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Abstract

A commercially available ultraviolet, visible, near-infrared spectrophotometer was modified to utilize an 8-inch-diameter modified Edwards-type integrating sphere. Software was written so that the reflectance spectra could be used to obtain solar absorptance values of 1-inch-diameter specimens. A description of the system, spectral reflectance results, and software for calculation of solar absorptance from reflectance data are presented.

Introduction

The Langley Research Center (LaRC) is engaged in a continuing program to develop and evaluate spacecraft thermal control coatings. In the external passive structural elements of a spacecraft, solar heat gain to surfaces facing the Sun or receiving reflections from the Sun and external heat radiated away from the spacecraft are the dominating factors in the heat balance (refs. 1 and 2). Temperature fluctuations can be minimized by the use of coatings with appropriate optical properties. In particular, the optical properties of solar absorptance α_s and thermal emittance ϵ determine the heat balance. Techniques are being developed to produce coatings of specified α_s and ϵ for spacecraft materials. Optical properties of the coatings are being optimized to give a low solar absorptance (or high spectral reflectance). This research requires measurements for large numbers of coating specimens. Spectral reflectance of opaque specimens is typically measured in a spectrophotometer with an integrating sphere attachment (ref. 3). The solar absorptance is calculated from the reflectance spectra. Several years ago a state-of-the-art instrument a Perkin-Elmer Model 330 spectrophotometer with a Model 3600 Data Station with a 2.36-inch-diameter (60-mm) integrating sphere and computerized calculation capability, was obtained by LaRC. However spectral data of specular specimens measured in the system typically contained errors. These errors were probably due to direct reflectance to the detectors from the specimens rather than from the sphere wall after multiple reflections. To alleviate this problem and to increase the ratio of sphere surface area to port area, which leads to improved signal-to-noise ratio, the system was modified with a larger 8-inch-diameter (20.3-cm) integrating sphere. Reflectance standards were used to correct spectra, and software was developed for computing solar absorptance from spectral reflectance. The values of α_s obtained for 13 representative coatings are shown to be in good agreement with values of α_s for the same coatings measured by an independent laboratory using a Beckman DK-2A spectrophotometer system (DK2A).

R. E. Wright, Jr., and E. C. Compton, Langley Research Center, designed the sphere and installed the electronic and optical components; D. W. Alderfer, Langley Research Center, assembled the sphere in its holding tray; Y. R. Yamaki, PRC Kentron, Inc., did engineering drawings of the sphere and its associated parts; and Perkin-Elmer Corporation provided the CONVT.OY file and helped in its modification.

Symbols

α	absorptance (in tables, measured from 1800 nm)
ϵ	thermal emittance
λ	wavelength, nm
$\Delta\lambda$	wavelength increment, nm
$E\lambda$	solar spectral irradiance averaged over small bandwidth centered at λ, W/m^2-nm
$(E\lambda)(\Delta\lambda)$	integrated solar extraterrestrial spectrum, W/m^2
ρ	reflectance
$\rho(E\lambda)$	reflected solar energy, W/m^2-nm
$\rho(E\lambda)(\Delta\lambda)$	integrated reflected solar energy, W/m^2
τ	transmittance

Subscript:

s	solar

Equipment

Spectrophotometer, Data Station, and Printer

The components of the unmodified spectrophotometer, a Perkin-Elmer Model 330 (PE330), are identified in figure 1. It is used for measuring transmittance and absorbance of liquid, solid, and gas samples in the ultraviolet, visible, and near-infrared regions of the electromagnetic spectrum. The data station is a Perkin-Elmer Model 3600, which includes a microprocessor-based programmable video display terminal. The visual display unit shows the system condition via the alphanumeric display. A graphics display is provided for the display of spectra. The data processing module houses the system electronics and two microfloppy disk drives. The left-hand drive (disk 0) is used for the program disk which contains the program (or task) in use; the right-hand drive (disk 1) is used for data storage (ref. 4). The spectrophotometer can be used independent of the data station. However, when the data station is connected to the spectrophotometer via the control and communications cable and to the printer, the resulting system permits acquisition of spectra, data storage and processing, data manipulation with user specific software, data printout, and alphanumeric and graphic display.

Integrating Sphere

The integrating sphere (fig. 2) is of the Edwards type (refs. 5 and 6) such that the specimen is mounted in the center for reflectance measurements. Figure 3 is a photograph of the specimen holder. Figure 4 is a photograph of the system with the sphere mounted in place. The integrating sphere is a Labsphere IS-WR series sphere (ref. 7) constructed from two anodized aluminum hemispheres with flanges which are bolted together. There are five ports (fig. 5). The sample, entrance, and detector ports are in a single plane. The sample port is 90° above the entrance port. The detector port is 90° below the entrance port. The centerline of the spare port is perpendicular to that plane. The view port is 45° from the sample port in a plane 45° from the first plane and from a plane including the sample, spare, and detector ports. The sphere interior was fine-bead blasted with glass microspheres and spray painted with white lacquer. Then the interior was spray painted with 10 coats of Eastman Kodak premixed $BaSO_4$, an homogenized mixture of $BaSO_4$, ethanol, water, and binder. A cylindrical baffle was installed around the detectors and a final coat of $BaSO_4$ was sprayed on to provide a coating thickness of about 1.5 mm. The sphere was mounted on a support bracket with the first-surface aluminized mirrors needed to deflect the reference and sample beams from the spectrophotometer into the integrating sphere. A lighttight enclosure was fabricated to house these mirrors and replace the original sample compartment in the PE330. Electronics, including detectors, plugs, and connectors, from the original equipment 60-mm-diameter sphere, were used where possible, to instrument the new 8-inch-diameter sphere.

Principles of Operation

Optical Layout and Signal Processing

Light from the source passes through two grating monochromators and is split by a chopper into two beams: a reference beam and a sample beam (fig. 6 and ref. 8). The beams pass into the integrating sphere, where the sample beam is focused on the center of the sample and the reference beam is focused on the sphere wall behind the specimen. After multiple reflections from the sphere wall, the light energy is sampled by a detector, either a photomultiplier or a lead sulfide cell, and converted into an electric signal. The electric signal provided from the detector is amplified by a preamplifier and converted into a digital variable by a 16-bit analog-to-digital (A/D) converter. At all the subsequent stages, the signal is processed by a central processing unit (cpu) and the computational result is displayed directly on the cpu or outputted to the recorder (no analog computations are performed in this signal processing system). The PE330 adopts the differential feedback system in which reference or sample signal, whichever is at the higher level, is kept constant by the cpu.

Reflectance Measurements

An Edwards-type integrating sphere (ref. 9) has the test sample mounted in the center of the sphere. The sphere is rotated about its vertical axis so that the sample beam focuses on the sphere wall when the 100-percent reference is being recorded. Both the sample and reference beams strike the sphere wall during this procedure. The sphere is rotated back so that the sample beam focuses on the test sample with the reference beam striking the sphere wall while the sample reflectance is being recorded. The sample reflectance is divided into the 100-percent reference reflectance at each wavelength to obtain the absolute reflectance of the specimen.

This new 8-inch-diameter sphere is a modified Edwards-type sphere which has the 1-inch-diameter test sample mounted in the center of the sphere but the sphere is fixed to one position. The sample beam is always focused on the specimen. Therefore, when the 100-percent reference is being recorded, a sample of barium sulfate or other reference material must be substituted for the test specimen. All data generated in this study used a National Institute of Standards and Technology (NIST) traceable 99-percent reflectance standard in the sample position for the 100-percent reference runs.

Equations for Reflectance and Solar Absorptance

The solar absorptance is calculated with a standard solar spectral irradiance as the weighting function by using the weighted ordinate method of reference 5. In this method the solar reflectance ρ_s is obtained by integrating the spectral reflectance over the standard spectral irradiance distribution $E\lambda$, as follows:

$$\rho_s = \frac{\sum_{i=1}^{n} \rho(\lambda_i) E\lambda_i \, \Delta\lambda_i}{\sum_{i=1}^{n} E\lambda_i \, \Delta\lambda_i}$$

where n is the number of wavelengths for which $E\lambda$ is given. Values of $E\lambda$ were obtained from table V of reference 10 and were stored in the solar absorptance software described in the next section.

The solar absorptance α_s is calculated by subtracting ρ_s from 1 with the assumption that transmittance τ_s is zero in the relationship

$$\alpha_s + \tau_s + \rho_s = 1$$

Procedures and Equipment

Reflectance Standards

Four certified standards traceable to NIST reflectance standards were purchased. Table I presents the reflectance factor values for the four standards. Spectral scans of the standards were made in the PE330 system. The scans were somewhat low in the UV/VIS (878 and 250 nm) and high in the NIR (1800 to 878 nm). A routine of the applications program PECUV (ref. 11) was used to multiply each of the scans by a factor. Multiplication factors of 1.07 for the UV/VIS and 0.98 for the NIR gave the best fit to the manufacturer's data. The corrected scans are compared with the manufacturer's data (standards) in figure 7. Variable factors as a function of wavelength cannot be used to correct the spectral data because the data are in binary format. In this format, the PECUV program can only be used to multiply the spectrum by a single factor. With data in ASCII format, however, and with the BASIC operating system, operations can be performed element by element. This would increase computing time and would not be warranted for the purpose of obtaining usable solar absorptance values.

Spectral File/ASCII File

Spectral scans were made with the Perkin-Elmer applications program IF320. The PE330 system was baseline corrected with the 99-percent reflectance standard in the sample beam path and similarly background corrected for the UV/VIS range. For the specimen scans, the reflectance standard was replaced with a specimen positioned 20° to the reference beam. Two spectral scans were made for each specimen, one from 1800 to 878 nm (NIR) and one from 878 to 250 nm (UV/VIS). The scans were multiplied by the same factors used to correct the scans of the reflectance standards, that is, 1.07 for the UV/VIS and 0.98 for the NIR. Another routine was used to connect the two scans into one continuous scan which was saved as a spectral file. Reference 5 recommends using the range of 2500 to 250 nm which covers approximately 96 percent of the energy in the solar spectrum. However, noise in the data at wavelengths greater than 1800 nm precluded this restricting these measurements to include approximately 92 percent of solar energy.

As explained previously, the spectral file had to be converted to ASCII to compute solar absorptance from a reflectance spectrum. A PECUV Obey program CONVT.OY (appendix A) was used to do this. Operating in the obey mode CONVT.OY converted the spectral data to ASCII file and stored the data. For example, the spectral file SCAN.SP was saved as SCAN.DA.

Compute Absorptance α

A Basic program, ALPHA.BA (appendix B), was written to compute solar absorptance from the spectral data on the ASCII file. The Basic operating system had to be loaded into the PE330 data station and ALPHA.BA loaded into disk drive 0 with the disk containing the ASCII file in disk drive 1. Following the prompts called for by the ALPHA.BA program, a solar absorptance value was computed and printed out. Lines 40 through 190 of ALPHA.BA contain a table of solar spectral irradiance values obtained from reference 10. These are given at 5-nm intervals for wavelengths from 200 to 610 nm, at 10-nm intervals from 610 to 1000 nm, and at 50-nm intervals from 1050 to 2000 nm. The user can select a data computation increment as small as 1 nm and the program interpolates values from this table. These values are then multiplied element by element with the spectral data from the spectrophotometer to obtain solar absorptance at each wavelength. The program as presented in appendix B will print out all the intermediate steps at selected wavelength intervals as well as the final value of solar absorptance.

Specimens

The accuracy of the PE330-integrating-sphere system was checked by comparing measurements of several specimens with measurements for the same specimens obtained from an outside laboratory. The specimens, listed in table II, are well known, documented, thermal control coatings (refs. 12 and 13). Some of the compositions were flown in the LDEF flight experiment S0010 (ref. 14). They were selected to cover a wide range of solar absorptances and represent a variety of materials and surface finishes.

After the specimens were selected, they were sent to a contractor where reflectance spectra were made on a Beckman DK-2A spectrophotometer and solar absorptances were calculated. The specimens were then returned to LaRC where spectra and solar absorptances were obtained in the PE330 system with the same specimens except for the three that were damaged and replaced by similar specimens. The wavelength range of the DK2A spectra was 295 to 2700 nm and was done in the hemispherical reflectance mode of operation. Solar absorptance for air mass zero was calculated with 2-percent energy intervals over the range of 295 to 2700 nm.

Results and Discussion

Reflectance spectra for 13 specimens are compared in figure 8. They are generally in good agreement in the UV/VIS, with the exception of silvered quartz (fig. 8(a)) and aluminized quartz (fig. 8(c)). These were two of the damaged specimens which had to be replaced for measurements in the PE330. Although the replacement specimens were similar to the ones measured in the DK2A, they were not identical. This may account for some of the differences. In the NIR from 1500 to 1800 nm, more than half of the PE330 measurements were lower than the DK2A measurements. However, the solar energy in this region of the spectrum is low and the influence of this portion on the solar absorptance is minimal.

Solar absorptances for the 13 specimens were calculated by using the reflectance data shown in figure 8. Calculations were made at 25-nm intervals. A typical printout of the calculation is presented in appendix C. The bottom value in the solar absorptance column is the value for the range 1800 to 250 nm. These values and the values calculated from the DK2A reflectances are shown in table III. Most of the PE330 values from the PE330 are slightly lower than those from the DK2A. The PE330 value for aluminized quartz was higher due to its lower reflectance spectrum noted before. It might be possible to use correction factors for the PE330 scans that would produce closer agreement with the DK2A solar absorptances. However, the 1.07 and 0.98 factors were obtained from corrections for the reflectance standards and changing these factors would impair the agreement between the PE330 system and the standard manufacturer's data shown in figure 7.

The solar absorptances of table III are plotted against each other in figure 9 and a linear regression calculated. Figure 9 shows that solar absorptances from the DK2A and PE330 are in good agreement and have a critical correlation coefficient of 0.99.

Summary of Results

The results of this investigation are summarized as follows:

1. A PE330 UV/VIS/NIR spectrophotometer was modified with an 8-inch-diameter modified Edwards-type integrating sphere so that reflectance spectra could be obtained for 1-inch-diameter specimens suspended in the sphere.

2. Software was written so that reflectance spectra obtained with the system could be used to calculate solar absorptance values.

3. Reflectance scans of reflectance standards were adjusted in each spectral region to bring the data into agreement with the manufacturer's data for the standards.

4. Reflectance spectra of 13 thermal control coating specimens were measured and were adjusted. The results were compared with DK2A reflectance spectra of the same or similar specimens obtained commercially.

5. Solar absorptances were calculated from PE330 reflectance spectra and correlated favorably with values obtained with the DK2A.

6. Use of the 8-inch-diameter sphere eliminated problems associated with spectral reflectance measurements of specular specimens made in the original equipment 2.36-inch-diameter (60-mm) integrating sphere and improved signal-to-noise ratio.

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Appendix A

Obey Program CONVT.OY

```
DO SCLEAR
DO VCLEAR
*
*
*    PROGRAM TO READ A SPECTRA FILE IN TO THE 3600
*        AND SAVE IT AS AN ASCII DATA FILE
*
*PRESS RETURN TO CONTINUE :
DO DISPLAY OFF
DO PAUSE
DO SCLEAR
DO DISPLAY ON
*
*
* ENTER SPECTRAL FILID :
&ENTER A1
*
*
*    INPUT FILE : &A1.SP        OUTPUT FILE = &A1.DA
*
*
*
*       CONVERSION TO ASCII FORMAT IN PROCESS
*
*
*
DO DISPLAY OFF
RETRVE X &A1
CALC V1=XSTRT
CALC V25=XFIN
CALC V2=V1+1
&L1 CALC V2=V2-1
CALC V24=V25-V2
&IF V24 L2 L99 L99
&L2 CALC V3=X(V2)
CALC V4=V2-2
CALC V24=V25-V4
&IF V24 L3 L99 L99
&L3 CALC V5=X(V4)
CALC V6=V2-3
CALC V24=V25-V6
&IF V24 L5 L99 L99
&L5 CALC V7=X(V6)
CALC V8=V2-4
CALC V24=V25-V8
&IF V24 L7 L99 L99
&L7 CALC V9=X(V8)
VSAVE &A1 V2,V3,V4,V5,V6,V7,V8,V9
CALC V2=V8
&GOTO L1
&L99 VSAVE &A1 V2,V3,V4,V5,V6,V7,V8,V9
DO DISPLAY ON
*
* END OF PROGRAM
ERROR23 END OF FILE
```

Appendix B

Basic Program ALPHA.BA

```
10 ‘CONVERT ASCII TRANSMITTANCE FILES TO SOLAR ALPHA VALUES
20 ‘NM PER DATA VALUE
30 ‘START, END WAVELENGTH
40 DATA 200, 5, 610, 10, 80, 50, 2000
50 ‘DATA VALUES
60 ‘200-300 NM
70 DATA .0107, .0168, .0229, .0402, .0575, .0649, .0667, .0593, .063, .0723, ,0704, .104,
   .130, .185, .232, .204, .222, .315, .482, .584, .514
80 ‘305-400 NM
90 DATA .603, .689, .764, .830, .975, 1.059, 1.081, 1.074, 1.069, 1.093, 1.083, 1.068,
   1.132, 1.181, 1.157, 1.120, 1.098, 1.098, 1.189, 1.429
100 ‘405-500 NM
110 DATA 1.644, 1.751, 1.774, 1.747, 1.693, 1.639, 1.663, 1.81, 1.922, 2.006, 2.057, 2.066,
   2.048, 2.033, 2.044, 2.074, 1.976, 1.95, 1.96, 1.942
120 ‘505-600 NM
130 DATA 1.92, 1.882, 1.833, 1.833, 1.852, 1.842, 1.818, 1.783, 1.754, 1.725, 1.72, 1.695,
   1.705, 1.712, 1.719, 1.715, 1.712, 1.7, 1.682, 1.666
140 ‘610-900 NM BY 10’S
150 DATA 1.635, 1.602, 1.570, 1.544, 1.511, 1.486, 1.456, 1.427, 1.402, 1.369, 1.344, 1.314,
   1.290, 1.260, 1.235, 1.211, 1.185, 1.159, 1.134, 1.109, 1.085, 1.06, 1.036, 1.013, .99,
   .968, .947, .926, .908, .891
160 ‘910-1000 NM
170 DATA .88, .869, .858, .847, .837, .820, .803, .785, .767, 748
180 ‘1050-2000 NM BY 50’S
190 DATA .668, .593, .535, .485, .438, .397, .358, .337, .312, .288, .267, .245, .223,
   .202, .18, .159, .142, .126, .114, .103
200 RESTORE
210 ON ERROR GOTO 900
220 OPEN "O", #1, "PRNT:"
230 PRINT #1, LOC<17> ‘SWITCH TO PAGE MODE
240 INPUT "DATA FILE NAME ", N$
250 N$="MFD1:"+N$+".DA"
260 OPEN "I", #2, N$
270 INPUT "INCREMENTAL WAVELENGTH ", DL
280 PRINT "BUILDING SOLAR INTENSITY TABLE--WAIT"
290 READ S1, N1, E1, N2, E2, N3, E3 ‘START, INCREMENT, END WAVELENGTH
300 SZ=<E3-S1>/N1+1 ‘SIZE OF SI VALUE ARRAY
310 DIM SI<SZ> ‘ALPHA VALUES <SOLAR INTENSITIES>
320 N=<E1-S1>/N1-1 ‘GET NO. OF 1ST GROUP OF INTENSITIES
330 FOR I=1 TO N: READ SI<I>: NEXT
340 EN=N+E2
350 J=N
360 READ SI<N+2>: SI<N+1>=<SI<N>+SI<N+2>>/2: N=N+2
370 IF N<EN THEN 360
380 EN=SZ: J=N
390 READ SI<N+10>: DT=<SI<N+10>-SI<N>>/10: FOR I=1 TO 9: SI<N+1>=SI<N>+DT*I: NEXT: N=N+10
400 IF N+.01<=EN THEN 390
410 ‘PRINT#1, "COMPLETE INTERPOLATED SOLAR INTENSITY TABLE FOR ALPHA PROGRAM"
420 ‘PRINT#1: PRINT#1
430 ‘PRINT#1," ";
440 ‘FOR I=1 TO EN: PRINT #1, USING "####"; I;: PRINT #1, USING "#####.#####"; SI
   <I>;: NEXT
450 ‘CLOSE #1
460 ‘STOP
```

```
470 PRINT#1, "ALPHA CALCULATIONS FOR FILE ";N$
480 PRINT#1, "DATA INCREMENT ";DL;" NANOMETERS"
490 PRINT#1
500 PRINT#1, "WAVE  % RH.L   RH.L*DL  H.L*DL ALPHA"
510 PRINT#1, "LNGT REFLT"
520 PRINT#1
530 INPUT #2, X
540 SF=1 'START FLAG
550 'GET WAVELENGTH, %TRANSMISSION, FILTERING OUT TRASH FROM P-E
560 IF X>0 THEN INPUT #2, WL ELSE INPUT #2, X: GOTO 560
570 X=X-1
580 IF X>0 THEN INPUT #2, TR ELSE INPUT #2, X: GOTO 580
590 X=X-1
600 'DISGARD ANYTHING OUT OF DESIRED RANGE
610 IF WL>E3 THEN 560
620 'ONLY CERTAIN VALUES GOOD: DL FILTERS OUT REPEATED VALUES FROM P-E
630 IF SF=1 THEN NL=WL
640 'NL IS NEXT GOOD WAVELENGTH
650 IF WL>NL THEN GOTO 560
660 NL=WL-DL
670 PO=<WL-S1>/N1+1 'POSITION IN SOLAR IRRADIATION ARRAY
680 K=INT <PO> 'INDEX INTO ARRAY
690 IF WL=E3 THEN HL=SI<K> ELSE HL=SI<K>+<PO-K>* <SI<K+1>-SI<K>>
700 RH=TR*HL/100
710 IF SF=1 OR CINT <2> THEN RD=RD+RH*DL/2 ELSE RD=RD+RH*DL
720 IF SF=1 OR CINT <2> THEN HD=HD+HL*DL/2 ELSE HD=HD+HL*DL
730 IF HD<>0 THEN AL=1.0-RD/HD ELSE AL=0
740 SF=0
750 PRINT #1, USING "####";WL;:PRINT #1," ";
760 PRINT #1, USING "##.##";TR;:PRINT #1," ";
770 'UN=HL: GOSUB 780
780 'PRINT #1, USING U$;HL;:PRINT #1," ";
790 UN=RH: GOSUB 930
800 PRINT #1, USING U$;RH;:PRINT #1," ";
810 UN=RD: GOSUB 930
820 PRINT #1, USING U$;RD;:PRINT #1," ";
830 UN=HD: GOSUB 930
840 PRINT #1, USING U$;HD;:PRINT #1," ";
850 UN=AL: GOSUB 930
860 PRINT #1, USING U$;AL
870 PRINT #1
880 IF NOT CINT <2> THEN 560
890 END
900 IF ERR=55 THEN PRINT "PETOS ERR ";EROS; " IN LINE "; ERL ELSE PRINT "BASIC ERROR ";
   ERR; " IN LINE "; ERL
910 END
920 'SET IMAGE STRINGS FOR VALUES FOUND IN DATA
930 IF UN>=10000 THEN U$="######": RETURN
940 IF UN>=1000 THEN U$="####.#": RETURN
950 IF UN>=100 THEN U$="###.##": RETURN
960 IF UN>=10 THEN U$="##.###": RETURN
970 IF UN>=1 THEN U$="#.####": RETURN
980 U$=".#####": IF UN<0 THEN U$="+"+U$: RETURN
990 RETURN
```

Appendix C

Typical Solar Absorptance Calculation for Specimen

[S13GLO coating; data increment 25 nm]

λ, nm	ρ, %	$\rho(E\lambda)$, W/m^2-nm	$\rho(E\lambda)(\Delta\lambda)$, W/m^2	$(E\lambda)(\Delta\lambda)$, W/m^2	α_s
1800	73.01	0.11609	1.4511	1.9875	0.26990
1775	70.82	0.12004	2.9516	4.1063	0.28120
1750	63.03	0.11345	4.3697	6.3563	0.31253
1725	68.21	0.13027	5.9981	8.7438	0.31401
1700	65.12	0.13153	7.6423	11.269	0.32182
1675	73.55	0.15628	9.5958	13.925	0.31089
1650	77.34	0.17247	11.752	16.713	0.29683
1625	78.42	0.18349	14.045	19.638	0.28477
1600	79.78	0.19545	16.488	22.700	0.27364
1575	79.37	0.20319	19.028	25.900	0.26532
1550	79.55	0.21239	21.683	29.238	0.25838
1525	80.11	0.22229	24.462	32.706	0.25208
1500	81.02	0.23332	27.378	36.306	0.24591
1475	81.45	0.24433	30.432	40.056	0.24026
1450	82.23	0.25656	33.639	43.956	0.23471
1425	82.72	0.26843	36.995	48.013	0.22948
1400	84.68	0.28537	40.562	52.225	0.22332
1375	88.30	0.30683	44.397	56.569	0.21516
1350	91.93	0.32911	48.511	61.044	0.20531
1325	90.36	0.34109	52.775	65.763	0.19750
1300	88.61	0.35170	57.172	70.725	0.19163
1275	88.40	0.36905	61.785	75.944	0.18644
1250	88.59	0.38802	66.635	81.419	0.18157
1225	88.36	0.40776	71.732	87.188	0.17726
1200	87.69	0.42530	77.049	93.250	0.17374
1175	85.65	0.43682	82.509	99.625	0.17181
1150	87.91	0.47029	88.387	106.31	0.16861
1125	89.10	0.50252	94.669	113.36	0.16490
1100	88.81	0.52661	101.25	120.78	0.16165
1075	89.03	0.56133	108.27	128.66	0.15847
1050	89.35	0.59682	115.73	137.01	0.15530
1025	89.20	0.63150	123.62	145.86	0.15244
1000	89.47	0.66924	131.99	155.21	0.14960
975	89.43	0.71003	140.86	165.13	0.14696
950	90.30	0.75577	150.31	175.59	0.14399
925	92.10	0.79528	160.25	186.39	0.14022
900	94.22	0.83946	170.74	197.53	0.13558
875	85.66	0.80221	180.77	209.23	0.13602
850	85.23	0.84378	191.32	221.61	0.13667
825	88.53	0.92779	202.92	234.71	0.13544
800	89.32	0.99056	215.30	248.57	0.13385
775	89.76	1.0520	228.45	263.22	0.13210
750	89.68	1.1075	242.29	278.66	0.13050

λ, nm	ρ, %	$\rho(E\lambda)$, W/m^2-nm	$\rho(E\lambda)(\Delta\lambda)$, W/m^2	$(E\lambda)(\Delta\lambda)$, W/m^2	α_s
725	90.69	1.1807	257.05	294.93	0.12844
700	90.64	1.2408	272.56	312.04	0.12653
675	91.04	1.3123	288.96	330.06	0.12452
650	90.96	1.3743	306.14	348.95	0.12267
625	91.72	1.4547	324.33	368.78	0.12053
600	92.09	1.5342	343.50	389.60	0.11831
575	92.68	1.5932	363.42	411.09	0.11596
550	92.45	1.5947	383.35	432.65	0.11394
525	91.98	1.7034	404.65	455.80	0.11223
500	95.02	1.8452	427.71	480.08	0.10908
475	90.07	1.8410	450.72	505.63	0.10858
450	91.13	1.8281	473.57	530.70	0.10764
425	87.99	1.4896	492.19	551.86	0.10812
400	77.38	1.1058	506.02	569.73	0.11182
375	6.73	0.07787	506.99	584.19	0.13215
350	5.36	0.05853	507.72	597.85	0.15076
325	5.15	0.05016	508.35	610.04	0.16669
300	5.57	0.02863	508.71	616.46	0.17480
275	6.13	0.01251	508.86	619.01	0.17795
250	7.08	0.00498	508.92	619.89	0.17901

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Table I. Certified Values for Reflectance Standards

Wavelength, nm	Reflectance factor for—			
	99 percent	75 percent	50 percent	2 percent
250	0.925	0.705	0.437	0.008
300	0.945	0.721	0.454	0.008
350	0.982	0.726	0.463	0.009
400	0.985	0.725	0.469	0.010
450	0.986	0.723	0.474	0.010
500	0.988	0.725	0.480	0.011
550	0.989	0.725	0.483	0.011
600	0.990	0.726	0.487	0.012
650	0.990	0.727	0.491	0.012
700	0.990	0.728	0.495	0.013
750	0.990	0.729	0.500	0.013
800	0.990	0.730	0.504	0.014
850	0.990	0.732	0.508	0.016
900	0.990	0.733	0.512	0.018
950	0.990	0.734	0.516	0.020
1000	0.990	0.735	0.515	0.022
1050	0.990	0.735	0.516	0.022
1100	0.989	0.735	0.517	0.022
1150	0.990	0.737	0.519	0.022
1200	0.988	0.737	0.520	0.023
1250	0.988	0.737	0.522	0.024
1300	0.987	0.737	0.523	0.024
1350	0.986	0.737	0.524	0.026
1400	0.987	0.739	0.527	0.026
1450	0.987	0.740	0.529	0.027
1500	0.988	0.741	0.531	0.028
1550	0.988	0.743	0.533	0.029
1600	0.988	0.744	0.534	0.029
1650	0.987	0.745	0.537	0.030
1700	0.986	0.745	0.538	0.031
1750	0.986	0.746	0.539	0.031
1800	0.986	0.746	0.539	0.032
1850	0.981	0.744	0.540	0.032
1900	0.979	0.743	0.539	0.033
1950	0.979	0.746	0.544	0.031
2000	0.975	0.747	0.544	0.033
2050	0.964	0.746	0.544	0.034
2100	0.957	0.747	0.546	0.034
2150	0.952	0.746	0.548	0.035
2200	0.971	0.750	0.548	0.035
2250	0.969	0.747	0.547	0.035
2300	0.960	0.746	0.547	0.035
2350	0.952	0.746	0.550	0.037
2400	0.951	0.748	0.551	0.037
2450	0.946	0.745	0.549	0.038
2500	0.951	0.747	0.572	0.040

Table II. Thermal Control Coating Specimens

Second-surface mirror:
- Silvered quartz
- Silvered Du Pont Teflon
- Aluminized quartz

Flat white paint:
- ITTRI YB-71 zinc orthotitanate pigmented silicate paint
- ITTRI S13G/LO zinc oxide pigmented silicone paint

Bright aluminum on rough composite:
- $Gr/Ep/SiO_2/Al/SiO_2$
- $Gr/Ep/Al/Al_2\ O_3$

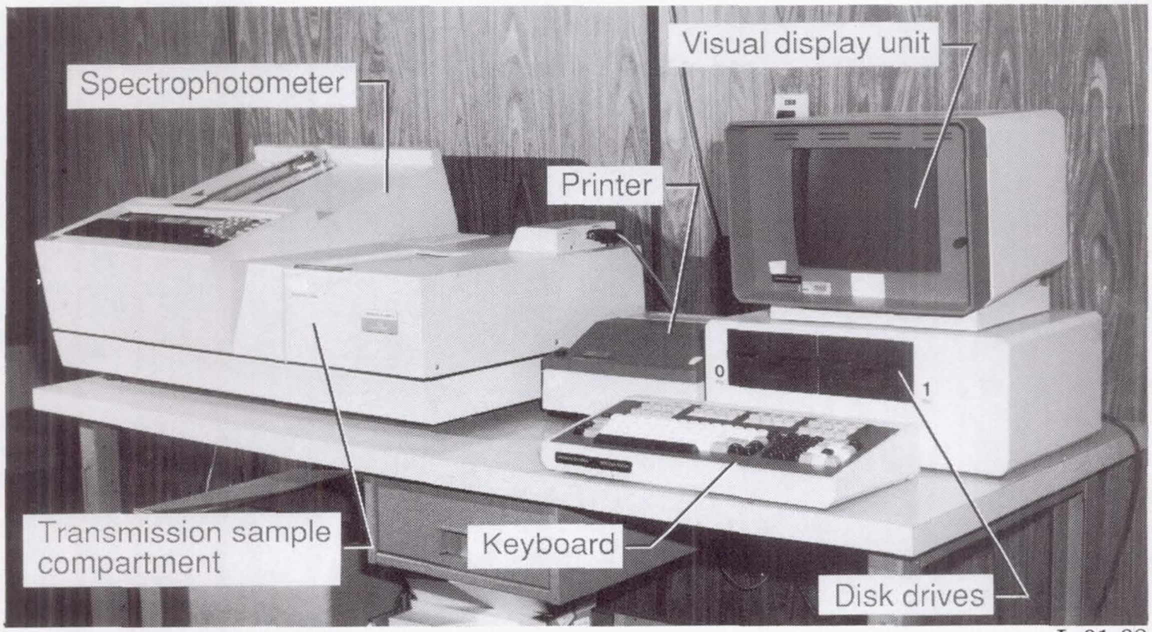
Chromic acid anodized aluminum:
- AA8
- AA29
- AC27
- AC31

Bright gold on rough composite:
- $Gr/Ep/SiO_2/Au/SiO_2$

Flat black paint:
- D111

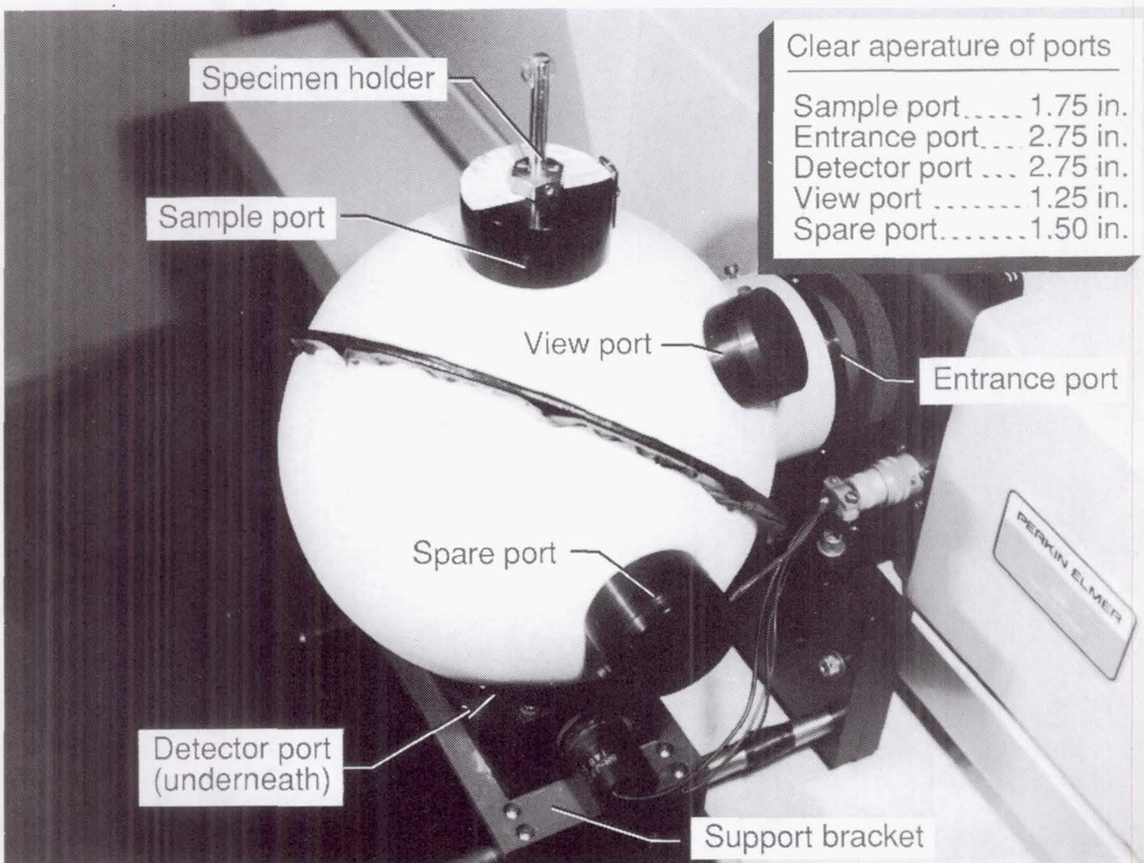
Table III. Solar Absorptances

Specimen	Solar absorptance measured by—	
	DK2A	PE330
Silvered quartz	0.10	0.08
Silvered Teflon	0.10	0.08
Aluminized quartz	0.11	0.15
YB-71 white paint	0.16	0.13
S13G/LO	0.22	0.18
$Gr/Ep/SiO_2/Al/SiO_2$	0.23	0.23
Anodized aluminum AA8	0.30	0.29
Anodized aluminum AA29	0.31	0.30
Anodized aluminum AA27	0.35	0.35
Anodized aluminum AA31	0.36	0.35
$Gr/Ep/Al/Al_2O_3$	0.37	0.36
$Gr/Ep/SiO_2/Au/SiO_2$	0.37	0.38
D111 black paint	0.98	0.96



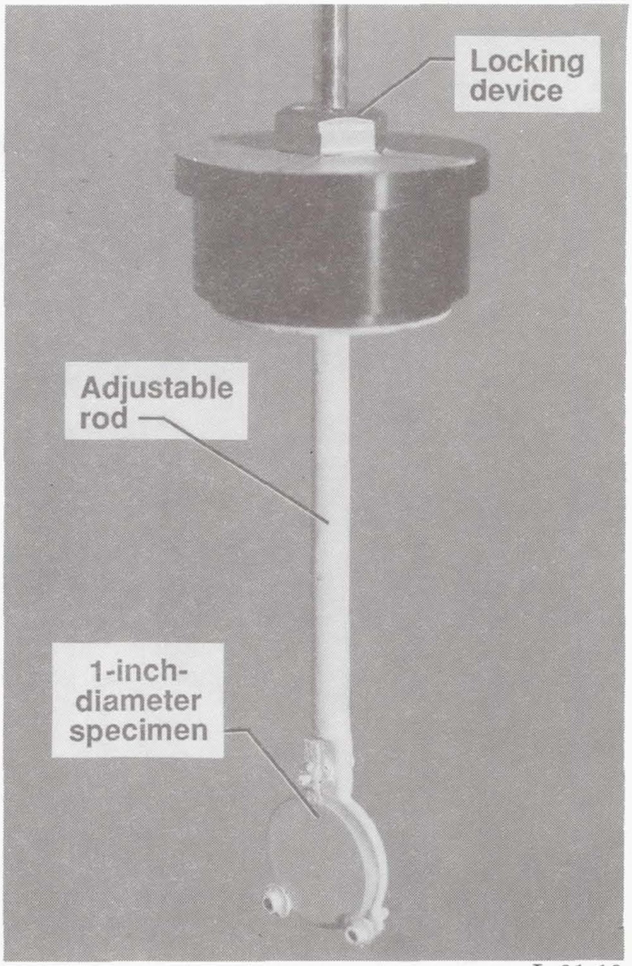
L-91-08

Figure 1. PE330 spectrophotometer with associated equipment.



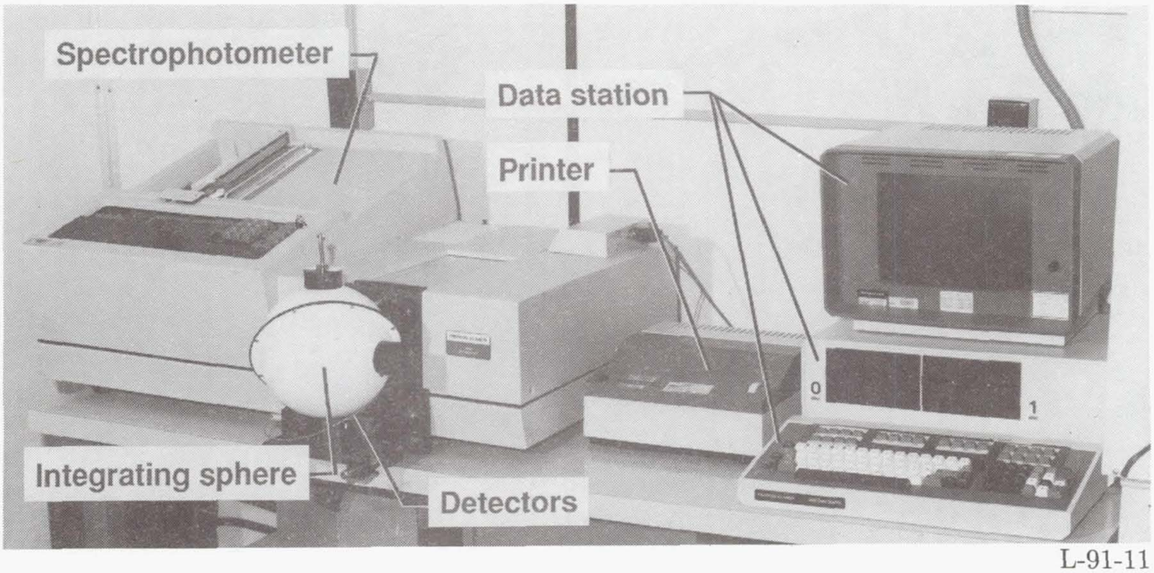
L-91-09

Figure 2. Integrating sphere.



L-91-10

Figure 3. Specimen holder.



L-91-11

Figure 4. PE330 system with sphere in place.

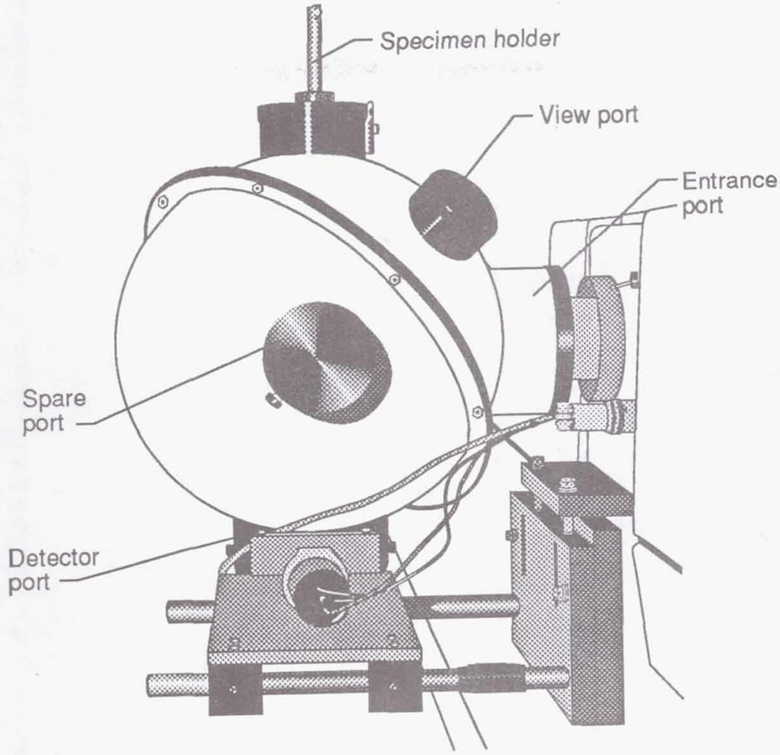


Figure 5. Location of sphere ports.

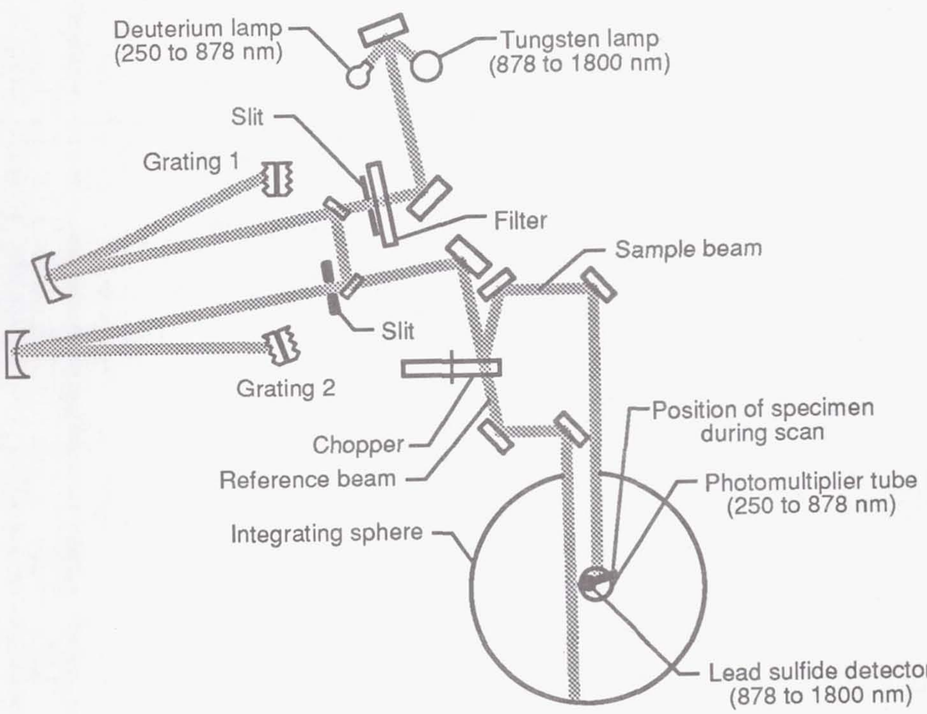


Figure 6. Diagram of light paths of PE330.

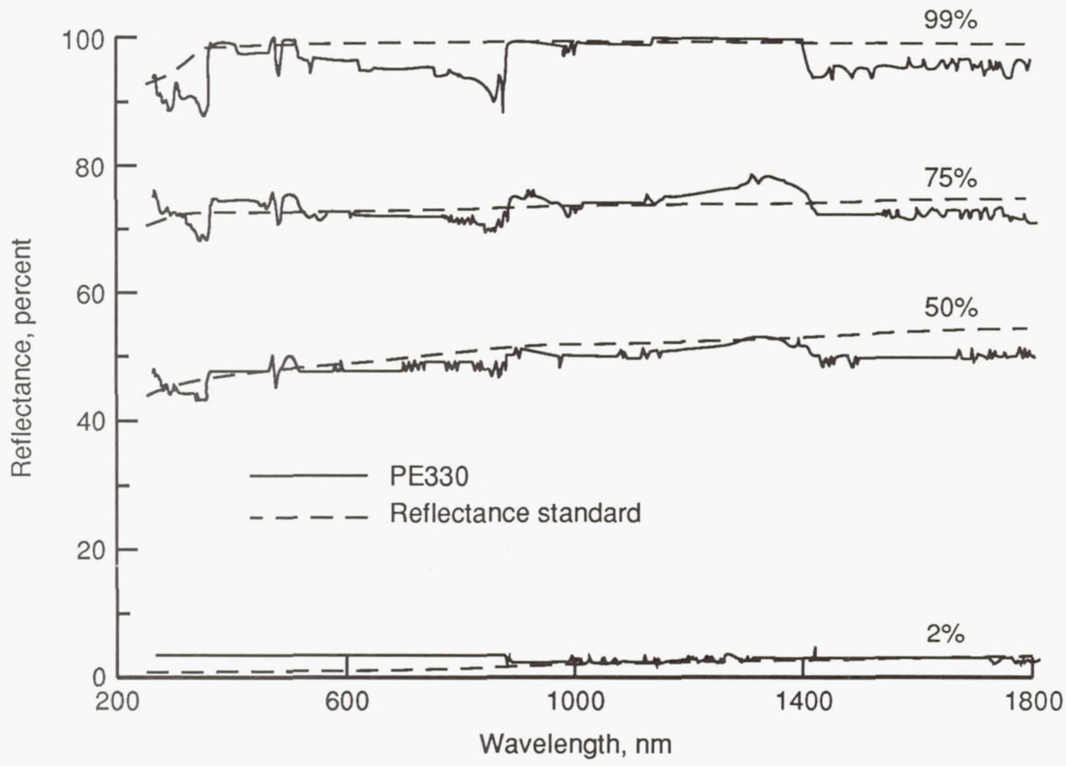


Figure 7. Corrected spectral scans of reflectance standards.

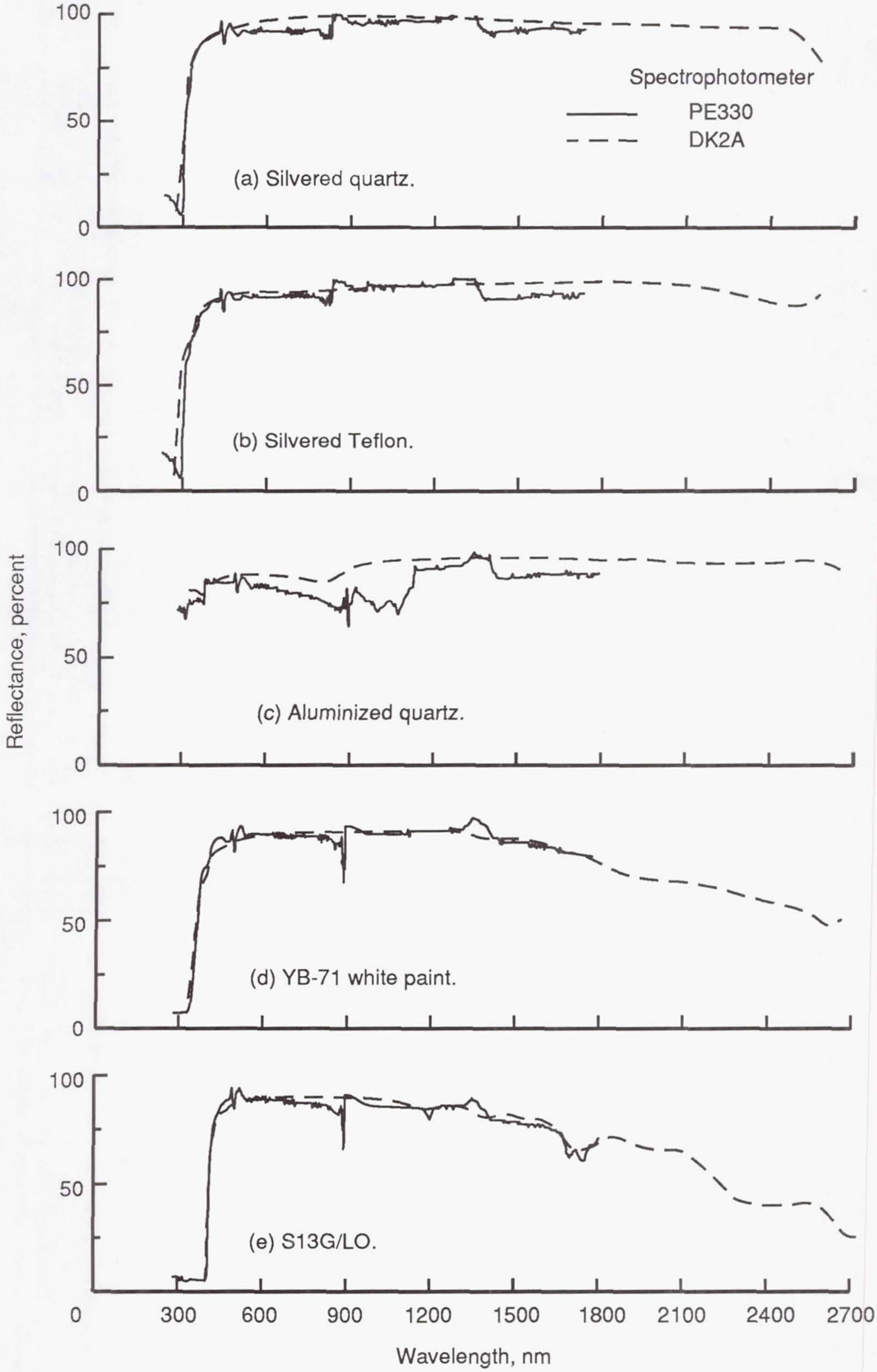


Figure 8. DK2A and PE330 spectral data for 13 specimens.

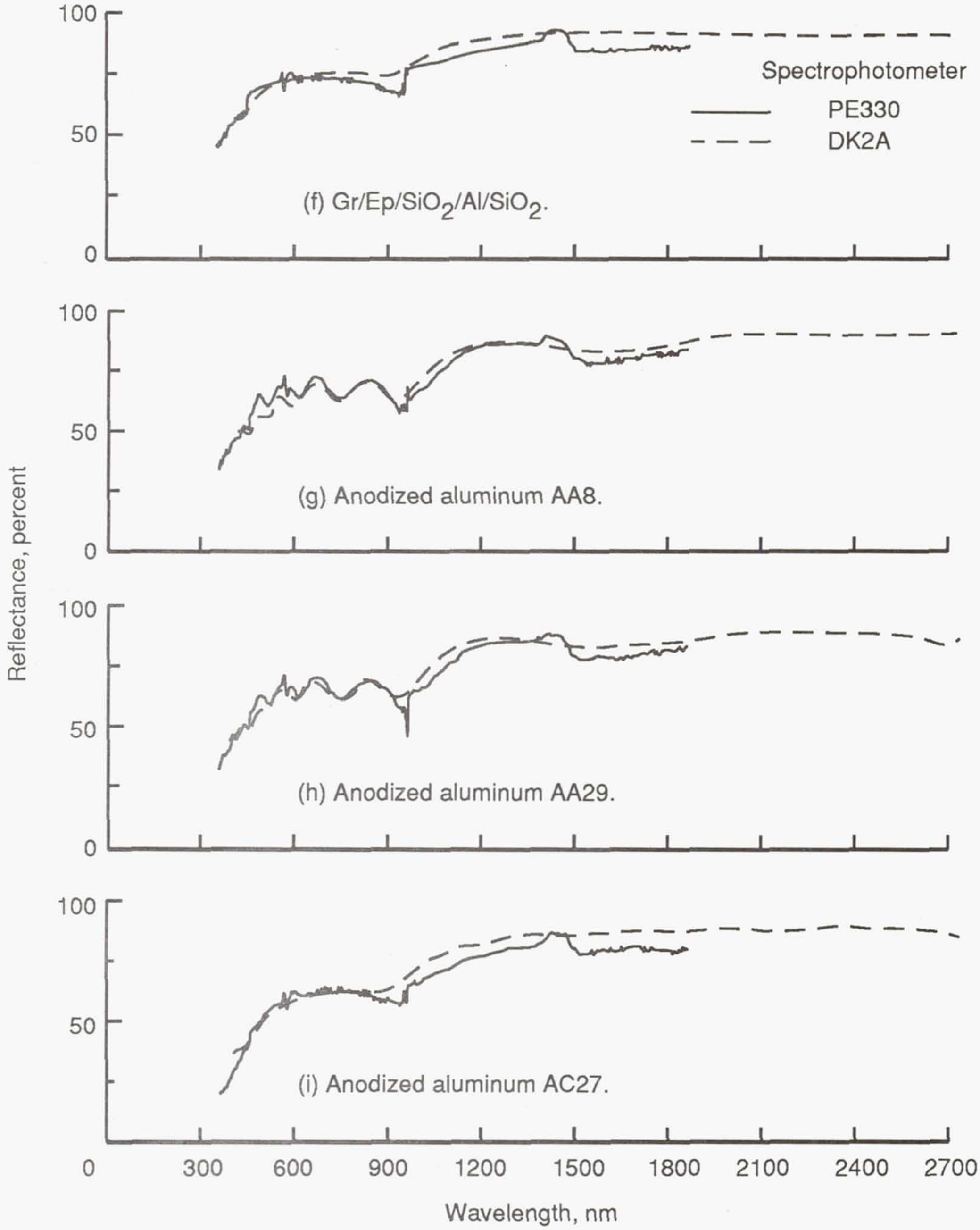


Figure 8. Continued.

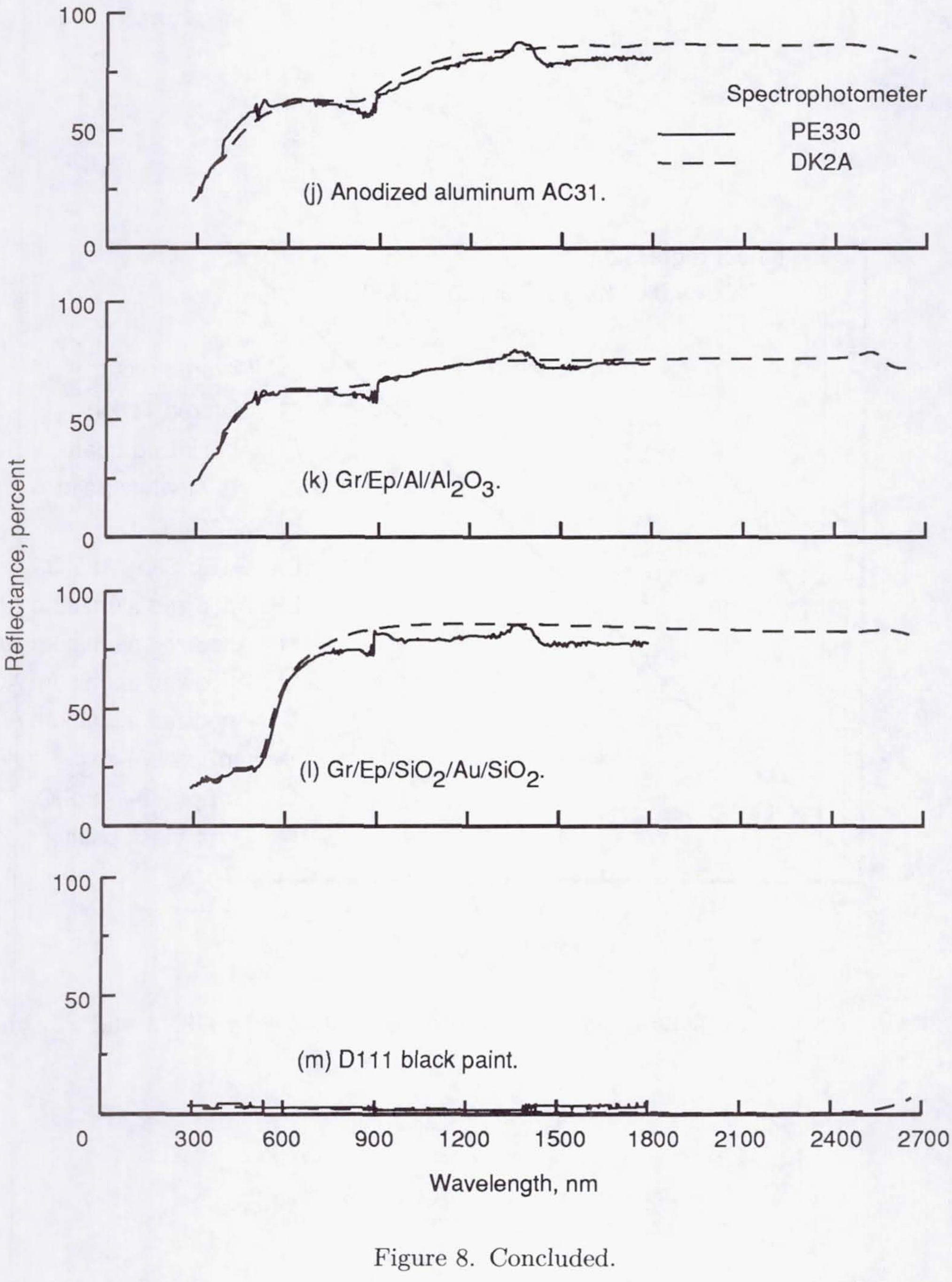


Figure 8. Concluded.

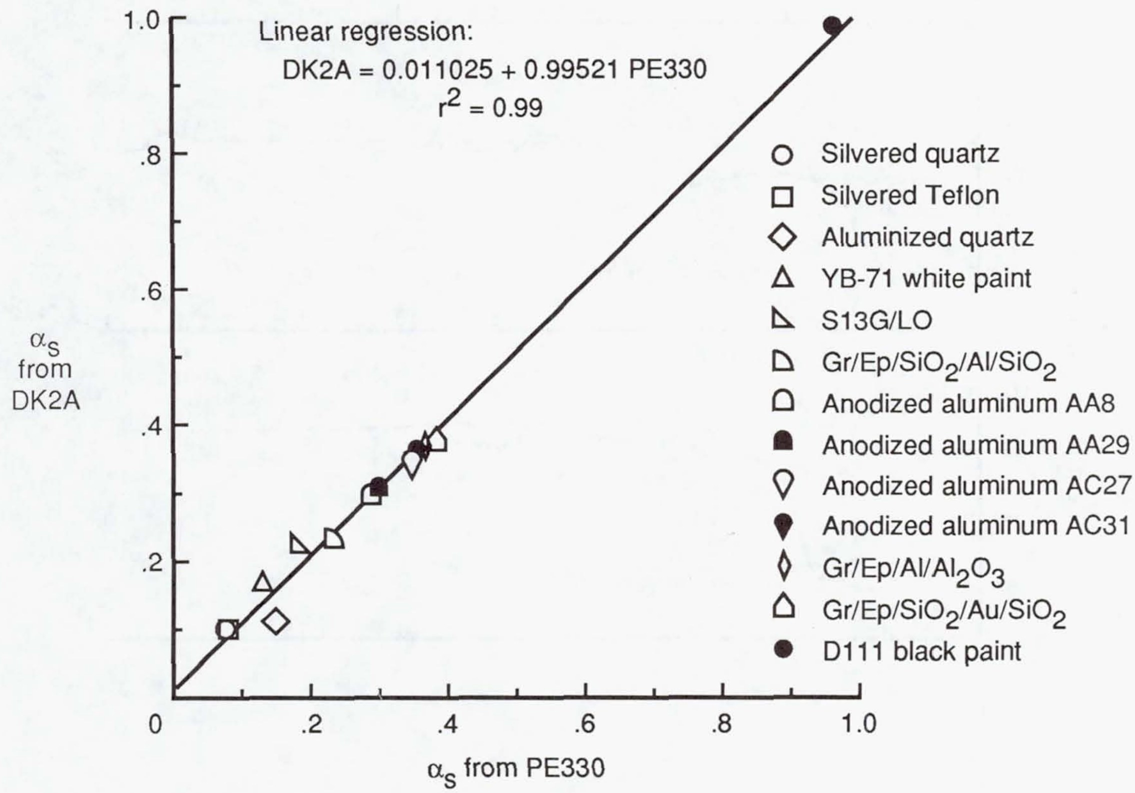


Figure 9. Linear regression of solar absorptance data obtained by DK2A and PE330.

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16. Abstract
A commerically available ultraviolet, visible, near-infrared spectrophotometer was modified to utilize an 8-inch-diameter modified Edwards-type integrating sphere. Software was written so that the reflectance spectra could be used to obtain solar absorptance values of 1-inch-diameter specimens. A description of the system, spectral reflectance results, and software for calculation of solar absorptance from reflectance data are presented.

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