) [126].	109
Figure 5-32: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 coating vs. wavelength, λ . Several binders and PBRs. From Touloukian, DeWitt & Hernicz (1972) [126].	110
Figure 5-33: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 coating vs. wavelength, λ . From Touloukian, DeWitt & Hernicz (1972) [126].	111
Figure 5-34: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 coating vs. wavelength, λ . From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	112
Figure 5-35: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 G coating vs. wavelength, λ . Two different pigment treatment processes. From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	113
Figure 5-36: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 G coating vs. wavelength, λ . Sweated pigment. Two different solvent systems. From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	114
Figure 5-37: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 G coating vs. wavelength, λ . Two different pigment treatment processes. Owens-Illinois 650 binder. From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	115
Figure 5-38: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_λ , of S-13 G coating vs. wavelength, λ . Pigment was sifted prior to wet grinding. Paint grind time 3 h. From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	116

Figure 5-39: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Silicated pigment with five mechanical perturbations. From Zerlaut, Rogers & Noble (1969) [144]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	117
Figure 5-40: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Plasma annealed and potassium silicate treated pigment. From Gilligan & Zerlaut (1971) [46].	118
Figure 5-41: Protons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 coating vs. wavelength, λ . LTV-602 silicone binder. From Gillette, Brown, Seiler & Sheldon (1966) [54]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	120
Figure 5-42: Protons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Plasma annealed and potassium silicate treated pigment. From Gilligan & Zerlaut (1971) [46].	121
Figure 5-43: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Radiation intensity 20 keV. Recovery after exposure. From Fogdall, Cannaday & Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	122
Figure 5-44: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Radiation intensity 80 keV. Recovery after exposure. From Fogdall, Cannaday & Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	124
Figure 5-45: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of GSFC, 101-7 coating vs. wavelength, λ . Radiation intensity 20 keV. Different integrated fluxes. 101-7 is a coating, similar to S-13 G, developed by NASA Goddard. From Fogdall, Cannaday Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	125
Figure 5-46: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of GSFC, 101-7 coating vs. wavelength, λ . Radiation intensity 80 keV. Different integrated fluxes. 101-7 is a coating, similar to S-13 G, developed by NASA Goddard. From Fogdall, Cannaday & Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	126
Figure 5-47: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of GSFC, 101-7 coating vs. wavelength, λ . Radiation intensity 20 keV. Recovery after exposure. 101-7 is a coating, similar to S-13 G, developed by NASA Goddard. From Fogdall, Cannaday & Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	127
Figure 5-48: Electrons exposure effects on normal-hemispherical spectral reflectance, ρ'_{λ} , of GSFC, 101-7 coating vs. wavelength, λ . Radiation intensity 80 keV. Recovery after exposure. 101-7 is a coating, similar to S-13 G, developed by NASA Goddard. From Fogdall, Cannaday Brown (1970) [43]. Drawn from Touloukian, DeWitt & Hernicz (1972) [126].	128
Figure 5-49: Effect of Combined Exposure on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G coating vs. wavelength, λ . Plasma annealed and potassium silicate treated pigment. From Gilligan & Zerlaut (1971) [46].	130
Figure 5-50: Effect of Combined Exposure, simulating up to three years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G/LO coating vs. wavelength, λ . From Paillous (1976) [96].	131

Figure 5-51: Effect of O ₂ bleaching, after Combined Exposure, on normal-hemispherical spectral reflectance, ρ'_{λ} , of S-13 G/LO coating vs. wavelength, λ . Curves of  and  are those shown in Figure 5-19. From Paillous (1976) [96].	132
Figure 5-52: Effect of Combined Exposure, simulating up to three years in geosynchronous orbit, on normal- hemispherical spectral reflectance, ρ'_{λ} , of S-13 G/LO coating vs. wavelength, λ . Curves of  and  are those shown in Figure 5-50. From Paillous (1976) [96].	133
Figure 5-53: Change in normal-hemispherical spectral absorptance, $\Delta\alpha'_{\lambda}$, of PSG 120 coating, due to Ultra-Violet Radiation, vs. exposure time, t . Wavelength, $\lambda = 0,46 \times 10^{-6}$ m. From Simon (1974) [118].	140
Figure 5-54: Change in normal-hemispherical spectral absorptance, $\Delta\alpha'_{\lambda}$, of PSG 120 coating, due to Ultra-Violet Radiation, vs. exposure time, t . Wavelength, $\lambda = 2,5 \times 10^{-6}$ m. Shaded zone in <i>a</i> is enlarged in <i>b</i> . See Explanation in the caption of Figure 5-53. From Simon (1974) [118].	141
Figure 5-55: Change in solar absorptance, $\Delta\alpha_s$, of PSG 120 coating, due to UV radiation, vs. exposure time, t . Shaded zone in <i>a</i> is enlarged in <i>b</i> . From Simon (1974) [118].	142
Figure 5-56: Estimated change in solar absorptance, α_s , of PSG 120 vs. time, t . From Paillous (1976) [96]. O: From Guillaumon & Guillin (1981) [52].	148
Figure 5-57: Bidirectional total radiation intensity of reflected flux, I'' , vs. cone angle, β' , for several values of the cone angle of the incident flux, β . PSG 120 coating. Incident and reflected fluxes are coplanar. I'' is measured by the response of a photocell attached to a photogoniometer. From ASTRAL (1976)a [6].	148
Figure 5-58: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Thick line: Before irradiation. $p < 1,3 \times 10^{-5}$ Pa. $T = 348$ K. Thin line: After irradiation. $p < 1,3 \times 10^{-5}$ Pa. $T = 348$ K. A Sun level. $t = 212$ ESH. From Simon (1973) [117].	149
Figure 5-59: Effect of Protons radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong 45$ keV. See Explanation in the caption of Figure 5-61. From Paillous, Amat, Marco & Panabiere (1977) [97].	150
Figure 5-60: Effect of Protons radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong 75$ keV. See Explanation in the caption of Figure 5-61. From Paillous, Amat, Marco & Panabiere (1977) [97].	151
Figure 5-61: Effect of Protons radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong 150$ keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	151
Figure 5-62: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong 40$ keV. See Explanation in the caption of Figure 5-63. From Paillous, Amat, Marco & Panabiere (1977) [97].	153
Figure 5-63: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong 80$ keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	153

Figure 5-64: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Radiation intensity $\cong$ 210 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	154
Figure 5-65: Change in normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating, due to particulate irradiation, vs. penetration range, X_d . Wavelength, $\lambda = 2,05 \times 10^{-6}$ m. From Bourrieau (1978) [19].	157
Figure 5-66: Effect of Combined Exposure, simulating up to three years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . From Paillous (1976) [96].	157
Figure 5-67: Effect of O ₂ bleaching, after Combined Exposure, on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSG 120 coating vs. wavelength, λ . Curves  and  are those shown in Figure 5-66. From Paillous (1976) [96].	158
Figure 5-68: Change in normal-hemispherical spectral absorptance, $\Delta\alpha'_{\lambda}$, of PSZ 184 coating, due to UV Radiation, vs. exposure time, t . Wavelength, $\lambda = 0,46 \times 10^{-6}$ m. See Explanation in the caption of Figure 5-69. From Simon (1974) [118].	166
Figure 5-69: Change in normal-hemispherical spectral absorptance, $\Delta\alpha'_{\lambda}$, of PSZ 184 coating, due to UV Radiation, vs. exposure time, t . Wavelength, $\lambda = 2,5 \times 10^{-6}$ m. From Simon (1974) [118].	167
Figure 5-70: Change in solar absorptance, $\Delta\alpha_s$, of PSZ 184 coating, due to UV Radiation, vs. exposure time, t . Shaded zone in <i>a</i> is enlarged in <i>b</i> . From Simon (1974) [118].	168
Figure 5-71: Estimated change in solar absorptance, α_s , of PSZ 184 vs. time, t . From Paillous (1976) [96].	173
Figure 5-72: Effect of Ultra-Violet Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating vs. wavelength, λ . Thick line: Before irradiation. $p < 1,3 \times 10^{-5}$ Pa. Thin line: After irradiation. $p < 1,3 \times 10^{-5}$ Pa. 1 Sun level. Neither sample temperature nor exposure time are given. From Simon (1974) [118].	174
Figure 5-73: Effect of Protons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating vs. wavelength, λ . <i>a</i> Coating on P 131 primer. <i>b</i> Coating on silicated primer. Radiation intensity $\cong$ 45 keV. See Explanation in the caption of Figure 5-74. From Paillous, Amat, Marco & Panabiere (1977) [97].	175
Figure 5-74: Effect of Protons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, on silicated primer, vs. wavelength, λ . Radiation intensity $\cong$ 75 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	176
Figure 5-75: Effect of Protons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, on silicated primer, vs. wavelength, λ . Radiation intensity $\cong$ 150 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	177
Figure 5-76: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, on silicated primer, vs. wavelength, λ . Radiation intensity $\cong$ 40 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	178
Figure 5-77: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, on silicated primer, vs. wavelength, λ .	

Radiation intensity $\cong$ 80 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	179
Figure 5-78: Effect of Electrons Radiation on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, on silicated primer, vs. wavelength, λ . Radiation intensity $\cong$ 210 keV. From Paillous, Amat, Marco & Panabiere (1977) [97].	180
Figure 5-79: Effect of Combined Exposure, simulating up to three years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, vs. wavelength, λ . From Paillous (1976) [96].	181
Figure 5-80: Effect of O ₂ bleaching, after Combined Exposure, on normal-hemispherical spectral reflectance, ρ'_{λ} , of PSZ 184 coating, vs. wavelength, λ . Curves  and  are those shown in Figure 5-79. From Paillous (1976) [96].	182
Figure 5-81: Solar absorptance, α_s , of PCBZ coating vs. UV Radiation exposure time, t . From Guillaumon (1982) [48].	189
Figure 5-82: Normal-hemispherical spectral reflectance, ρ'_{λ} , of PCBZ coating, sample A, vs. wavelength, λ . Effect of Ultra-Violet radiation.	192
Figure 5-83: Normal-hemispherical spectral reflectance, ρ'_{λ} , of PCBZ coating, sample C, vs. wavelength, λ . Effect of Ultra-Violet radiation.	193
Figure 5-84: Hemispherical total emittance, ε , of OCLI Type SI-100 Thermal Control Mirrors as a function of temperature, T . $\circ$:> From Breuch (1967) [22]. $\square$:> From Marshall & Breuch (1968) [80]. Δ :> From Cunningham, Grammer & Smith (1969) [33]. Uncertainty limits are from Marshall & Breuch (1968) [80].	201
Figure 5-85: Solar absorptance, α_s , of OCLI Type SI-100 Thermal Control Mirrors vs. incidence angle, β . The full lines in a correspond to the analytical geometries sketched in b. Circles are from solar reflectance measurements, and the dotted line is based on flight temperatures of the NEMS radiator. From Stultz (1976) [123].	203
Figure 5-86: Change in solar absorptance, $\Delta\alpha_s$, of OCLI Type SI-100 Thermal Control Mirror vs. incidence angle, β , as deduced from data of COMSTAR D-1, D-2 and D-3 satellites. The envelopes contain all the data points. $\circ$:> Integrated sphere spectrophotometer measurements made on a single mirror. From Hyman (1981) [62].	204
Figure 5-87: Change in solar absorptance, $\Delta\alpha_s$, of OCLI Type SI-100 Thermal Control Mirrors vs. exposure time, t .	207
Figure 5-88: Solar absorptance, α_s , of OSR Fused Silica Mirrors vs. orbital time, t , as deduced from data of NavStar 5.	215
Figure 5-89: Solar absorptance, α_s , of OCLI Type SI-100 Thermal Control Mirrors vs. exposure time, t , as deduced from data of COMSTAR D-1, D-2 and D-3 satellites.  : Derived from> temperature telemetry.  : Corrected to> normal solar incidence.	220
Figure 5-90: Solar absorptance, α_s , of OCLI Type SI-100 Thermal Control Mirrors vs. exposure time, t , as deduced from data of SCATHA spacecraft.	223
Figure 5-91: Change in solar absorptance, $\Delta\alpha_s$, of OCLI Type SI-100 Thermal Control Mirrors vs. exposure time, t , as deduced from data of HELIOS-A and B spacecraft.	227

Figure 5-92: Summary data on the change in solar absorptance, $\Delta\alpha_s$, of OCLI Type SI-100 Thermal Control Mirrors vs. exposure time, t .	229
Figure 5-93: Normal-hemispherical spectral reflectance, ρ'_λ , of OCLI Type SI-100 Thermal Control Mirrors vs. wavelength, λ . From Cunningham, Grammer & Smith (1969) [33].	230
Figure 5-94: Effect of Ultra-Violet radiation on normal-hemispherical spectral reflectance, ρ'_λ , of OCLI Type SI-100 Thermal Control Mirrors vs. wavelength, λ . From Cunningham, Grammer & Smith (1969) [33].	231
Figure 5-95: Effect of Combined Exposure, simulating up to seven years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_λ , of OCLI Type SI-100 Thermal Control Mirrors vs. wavelength, λ . a Bonded sample. b Sample fastened bare. From Paillous (1975) [95].	240
Figure 5-96: Effect of Combined Exposure, simulating up to seven years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_λ , of OCLI Type SI-100 Thermal Control Mirrors vs. wavelength, λ . Sample fastened bare. From Paillous (1975) [95].	241
Figure 5-97: Solar absorptance, α_s , of OCLI Type CC-SSM vs. incidence angle, β . Circles are calculated values. From Winkler & Stampfl (1975) [139].	255
Figure 5-98: Estimated change in solar absorptance, $\Delta\alpha_s$, of OCLI Type CC-SSM vs. exposure time, t . The tests simulate geosynchronous orbit exposure of the Orbital Test Satellite (OTS) equatorial faces.	256
Figure 5-99: Change in solar absorptance, $\Delta\alpha_s$, of OCLI Type CC-SSM vs. exposure time, t . The insert shows the changes in α_s which suddenly results when ultra-violet exposure, at 16 Suns, begins.	258
Figure 5-100: Solar absorptance, α_s , of OCLI Type CC-SSM vs. exposure time, t as deduced from data of SCATHA spacecraft.	260
Figure 5-101: Change in solar absorptance, $\Delta\alpha_s$, of OCLI Type CC-SSM vs. exposure time, t as deduced from data of HELIOS-A and B spacecraft. Line of circles: First HELIOS-A orbit. Simplified model of data analysis.	261
Figure 5-102: Summary on the change in solar absorptance, $\Delta\alpha_s$, of OCLI Type CC-SSM vs. exposure time, t . The estimated values of the initial solar absorptance, α_{so} , are shown near each curve.	262
Figure 5-103: Effect of Combined Exposure, simulating up to three years in geosynchronous orbit, on normal-hemispherical spectral reflectance, ρ'_λ , of OCLI Type CC-SSMs vs. wavelength, λ . From Paillous (1976) [96].	263
Figure 5-104: a. Electrical resistance, R , of six CC-SSM samples as a function of temperature, T . b shows the two alternative configurations of the electrical contacts set for performing the measurements. From Joslin & Kan (1975) [67].	264
Figure 5-105: a. Sheet electrical resistance, R , of three OCLI Type CC-SSMs vs. time in simulated geosynchronous orbit, t . b. Configuration of the electrical contacts and position of the mirrors on the sample holder for irradiation and measurements. From Paillous (1976) [96].	269
Figure 5-106: Normal-hemispherical spectral reflectance, ρ'_λ , of Fuller 172A1, vs. wavelength, λ . From Touloukian, DeWitt & Hernicz (1972) [126].	277

Figure 5-107: Normal-hemispherical spectral reflectance, ρ'_{λ} , of Fuller 172A1, exposed to gamma radiation, vs. wavelength, λ . From Touloukian, DeWitt & Hernicz (1972) [126].	278
Figure 5-108: Normal-hemispherical spectral reflectance, ρ'_{λ} , of Kemacryl M49BC12, vs. wavelength, λ . From Touloukian, DeWitt & Hernicz (1972) [126].	281
Figure 5-109: Normal-hemispherical spectral reflectance, ρ'_{λ} , of Kemacryl M49BC12, exposed to gamma radiation, vs. wavelength, λ . Points of white circles are those represented in Figure 5-108. From Touloukian, DeWitt & Hernicz (1972) [126].	282
Figure 6-1: Peel force, probe tack and rolling ball tack, F , as functions of resin concentration, c , for a rubber adhesive on a polyethylene terephthalate (polyester) film.	284
Figure 6-2: Peel adhesion, F/w , measured at 393 K as a function of curing temperature, T . Rubber based adhesive. From Toyama & Ito (1974) [127].	285
Figure 6-3: Space degradation of second surface mirrors based on $1,27 \times 10^{-4}$ m thick FEP Teflon. All data are from Triolo (1973) [128] except those corresponding to IMP-I which are from Hoffman (1973) [61].	303
Figure 6-4: Sketch of a blistering tape. From Brown & Merschel (1970) [23].	304
Figure 6-5: Solar absorptance, α_s , vs. total hemispherical emittance, ε , of several thermal control tapes.	307

Tables

Table 5-1: Ultra-Violet Radiation Effects on Spectral Absorptance of Thermatrol 2A-100.	27
Table 5-2: Solar Absorptance of Zinc Oxide-Potassium Silicate Paint	34
Table 5-3: Ultra-Violet Radiation Effects on Spectral Absorptance of Zinc Oxide-Potassium Silicate Paint.	36
Table 5-4: Ultra-Violet Radiation Effects on Solar Absorptance of Zinc Oxide-Potassium Silicate Paint	43
Table 5-5: Literature Search for Thermal radiation Properties of ZOT Coatin	55
Table 5-6: Solar Absorptance of Zinc Orthotitanate-Potassium Silicate Coatings ^a	61
Table 5-7: Ultra-Violet Radiation Effects on Solar Absorptance of Zinc Orthotitanate-Potassium Silicate Coatings ^a	63
Table 5-8: Hemispherical Total Emittance of S-13 and S-13 G Coating	85
Table 5-9: Ultra-Violet Radiation Effects on Hemispherical Total Emittance of S-13 and S-13 G Coating	86
Table 5-10: Normal Total Emittance of S-13 G and S-13 G-LO Coatings	88
Table 5-11: Ultra-violet radiation effects on spectral absorptance of S-13 coating (samples 27 & 28)	90
Table 5-12: Ultra-Violet Radiation Effects on Solar Absorptance of S-13 and S-13 G Coatings	93
Table 5-13: Combined Exposure Effects on Solar Absorptance of S-13 G/LO Coating	102
Table 5-14: Outgassing Characteristics of PSG 120 Coating	138

Table 5-15: Protons Radiation Effects Solar Absorptance of PSG 120 Coating	144
Table 5-16: Electrons Radiation Effects on Solar Absorptance of PSG 120 Coating	145
Table 5-17: Combined Exposure Effects on Solar Absorptance of PSG120 Coating	146
Table 5-18: Application of the Degradation Model to PSG 120 Coating	156
Table 5-19: Test Conditions Simulating up to Three Years in Geosynchronous Orbit	159
Table 5-20: Hemispherical Total Emittance, ε , and Solar Absorptance, α_s , of PSZ 184	165
Table 5-21: Protons Radiation Effects on Solar Absorptance of PSZ 184 Coating	169
Table 5-22: Electrons Radiation Effects on Solar Absorptance of PSZ 184 Coating	170
Table 5-23: Combined Exposure Effects on Solar Absorptance of PSZ 184 Coating	171
Table 5-24: Outgassing Characteristics of PCB Z Coating	187
Table 5-25: Ultra-Violet Radiation Effects on Solar Absorptance of PCBZ Coating	189
Table 5-26: Charging Tests with PCBZ Coating	194
Table 5-27: Candidate Adhesives for OSR Fused Silica Application	198
Table 5-28: Ultra-Violet Radiation Effects on Spectral Absorptance of OCLI Type SI-100 Thermal Control Mirrors	205
Table 5-29: Test Conditions Simulating up to Seven Years in Geosynchronous Orbit	232
Table 5-30: Combined Exposure Effects of Reflectance of OCLI Type SI-100. Thermal Control Mirrors.	234
Table 5-31: Charging-Arcing Tests with OCLI Type SI-100 Thermal Control Mirrors	243
Table 5-32: Normal Total Emittance, ε' , and Solar Absorptance, α_s , of Several OCLI Type Thermal Control Mirrors	255
Table 5-33: Effects of Simulated Geosynchronous Orbit Exposure on Solar Absorptance of OCLI Type CC-SSM	257
Table 5-34: Protons (Electrons) Only Exposure Effects on Sheet Resistance of OCLISolar Cell Cover Slides	265
Table 5-35: Protons (Electrons) Only Exposure Effects on Resistance of Conductive Coated Fused Silica	266
Table 5-36: Change in the Specific Electrical Cross Resistance, ρ_c , of OCLI Type CC-SSMs by Outgassing Silastic Materials	268
Table 5-37: Charging Tests with OCLI Type CC-SSMs	271
Table 5-38: Hemispherical Total Emittance and Solar Absorptance of Leafing Aluminium-Silicone	275
Table 5-39: Hemispherical Total Emittance and Solar Absorptance of Carbon Black-Acrylic Resin	280
Table 6-1: Thermosetting Cure Cycles and Useful Temperature Range of Several MYSTIK Adhesive Tapes.	286
Table 6-2: Properties of Double-Faced Adhesive Tapes ^a	287
Table 6-3: Properties of Unsupported Adhesive Tapes ^a	296
Table 6-4: Several Solvents of the Adhesives	299
Table 6-5: Rubbing Degradation of the Optical Properties of Aluminized Films	299

Table 6-6: Thermal radiation Properties of Second Surface Silver-Teflon ($1,27 \times 10^{-4}$ m thick)	301
Table 6-7: Exposure Conditions of Silver-Teflon on IMP-I Spacecraft.....	304
Table 6-8: Blistering Temperatures of Tapes Applied to an Aluminium Substrate ^a	305
Table 6-9: Properties of First Surface Metallized Tapes ^a	308
Table 6-10: Properties of Second Surface Metallized Tapes ^a	314
Table 6-11: Properties of Clear Tapes ^a	324
Table 6-12: Mass-Area Ratio of Several Foils and Tapes.....	328
Table 6-13: Characteristics of Low-Outgassing Tapes ^a	329

European Foreword

This document (CEN/CLC/TR 17603-31-06:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-31.

This Technical report (TR 17603-31-06:2021) originates from ECSS-E-HB-31-01 Part 6A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

1

Scope

This Part 6 of the spacecraft thermal control and design data handbooks, provides information on coatings on spacecrafts for the purposes of thermal and thermo-optical regulation.

Properties of pigmented and contact coatings, are described and are classified according to their thermal radiation characteristics.

Also included in this Part are the properties and characteristics of foils and tapes with particular emphasis on their adhesive characteristics; these are not classified according to their thermal radiation properties.

The Thermal design handbook is published in 16 Parts

TR 17603-31-01	Thermal design handbook – Part 1: View factors
TR 17603-31-02	Thermal design handbook – Part 2: Holes, Grooves and Cavities
TR 17603-31-03	Thermal design handbook – Part 3: Spacecraft Surface Temperature
TR 17603-31-04	Thermal design handbook – Part 4: Conductive Heat Transfer
TR 17603-31-05	Thermal design handbook – Part 5: Structural Materials: Metallic and Composite
TR 17603-31-06	Thermal design handbook – Part 6: Thermal Control Surfaces
TR 17603-31-07	Thermal design handbook – Part 7: Insulations
TR 17603-31-08	Thermal design handbook – Part 8: Heat Pipes
TR 17603-31-09	Thermal design handbook – Part 9: Radiators
TR 17603-31-10	Thermal design handbook – Part 10: Phase – Change Capacitors
TR 17603-31-11	Thermal design handbook – Part 11: Electrical Heating
TR 17603-31-12	Thermal design handbook – Part 12: Louvers
TR 17603-31-13	Thermal design handbook – Part 13: Fluid Loops
TR 17603-31-14	Thermal design handbook – Part 14: Cryogenic Cooling
TR 17603-31-15	Thermal design handbook – Part 15: Existing Satellites
TR 17603-31-16	Thermal design handbook – Part 16: Thermal Protection System

2 References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms
TR 17603-31-09	ECSS-E-HB-31-01 Part 9	Thermal design handbook – Part 9: Radiators
TR 17603-31-12	ECSS-E-HB-31-01 Part 12	Thermal design handbook – Part 12: Louvers
TR 17603-31-15	ECSS-E-HB-31-01 Part 15	Thermal design handbook – Part 15: Existing Satellites

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in ECSS-S-ST-00-01 apply.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

AU	astronomical unit, 1 AU = 1,495x10 ¹¹ m
CC	conductive coated
COP	coprecipitation
CVCM	collected volatile condensable materials
ESH	equivalent sun hours
EWB	equivalent (solar) wind hours
GY	gray, 1 GY = 1 J.kg ⁻¹
IR	infrared
ITO	indium-tin oxide
LDEF	long duration exposure facility
MLI	multilayer insulation
MOX	mixed oxalate process
OSR	optical solar reflector
PBR	pigment to binder ratio by weight
RML	remainder mass loss
RMS	root mean square

RTV	room temperature vulcanizing
SCATHA	spacecraft charging at high altitudes
SSM	second surface mirror
SSR	solid state reaction
TML	total mass loss
TWL	total weight loss
UV	ultra-violet
VCM	volatile condensable materials

3.3 Symbols

A	area of the sensor, [m ²]
C	conductive thermal coupling constant between sensor and tray, [W.K ⁻¹]
D	irradiation dose, [GY/particle]
F	view factor from the sun
F	adhesive force, [N]
F_a	view factor for Albedo
F_{sp}	view factor for earth infrared radiation
K	radiative thermal coupling constant between sensor and tray, [W.K ⁻⁴]
P	earth infrared radiation, [W.m ⁻²]
Q	heat transfer rate through sensor insulation from external sources, [W]
Q_i	internal dissipated power or heat load, [W]
R	sheet electrical resistance, [Ω per square, Ω /square]
S	solar flux, [W.m ⁻⁴]
T	temperature, [K]
T_R	equilibrium temperature for an isothermal sphere at 1 AU, [K]

T_c	tray or sample-housing temperature, [K]
T_s	equivalent surrounding temperature, [K]
T_{max}	maximum temperature, [K]
T_{min}	minimum temperature, [K]
X_d	irradiation penetration range, [kg.m ⁻²]
X_u	photon absorption and scattering range, [kg.m ⁻²]
a	mean Albedo of the Earth
c	specific heat of a sample, [J.kg ⁻¹ .K ⁻¹]
c	resin concentration in an adhesive
p	pressure, [Pa]
t	thickness, [m]
t_c	coating thickness, [m]
t	time, [h] or [ESH]
n	number of experimental data points
w	width, [m]
α	hemispherical total absorptance
α_p	Earth infrared radiation absorptance
α_s	solar absorptance
$\alpha'_{\lambda}(\lambda, \beta, \theta)$	directional-hemispherical spectral absorptance
β	angle between surface normal and direction of incident flux, [angular degrees]
β	angle between surface normal and direction of emitted, reflected or transmitted flux, [angular degrees]
ε	hemispherical total emittance
$\varepsilon'(\beta', \theta')$	directional total emittance
θ	azimuthal angle of incident flux, [angular degrees]
θ'	azimuthal angle of emitted, reflected or transmitted flux, [angular degrees]
λ	wavelength, [m]

ρ	electrical resistivity, [$\Omega \cdot m$]
ρ_c	specific electrical cross resistance, [$\Omega \cdot m^2$]
ρ_s	solar reflectance
ρ_{sIR}	solar reflectance in the infrared range
ρ_{sUV}	solar reflectance in the UV range
ρ_{sV}	solar reflectance in the visible range
$\rho'_\lambda(\lambda, \beta, \theta)$	directional-hemispherical spectral reflectance
σ	Stefan-Boltzmann constant, $\sigma = 5,6697 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$
σ	standard deviation
ω	solid angle of incident radiation beam, [steradians]
ω'	solid angle of emitted, reflected or transmitted radiation beam, [steradians]

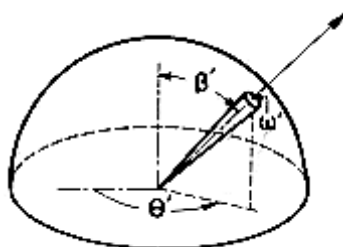
Subscripts

o	refers to initial values
f	refers to after-exposure values

Superscripts

—	mean value
---	------------

Angles used to define directional emittance.



Angles used to define bidirectional reflectance.

4

General introduction

A coating consists of a layer (or layers) of any substance (s) upon a substrate.

Optical coatings have been used to control the temperature of satellites since the first successful orbital flight in 1958. Since then coating materials have been developed to the point where reasonably stable coatings are available, that give any desired value of the hemispherical total emittance, ε , between 0,1 and 0,9 for any desired value of the solar absorptance, α_s , between 0,1 and 0,9.

According to Touloukian, DeWitt & Hernicz (1972) [126] three types of coatings can be identified:

1. Pigmented coatings which are mixtures of a pigment and a vehicle.
2. Contact coatings, formed by layers of a substance coated on a substrate without chemical reaction occurring between the coating material and the substrate.
3. Conversion coatings which are layers of compounds formed by a chemical reaction of the substrate with another material.

Figure 4-1, from Touloukian et al. (1972) [126] is a plot of solar absorptance, α_s , vs. hemispherical total emittance, ε . For each ray from the origin two values are given. The first one, T_R , is the equilibrium temperature for an isothermal sphere at 1 AU; the second value is the ratio α_s/ε .

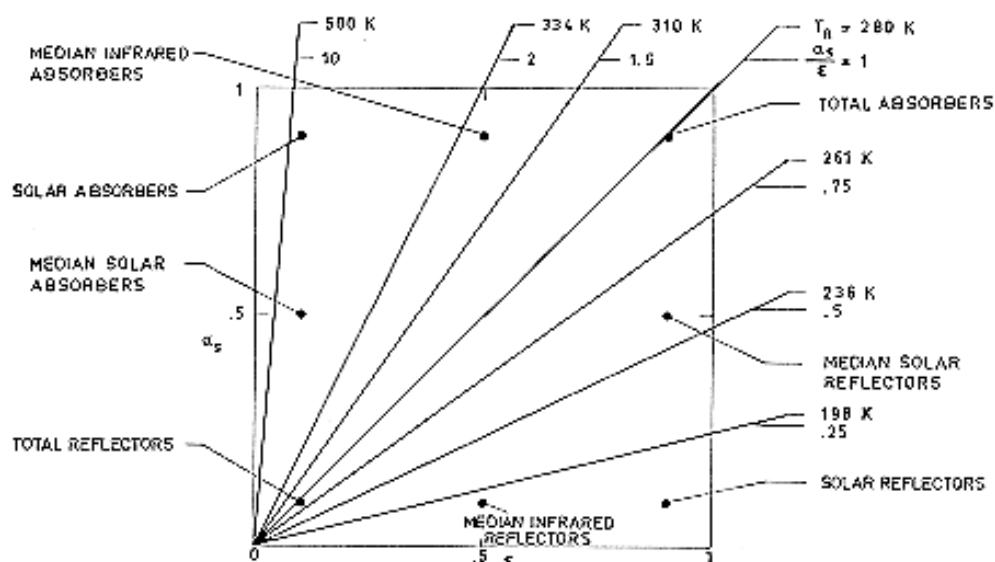


Figure 4-1: Basic types of thermal control coatings. T_R [K] is the equilibrium temperature of a coated isothermal sphere at 1 AU. From Touloukian, DeWitt & Hernicz (1972) [126].

Figure 4-2, from the same source, indicates how to obtain the various types of surfaces exhibiting the characteristics shown in the previous figure.

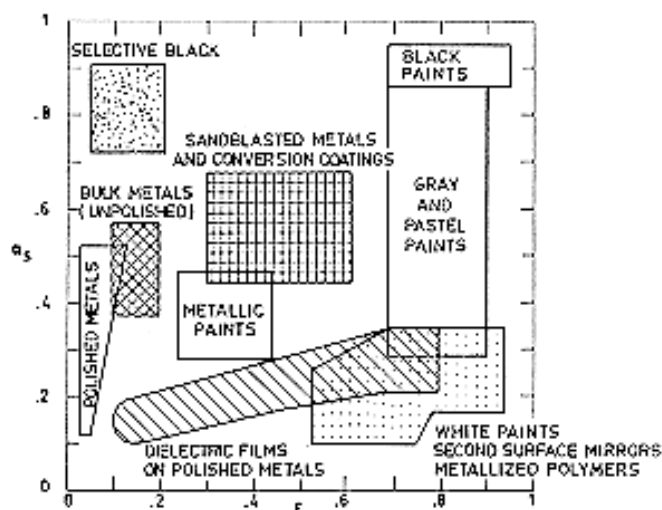


Figure 4-2: Range of solar absorptance, α_s , and hemispherical total emittance, ϵ , covered by available thermal control coatings. From Touloukian, DeWitt & HERNICZ (1972) [126].

The basic requirement for a coating to be used in spacecraft is long-term space stability for periods of months and even of years. This objective, however, has not yet been achieved in many instances.

The problem of selecting the specific coating for a given α_s/ϵ is somewhat circumvented by the use of mosaics or coating patterns, normally combining white and black paints. Nevertheless, the possibility of using a single paint should not be lay aside; for example, Triolo (1973) [128] reports that encouraging results have been obtained by using green paints to take the place of white and black paint patterns.

This data item, which is intended to give information on several pigmented and contact coatings, has two clearly different parts. In the first one data concerning several coating materials are gathered. These coatings are classified according to their thermal radiation characteristics.

The second part deals with coated foils and tapes. The main characteristic of these coating is that they are flexible and can be applied to a surface by mere pressure, although a double-faced adhesive tape can be used in several case. Since ease of application and removal is the peculiar feature of these coatings, particular emphasis has been placed on their adhesive characteristics.

No attempt has been made to classify foils and tapes according to their thermal radiation properties. On the other hand, this classification is by no means obvious in several cases. For example: Series Emittance Tapes are coatings whose emittance is controlled by the thickness of a Teflon Type A film, and their solar absorptance by a metallic second surface. By choosing the proper Teflon thickness and the appropriate metal it is possible to specify a thermal control surface within a wide range of α_s/ϵ values.

In addition to the data collected here, information concerning aluminium coating can be found in G, Clause 5.2.

5 Coatings

5.1 General

The data concerning each coating have been arranged, whenever possible and meaningful, as indicated below. When no data on a given property are available the corresponding heading has been normally omitted.

1. COMPOSITION

2. FORMULATION

3. USUAL DESIGNATION

4. SUBSTRATE

5. METHOD OF APPLICATION

5.1. Preparation of paint for application

5.2. Preparation of surfaces for painting

5.3. Application of paint

5.4. Coating thickness

5.5. Curing process

6. SOLVENTS RESISTANCE

7. PHYSICAL PROPERTIES

7.1. Density

7.2. Outgassing

7.3. Thermal radiation properties

7.3.1. Emittance

7.3.1.1. Hemispherical total emittance

7.3.1.2. Variation of hemispherical total emittance with coating thickness

7.3.1.3. Effects of the space environment on hemispherical total emittance

7.3.1.3.1. Ultra-violet radiation

7.3.2. Absorptance

7.3.2.1. Solar absorptance

7.3.2.2. Variation of solar absorptance with coating thickness

7.3.2.3. Variation of solar absorptance with incidence angle

7.3.2.4. Earth albedo normal absorptance

7.3.2.5. Effects of space environment on absorptance

7.3.2.5.1. Ultra-violet radiation

7.3.2.5.2. Gamma radiation

7.3.2.5.3. Protons only exposure

7.3.2.5.4. Electrons only exposure

7.3.2.5.5. Contamination

7.3.2.5.6. Combined exposure

7.3.2.6. Effects of the space environment on solar absorptance to emittance ratio

7.3.3. Reflectance

7.3.3.1. Normal-hemispherical spectral reflectance

7.3.3.2. Effects of the space environment on reflectance

7.3.3.2.1. Ultra-violet radiation

7.3.3.2.2. Gamma radiation

7.3.3.2.3. Protons only exposure

7.3.3.2.4. Electrons only exposure

7.3.3.2.5. Contamination

7.3.3.2.6. Combined exposure

7.4. Electrical resistance

7.4.1. Effects of temperature on electrical resistance

7.4.2. Effects of the space environment on electrical resistance

7.4.2.1. Ultra-violet radiation

7.4.2.2. Gamma radiation

7.4.2.3. Protons only exposure

7.4.2.4. Electrons only exposure

7.4.2.5. Contamination

7.4.2.6. Combined exposure

7.4.3. Charging

8. ENVIRONMENTAL BEHAVIOR

8.1. Prelaunch

8.2. Postlaunch

8.2.1. Ascent

8.2.2. Orbital

9. THERMAL CYCLING

10. SOURCE

11. COST

12. PAST SPATIAL USE

5.2 Solar reflectors

5.2.1 Titanium Dioxide-Polymethyl Vinyl Siloxane

1. COMPOSITION

Pigment: Titanox Ra-NC, Titanium Pigment Corp. proprietary, calcined rutile TiO_2 , 93% TiO_2 .

Vehicle: Dow-Corning proprietary, Q 92-007. 33% nonvolatile content by weight after 24 h at 343 K.

From Cunningham, Grammer & Smith (1969) [33], Cunningham (1974) [32].

2. FORMULATION

1:1 by weight of pigment and vehicle (Cunnington et al. (1969) [33]).

3. USUAL DESIGNATION

LMSC/Dow-Corning Thermatrol 2A-100.

4. SUBSTRATE

Any clean substrate, either rigid or non-rigid (Breuch (1967) [22]).

5. METHOD OF APPLICATION

5.2. Preparation of surfaces for painting. The entire surface is primed with one coat of silicone primer, Dow Corning Corp. A-4094 or equivalent, to a thickness of approximately 5×10^{-6} m. The primer is air cured 30 min minimum prior to application of top coats.

5.3. Application of paint. By spray techniques.

5.4. Coating thickness. For internal application, where emittance is of primary interest, a minimum thickness of $2,54 \times 10^{-5}$ m should be maintained. For external surfaces, where both α_s and ε are important, the minimum thickness for opacity is $0,9 \times 10^{-4}$ to $1,3 \times 10^{-4}$ m.

5.5. Curing process. 24 h minimum at room temperature and normal pressure, after final coat.

From Breuch (1967) [22], Cunningham, Grammer & Smith (1969) [33].

6. SOLVENTS RESISTANCE

The following data, concerning resistance of elastomeric silicones to chemical attack, have been reported by the producer of the vehicle.

Solvent and Fuels (after 7 d at room temperature) Volume Variation (per cent)

Acetone.....15 to 25

Carbon tetrachloride.....above 150

Ethyl alcohol.....0 to 20

Isooctane.....above 150

Xylene.....above 150

B type fuel.....above 150

JP-4 jet fuel.....above 150

Oils (after 70 h at $T = 423$ K)

ASTM No. 1 Oil.....5 to 10

ASTM No. 3 Oil.....35 to 60

Hydraulic fluid Mil-0-5606 (Univis J-43)..... above 150

Oronite 8200 (silicate ester)..... above 150

From DOW-CORNING (1970) [37].

7. PHYSICAL PROPERTIES

7.1. Density. 1500 kg.m^{-3} after curing (Cunnington et al. (1969) [32]).

7.2. Outgassing. Negligible after coating has been fully cured (Cunnington, Grammer & Smith (1969) [33]).

7.3. Thermal radiation properties

7.3.1. Emittance.

7.3.1.1. Hemispherical total emittance.

$T \text{ [K]}$	ϵ^a	ϵ^b
295	$0,86 \pm 0,03$	0,84
395	$0,86 \pm 0,02$	0,84

^a Determined calorimetrically. Chamber pressure: $1,33 \times 10^{-5} \text{ Pa}$.

^b From spectral reflectance data in the range 2×10^{-6} to $2,5 \times 10^{-5} \text{ m}$ and the blackbody function corresponding to the temperature quoted.

NOTE From Cunnington et al. (1969) [33].

7.3.1.3. Effects of the Space Environment on hemispherical total emittance.

7.3.1.3.1. Ultra-Violet Radiation.

$t[\text{h}]$	0,25	5	69	117	168	250	360	410	457	486	550
ϵ	0,87	0,87	0,87	0,85	0,88	0,88	0,87	0,85	0,86	0,85	0,85

Degrading Source: 2×10^{-7} to 4×10^{-7} Xenon lamp, 1 Sun level.

Method of obtaining data: Calorimetric. Chamber pressure: $1,33 \times 10^{-5} \text{ Pa}$.

Probe temperature 395 K.

t , exposure time.

From Cunnington et al. (1969) [32].

7.3.2. Absorptance.

7.3.2.1. Solar Absorptance.

T [K]	α_s
278	$0,16 \pm 0,03^a$
295	$0,15 \pm 0,02^b$
389	$0,16 \pm 0,03^a$
395	$0,18 \pm 0,01^b$

^a From Breuch (1967) [22].^b From Cunningham, Grammer & Smith (1969) [33].

7.3.2.5. Effects of the Space Environment on absorptance.

7.3.2.5.1. Ultra- Violet Radiation. Laboratory data concerning the effects of UV radiation on spectral absorptance are given in Table 5-1. Calculated values of α_s are also included.

Table 5-1: Ultra-Violet Radiation Effects on Spectral Absorptance of Thermatrol 2A-100.

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
395	0,25	0,70	0,12	0,07	0,13	0,18	0,18
395	5	0,70	0,17	0,07	0,19	0,21	0,21
395	69	0,85	0,25	0,16	0,22	0,29	0,29
395	117	0,85	9,24	0,18	0,26	0,30	0,31
395	168	0,85	0,25	0,18	0,28	0,31	0,32
395	360	0,80	0,24	0,17	0,27	0,29	0,31
395	410	0,85	0,25	0,18	0,26	0,30	0,31
395	457	0,85	0,24	0,18	0,26	0,30	0,31
395	486	0,90	0,25	0,18	0,27	0,31	0,32
395	550	0,90	0,25	0,19	0,27	0,31	0,32
Before Exposure ^a		0,69	0,08	0,06	0,07	0,14	0,15
After Exposure ^a		0,79	0,27	0,15	0,13	0,24	0,26

^a Values deduced from spectral reflectance data.

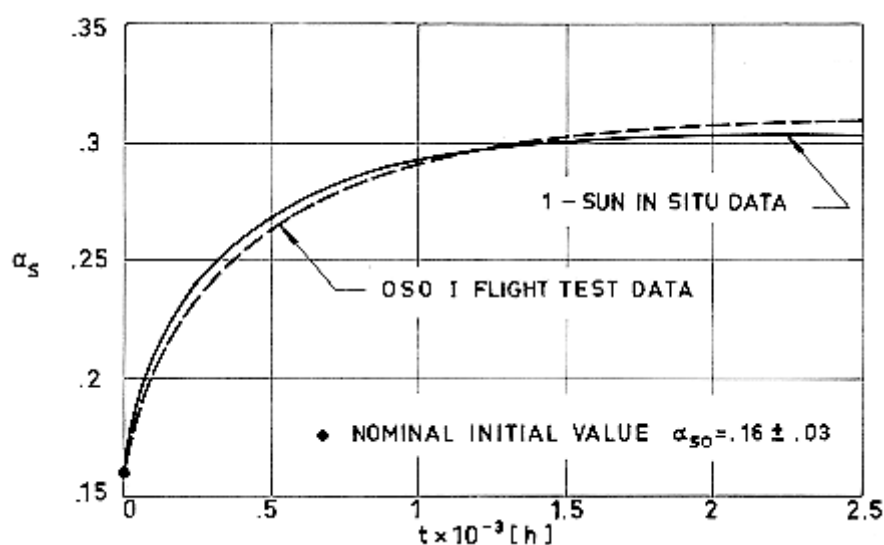
Degrading Source: 2×10^{-7} to 4×10^{-7} Xenon lamp, 1 Sun level.

Method of obtaining data: Calorimetric in situ absorptance.

Chamber pressure: $1,33 \times 10^{-5}$ Pa.

From Cunningham, Grammer & Smith (1969) [33].

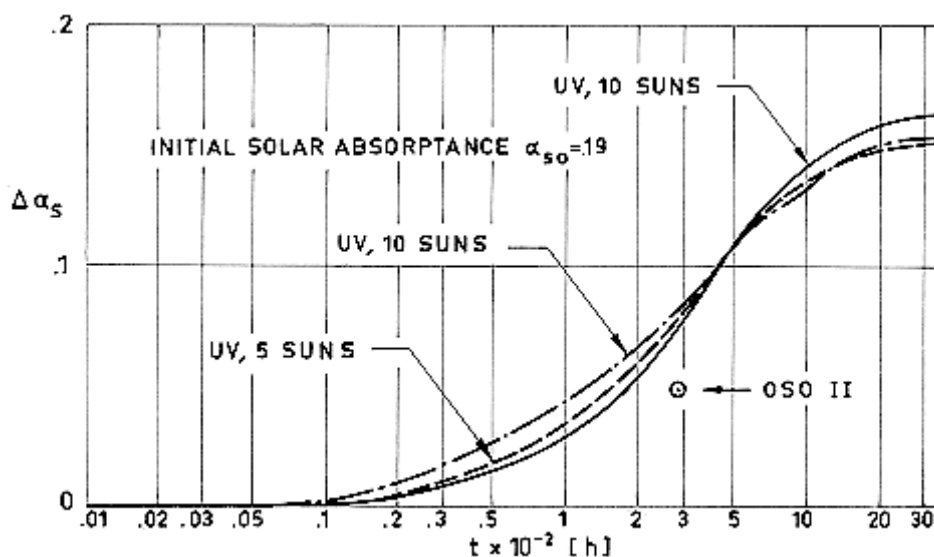
Similar laboratory data are compared with those corresponding to orbital flight in Figure 5-1.



Note: non-si units are used in this figure

Figure 5-1: UV radiation effects on solar absorptance, α_s , of Thermatrol 2A-100 vs. exposure time, t . From Breuch (1967) [22].

The influence of different radiation conditions on the degradation of solar absorptance is represented in Figure 5-2. It can be deduced from this figure that the intensity of the radiating source does not affect significantly the results, since the difference between the curves labeled 5 Suns and 10 Suns seems to be smaller than the experimental error.

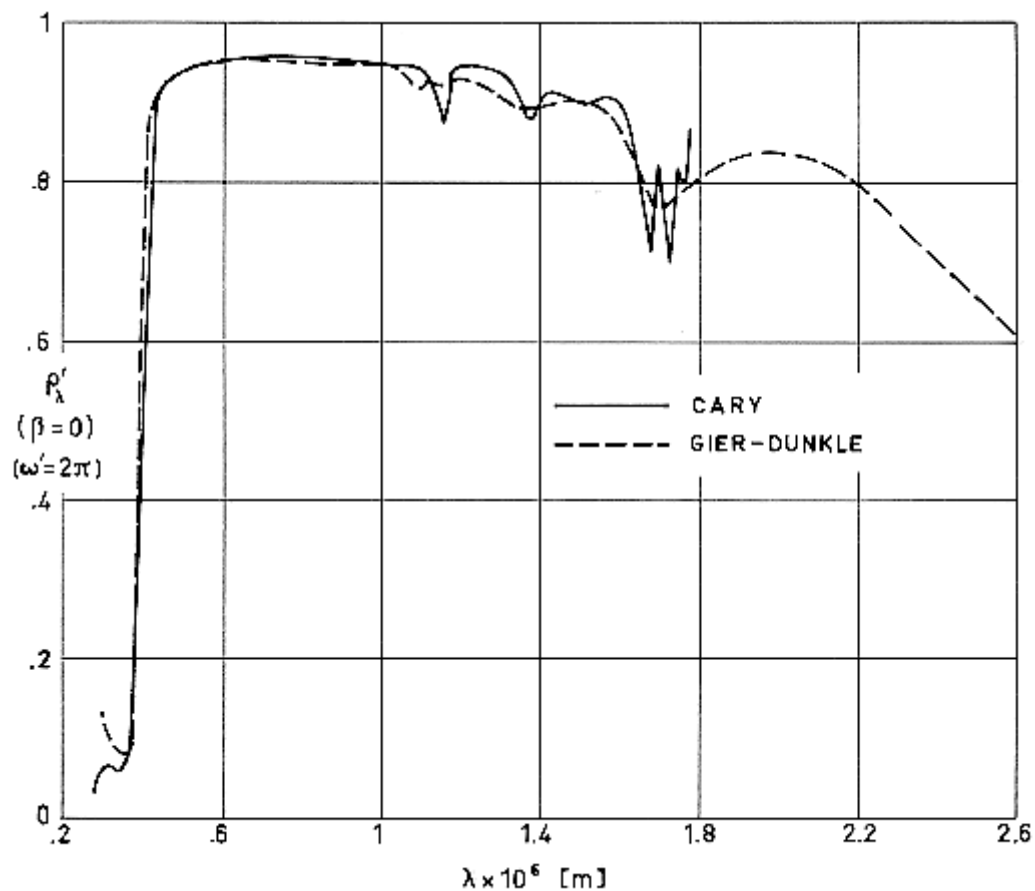


Note: non-si units are used in this figure

Figure 5-2: Change in solar absorptance, $\Delta\alpha_s$, of Thermatrol 2A-100, under various radiation conditions, vs. exposure time, t . From McCargo et al. (1971) [82].

7.3.3. Reflectance.

7.3.3.1. Normal-hemispherical spectral reflectance: Figure 5-3.

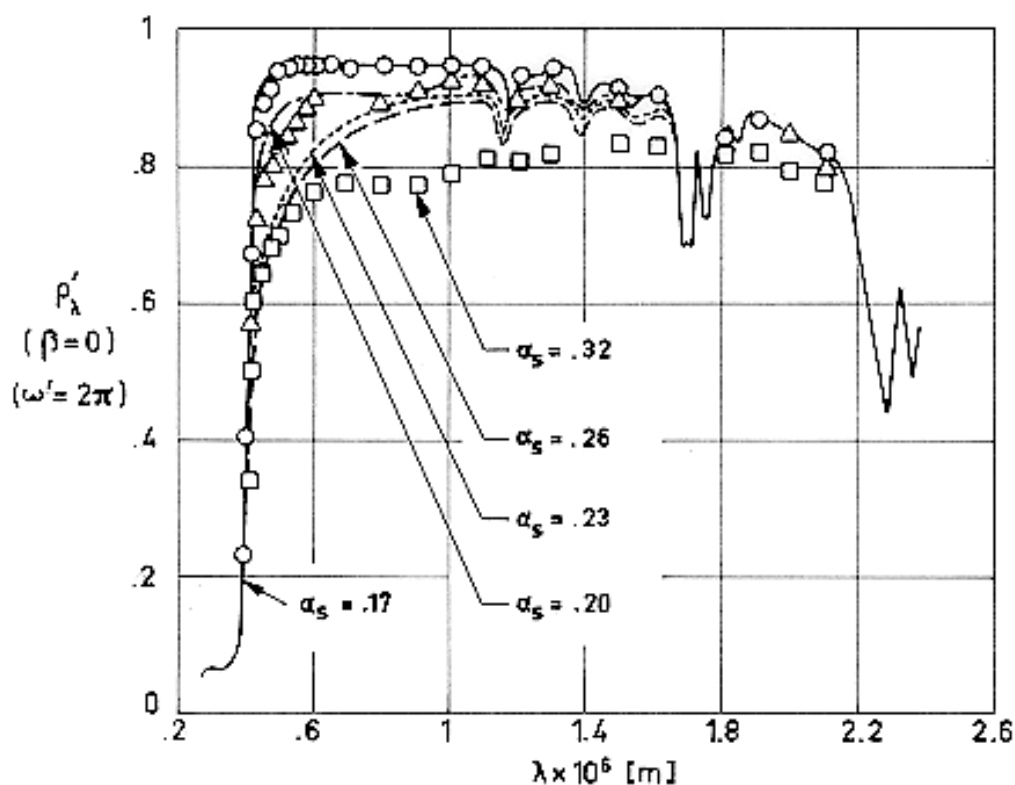


Note: non-si units are used in this figure

Figure 5-3: Normal-hemispherical spectral reflectance, ρ'_λ , of Thermatrol 2A-100, measured by two different methods, vs. wavelength, λ . From Cunningham, Grammer & Smith (1969) [33].

7.3.3.2. Effects of the Space Environment on reflectance.

7.3.3.2.1. Ultra-Violet Radiation: Figure 5-4.



Note: non-si units are used in this figure

Figure 5-4: Effect of Ultra-Violet Radiation on spectral reflectance, ρ_{λ}' , of Thermatrol 2A-100 vs. wavelength, λ . Most of the data, concerning bidirectional reflectance, are from Rittenhouse & Singletary (1969) [105], while dashed line and dotted line, normal-hemispherical reflectance, are from Cunningham, Grammer & Smith (1969) [33].

Explanation

Key	Description	Comments
—		$T = 313$ K. Near-normal reflectance (Cary).
○		$T = 313$ K. Measured in vacuum ($6,65 \times 10^{-5}$ Pa).
□		Same as ○ except exposed to UV radiation (PEK Type C(A-H6) lamp, 20 Suns). ESH 1330. During exposure $p = 9,3 \times 10^{-5}$ Pa.
△		Same as □ except sample in air at 40 Pa for 24 h after exposure.
—•—		Same as — except exposed to the same radiation as □.

Key	Description	Comments
— —	6061-T6 Al substrate polished and then machined to a $(30 \pm 3) \times 10^{-6}$ m RMS finish.	$T = 395$ K. Exposed to UV radiation (900 W Hanovia, Xenon lamp, 1 Sun) ESH 550. Sample in air for 5 min after exposure.
.....	Same as — — .	Same as — — .> Sample in air for 30 min.

8. ENVIRONMENTAL BEHAVIOR

8.1. Prelaunch. The surface is soft and rubbery and should be protected from abrasion or scratches. Since this paint is electrostatic, contamination should be avoided.

8.2. Postlaunch. In order to avoid blistering during ascent heating, the paint is be cured, at room temperature, at least for 24 h. In this manner, volatile materials are removed.

8.2.1. Ascent. Ascent heating histories with peak temperatures below 615 K cause an increase in α_s of 0,03 or less, while ε is unaffected.

8.2.2. Orbital. The primary source of degradation appears to be the near-ultra-violet portion of incident solar and albedo radiation.

From Breuch (1967) [22].

9. THERMAL CYCLING

The maximum and minimum temperatures at which the paint has been tested without major changes in properties were:

$$T_{min} = 211 \text{ K}$$

$$T_{max} = 366 \text{ K}$$

(Rittenhouse & Singletary (1969) [105]).

10. SOURCE

Lockheed Missiles and Space Company Inc. 3251 Hanover Street. Palo Alto, California 94304.

11. COST

Varies depending on quantity; Cunningham et al. (1969) [33] indicate that the nominal price is 16 US \$ per litre.

12. PAST SPATIAL USE

Thermatrol 2A-100 has been used for thermal control in Explorer 33 (launched July 1, 1966), Rittenhouse & Singletary (1969) [105]. According to Neel (1967) [91], this paint has been tested on board OSO I (launched March 7, 1962) and OSO II (Feb. 3, 1965). The results obtained have been presented in

5.2.2 Zinc Oxide-Potassium Silicate

1. COMPOSITION

Pigment: New Jersey Zinc Co., SP500 zinc oxide; calcined at 873 to 973 K for 16 h. (Heating and cooling rates are not critical).

Binder: Sylvania Electric Products Corp., PS7 potassium silicate.

From Cunningham, Grammer & Smith (1969) [33].

2. FORMULATION

4,3:1 by weight of pigment and binder (Cunnington et al (1969) [33]).

3. USUAL DESIGNATION

Z-93. IIT Research Institute.

4. SUBSTRATE

All metals except noble; Aluminium is preferred (IITRI (1974)).

5. METHOD OF APPLICATION

5.1. Preparation of paint for application. The components are mixed in a pigment to binder ratio of 4,3 with a solids content of 56,9%. A typical batch may be 0,1 kg of ZnO, 50 cm³ of PS7 (35% solution), and 50 cm³ distilled water.

The paint should be prepared just before use. Shelf life is limited. Actual shelf life should exceed 24 h. The mixture should be shaken to maintain the pigment in suspension (Cunnington et al. (1969) [33]).

5.2. Preparation of surfaces for painting. The substrate should be abraded and thoroughly washed with detergent and water.

According to the supplier, chromate treatments are not permissible.

5.3. Application of paint. By spray-painting. Because of the porous nature of the cured coating, heavy spraying upon application of a second coat is required to achieve a satisfactory finished texture (Breuch (1967) [22]).

For process specification see Stevens (1971) [120].

5.4. Coating thickness. A thickness of about $2,54 \times 10^{-5}$ m is achieved per cycle. Total thickness should be of the order of $1,1 \times 10^{-4}$ to $1,5 \times 10^{-4}$ m.

5.5. Curing process. Satisfactory physical properties are obtained by an air-drying cure for 4 h. The supplier recommends, as optional, a cure at 366 K for 16 h, while Cunningham et al. (1969) [33] indicate that improved hardness is obtained by heat curing at 413 K.

6. SOLVENTS RESISTANCE

Not attacked by the solvents.

7. PHYSICAL PROPERTIES

7.2. Outgassing. Initial weight loss in 20 h: $8,0 \times 10^{-4}$ kg.m⁻².

Stationary loss rate: $5,6 \times 10^{-10}$ kg.m⁻².s⁻¹ (McCargo, Spradley, Greenberg & McDonald (1971) [82]).

7.3. Thermal radiation properties

7.3.1. Emittance.

7.3.1.1. Hemispherical total emittance.

T [K]	ε^a	ε^b	Ref.
295	$0,90 \pm 0,05$	0,87	c
310	0,96	0,88	d
394		0,88	c
533			c

^a Determined calorimetrically. Chamber pressure: $1,33 \times 10^{-5}$ Pa.

^b From spectral reflectance data in the range 2×10^{-6} m to $2,5 \times 10^{-5}$ m and the blackbody function corresponding to the temperatures quoted.

^c From Cunningham, Grammer & Smith (1969) [33].

^d From Westcott (1968) [132].

7.3.1.3. Effects of the Space Environment on hemispherical total emittance.

7.3.1.3.1. Ultra-Violet Radiation. The following table has been prepared using data given by Cunningham et al. (1969) [33].

T [K]	t [h]	n	ε_0	ε_f	$\bar{\varepsilon}$	σ
300	2001	28	0,90	0,88	0,882	0,012
366	2024	33	0,89	0,88	0,887	0,007
422	10517	140	0,88	0,87	0,878	0,010
450	1004	19	0,87	0,87	0,871	0,004
534	502	12	0,81	0,81	0,811	0,009

Degrading Source: 2×10^{-7} to 4×10^{-7} m Xenon Lamp, 1 Sun level.

Method of obtaining data: Calorimetric. Chamber pressure: $1,33 \times 10^{-5}$ Pa.

t , total exposure time. [h].

n , number of data points given in the source.

ε_0 , ε_f , initial and after-exposure values of the hemispherical total emittance.

$\bar{\varepsilon}$, mean value.

$$\bar{\varepsilon} = \frac{\sum_{i=1}^n \varepsilon_i \Delta t_i}{t} \quad [5-1]$$

σ standard deviation.

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (\varepsilon_i - \bar{\varepsilon})^2 \Delta t_i}{t - 1}} \quad [5-2]$$

7.3.2. Absorptance.

7.3.2.1. Solar absorptance: Table 5-2.

Table 5-2: Solar Absorptance of Zinc Oxide-Potassium Silicate Paint

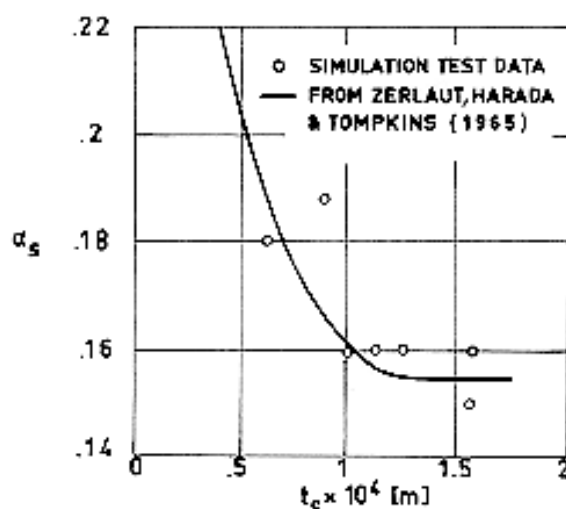
No	T [K]	α_s	Comments
1	278	0,114	Measured in vacuum ($1,2 \times 10^{-4}$ Pa).
2	278	0,112	Similar to above specimen and conditions.
3	279	0,153	Air dried at 100% relative humidity; measured in vacuum ($1,3 \times 10^{-4}$ Pa).
4	279	0,168	Similar to above specimen and conditions except air dried at 0% relative humidity.
5	279	0,161	Similar to No. 3 specimen and conditions except air dried at 35% relative humidity.
6	279	0,147	Spray application; measured in vacuum ($1,3 \times 10^{-4}$ Pa); fresh preparation.
7	279	0,150	Similar to above specimen and conditions except measured in vacuum ($6,7 \times 10^{-4}$ Pa).
8	279	0,150	Similar to No. 6 specimen and conditions except measured in vacuum ($4,7 \times 10^{-4}$ Pa).
9	279	0,138	Spray application; measured in vacuum ($1,3 \times 10^{-4}$ Pa); preparation aged 120 d.
10	279	0,119	Above specimen and conditions except heat-treated at 773 K for 2 h.
11	279	0,131	Similar to No. 9 except measured at pressure of $6,7 \times 10^{-4}$ Pa.
12	279	0,126	Above specimen and conditions except heat-treated at 773 K for 2 h.
13	279	0,140	Similar to No. 9 specimen and conditions except measured at pressure of $4,7 \times 10^{-4}$ Pa.
14	279	0,119	Above specimen and conditions except heat-treated at 773 K for 2 h.
15	279	0,120	Spray application; measured in vacuum ($1,3 \times 10^{-4}$ Pa); preparation aged 120 d.
16	279	0,133	Similar to above specimen and conditions except measured in vacuum ($6,7 \times 10^{-4}$ Pa).
17	279	0,124	Similar to No. 15 specimen and conditions except measured at pressure of $4,7 \times 10^{-4}$ Pa.
18	298	0,164	Substrate abraded with No. 60 Aloxite cloth. Sample cured at 413 K for 18 h.
19	298	0,158	Above specimen and conditions except heat-treated (418 K for 16 h); time lapse, 1 d.
20	298	0,149	Similar to No. 18 specimen and conditions except heat-treated (773 K for 2 h); time lapse, 6 h.
21	298	0,160	Similar to No. 18 specimen and conditions except after time lapse of 90 d.
22	298	0,165	Abraded magnesium silicate substrate.
23	298	0,158	Similar to above specimen and conditions except heat-treated (418 K for 16 h); time lapse, 1 d.
24	298	0,158	Similar to No. 22 specimen and conditions except heat-treated (973 K for 2 h); time lapse, 1 d.
25	298	0,159	Similar to No. 22 specimen and conditions except heat-treated (1073 K for 2 h); time lapse, 1 d.
26	298	0,161	Similar to No. 22 specimen and conditions except heat-treated (1073 K for 2 h); time lapse, 1 d.

No	T [K]	α_s	Comments
			h); time lapse, 6 h. Similar to No. 22 specimen and conditions except after time lapse of 90 d.
27	298	0,168	Abraded alumina substrate.
28	298	0,159	Similar to above specimen and conditions except heat-treated (418 K for 16 h);
29	298	0,160	time lapse, 1 d.
30	298	0,160	Similar to No. 27 specimen and conditions except heat-treated (973 K for 2 h);
31	298	0,165	time lapse, 1 d. Similar to No. 27 specimen and conditions except heat-treated (1073 K for 2 h); time lapse, 6 h. Similar to No. 27 specimen and conditions except after time lapse of 90 d.
32	298	0,153	Measured in vacuum (4×10^{-3} Pa).
33	298	0,120	Aluminium substrate; supplied by IITRI.
34	298	0,220	Similar to above specimen and conditions except supplied by ESRO I Project
35	298	0,260	Group; coating thickness $8,9 \times 10^{-5}$ m. Similar to above specimen and conditions except soiled.
36	298	0,184	Property calculated from reflectance; lab data taken on sample to be tested on Lunar Orbiter V.
37	293	0,14±	Substrate abraded with No. 60 Aloxite cloth. ^a
38	289	0,02	Same as above ^a .
39	533	0,14±	Same as above ^a .
		0,02	
		0,14±	
		0,02	

^a From Breuch (1967) [22].

NOTE All data, unless otherwise stated, are from Touloukian, DeWitt & Hearn (1972) [126].

7.3.2.2. Variation of solar absorptance with coating thickness: Figure 5-5.



Note: non-si units are used in this figure

Figure 5-5: Variation of solar absorptance, α_s , with thickness, t_c . From Stevens (1971) [120].

7.3.2.4. Earth Albedo normal absorptance. The value $\alpha = 0,26$ has been obtained by Westcott (1968) [132] from spectral data. Albedo radiation is approximated by the solar spectrum truncated below $3,5 \times 10^{-7}$ m. Aluminium substrate.

7.3.2.5. Effects of the Space Environment on absorptance.

7.3.2.5.1. Ultra-Violet Radiation. Fairly detailed laboratory data on the effects of UV radiation on spectral absorptance are given in Table 5-3. Table 5-4 has a broader scope, it is intended to illustrate how the experimental conditions influence the results.

Changes in solar absorptance during the total mission profile for a near-Earth orbit, as estimated by McCargo, Spradley, Greenberg & McDonald(1971) [82] are shown in Figure 5-6.

Table 5-3: Ultra-Violet Radiation Effects on Spectral Absorptance of Zinc Oxide-Potassium Silicate Paint

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
300	0	0,72	0,10	0,05	0,08	0,14	0,14
300	43	0,70	0,09	0,05	0,09	0,14	0,14
300	293	0,67	0,11	0,06	0,08	0,15	0,14
300	365	0,67	0,15	0,04	0,09	0,14	0,15
300	461	0,66	0,15	0,05	0,09	0,15	0,15
300	509	0,65	0,14	0,06	0,09	0,15	0,15
300	605	0,69	0,14	0,06	0,09	0,15	0,16
300	701	0,70	0,16	0,07	0,09	0,15	0,16
300	773	0,67	0,19	0,09	0,08	0,16	0,16
300	821	0,71	0,18	0,05	0,09	0,15	0,17
300	869	0,70	0,19	0,08	0,09	0,16	0,17

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
300	941	0,65	0,19	0,08	0,09	0,15	0,17
300	989	0,70	0,15	0,09	0,08	0,16	0,17
300	1039	0,65	0,19	0,09	0,08	0,15	0,17
300	1109	0,66	0,20	0,08	0,08	0,16	0,17
300	1157	0,73	0,19	0,10	0,08	0,16	0,17
300	1205	0,69	0,20	0,09	0,08	0,16	0,18
300	1277	0,68	0,20	0,07	0,09	0,16	0,17
300	1325	0,63	0,23	0,07	0,09	0,16	0,18
300	1373	0,65	0,22	0,10	0,08	0,16	0,17
300	1445	0,66	0,23	0,10	0,08	0,16	0,18
300	1545	0,65	0,22	0,08	0,09	0,16	0,18
300	1617	0,68	0,22	0,10	0,08	0,16	0,19
300	1665	0,67	0,24	0,08	0,08	0,16	0,18
300	1713	0,67	0,22	0,08	0,09	0,16	0,18
300	1785	0,69	0,22	0,09	0,09	0,17	0,18
300	1953	0,69	0,21	0,09	0,08	0,17	0,18
300	2001	0,68	0,21	0,09	0,09	0,17	0,18
After Exposure ^a		0,75	0,17	0,06	0,08	0,16	0,17
366	0	0,84	0,05	0,04	0,08	0,14	0,14
366	17	0,88	0,10	0,06	0,08	0,16	0,16
366	70	0,89	0,14	0,08	0,08	0,17	0,18
366	93	0,89	0,16	0,06	0,08	0,17	0,18
366	161	0,90	0,14	0,09	0,08	0,17	0,18
366	233	0,90	0,16	0,07	0,08	0,18	0,18
366	329	0,91	0,16	0,10	0,08	0,18	0,19
366	377	0,90	0,16	0,10	0,08	0,18	0,19
366	425	0,90	0,16	0,09	0,08	0,18	0,19
366	497	0,89	0,16	0,09	0,09	0,18	0,19
366	545	0,85	0,17	0,10	0,09	0,17	0,19
366	593	0,85	0,20	0,09	0,09	0,18	0,20
366	665	0,82	0,18	0,08	0,09	0,18	0,18
366	713	0,87	0,18	0,10	0,09	0,19	0,20
366	761	0,87	0,19	0,10	0,09	0,19	0,20
366	833	0,85	0,19	0,11	0,09	0,18	0,20
366	881	0,85	0,18	0,11	0,09	0,18	0,19
366	939	0,80	0,20	0,12	0,09	0,19	0,20
366	1011	0,80	0,19	0,10	0,09	0,17	0,20
366	1059	0,83	0,19	0,10	0,09	0,18	0,19
366	1179	0,84	0,18	0,09	0,09	0,17	0,19
366	1227	0,85	0,19	0,13	0,09	0,19	0,20
366	1275	0,82	0,21	0,12	0,08	0,181	0,19
366	1347	0,84	0,21	0,11	0,09	0,183	0,20

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
366	1395	0,84	0,19	0,13	0,09	0,187	0,20
366	1443	0,85	0,18	0,11	0,09	0,173	0,19
366	1575	0,85	0,18	0,10	0,09	0,173	0,19
366	1621	0,82	0,19	0,12	0,09	0,183	0,20
366	1693	0,82	0,19	0,12	0,09	0,183	0,20
366	1741	0,81	0,22	0,11	0,09	0,187	0,20
366	1909	0,80	0,22	0,11	0,09	0,183	0,20
366	1957	0,80	0,22	0,12	0,085	0,183	0,20
366	2024	0,80	0,22	0,11	0,085	0,185	0,20
After Exposure ^a		0,75	0,25	0,12	0,10	0,18	0,21
422	0	0,75	0,11	0,05	0,05	0,0126	0,137
422	22	0,90	0,16	0,05	0,05	0,15	0,16
422	96	0,92	0,16	0,07	0,07	0,17	0,18
422	144	0,87	0,17	0,07	0,07	0,16	0,18
422	192	0,80	0,20	0,07	0,07	0,16	0,18
422	264	0,80	0,18	0,10	0,07	0,16	0,19
422	312	0,78	0,20	0,07	0,08	0,16	0,18
422	360	0,80	0,17	0,08	0,09	0,16	0,18
422	432	0,76	0,19	0,07	0,08	0,16	0,18
422	480	0,76	0,20	0,09	0,08	0,16	0,18
422	528	0,76	0,19	0,08	0,08	0,16	0,18
422	600	0,80	0,17	0,10	0,08	0,16	0,19
422	648	0,80	0,19	0,09	0,08	0,16	0,19
422	768	0,77	0,18	0,07	0,08	0,15	0,18
422	816	0,80	0,17	0,08	0,08	0,15	0,19
422	864	0,75	0,18	0,07	0,08	0,14	0,17
422	936	0,78	0,16	0,08	0,08	0,14	0,17
422	984	0,78	0,18	0,08	0,08	0,15	0,18
422	1032	0,78	0,18	0,08	0,08	0,14	0,18
422	1152	0,70	0,16	0,08	0,08	0,14	0,17
422	1200	0,72	0,17	0,09	0,08	0,15	0,17
422	1272	0,73	0,17	0,08	0,08	0,14	0,17
422	1320	0,72	0,18	0,08	0,08	0,14	0,17
422	1488	0,70	0,19	0,08	0,08	0,14	0,17
422	1536	0,68	0,21	0,09	0,09	0,15	0,18
422	1608	0,66	0,18	0,09	0,09	0,15	0,17
422	1656	0,65	0,18	0,10	0,08	0,15	0,17
422	1704	0,67	0,18	0,10	0,08	0,15	0,17
422	1776	0,68	0,20	0,09	0,08	0,15	0,18
422	1824	0,70	0,18	0,11	0,08	0,16	0,18
422	1872	0,70	0,19	0,09	0,09	0,16	0,18
422	1944	0,70	0,18	0,09	0,09	0,16	0,18

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
422	2016	0,68	0,19	0,10	0,08	0,16	0,18
422	2256	0,69	0,19	0,09	0,08	0,16	0,17
422	2424	0,69	0,17	0,11	0,08	0,15	0,17
422	2472	0,66	0,19	0,10	0,08	0,15	0,17
422	2560	0,68	0,17	0,11	0,08	0,15	0,18
422	2644	0,67	0,18	0,10	0,09	0,15	0,17
422	2736	0,68	0,18	0,10	0,08	0,15	0,17
422	2784	0,68	0,18	0,11	0,09	0,15	0,18
Xenon Lamp off 2832 to 3335 h.							
422	3336	0,66	0,17	0,10	0,09	0,16	0,17
422	3408	0,64	0,16	0,11	0,09	0,15	0,17
422	3508	0,64	0,18	0,10	0,09	0,15	0,17
422	3580	0,64	0,18	0,11	0,09	0,15	0,17
422	3678	0,62	0,16	0,12	0,09	0,16	0,17
422	3676	0,64	0,20	0,11	0,09	0,16	0,18
422	3798	0,63	0,17	0,12	0,09	0,16	0,18
422	3866	0,66	0,17	0,11	0,09	0,16	0,18
422	3914	0,64	0,20	0,12	0,09	0,16	0,18
422	3962	0,61	0,17	0,13	0,09	0,16	0,17
422	4034	0,65	0,20	0,12	0,09	0,17	0,18
422	4082	0,66	0,21	0,12	0,09	0,17	0,18
422	4202	0,65	0,20	0,13	0,09	0,16	0,19
422	4298	0,66	0,20	0,12	0,09	0,17	0,19
422	4370	0,65	0,20	0,12	0,09	0,17	0,18
422	4466	0,63	0,20	0,13	0,09	0,17	0,18
422	4530	0,62	0,21	0,13	0,09	0,17	0,19
422	4634	0,61	0,20	0,13	0,10	0,17	0,19
422	4706	0,61	0,25	0,12	0,09	0,17	0,19
422	4754	0,66	0,22	0,12	0,09	0,17	0,19
422	4802	0,65	0,23	0,12	0,09	0,17	0,19
422	4874	0,62	0,21	0,12	0,10	0,17	0,20
422	4921	0,63	0,22	0,11	0,10	0,17	0,19
422	4969	0,66	0,20	0,11	0,10	0,17	0,19
422	5089	0,62	0,22	0,10	0,11	0,17	0,18
422	5137	0,59	0,24	0,11	0,09	0,17	0,18
422	5209	0,63	0,24	0,10	0,10	0,17	0,19
422	5329	0,60	0,25	0,11	0,10	0,17	0,19
422	5401	0,61	0,25	0,11	0,11	0,17	0,19
422	5449	0,64	0,25	0,13	0,09	0,17	0,20
422	5497	0,59	0,26	0,12	0,09	0,17	0,20
422	5617	0,62	0,25	0,12	0,10	0,18	0,20
422	5665	0,58	0,25	0,11	0,10	0,17	0,19

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
422	5737	0,59	0,26	0,12	0,09	0,17	0,19
422	5785	0,58	0,26	0,14	0,09	0,17	0,20
422	5833	0,59	0,25	0,11	0,10	0,17	0,19
422	5905	0,58	0,22	0,14	0,10	0,17	0,19
422	5953	0,58	0,25	0,11	0,10	0,17	0,19
422	6001	0,61	0,25	0,11	0,10	0,17	0,19
422	6073	0,62	0,22	0,11	0,10	0,17	0,19
422	6121	0,60	0,26	0,09	0,10	0,17	0,19
422	6169	0,63	0,22	0,11	0,09	0,17	0,19
422	6241	0,64	0,23	0,09	0,10	0,17	0,19
422	6289	0,64	0,22	0,08	0,10	0,16	0,19
422	6457	0,68	0,20	0,10	0,10	0,17	0,19
422	6505	0,64	0,23	0,08	0,10	0,17	0,19
422	6577	0,63	0,22	0,11	0,09	0,17	0,19
422	6625	0,65	0,20	0,11	0,10	0,17	0,19
422	6673	0,62	0,24	0,10	0,09	0,17	0,19
422	6745	0,62	0,22	0,11	0,10	0,16	0,19
422	6793	0,62	0,22	0,10	0,09	0,16	0,19
422	6913	0,62	0,23	0,10	0,09	0,17	0,19
422	6961	0,62	0,23	0,10	0,10	0,16	0,19
422	7009	0,62	0,20	0,10	0,10	0,16	0,19
422	7081	0,66	0,19	0,10	0,10	0,16	0,18
422	7129	0,63	0,19	0,09	0,10	0,16	0,19
422	7177	0,65	0,21	0,09	0,10	0,16	0,18
422	7249	0,65	0,18	0,10	0,10	0,16	0,18
422	7345	0,60	0,18	0,11	0,10	0,16	0,18
422	7417	0,62	0,18	0,10	0,10	0,16	0,18
422	7465	0,63	0,19	0,09	0,10	0,16	0,18
422	7513	0,65	0,20	0,11	0,10	0,16	0,19
422	7585	0,62	0,22	0,10	0,10	0,16	0,19
422	7633	0,65	0,20	0,10	0,10	0,17	0,19
422	7681	0,63	0,17	0,10	0,10	0,16	0,18
422	7753	0,64	0,18	0,12	0,10	0,16	0,18
422	7801	0,60	0,19	0,10	0,10	0,16	0,18
422	7849	0,62	0,20	0,11	0,09	0,17	0,18
422	7921	0,63	0,20	0,09	0,09	0,17	0,18
422	8017	0,62	0,21	0,09	0,10	0,16	0,18
422	8029	0,62	0,20	0,10	0,10	0,16	0,18
422	8125	0,62	0,20	0,10	0,10	0,16	0,18
422	8251	0,57	0,17	0,12	0,10	0,16	0,18
422	8301	0,56	0,17	0,12	0,10	0,16	0,18
422	8349	0,57	0,18	0,11	0,10	0,16	0,18
422	8421	0,55	0,17	0,13	0,10	0,16	0,18
422	8517	0,54	0,17	0,12	0,10	0,16	0,18

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
422	8589	0,57	0,17	0,12	0,10	0,16	0,18
422	8781	0,59	0,19	0,13	0,10	0,16	0,18
422	9021	0,54	0,21	0,11	0,11	0,17	0,18
422	9093	0,57	0,19	0,11	0,10	0,16	0,17
422	9189	0,50	0,20	0,09	0,10	0,15	0,17
422	9285	0,53	0,21	0,11	0,10	0,16	0,18
422	9357	0,54	0,23	0,14	0,10	0,17	0,19
422	9424	0,54	0,21	0,12	0,10	0,17	0,18
422	9501	0,52	0,20	0,09	0,10	0,16	0,17
422	9597	0,54	0,19	0,13	0,10	0,16	0,18
422	9645	0,52	0,21	0,11	0,10	0,15	0,18
422	9693	0,52	0,19	0,11	0,10	0,16	0,18
422	9789	0,59	0,19	0,09	0,11	0,16	0,18
422	9861	0,50	0,19	0,11	0,11	0,15	0,17
422	9885	0,53	0,20	0,12	0,10	0,15	0,18
422	9975	0,50	0,18	0,11	0,11	0,16	0,17
422	10071	0,48	0,19	0,10	0,11	0,15	0,17
422	10143	0,50	0,17	0,13	0,10	0,14	0,17
422	10239	0,49	0,19	0,12	0,10	0,15	0,17
422	10431	0,49	0,21	0,11	0,10	0,15	0,17
422	10454	0,49	0,19	0,12	0,10	0,14	0,17
422	10517	0,45	0,19	0,13	0,10	0,15	0,17
422	10517	0,62	0,22	0,14	0,12	0,17	0,19
Before Exposure ^a		0,60	0,06	0,06	0,07	0,13	0,15
After Exposure ^a		0,66	0,23	0,14	0,10	0,20	0,21
450	0	0,50	0,10	0,04	0,08	0,12	0,12
450	20	0,75	0,15	0,07	0,08	0,16	0,16
450	58	0,80	0,17	0,08	0,08	0,18	0,18
450	106	0,84	0,23	0,09	0,09	0,18	0,20
450	154	0,85	0,23	0,10	0,10	0,19	0,20
450	226	0,91	0,23	0,12	0,10	0,20	0,22
450	274	0,90	0,23	0,11	0,11	0,21	0,22
450	322	0,94	0,29	0,10	0,11	0,21	0,24
450	394	0,95	0,27	0,10	0,11	0,20	0,24
450	488	0,87	0,28	0,13	0,11	0,22	0,24
450	560	0,87	0,24	0,14	0,12	0,20	0,23
450	608	0,85	0,30	0,14	0,13	0,22	0,24
450	656	0,88	0,28	0,18	0,13	0,22	0,24
450	728	0,85	0,31	0,16	0,13	0,24	0,26
450	776	0,80	0,31	0,16	0,14	0,25	0,25
450	824	0,75	0,35	0,20	0,14	0,25	0,26

T [K]	t [h]	α for Xenon Lamp					α_s
		Range of $\lambda \times 10^7$ [m]					
		2-4,1	4,1-6	6-8,5	8,5-	Total	
450	896	0,80	0,30	0,20	0,14	0,25	0,26
450	944	0,80	0,30	0,19	0,14	0,25	0,25
450	1004	0,85	0,30	0,20	0,14	0,25	0,26
Before Exposure ^a		0,60	0,05	0,05	0,07	0,12	0,14
After Exposure ^a		0,90	0,25	0,15	0,10	0,21	0,23
534	0	-	-	-	-	0,11	-
534	0	0,60	0,03	0,05	0,08	0,11	0,12
534	12	0,55	0,20	0,08	0,09	0,16	0,16
534	60	0,55	0,27	0,10	0,12	0,20	0,20
534	140	0,55	0,28	0,13	0,16	0,21	0,22
534	181	0,55	0,27	0,15	0,17	0,22	0,23
534	256	0,55	0,25	0,20	0,16	0,23	0,24
534	304	0,55	0,25	0,20	0,18	0,23	0,24
534	356	0,50	0,25	0,20	0,18	0,23	0,24
534	404	0,50	0,25	0,23	0,19	0,24	0,25
534	426	0,55	0,26	0,22	0,19	0,24	0,25
534	502	0,55	0,26	0,23	0,19	0,24	0,25
Before Exposure ^a		0,64	0,05	0,05	0,07	0,13	0,14
After Exposure ^a		0,70	0,28	0,19	0,16	0,25	0,26

^a Values deduced from spectral reflectance data.

Degrading Source: 2×10^{-7} to 4×10^{-7} m Xenon Lamp, 1 Sun level

Method of obtaining data: Calorimetric in situ absorptance. Chamber pressure: $1,33 \times 10^{-5}$ Pa.

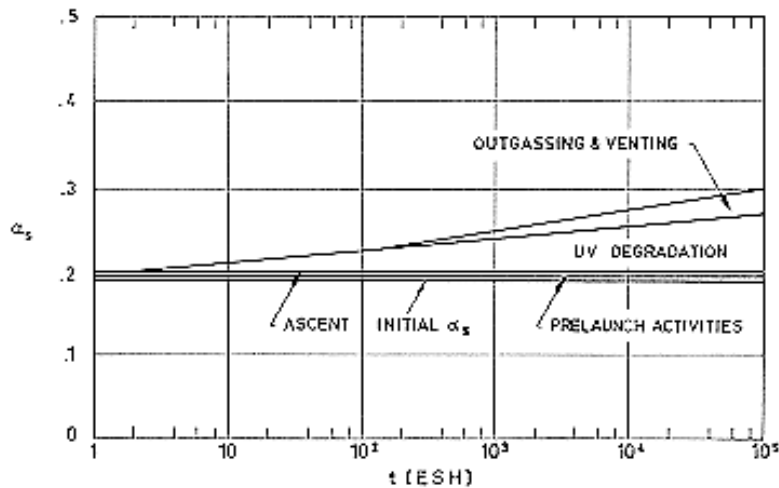
From Cunningham, Grammer & Smith (1969) [33].

Table 5-4: Ultra-Violet Radiation Effects on Solar Absorptance of Zinc Oxide-Potassium Silicate Paint

T [K]	Intensity Suns	Exp. Time ESH	$\Delta\alpha$	Comments
258-280		0 310 444 661 881 1194 1629 1995	0,003 0,022 0,029 0,038 0,047 0,058 0,071 0,081	Calculated from sample temperature; flight data of Lunar Orbiter I. Data from smooth curve.
278 279 279 279 279 279 279 279 279 279 279 279 279 279 293	3,9 10 10 10 4,8 6,1 5,8 4,8 6,1 5,8 4,8 6,1 5,8 11,7	1020 2160 2160 2160 300 4500 7900 300 4500 7900 300 4500 7900 1000	0,010 0,006 0,006 0,004 0,003 0,024 0,049 0,005 0,026 0,053 0,005 0,024 -0,004 0,006	Sample No. 1 of Table 5-2 Sample No. 3 Sample No. 4 Sample No. 5 Sample No. 6 Sample No. 7 Sample No. 8 Sample No. 10 Sample No. 12 Sample No. 14 Sample No. 15 Sample No. 16 Sample No. 17 Sample No. 32
298 ~ 298	6	800 100 500 1000 3000	0,010 0,000 0,005 0,009 0,019	UV from a G.E.AH-6 lamp in vacuum. Absorptance calculated from reflectance measured in situ. UV from a AH-6 lamp in vacuum; property measured in situ. Data from smooth curve.
~ 298	1	100 500 1000 1800	0,083 0,129 0,152 0,155	UV from Xenon lamp in vacuum at 460 K, property measured in situ. Data from smooth curve.
~ 298	1	100 500 1000 2100	0,000 0,012 0,024 0,041	UV from Xenon lamp in vacuum; property measured in situ. Data from smooth curve.
unknown		100 500	0,010 0,046	Calculated from flight data of Mariner IV.

T [K]	Intensity Suns	Exp. Time ESH	$\Delta\alpha$	Comments
		650 1000 2650	0,050 0,068 0,118	
unknown		0,46 1,1 3,9 4,0 4,3 4,9 5,2 7,1 7,4 7,7 8,1 8,5 8,7 721 717 727 751 1336 1336 1336 1336 1513 1577 1577 1577	0,002 -0,001 -0,004 -0,001 -0,001 -0,001 0,002 -0,003 0,001 -0,001 0,000 -0,004 0,001 -0,004 0,000 0,002 0,000 -0,004 -0,001 0,000 0,003 0,005 0,002 0,003 0,005	Calculated from temperature of substrate from flight data of OSO III.
unknown		0,1 1,0 10 100 1000 2500	0,000 0,000 0,000 0,000 0,000 0,000	Calculated from temperature of substrate from flight data of Pegasus II. Data from smooth curve.
unknown		0,1 1,0 10 100 1000 2500	0,000 0,000 0,000 0,000 0,000 0,000	Calculated from temperature of substrate from flight data of OSO III. Data from smooth curve.

NOTE From Touloukian, DeWitt & Hernincz (1972) [126].



Note: non-si units are used in this figure

Figure 5-6: Estimated changes in the solar absorptance, α_s , of Z-93 during the total mission profile for a near-Earth orbit. From McCargo, Spradley, Greenberg & McDonald (1971) [82].

7.3.2.5.3. Protons only exposure. The available data are given in the following table.

Radiation Exposure		α_{s0} Initial	$\Delta\alpha_s$	Comments
Intensity [keV]	Integrated Flux [protons.m ⁻²]			
150	1x10 ¹⁸	0,17	0,02	Protons in situ
20	1x10 ²⁰	0,17	0,13	Solar wind protons
2	5x10 ²⁰	0,15	0,26	Solar wind protons
1	4,2x10 ²¹	0,15	0,35	
1	1,9x10 ²²		0,67	

NOTE From Rittenhouse & Singletary (1969) [105].

7.3.2.5.4. Electrons only exposure.

Radiation Exposure		α_{s0} Initial	$\Delta\alpha_s$	Comments
Intensity [keV]	Integrated Flux [protons.m ⁻²]			
2x10 ³	1x10 ²⁰	0,17	0,03	

NOTE From Rittenhouse & Singletary (1969) [105].

7.3.2.5.6. Combined exposure.

Near UV ESH	Lyman ESH	Protons		T [K]	α_{so} Initial	$\Delta\alpha_s$
		[keV]	[protons.m ⁻²]			
375-450	750	10	1,4x10 ¹⁹	304	0,139	0,019
375-450	750	-	-	304	0,139	0,004
-	-	-	-	304	0,139	0,002
375-450	750	10	1x10 ¹⁹	301	0,143	0,023
375-450	750	-	-	301	0,144	0,005
-	-	10	1x10 ¹⁹	290	0,147	0,020
-	-	10	1x10 ¹⁹	291	0,142	0,026
750	750	10	2x10 ¹⁹	300	0,145	0,030
750	750	-	-	300	0,145	0,007
-	-	-	-	300	0,148	0,001
750	750	10	2x10 ¹⁹	304	0,144	0,035
750	750	-	-	304	0,146	0,014
750	750	10	2x10 ¹⁹	295	0,144	0,029
750	750	-	-	295	0,144	0,011

NOTE From Stevens (1971) [120].

7.3.2.6. Effects of the Space Environment on solar absorptance to emittance ratio.

T [K]	ESH	α_s/ε	Comments
~ 298	1160	0,183	Data taken from flight of Pegasus II. Values deduced from the temperature of the substrate.
	1169	0,226	
	1178	0,199	
	1198	0,231	
	1258	0,212	
	1291	0,240	
	1308	0,208	
	1537	0,259	
	2048	0,188	
	2070	0,200	
	2089	0,221	
	2100	0,200	
	2110	0,173	
	2133	0,254	
	2141	0,282	
	2243	0,245	
	2246	0,229	
	2260	0,243	
	2291	0,173	
	2300	0,234	
	2300	0,279	

T [K]	ESH	α_s/ε	Comments
	2423	0,173	
	2431	0,240	
	2431	0,270	
	2442	0,216	
258-280	0	0,185	Data taken from flight of Lunar Orbiter V. Values deduced from the temperature of the substrate. Data stracted from smooth curve.
	54	0,226	
	120	0,251	
	214	0,285	
	346	0,309	
	783	0,336	
	2038	0,416	

NOTE From Touloukian, DeWitt & Hernicz (1972) [126].

7.3.3. Reflectance.

7.3.3.1. Normal-hemispherical spectral reflectance: Figure 5-7.

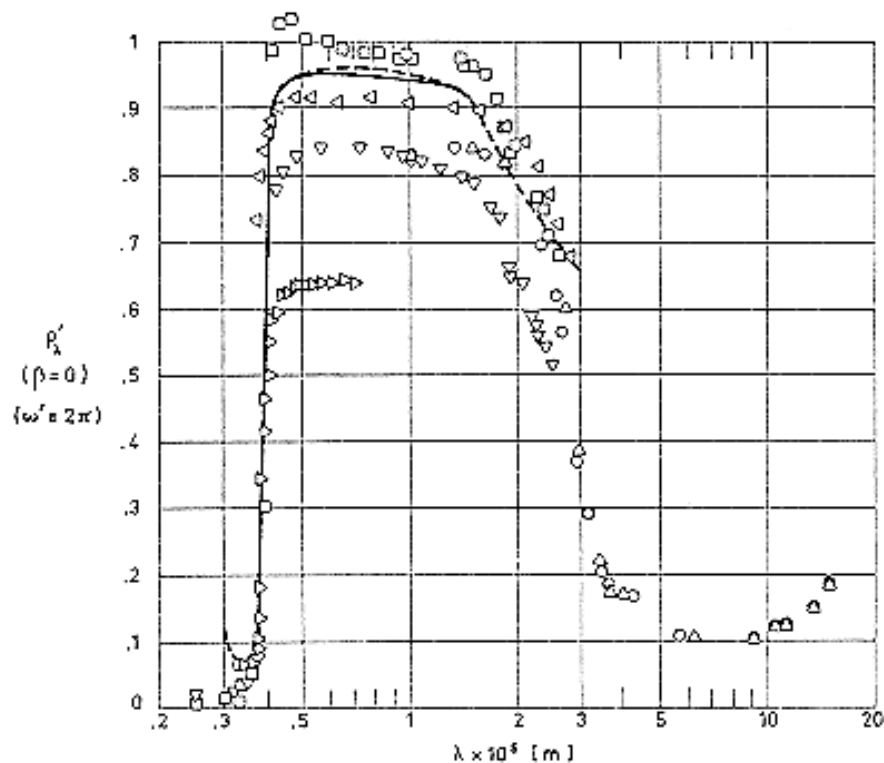


Figure 5-7: Normal-hemispherical spectral reflectance, ρ_{λ}' , of Z-93 vs. wavelength, λ . All data are from Touloukian, DeWitt & Hernicz (1972) [126] except solid and dashed lines which are from Cunningham, Grammer & Smith (1969) [33].

Explanation

Key	Description	Comments
○	Sprayed onto $1,27 \times 10^{-3}$ m thick aluminium substrate.	$T \sim 300$ K. Measured in vacuum ($1,33 \times 10^{-4}$ Pa). Data from smooth curve.
□	Sprayed on an aluminium substrate.	$T \sim 298$ K. Measured relative to MgO. Data from smooth curve.
△	Same as □.	Same as □. > Not referenced to MgO.
▽		$T \sim 298$ K. Data from smooth curve.
▷		$T \sim 298$ K. Measured in vacuum. data from smooth curve.
◁		$T \sim 298$ K. Exposed to vacuum. Measured in situ.
—	Applied to disc substrates of 6061-T6 Aluminium. The discs, $2,54 \times 10^{-2}$ m diameter by $1,27 \times 10^{-3}$ m thick, were polished on one side and the edge. The surface to be coated was machined to a $(30 \pm 3) \times 10^{-6}$ m RMS finish.	$T \sim 298$ K. Measured in vacuum ($1,33 \times 10^{-5}$ Pa) by using an integrating sphere attached to a Cary Model 14 Spectrophotometer. Reported error 2%.
— —	Same as —.	Same as — except measured using a Gier-Dunkle reflectometer. Reported error $\pm 1\%$.

7.3.3.2. Effects of Space Environment on reflectance.

7.3.3.2.1. Ultra-Violet Radiation: Figure 5-8.