ADA116350

# STANDARDIZATION PROCEDURE FOR TWO INSTRUMENTS FOR COLOR MEASUREMENT


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CONTRACT NO. DAAK60-[illegible]

SEPTEMBER 19[illegible]


UNITED STATES ARMY NATICK
RESEARCH & DEVELOPMENT LABORATORIES
NATICK, MASSACHUSETTS 01760


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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER NATICK/TR-82/024 | 2. GOVT ACCESSION NO. AD-A116350 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) STANDARDIZATION PROCEDURE FOR TWO INSTRUMENTS FOR COLOR MEASUREMENT | | 5. TYPE OF REPORT & PERIOD COVERED |
| | | 6. PERFORMING ORG. REPORT NUMBER IPL - 239 |
| 7. AUTHOR(s) Frederick T. Simon, Judith H. Lubar | | 8. CONTRACT OR GRANT NUMBER(s) DAAK60-79-C-0096 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Color Science Center, Clemson University, Clemson, S.C. | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Manufacturing Testing Technology |
| 11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research & Development Laboratories, ATTN: DRDNA-ITC, Natick, MA 01760 | | 12. REPORT DATE September 1981 |
| | | 13. NUMBER OF PAGES 56 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report) Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

COLOR, COLOR MEASUREMENT, CALIBRATION, STANDARDS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A standardization method was developed to check that a color measuring instrument will perform satisfactorily and that measurements made with it are within acceptable tolerances. Four types of materials were selected to test the instrument: a white opal tile to check nominal 100% reflectance; an amber glass filter to check low and high photometric scale and the wavelength scale at mid range; a gray porcelain tile to check the reflectance scale at mid range; and a pair of polyester plastic samples to check that proper color differences are being measured and calculated. Two instruments were used in this study, a Hunterlab D54 spectrophotometer and a

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20. Diano Match-Scan spectrophotometer. Each was interfaced to a mini-computer for collecting data on the test materials. Based on statistical studies of the measurements made on the instruments, two slightly different computer programs were developed which provide guidance for the operator of the instrument through the standardization procedure and make comparisons of the current measured data to previously established norms and tolerances for the same material. The computer programs are "fail-safe" in the sense that the instrument cannot be used to perform routine tests unless all of the standardization criteria are met.

## PREFACE

The work reported was performed as part of Phase II of a project to develop a color measuring system to be used for instrument judgment of color of textile fabrics procured by the Defense Department. The heart of the system is a spectrophotometer to be controlled by a computer that also performs required colorimetric calculations.

Phase I was limited to an evaluation of commercially available spectrophotometers, each with a small microprocessor. The evaluation was performed under Contract DAAK60-77-C-0093 by Rensselaer Polytechnic Institute and published as NATICK/TR-79/044. All three instruments evaluated were judged capable of meeting the color requirements. Because the system also must be capable of measuring infrared reflectance, however, one of the three instruments was dropped from further consideration in the system development.

The purpose of Phase II was to design the color measurement system to meet the needs of the program. One step in the design was the development of a mathematical means for expressing acceptability of slight deviations from standard shade. This work was performed under Contract DAAK60-78-C-0084 by Lehigh University and published as NATICK/TR-80-0036. A second step was development of a rigid system calibration procedure, which is the subject of this report. The work was performed under Contract DAAK60-79-C-0096 by Clemson University. The third step under Phase II was design and procurement of a prototype, two-unit system.

Support of the program was provided by the Manufacturing Testing Technology program. The Project Officer throughout both Phase I and Phase II was Alvin O. Ramsley; Alternate Project Officer was Therese R. Commerford.

The project officers acknowledge with thanks the constructive suggestions made by the Committee on Color Measurement of the National Research Council. Committee members are David L. MacAdam, Chairman, Ellen C. Carter, Franc Grum, Robert F. Hoban, Michael E. Breton and John J. Hanlon.

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## Introduction

The U.S. Army Natick Research and Development Laboratories entered into a contract with Clemson University to have a method developed for the standardization of color measuring instruments. This is one part of the longer range program to evolve an inspection procedure for the acceptance of the color of military fabrics through instrumental measurement rather than by visual estimation. Although there are several problems to be solved before a reliable procedure is achieved, two of the major aspects of the project have been investigated under contract and reported separately. In one of these contracts Billmeyer and Alessi addressed the general reliability of commercial color instruments, and in the other one Allen and Yuhas developed the mathematics of the color acceptability criteria.[1,2] The present work covers a third aspect which involves the technique that would be used to assure reliability of the instrumental measurement through proper calibration.

## Instrumentation used in study

Two instruments were used to develop and test the standardization procedure. Both instruments are commercially available and had been investigated in an earlier contract and had been found in the main to be suitable. One instrument is the Hunter D54 spectrophotometer (Christie and McConnell, 1977) and the other is the Diano Match-Scan spectrophotometer.[3] Except for the fact that both instruments involve integrating spheres and diffuse polychromatic illumination, the optical arrangement of the two is quite different. Nevertheless, the measurement data obtained in this study with both instruments were quite comparable although they were not exactly interchangeable. No attempts were made to introduce adjustments to compensate for these small differences in results.

The Hunter spectrophotometer was loaned to Clemson by Natick Laboratories for the purpose of this study. It consisted of three interconnected units: a measuring head, power supply, and a microprocessor push-button controller. In order to collect the large amount of statistical data required in this work, the instrument controller was interfaced to a General Automation SPC-16/45 minicomputer. On occasions when graphical data were needed, the spectrophotometer was connected to a Tektronik 4662 plotter. The SPC-16 was programmed in Fortran to aid in the data collection and the standardization test procedure.

1. F. W. Billmeyer, Jr. and P. J. Alessi (1979, "Assessment of Color-Measuring Instruments for Objective Textile Acceptability Judgement" Technical Report NATICK/TR-79/044, U.S. Natick Research and Development Command, Natick, MA 01760, March 1979.

2. E. Allen, and B. Yuhas (1980), "Investigations to Define Acceptability Tolerance Ranges in Various Regions of Color Space," Technical Report, NATICK/TR-80/036, U.S. Army Natick Research and Development Command, Natick, MA 01760, September 1980.

3. J. S. Christie, and G. McConnell, Color 77, p. 309, Adam Hilger Ltd., Bristol, England, 1977.

The Diano Match-Scan spectrophotometer is part of an integrated instrument computer system called the Match-Mate 3000. The instrument is entirely computer-controlled which means that special test programs were written in Fortran around operating software that was furnished by the manufacturer. The Tektronik 4662 plotter was also interfaced to the Match-Mate 3000 system for drawing special graphs.

Basic calibration methods

Spectrophotometric reflectance data are the basic measurements used for calculating color difference values which in turn express the acceptability of the color of test materials compared to established standards. Therefore, it is necessary to evolve a method that would establish with a fair degree of certainty that the instrumental measurement is reliable in order that a high degree of confidence can be placed on tests performed with the equipment. Such a premise infers that the instrument is set up for operation and then checked according to prescribed methods. It must be relative to some accurately known set of data. If these data are based on fundamental measurement of wavelength and spectral power, then this is an absolute method, Alternatively, the values of a set of calibrating materials can be known relative to a master set of similar materials; when the instrument is performing satisfactorily, the results obtained on a specific set of materials will be within specified tolerances. This is a relative calibration method. In this application, long term repeatability of measurements of a given instrument and reproducibility of measurements between locations are of paramount importance, therefore, the relative calibration method is followed in the present study.

Wavelength scale calibration has been done for many years on several commercial spectrophotometers using the well-known absorption maximum of the Corning 5120 didymium glass. Gibson, and Keegan found that several maxima can be used with spectrophotometers having a constant bandwidth in the range between 2 and 10 nm; this offers a method for checking spectrophotometers that have such resolution.[4] Although the Match-Scan can be calibrated with didymium, this procedure is inappropriate for the D54 instrument which has a bandwidth that changes from 12 nm at 400 nm to 18 nm to 700 nm, making the didymium filter less suited to this purpose. This is shown in Figure 1. Venable and Eckerele (1979) have described a more advanced method for wavelength calibration with a didymium filter which is suitable for any wavelength bandpass.[5]

4. K. S. Gibson, and H. J. Keegan, J. Opt. Soc. Am. 31, 462 (1941).

5. W. H. Venable, Jr., and K. L. Eckerle, (1979), "Didymium Glass Filters for Calibrating Wavelength Scale of Spectrophotometer-SRM 2009, 2010, 2013 and 2014," NBS Special Publication 260-66. National Bureau of Standards, Washington, DC 20234.

An alternative method for wavelength calibration was described by Van den Akker and adapted for the D54 instrument by Stanziola et al.[6,7] It requires pairs of glass filters having spectrophotometric curves that cross at a determinable wavelength. In the region of the crossing, it is best that the transmission curves be approximately linear. Two sets of filters have been used to check the wavelength scales around 440 nm and 590 nm which presumes to cover the limits of the visible spectrum. The Van den Akker method is applicable to both the D54 and Match-Scan; curves obtained with each instrument are shown in Figures 2 and 3.

There are caveats to the crossing-filter method. Individual sets of filters give particular wavelength crossings which are dependent as well upon bandwidth and instrument geometry. Different values for the intersection wavelength will also be obtained depending upon what wavelength increment is used to interpolate among the transmission measurements for each pair of filters. The crossing wavelength can be computed with data from any wavelength interval according to the following formula:

$$X = I\,(t_3 - t_1)/(t_2 + t_3 - t_1 - t_4) + W$$

where,

X is the crossing wavelength

I is the wavelength increment

$t_1$, $t_2$ are the transmittances for the first filter at wavelength, W, and wavelength, W + I, respectively

$t_3$, $t_4$ are the transmittances for the second filter at the same wavelengths as the first filter

W is the first wavelength

A 10-nm increment is preferred because it is a normal mode of operation for the D54 instrument and this makes for a convenient procedure. Hunterlab makes their determinations at 1-nm intervals, which give slightly more variable data (see below) than with 10-nm intervals. There is a small difference in the crossing wavelength dependent upon the wavelength increment, but as long as the same procedure is used at all times, the resulting values should be consistent.

Another method based on mercury emission lines is suited to the Match-Scan instrument but not the D54. The Match-Scan is provided with a Stand-Alone

6. J. A. Van den Akker, J. Opt. Soc. Am. 33, 257 (1943).

7. R. Stanziola, B. Momiroff, and H. Hemmendinger, Color Research Application 4, 36 (1979).

Program (SAP) which allows for single-beam radiometric measurements at 0.2-nm intervals. The output of a mercury arc lamp can be scanned around the emission peaks at 404.7, 435.7, 546.1, 557-578 to determine whether the instrument wavelength scale is correct. This has been done with the Match-Scan and the results are shown in Figure 4. Although the instrument has not been reset to the correct wavelength, the wavelength error is repeatable over a six-month period indicating that reproducible measurements can be achieved.

The D54 is routinely calibrated by the manufacturer, Hunterlab, using a series of filters of known spectral transmittance values for corresponding wavelengths.[8] Diano, on the other hand, calibrates the Match-Scan using the didymium filter absorption points. However, the purpose of this procedure is to recognize whether an instrument is performing in the same way that it had been when it was put into service. To that end a simple wavelength check is made with the transmittance of an anber filter at about the middle of the visible spectral range.

Several methods have been cited for wavelength checking but there are not generally accepted methods for establishing the validity of the photometric (reflectance or transmittance) scale for a spectrophotometer. In cooperation with the National Bureau of Standards we have developed a set of four neutral gray glass filters of ascending transmittances from about 0.5% to 31%. These were measured on the NBS high-accuracy spectrophotometer at 511 nm, which is in an area of relatively flat transmittance.[9] Since the high-accuracy spectrophotometer will give transmittance values at least more precise than any commercial instrument, it was felt that these filters would serve as a good reference for both instruments in this study.

The measurements obtained on the instruments are given in Tables 1 and 2. It will be noted that 1-nm data obtained with the D54 are slightly less consistent than data obtained with the Match-Scan. For reasons not known, these data are not in keeping with the 10-nm data obtained on the D54 in other parts of this study. Although the photometric readings on both instruments are not equal to those of the NBS, repeat tests done weeks apart indicate that the departure from the Bureau's values remains constant. One can presume from this that either the method of measurement in the commercial instruments produces a specific bias or that the normal standardization methods for these instruments do not compensate for nonlinearity in the photometric scale. Nonetheless, consistency of results is the overwhelming requirement.

<u>Routine calibration</u>

The calibration method which was finally developed as a result of this investigation considered that the following criteria were important:

a. Physical samples should be measured on the instrument and should be stable, easily cleaned, and of a convenient size.

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8. See Reference 3.

9. See Reference 5.

b. Measurements should check the performance of the instrument as for wavelength reliability as well as low range (below 5%) and high range (above 70%) photometric response.

c. Measurements should also check the 100% line and the mid-scale correction in the reflection mode.

d. A final check should be made of the ability of the instrument and computer system to give reproducible color difference values on a pair of samples of known color difference.

e. Backup calibration materials should be available to check the instrument wavelength if there are indications of wavelength uncertainty in the routine test.

These objectives were satisfied by selection of the following materials:

a. A white opal glass, 50 mm square by 10 mm thick which is covered on back and sides with black paper. See Figures 5 and 6.

b. A Corning 3307 Signal Yellow filter, 50 mm square by 2.3 thick. See Figures 7 and 8.

c. A gray porcelain enamel plaque, 10.7 cm square. See Figures 5 and 6.

d. A pair of tan polyester gelcoat plaques, 7.8 mm square. See Figures 9 and 10.

e. Four glass filters for wavelength checking. Each is 50 mm square. These filters were obtained through Hunter Associates Laboratory (the Corning description is only given for reference).

Blue-Corning 5851, 2.8 mm thick
Green-Corning 4445, 5.0 mm thick
Yellow-Corning 3387, 3.0 mm thick
Red-Corning 2424, 3.1 mm thick

Six sets of these calibration materials were obtained and checked for similarity. Only one set of materials was used throughout this study; individual values for the remaining five sets are given in Table 3 of this report.

In order to establish the range of expected values that would be obtained when the calibrating materials are measured on each instrument, two Fortran programs were written to assist in the collection and evaluation of the resulting data. The programs are the same in principle, but since each instrument operates differently and is interfaced to its own computer, small changes were made to fit each case. QMSTAT is the program used with the Diano Match-Scan and its Digital Equipment Company LSI-11 computer and QMSTA1 is used with the Hunter D54 spectrophotometer and the General Automation SPC-16 computer.

The procedure used for the calibration samples with the Match-Scan, made it simple to measure the samples in sequence:

Opal glass
Amber filter
Gray porcelain enamel tile
Standard tan plastic
Sample tan plastic

Each sample was carefully washed with a 1% solution of Sparkleen (Fisher Scientific Company), rinsed with distilled water and carefully dried with Kimwipes. This was done before every measurement.

In the case of the D54 instrument, a procedure that includes instrument setup was added:

Set up D54 for <u>transmittance</u>:

a. Press "TRANS" button
b. Block beam with black cardboard and press "ZERO"
c. Insert white tile and press "STDZ"

Measure Amber filter

Set up D54 for <u>reflectance</u>:

a. Press "R-SIN" button
b. Place black trap over port and press "ZERO"
c. Place white tile over port and press "STDZ"
d. Place gray tile over port and press "STDZ"

Measure Opal glass
Measure Gray porcelain enamel tile
Measure Standard tan plastic
Measure Sample tan plastic

Both QUMSTAT and QMSTA1 programs provide the necessary prompting so that the operator follows the proper sequence. In the QMSTAT program the paired white opal glasses are assumed to be approximately matched, and all of the subsquest measures are corrected to a value which compensates for any mismatch. A set of measurements and calculations for both instruments are given as Figures 11 and 12. Note that all spectral data lists the results of a single measurement, the average of two measurements and the average of ten measurements. Based on these data and the calculated standard deviation (sigma), it was concluded that the average of two measurements was suitable. Since we were not able to actuate the D54 through the program on the SPC-16 computer, we were obliged to operate the spectrophotometer through the keyboard and collect the resulting data through and ASCII interface to the computer. This was accomplished by first pressing the "READ" button; then when the "BUSY" light went out, the "10 NM" button on spectrophotometer console and the "RETURN" on the computer keyboard were pressed simultaneously.

A "PAUSE" was built into the computer program to allow for these operations to take place. Figure 12 shows that the ten repeat measurements were made with a PAUSE between each set. Analogous data to those shown for the Match-Scan in Figure 11 were obtained for the D54 instrument. In preparing Figure 12, the intermediate PAUSE statements have not been shown.

Working Calibration Method

The statistical studies with the two instruments were carried on for several months to establish a long term record of performance with the calibrating materials. Based on these experiments, two new programs QMSTAN for the Match-Scan and QMSTANH for the D54 were written to serve as a "fail-safe" calibration procedure that will not permit operation of the instrument if it fails within the limits set for each material. Again there are some differences between the instruments in the procedure itself as well as the specific limits set for each material. Figures 13 and 14 give a diagram of the information needed to effect the calibration of each instrument. Figure 15 shows a set of data obtained with the Match-Scan and Figure 16 shows a set of data obtained with the D54 spectrophotometer.

Observations

Table 3 summarizes the values obtained with each set of materials that are recommended for standardization of any spectrophotometer similar to the D54 or Match-Scan. The tolerances given in the Table reflect the experience obtained from this study. In the main, the tolerance that were determined for acceptable instrument performance in the QMSTAN and QSTANH programs are similar, since both instruments performed in a comparable manner. The data that were obtained on Set #1 were specifically determined on both instruments at $76^{\circ} \pm 1^{\circ}$F. All of the other data were obtained on the Match-Scan.

Slightly larger tolerances are given for the D54 than the Match-Scan, which allows for the change in transmittance when the D54 is operated at $84^{\circ}$F. Experiments were repeated twice with the temperature in the Clemson Color Science Center laboratory raised to $84^{\circ}$F. When this was done, the transmittance of the amber filter as measured by the D54 was slightly lower than typical results obtained at $76^{\circ}$F. The measurements performed on the Match-Scan at the same time did not show any difference between the two temperatures. If one can assume that the transmittance of the amber filter is approximately linear between 520 and 530 nm, 1% change in transmittance is equivalent to a 0.63 nm wavelength change. Therefore, the tolerance of 0.3% is equivalent to about 0.19 nm for the D54 and 0.13 for the Match-Scan. No statistically significant color differences were determined for the twn plastic samples when the data obtained at $76^{\circ}$F were compared to those at $84^{\circ}$F.

This document reports research undertaken in cooperation with the US Army Natick Research and Development Command under Contract No. DAAK60-79-C-0096 and has been assigned No. NATICK/TR-82/024 in the series of reports approved for publication.

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**Table 1. Transmission Data on NG-9 and NG-3 Neutral Gray Filters Calibrated by National Bureau of Standards at 511 nm; measurements at 1-nm intervals.**

SAMPLE NAME?
NG-9 NBS Value 0.807%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

D 54

| Matchscan W/L | %R |
|---|---|
| 505.0 | 0.82 |
| 506.0 | 0.82 |
| 507.0 | 0.82 |
| 508.0 | 0.82 |
| 509.0 | 0.81 |
| 510.0 | 0.82 |
| 511.0 | 0.81 |
| 512.0 | 0.82 |
| 513.0 | 0.81 |
| 514.0 | 0.82 |
| 515.0 | 0.82 |
| 516.0 | 0.82 |
| 517.0 | 0.82 |
| 518.0 | 0.82 |
| 519.0 | 0.82 |
| 520.0 | 0.82 |

CONTINUE? [Y/N] Y

| TRANSMITTANCE | |
|---|---|
| 505 | .83 |
| 506 | .84 |
| 507 | .82 |
| 508 | .83 |
| 509 | .84 |
| 510 | .81 |
| 511 | .87 |
| 512 | .84 |
| 513 | .81 |
| 514 | .86 |
| 515 | .83 |
| 516 | .84 |
| 517 | .80 |
| 518 | .80 |
| 519 | .86 |
| 520 | .82 |

SAMPLE NAME?
NG-3 NBS Value 2.693%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

D 54

| Matchscan W/L | %R |
|---|---|
| 505.0 | 2.74 |
| 506.0 | 2.74 |
| 507.0 | 2.74 |
| 508.0 | 2.73 |
| 509.0 | 2.74 |
| 510.0 | 2.74 |
| 511.0 | 2.74 |
| 512.0 | 2.74 |
| 513.0 | 2.74 |
| 514.0 | 2.74 |
| 515.0 | 2.74 |
| 516.0 | 2.75 |
| 517.0 | 2.74 |
| 518.0 | 2.75 |
| 519.0 | 2.75 |
| 520.0 | 2.76 |

CONTINUE? [Y/N] N

| TRANSMITTANCE | |
|---|---|
| 505 | 2.74 |
| 506 | 2.77 |
| 507 | 2.72 |
| 508 | 2.76 |
| 509 | 2.73 |
| 510 | 2.73 |
| 511 | 2.75 |
| 512 | 2.74 |
| 513 | 2.74 |
| 514 | 2.76 |
| 515 | 2.72 |
| 516 | 2.78 |
| 517 | 2.75 |
| 518 | 2.73 |
| 519 | 2.75 |
| 520 | 2.72 |

Table 2. **Transmission Data on NG-4 and NG-5 Neutral Gray Filters Calibrated by National Bureau of Standards at 511 nm; Measurements at 1-nm intervals.**

SAMPLE NAME?
NG-4 NBS Value 4.384
AVERAGE READINGS ? [Y/N Y
NO. OF READINGS TO AVERAGE? 2

| Matchscan W/L | Matchscan %R | D 54 | D 54 TRANSMITTANCE |
|---|---|---|---|
| 505.0 | 4.49 | 505 | 4.51 |
| 506.0 | 4.48 | 506 | 4.52 |
| 507.0 | 4.48 | 507 | 4.44 |
| 508.0 | 4.47 | 508 | 4.50 |
| 509.0 | 4.48 | 509 | 4.49 |
| 510.0 | 4.47 | 510 | 4.48 |
| 511.0 | 4.47 | 511 | 4.50 |
| 512.0 | 4.47 | 512 | 4.47 |
| 513.0 | 4.47 | 513 | 4.49 |
| 514.0 | 4.47 | 514 | 4.49 |
| 515.0 | 4.49 | 515 | 4.47 |
| 516.0 | 4.49 | 516 | 4.54 |
| 517.0 | 4.50 | 517 | 4.53 |
| 518.0 | 4.51 | 518 | 4.47 |
| 519.0 | 4.52 | 519 | 4.51 |
| 520.0 | 4.53 | 520 | 4.48 |

CONTINUE? [Y/N] Y

SAMPLE NAME?
NG-5 NBS Value 31.145%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

| Matchscan W/L | Matchscan %R | D 54 | D 54 TRANSMITTANCE |
|---|---|---|---|
| 505.0 | 31.47 | 505 | 31.59 |
| 506.0 | 31.47 | 506 | 31.61 |
| 507.0 | 31.47 | 507 | 31.61 |
| 508.0 | 31.45 | 508 | 31.65 |
| 509.0 | 31.48 | 509 | 31.62 |
| 510.0 | 31.46 | 510 | 31.65 |
| 511.0 | 31.47 | 511 | 31.70 |
| 512.0 | 31.46 | 512 | 31.69 |
| 513.0 | 31.47 | 513 | 31.64 |
| 514.0 | 31.48 | 514 | 31.67 |
| 515.0 | 31.50 | 515 | 31.63 |
| 516.0 | 31.51 | 516 | 31.69 |
| 517.0 | 31.53 | 517 | 31.59 |
| 518.0 | 31.55 | 518 | 31.69 |
| 519.0 | 31.55 | 519 | 31.62 |
| 520.0 | 31.61 | 520 | 31.66 |

CONTINUE? [Y/N] Y

Table 3. Measured Values for Calibration Materials.

| | | Set Number 1 | | | | Mean T or R in % - other sets | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Match-scan | | D54 | | #2 | #3 | #4 | #5 | #6 | |
| | Mean Length | Mean T or R | Tolerance | Mean T or R | Tolerance | | | | | | |
| White Tile | 540 | 100.02* | ±0.07 | 98.36 | ±0.10 | 100.08 | 100.17 | 99.96 | 100.03 | 99.96 | % |
| Amber Filter | 420 | 3.50 | ±0.03 | 3.48 | ±0.03 | 3.81 | 3.57 | 3.39 | 3.02 | 2.54 | % |
| | 520 | 39.15 | ±0.12 | 38.68 | ±0.18 | 40.21 | 39.36 | 38.96 | 37.66 | 35.86 | % |
| | 660 | 79.97 | ±0.12 | 80.20 | ±0.12 | 80.06 | 79.81 | 79.61 | 79.19 | 78.43 | % |
| Gray Porcelain Tile | 540 | 43.90 | ±0.10 | 42.96 | ±0.10 | 44.66 | 44.57 | 43.96 | 44.33 | 45.03 | % |
| Tan Plastic - | | Mean | Tolerance | Mean | Tolerance | Mean | Mean | Mean | Mean | Mean | |
| CIEL* a* b* 1976 | | 1.89 | ±0.05 | 1.88 | ±0.05 | 2.06 | 1.98 | 1.97 | 2.10 | 1.90 | Delta E |
| | Wave Length | | | | | | | | | | |
| Filter Pair | | | | | | | | | | | |
| Dk Blue - Yellow | 441.3 | | | | | 441.3 | 438.9 | 441.3 | 440.4 | 442.2 | nm |
| Red-Blue Green | 590.1 | | | | | 590.1 | 589.3 | 590.1 | 591.0 | 589.6 | nm |

*Sample versus Standard tile

Revised July 2, 1981

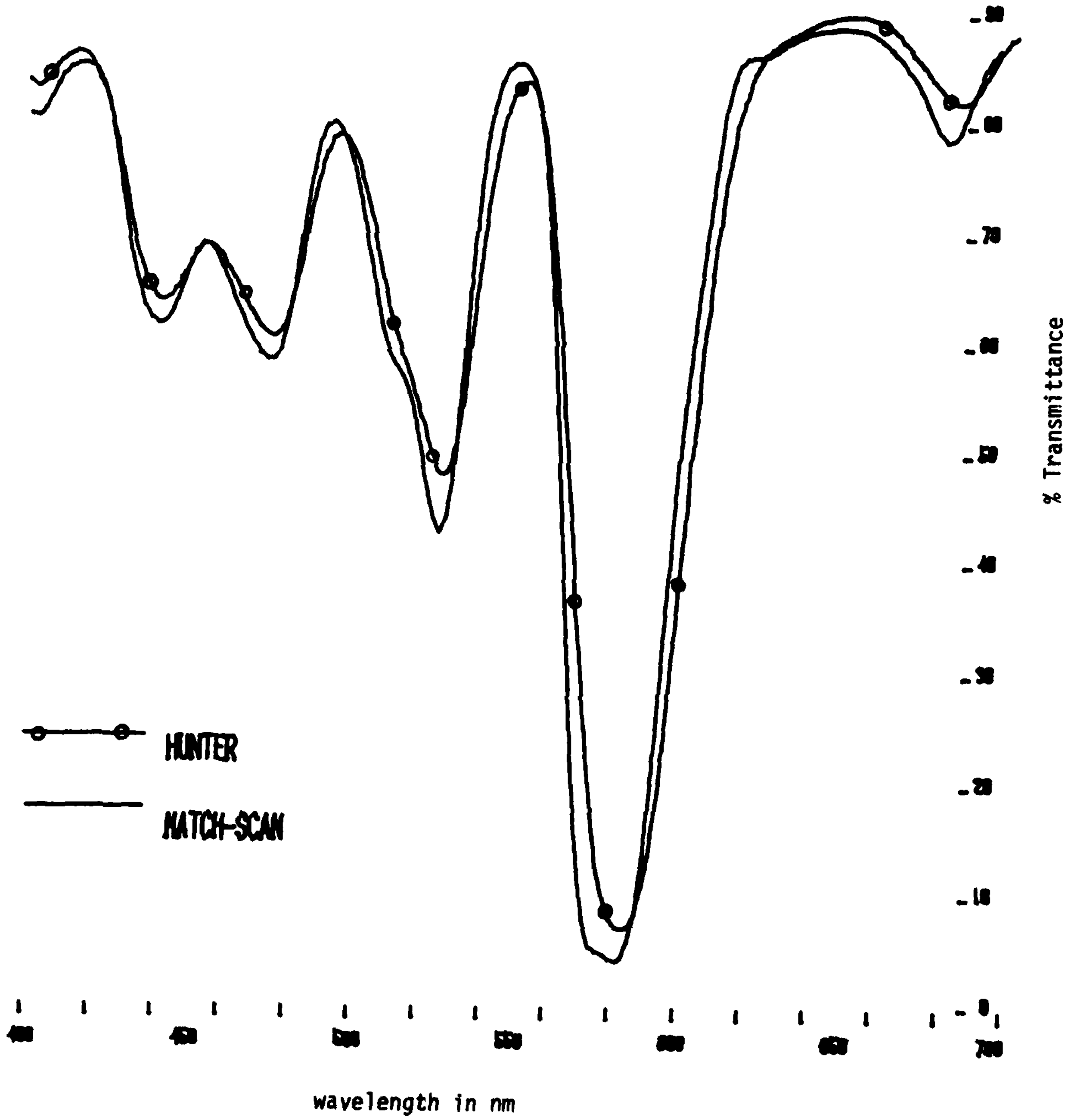


**Figure 1. Transmission curves of didymium filter for Hunter D54 and Match-Scan instruments.**

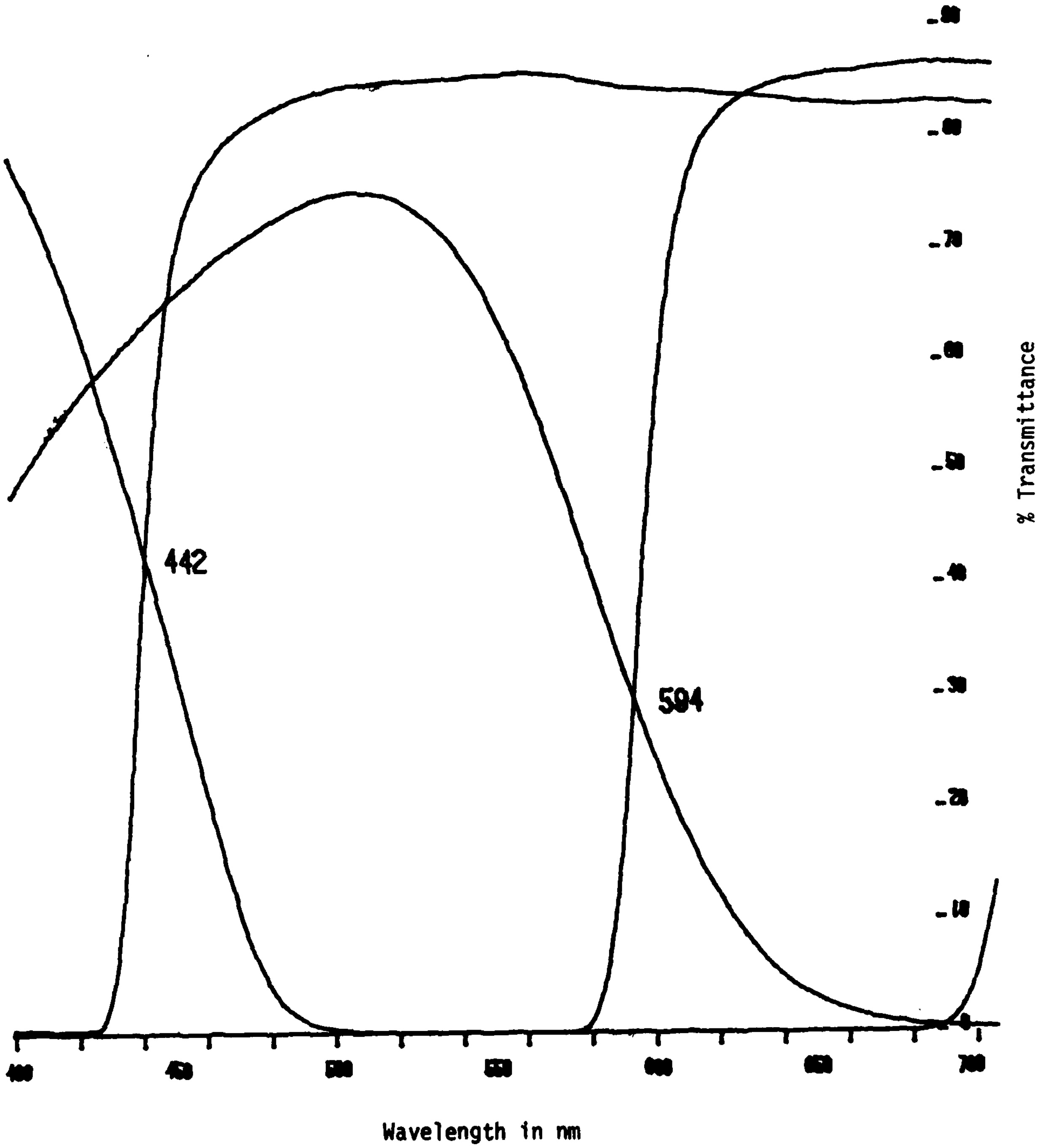


Figure 2. Match-Scan wavelength calibrating filter transmission curves.

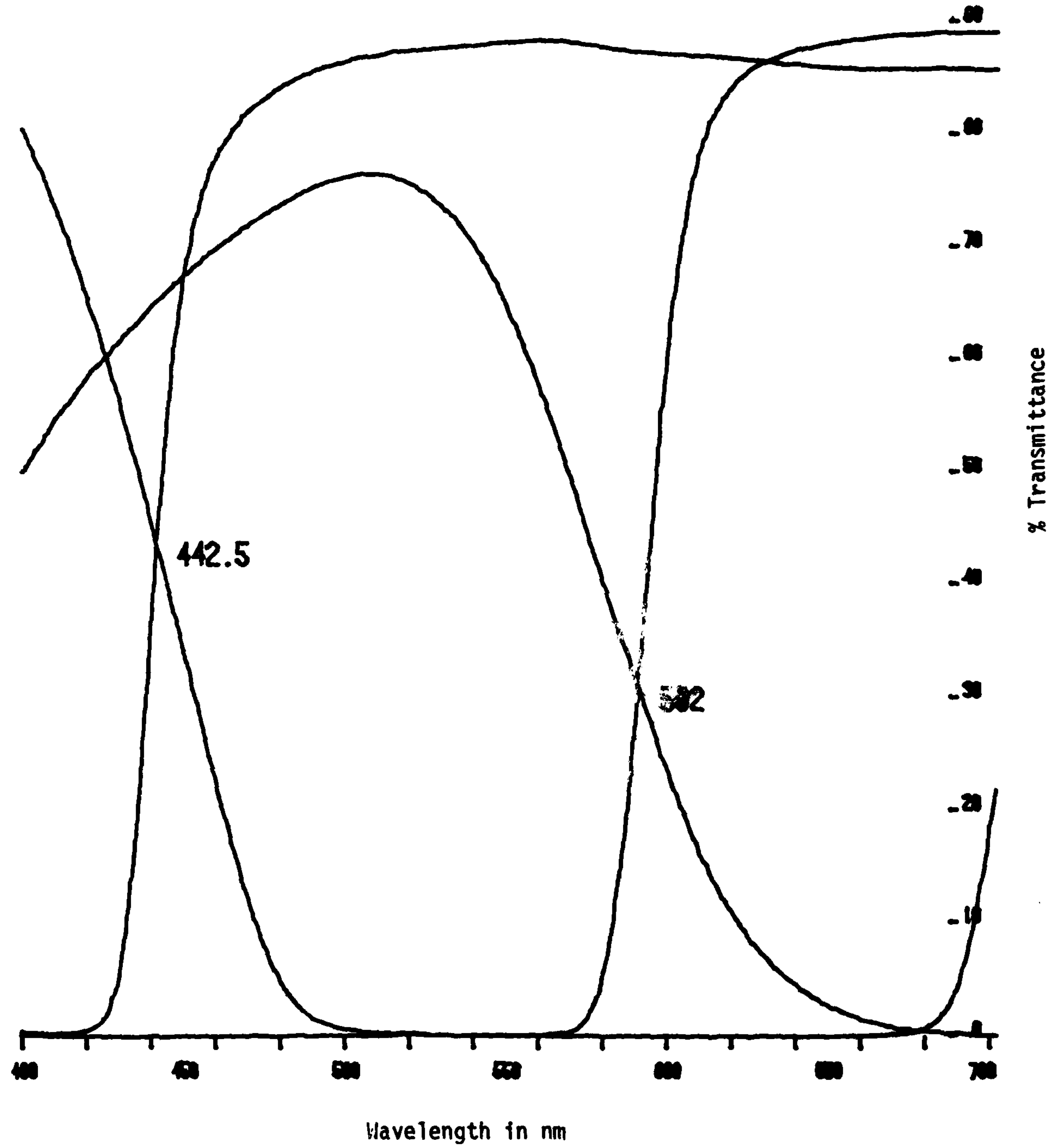


Figure 3. Hunter D54 wavelength calibrating filter transmission curves.

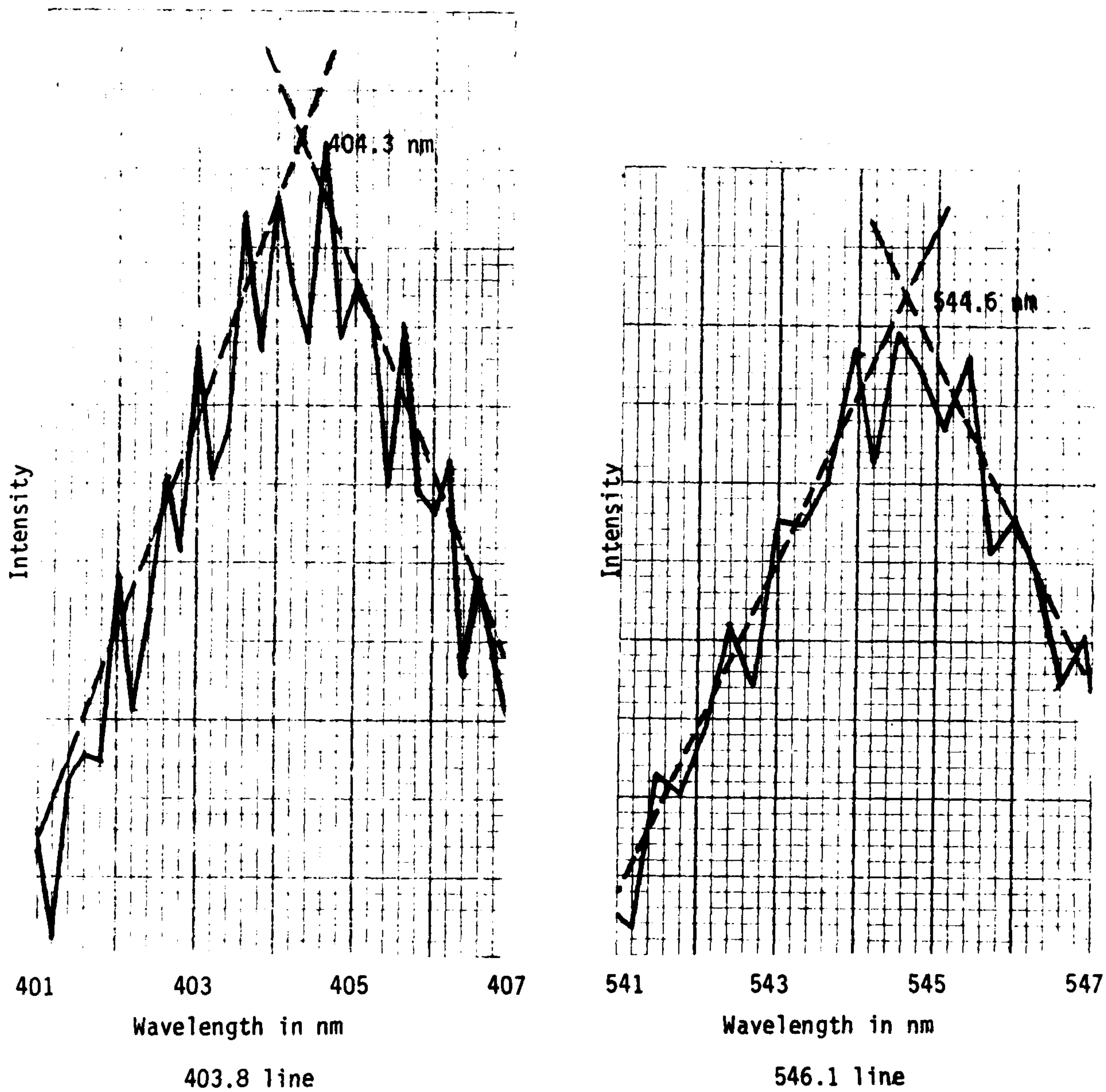


Figure 4. Mercury emission lines on the Match-Scan instrument.

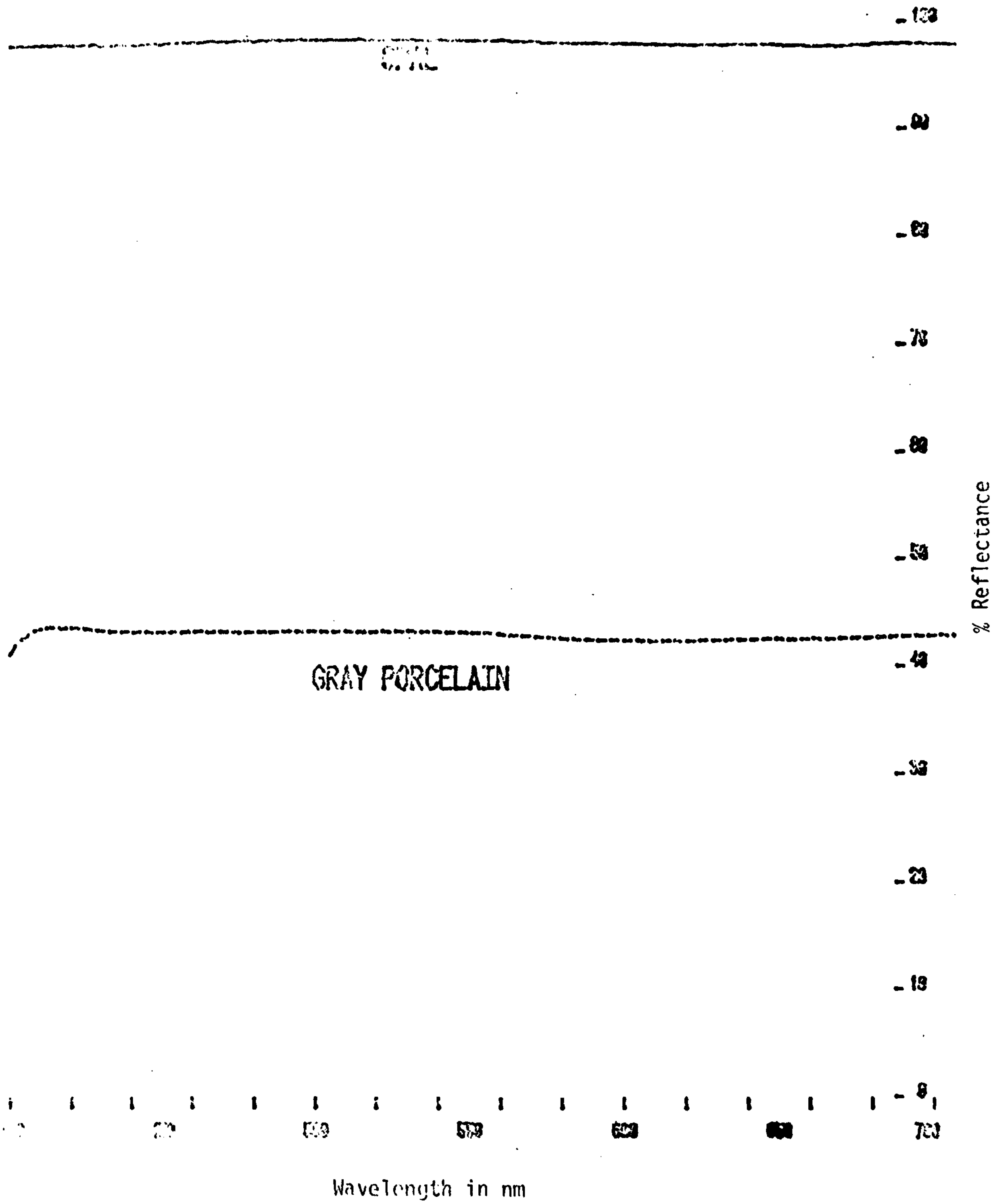


**Figure 5. Reflectance of opal and gray porcelain tiles with Match-Scan.**

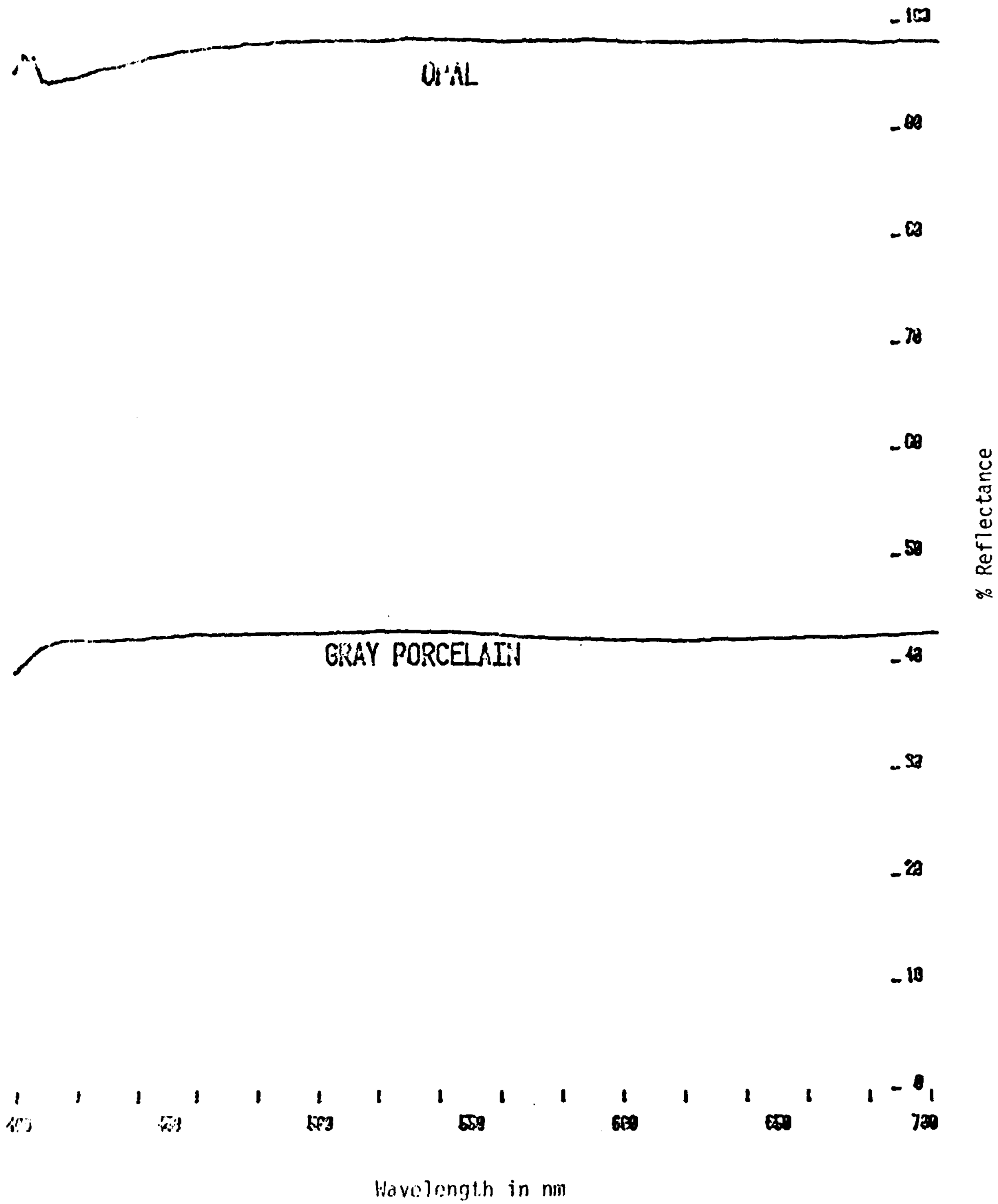


Figure 6. Reflectance of opal and gray porcelain tiles with Hunter D54.

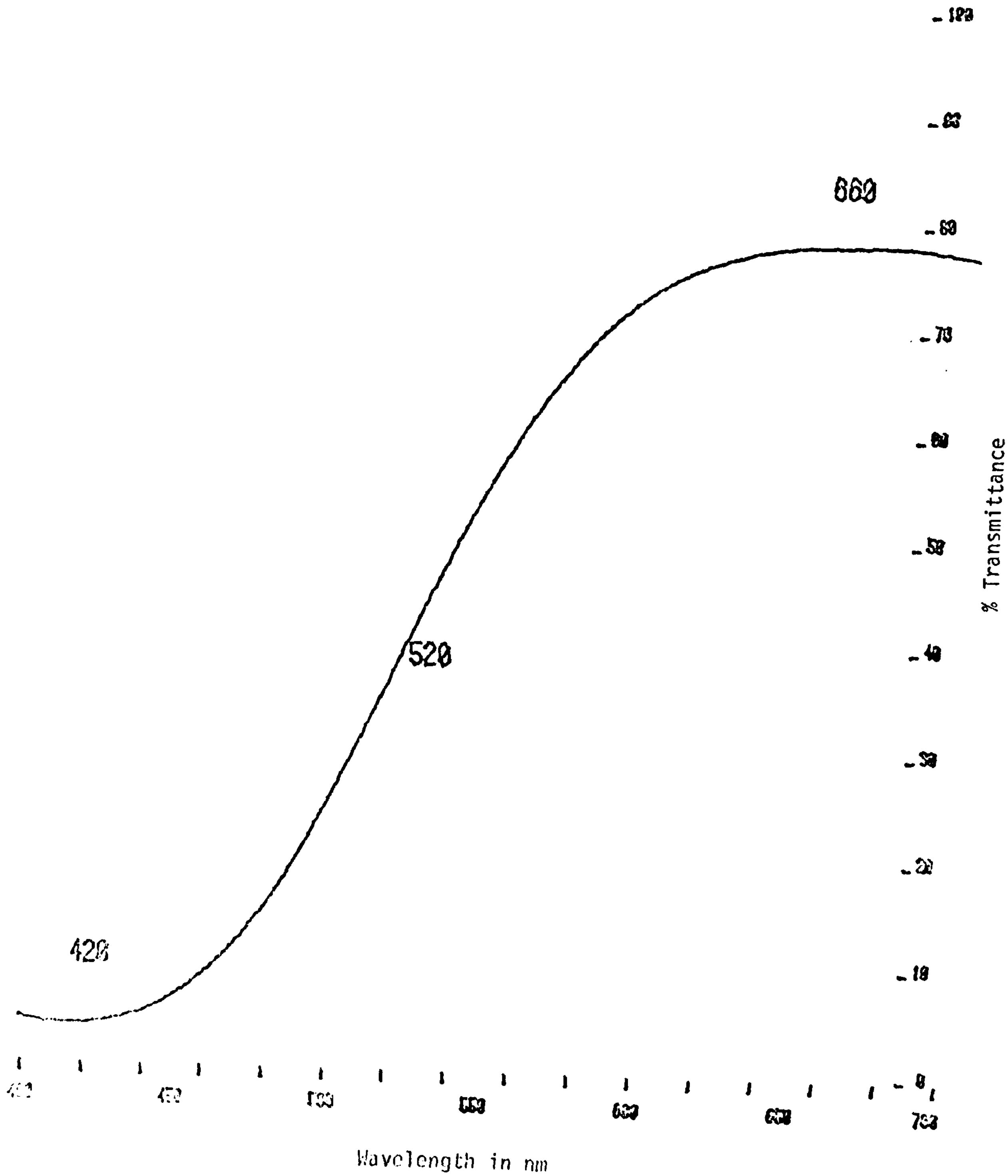


Figure 7. Transmittance of amber filter with Match-Scan.

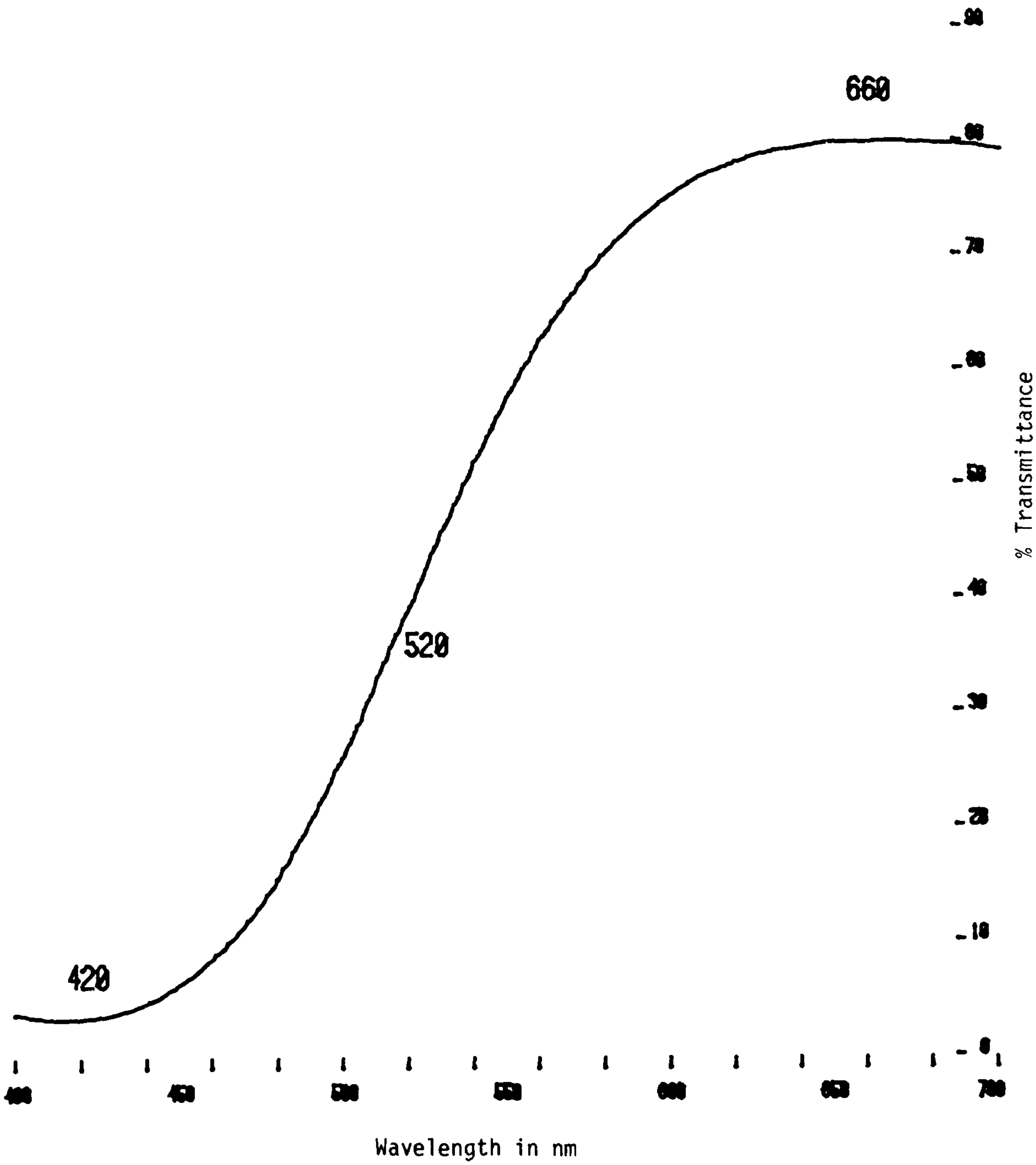


Figure 8. Transmittance of amber filter with Hunter D54.

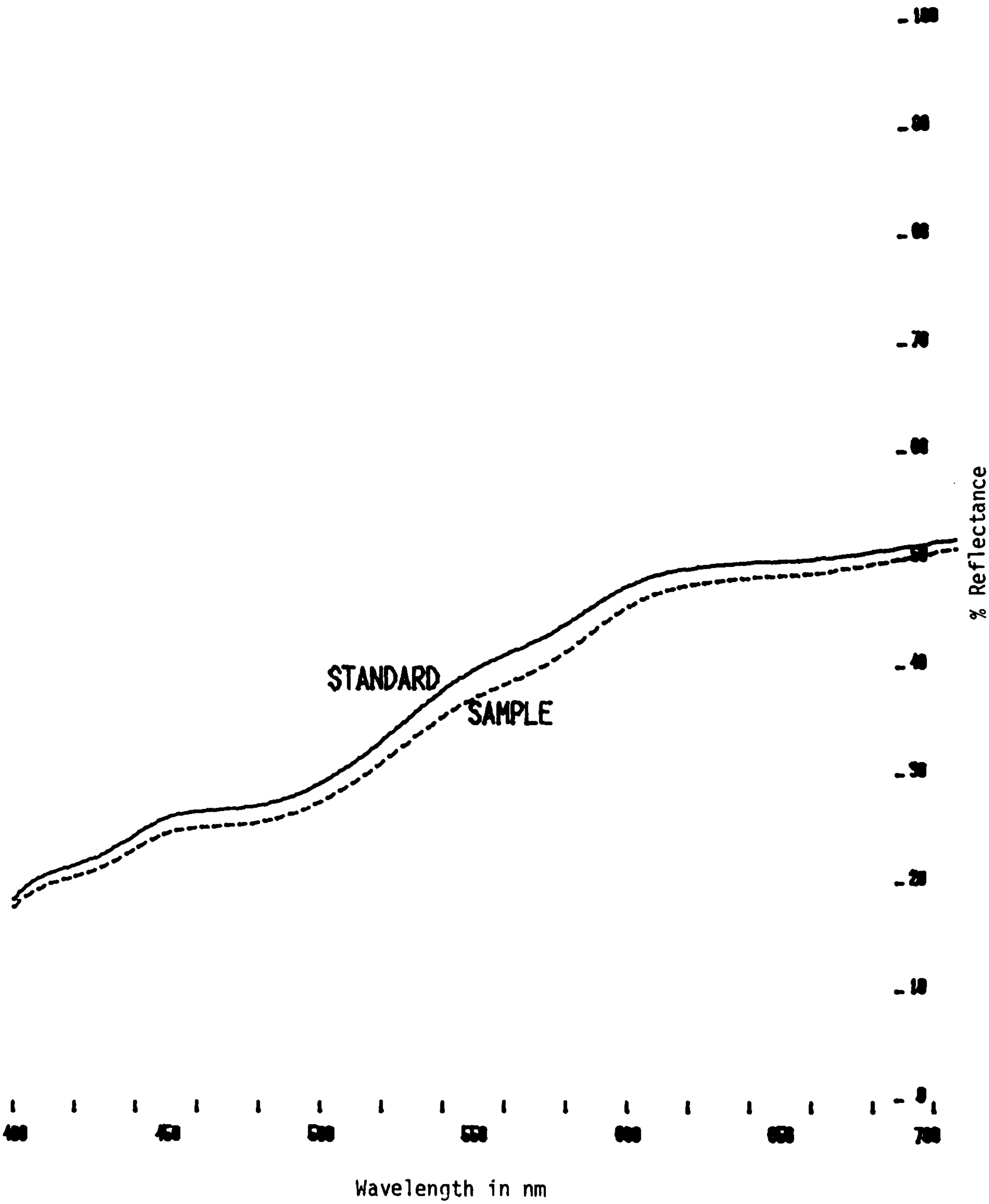


Figure 9. Reflectance curves of a pair of tan specimens with the Match-Scan.

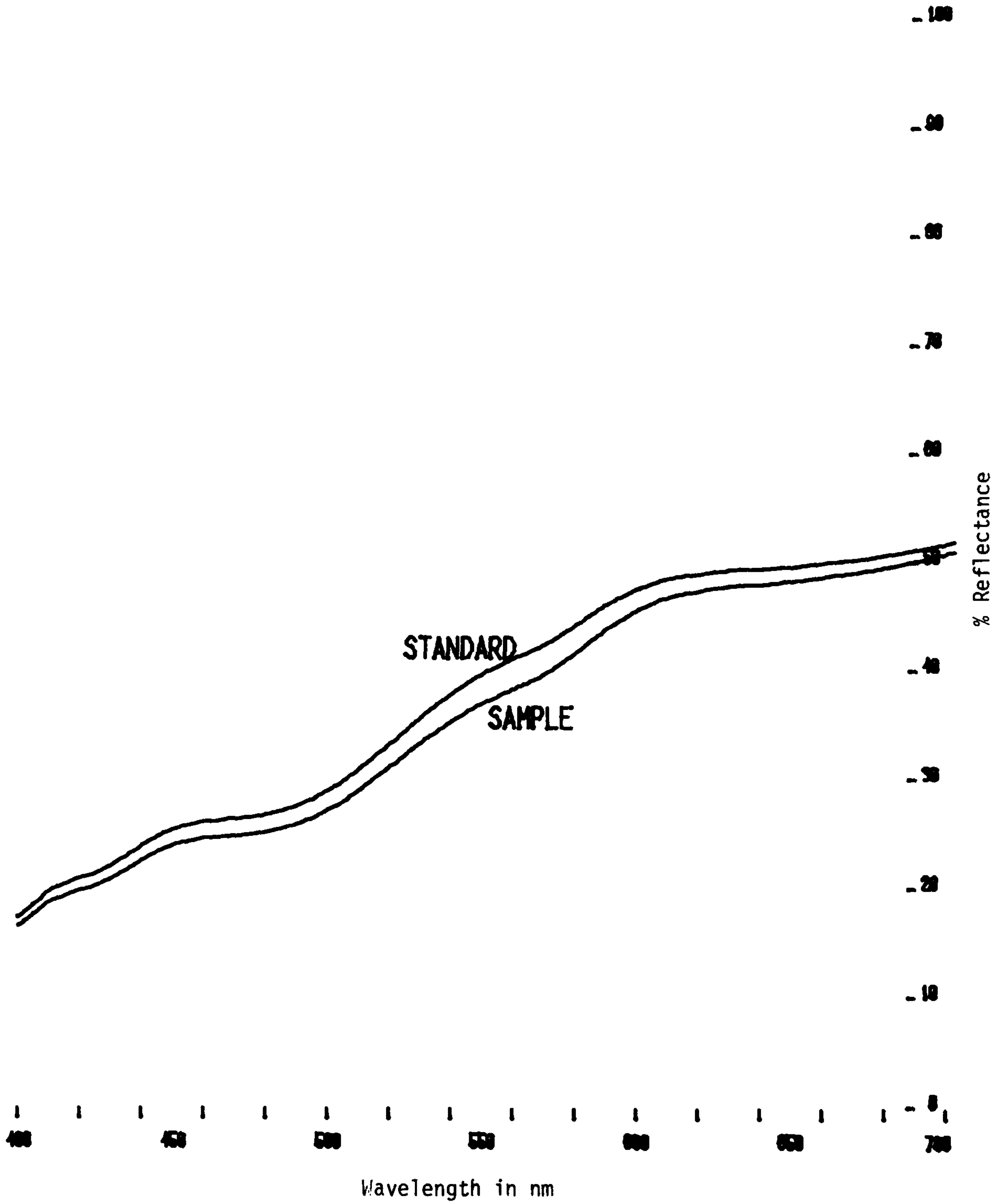


Figure 10. Reflectance curves of a pair of tan specimens with the Hunter D54.

.R QMSTAT
DATE: 10/11/80
BEGIN WITH SAMPLE NO.?(2-5) 2

MEASURE: WHITE TILES INSERT SAMPLE THEN HIT RETURN

PAUSE --

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 99.56 | 99.56 | 99.60 | 0.046 |
| 410 | 99.64 | 99.66 | 99.62 | 0.037 |
| 420 | 99.70 | 99.67 | 99.63 | 0.039 |
| 430 | 99.69 | 99.66 | 99.62 | 0.044 |
| 440 | 99.66 | 99.66 | 99.63 | 0.029 |
| 450 | 99.61 | 99.61 | 99.62 | 0.024 |
| 460 | 99.67 | 99.65 | 99.63 | 0.030 |
| 470 | 99.66 | 99.63 | 99.62 | 0.027 |
| 480 | 99.59 | 99.61 | 99.64 | 0.032 |
| 490 | 99.63 | 99.62 | 99.63 | 0.013 |
| 500 | 99.63 | 99.61 | 99.60 | 0.013 |
| 510 | 99.59 | 99.58 | 99.59 | 0.018 |
| 520 | 99.59 | 99.58 | 99.59 | 0.014 |
| 530 | 99.61 | 99.59 | 99.60 | 0.019 |
| 540 | 99.57 | 99.59 | 99.60 | 0.020 |
| 550 | 99.62 | 99.61 | 99.59 | 0.022 |
| 560 | 99.59 | 99.60 | 99.57 | 0.023 |
| 570 | 99.57 | 99.57 | 99.59 | 0.013 |
| 580 | 99.61 | 99.61 | 99.59 | 0.024 |
| 590 | 99.58 | 99.59 | 99.60 | 0.021 |
| 600 | 99.59 | 99.60 | 99.60 | 0.020 |
| 610 | 99.63 | 99.63 | 99.62 | 0.023 |
| 620 | 99.58 | 99.60 | 99.61 | 0.023 |
| 630 | 99.62 | 99.61 | 99.62 | 0.025 |
| 640 | 99.57 | 99.58 | 99.63 | 0.028 |
| 650 | 99.66 | 99.67 | 99.66 | 0.021 |
| 660 | 99.65 | 99.66 | 99.66 | 0.020 |
| 670 | 99.70 | 99.70 | 99.68 | 0.030 |
| 680 | 99.74 | 99.72 | 99.71 | 0.041 |
| 690 | 99.63 | 99.68 | 99.69 | 0.041 |
| 700 | 99.74 | 99.72 | 99.72 | 0.048 |
| 710 | 99.79 | 99.80 | 99.77 | 0.049 |

Figure 11. Statistical study for Match-Scan.

MEASURE: AMBER FILTER      INSERT SAMPLE THEN HIT RETURN

PAUSE --

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 3.99 | 3.98 | 3.98 | 0.009 |
| 410 | 3.53 | 3.54 | 3.53 | 0.007 |
| 420 | 3.52 | 3.53 | 3.52 | 0.007 |
| 430 | 3.94 | 3.94 | 3.95 | 0.005 |
| 440 | 4.88 | 4.88 | 4.88 | 0.005 |
| 450 | 6.44 | 6.44 | 6.44 | 0.006 |
| 460 | 8.73 | 8.74 | 8.74 | 0.005 |
| 470 | 11.84 | 11.85 | 11.86 | 0.007 |
| 480 | 15.92 | 15.91 | 15.90 | 0.009 |
| 490 | 21.01 | 21.01 | 21.01 | 0.008 |
| 500 | 26.81 | 26.81 | 26.81 | 0.010 |
| 510 | 32.80 | 32.81 | 32.82 | 0.010 |
| 520 | 39.17 | 39.18 | 39.20 | 0.012 |
| 530 | 45.61 | 45.63 | 45.62 | 0.011 |
| 540 | 51.84 | 51.83 | 51.82 | 0.007 |
| 550 | 57.48 | 57.49 | 57.51 | 0.013 |
| 560 | 62.54 | 62.53 | 62.55 | 0.014 |
| 570 | 66.88 | 66.86 | 66.84 | 0.022 |
| 580 | 70.43 | 70.43 | 70.43 | 0.015 |
| 590 | 73.27 | 73.27 | 73.28 | 0.024 |
| 600 | 75.52 | 75.51 | 75.49 | 0.017 |
| 610 | 77.14 | 77.13 | 77.11 | 0.019 |
| 620 | 78.28 | 78.27 | 78.28 | 0.015 |
| 630 | 79.06 | 79.07 | 79.08 | 0.027 |
| 640 | 79.65 | 79.63 | 79.59 | 0.017 |
| 650 | 79.84 | 79.84 | 79.85 | 0.016 |
| 660 | 79.94 | 79.96 | 79.97 | 0.016 |
| 670 | 79.94 | 79.95 | 79.93 | 0.025 |
| 680 | 79.69 | 79.71 | 79.73 | 0.029 |
| 690 | 79.50 | 79.47 | 79.47 | 0.034 |
| 700 | 79.11 | 79.08 | 79.07 | 0.031 |
| 710 | 78.49 | 78.53 | 78.54 | 0.028 |

Figure 11. Statistical study for Match-Scan (continued).

MEASURE: GRAY PORCELAIN    INSERT SAMPLE THEN HIT RETURN

PAUSE --

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 42.05 | 42.07 | 42.07 | 0.028 |
| 410 | 44.43 | 44.39 | 44.40 | 0.024 |
| 420 | 44.42 | 44.45 | 44.46 | 0.016 |
| 430 | 44.23 | 44.24 | 44.24 | 0.020 |
| 440 | 44.07 | 44.08 | 44.10 | 0.012 |
| 450 | 44.02 | 44.03 | 44.03 | 0.019 |
| 460 | 43.98 | 44.00 | 44.00 | 0.011 |
| 470 | 43.97 | 43.97 | 43.98 | 0.013 |
| 480 | 44.00 | 43.98 | 43.97 | 0.012 |
| 490 | 43.96 | 43.98 | 43.97 | 0.010 |
| 500 | 43.92 | 43.93 | 43.95 | 0.010 |
| 510 | 43.95 | 43.94 | 43.94 | 0.009 |
| 520 | 43.95 | 43.97 | 43.97 | 0.016 |
| 530 | 43.95 | 43.95 | 43.95 | 0.011 |
| 540 | 43.91 | 43.90 | 43.89 | 0.012 |
| 550 | 43.81 | 43.80 | 43.80 | 0.016 |
| 560 | 43.63 | 43.63 | 43.65 | 0.010 |
| 570 | 43.49 | 43.49 | 43.48 | 0.009 |
| 580 | 43.35 | 43.35 | 43.35 | 0.011 |
| 590 | 43.27 | 43.26 | 43.26 | 0.013 |
| 600 | 43.23 | 43.23 | 43.22 | 0.010 |
| 610 | 43.25 | 43.25 | 43.25 | 0.011 |
| 620 | 43.35 | 43.35 | 43.34 | 0.015 |
| 630 | 43.39 | 43.42 | 43.40 | 0.017 |
| 640 | 43.48 | 43.47 | 43.46 | 0.011 |
| 650 | 43.47 | 43.48 | 43.49 | 0.017 |
| 660 | 43.54 | 43.52 | 43.52 | 0.014 |
| 670 | 43.55 | 43.53 | 43.55 | 0.016 |
| 680 | 43.61 | 43.62 | 43.64 | 0.015 |
| 690 | 43.80 | 43.78 | 43.77 | 0.008 |
| 700 | 43.83 | 43.87 | 43.86 | 0.020 |
| 710 | 44.06 | 44.05 | 44.02 | 0.025 |

Figure 11. Statistical study for Match-Scan (continued).

```
MEASURE: STD TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN
PAUSE --

MEASURE: SPL TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN
PAUSE --

  STD   ONE  X= 0.4249 Y= 0.4023 Z= 0.2605
  STD   AV2  X= 0.4249 Y= 0.4023 Z= 0.2605
  STD   AV10 X= 0.4248 Y= 0.4022 Z= 0.2605
  STD   SIG  X=0.00003 Y=0.00002 Z=0.00003
  SPL   ONE  X= 0.4050 Y= 0.3801 Z= 0.2459
  SPL   AV2  X= 0.4050 Y= 0.3800 Z= 0.2459
  SPL   AV10 X= 0.4048 Y= 0.3799 Z= 0.2459
  SPL   SIG  X=0.00010 Y=0.00010 Z=0.00007
  STD   ONE  L*=  69.63 A*=   6.80 B*=  19.91
  STD   AV2  L*=  69.63 A*=   6.79 B*=  19.91
  STD   AV10 L*=  69.63 A*=   6.79 B*=  19.91
  STD   SIG  L*=  0.002 A*=  0.006 B*=  0.004
  SPL   ONE  L*=  68.03 A*=   7.76 B*=  19.57
  SPL   AV2  L*=  68.02 A*=   7.76 B*=  19.57
  SPL   AV10 L*=  68.01 A*=   7.75 B*=  19.56
  SPL   SIG  L*=  0.007 A*=  0.004 B*=  0.008
ONE  DL=   1.61 DC=   0.94 DE=   1.86
AV2  DL=   1.61 DC=   0.95 DE=   1.87
AV10 DL=   1.62 DC=   0.94 DE=   1.87
SIG  DL=  0.006 DC=  0.013 DE=  0.014
STOP --
```

Figure 11. Statistical study for Match-Scan (continued).

```
?$Q"STA1
  DATE: 10/14/80
  BEGIN WITH SAMPLE NO.?(1-5)
?1

  1. ON HUNTER PRESS "TRANS",PUT WHITE TILE OVER PORT,
       BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON  HUNTER,
  4. PRESS "ASCII", THEN "2"
  5. PRESS RETURN ON SPC-16 CONSOLE
 PAUSE
?

  MEASURE: AMBER FILTER      INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10NM
 PAUSE
```

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 3.99 | 3.97 | 3.96 | 0.019 |
| 410 | 3.50 | 3.51 | 3.51 | 0.010 |
| 420 | 3.50 | 3.50 | 3.50 | 0.005 |
| 430 | 3.90 | 3.90 | 3.89 | 0.010 |
| 440 | 4.82 | 4.82 | 4.82 | 0.004 |
| 450 | 6.39 | 6.39 | 6.39 | 0.004 |
| 460 | 8.57 | 8.57 | 8.57 | 0.005 |
| 470 | 11.48 | 11.48 | 11.48 | 0.006 |
| 480 | 15.46 | 15.45 | 15.46 | 0.008 |
| 490 | 20.46 | 20.46 | 20.45 | 0.010 |
| 500 | 26.02 | 26.02 | 26.02 | 0.006 |
| 510 | 32.18 | 32.16 | 32.16 | 0.014 |
| 520 | 38.72 | 38.72 | 38.70 | 0.013 |
| 530 | 45.02 | 45.02 | 45.03 | 0.013 |
| 540 | 51.16 | 51.16 | 51.15 | 0.013 |
| 550 | 56.92 | 56.92 | 56.90 | 0.014 |
| 560 | 61.95 | 61.96 | 61.95 | 0.014 |
| 570 | 66.33 | 66.33 | 66.33 | 0.015 |
| 580 | 70.14 | 70.14 | 70.12 | 0.015 |
| 590 | 72.79 | 72.79 | 72.78 | 0.015 |
| 600 | 75.20 | 75.20 | 75.19 | 0.015 |
| 610 | 77.19 | 77.19 | 77.19 | 0.014 |
| 620 | 78.24 | 78.25 | 78.24 | 0.017 |
| 630 | 79.00 | 79.01 | 78.99 | 0.029 |
| 640 | 79.64 | 79.64 | 79.65 | 0.017 |
| 650 | 80.13 | 80.14 | 80.12 | 0.019 |
| 660 | 80.15 | 80.16 | 80.15 | 0.016 |
| 670 | 79.94 | 79.94 | 79.95 | 0.011 |
| 680 | 79.96 | 79.96 | 79.97 | 0.014 |
| 690 | 79.96 | 79.96 | 79.93 | 0.016 |
| 700 | 79.52 | 79.52 | 79.50 | 0.019 |
| 710 | 79.04 | 79.06 | 79.06 | 0.023 |

**Figure 12. Statistical study for Hunter D54.**

```
*** REMOVE AMBER FILTER***
 1. ON HUNTER, PRESS "R-SIN", PUT ZERO TRAP OVER PORT
 2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
 3. PRESS "STDZ PUT GRAY PORCELAIN OVER PORT.
4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON HUNTER,
5. PRESS RETURN ON SPC-16 CONSOLE
PAUSE

MEASURE: WHITE TILE        INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10N
```

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 95.64 | 95.63 | 95.57 | 0.050 |
| 410 | 94.66 | 94.65 | 94.63 | 0.023 |
| 420 | 94.95 | 94.94 | 94.95 | 0.012 |
| 430 | 95.71 | 95.70 | 95.71 | 0.011 |
| 440 | 96.32 | 96.32 | 96.33 | 0.012 |
| 450 | 96.95 | 96.94 | 96.95 | 0.014 |
| 460 | 97.42 | 97.42 | 97.41 | 0.019 |
| 470 | 97.71 | 97.71 | 97.69 | 0.018 |
| 480 | 97.93 | 97.92 | 97.92 | 0.012 |
| 490 | 98.12 | 98.12 | 98.12 | 0.012 |
| 500 | 98.21 | 98.20 | 98.22 | 0.019 |
| 510 | 98.20 | 98.21 | 98.22 | 0.013 |
| 520 | 98.26 | 98.26 | 98.26 | 0.006 |
| 530 | 98.49 | 98.49 | 98.51 | 0.019 |
| 540 | 98.33 | 98.33 | 98.35 | 0.020 |
| 550 | 98.35 | 98.35 | 98.36 | 0.010 |
| 560 | 98.26 | 98.24 | 98.24 | 0.019 |
| 570 | 98.34 | 98.33 | 98.34 | 0.011 |
| 580 | 98.27 | 98.26 | 98.27 | 0.011 |
| 590 | 98.45 | 98.45 | 98.46 | 0.013 |
| 600 | 98.16 | 98.14 | 98.14 | 0.014 |
| 610 | 98.14 | 98.14 | 98.15 | 0.019 |
| 620 | 98.08 | 98.06 | 98.06 | 0.013 |
| 630 | 98.16 | 98.14 | 98.14 | 0.016 |
| 640 | 98.18 | 98.17 | 98.18 | 0.009 |
| 650 | 98.15 | 98.14 | 98.17 | 0.018 |
| 660 | 98.09 | 98.08 | 98.10 | 0.015 |
| 670 | 98.19 | 98.19 | 98.20 | 0.011 |
| 680 | 97.97 | 97.97 | 97.97 | 0.007 |
| 690 | 98.21 | 98.21 | 98.20 | 0.007 |
| 700 | 98.11 | 98.10 | 98.10 | 0.014 |
| 710 | 97.94 | 97.94 | 97.98 | 0.028 |

**Figure 12. Statistical study for Hunter D54 (continued).**

MEASURE: GRAY PORCELAIN   INSERT SAMPLE,PRESS READ ON HUNTER,THEN [illegible]
PAUSE

| W/L | FIRST | AVG OF 2 | AVG OF 10 | SIGMA |
|---|---|---|---|---|
| 400 | 39.25 | 39.25 | 39.25 | 0.042 |
| 410 | 41.76 | 41.75 | 41.77 | 0.019 |
| 420 | 42.20 | 42.19 | 42.21 | 0.018 |
| 430 | 42.19 | 42.19 | 42.19 | 0.007 |
| 440 | 42.31 | 42.31 | 42.32 | 0.007 |
| 450 | 42.47 | 42.47 | 42.48 | 0.014 |
| 460 | 42.70 | 42.70 | 42.72 | 0.013 |
| 470 | 42.68 | 42.68 | 42.69 | 0.012 |
| 480 | 42.76 | 42.76 | 42.76 | 0.005 |
| 490 | 42.84 | 42.84 | 42.84 | 0.008 |
| 500 | 42.87 | 42.86 | 42.85 | 0.011 |
| 510 | 42.87 | 42.87 | 42.87 | 0.011 |
| 520 | 43.01 | 43.01 | 43.01 | 0.008 |
| 530 | 43.04 | 43.03 | 43.03 | 0.011 |
| 540 | 42.92 | 42.92 | 42.93 | 0.017 |
| 550 | 42.85 | 42.85 | 42.86 | 0.019 |
| 560 | 42.68 | 42.68 | 42.68 | 0.006 |
| 570 | 42.42 | 42.42 | 42.43 | 0.014 |
| 580 | 42.28 | 42.28 | 42.29 | 0.010 |
| 590 | 42.28 | 42.28 | 42.29 | 0.010 |
| 600 | 42.14 | 42.14 | 42.14 | 0.006 |
| 610 | 42.14 | 42.14 | 42.13 | 0.013 |
| 620 | 42.10 | 42.10 | 42.11 | 0.011 |
| 630 | 42.25 | 42.25 | 42.26 | 0.013 |
| 640 | 42.23 | 42.23 | 42.23 | 0.013 |
| 650 | 42.33 | 42.33 | 42.34 | 0.009 |
| 660 | 42.39 | 42.39 | 42.40 | 0.011 |
| 670 | 42.37 | 42.37 | 42.37 | 0.007 |
| 680 | 42.53 | 42.53 | 42.55 | 0.009 |
| 690 | 42.65 | 42.65 | 42.66 | 0.012 |
| 700 | 42.80 | 42.80 | 42.79 | 0.010 |
| 710 | 42.86 | 42.86 | 42.87 | 0.015 |

**Figure 12. Statistical study on Hunter D54 (continued).**

```
MEASURE: STD TAN PLASTIC  INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10NM
PAUSE
MEASURE: SPL TAN PLASTIC  INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10NM
PAUSE
STD   ONE  X= 0.4127 Y= 0.3911 Z= 0.2500
STD   AV2  X= 0.4127 Y= 0.3911 Z= 0.2500
STD   AV10 X= 0.4127 Y= 0.3911 Z= 0.2500
STD   SIG  X=0.00003 Y=0.00002 Z=0.0000[illegible]
SPL   ONE  X= 0.3927 Y= 0.3689 Z= 0.2358
SPL   AV2  X= 0.3928 Y= 0.3690 Z= 0.2358
SPL   AV10 X= 0.39[illegible] Y= 0.3691 Z= 0.2358
SPL   SIG  X=0.0000[illegible] Y=0.00008 Z=0.00005
STD   ONE  L*=  68.83 a*=    6.60 b*=   20.27
STD   AV2  L*=  68.83 a*=    6.61 b*=   20.27
STD   AV10 L*=  68.83 a*=    6.60 b*=   20.28
STD   SIG  L*=  0.001 a*=   0.007 b*=   0.005
SPL   ONE  L*=  67.20 a*=    7.54 b*=   19.[illegible]
SPL   AV2  L*=  67.20 a*=    7.54 b*=   19.89
SPL   AV10 L*=  67.21 a*=    7.54 b*=   19.90
SPL   SIG  L*=  0.006 a*=   0.00[illegible] b*=   0.005
ONE   DL=     1.[illegible] DC=     0.[illegible] DE=    1.86
AV2   DL=     1.6[illegible] DC=     0.[illegible] DE=    1.85
AV10  DL=     1.62 DC=     0.90 DE=    1.85
SIG   DL=   0.006 DC=   0.022 DE=    0.023
STOP
```

Figure 12. Statistical study of Hunter D54 (continued).

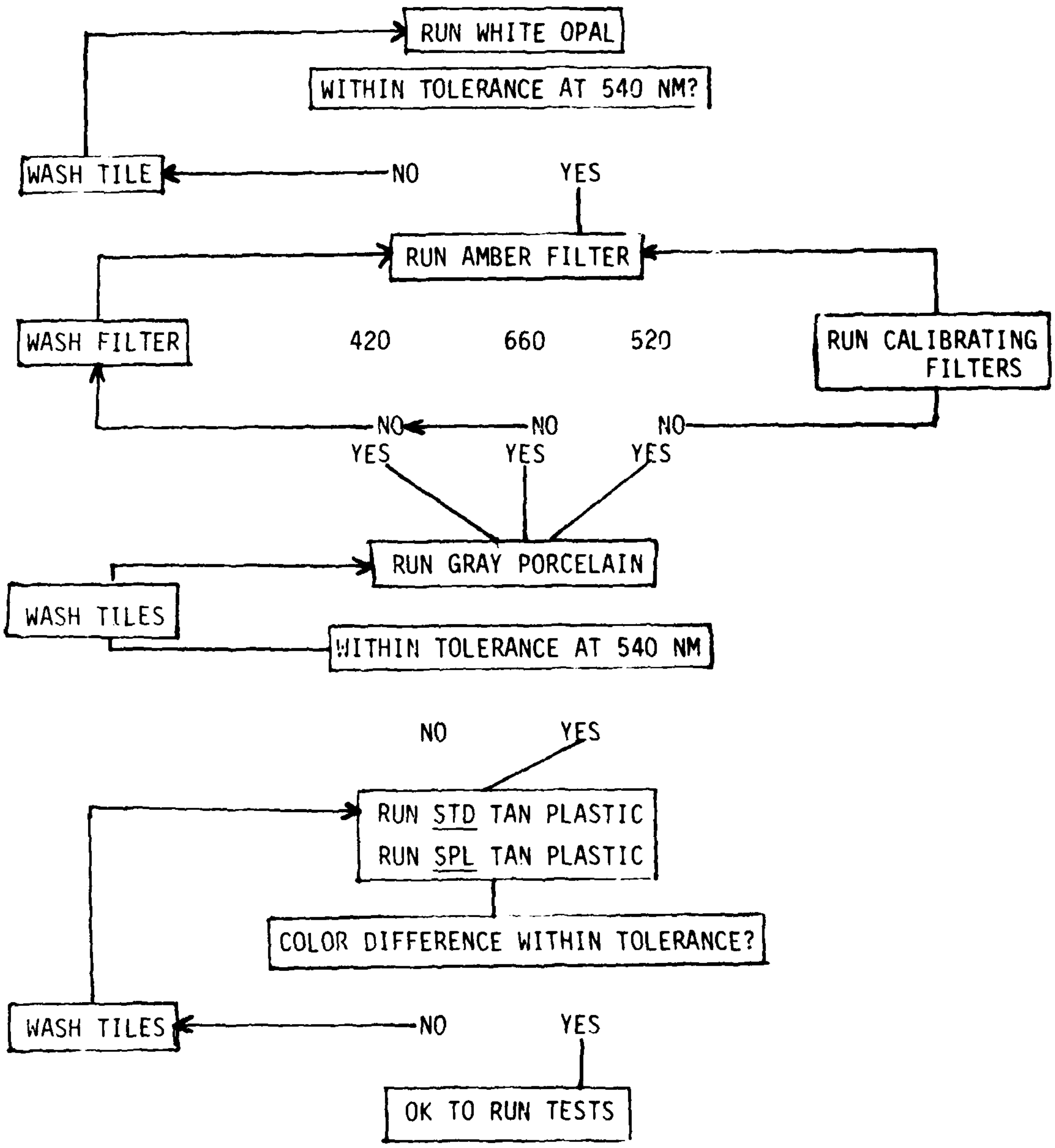


Figure 13. Schematic of standardization of Match-Scan.

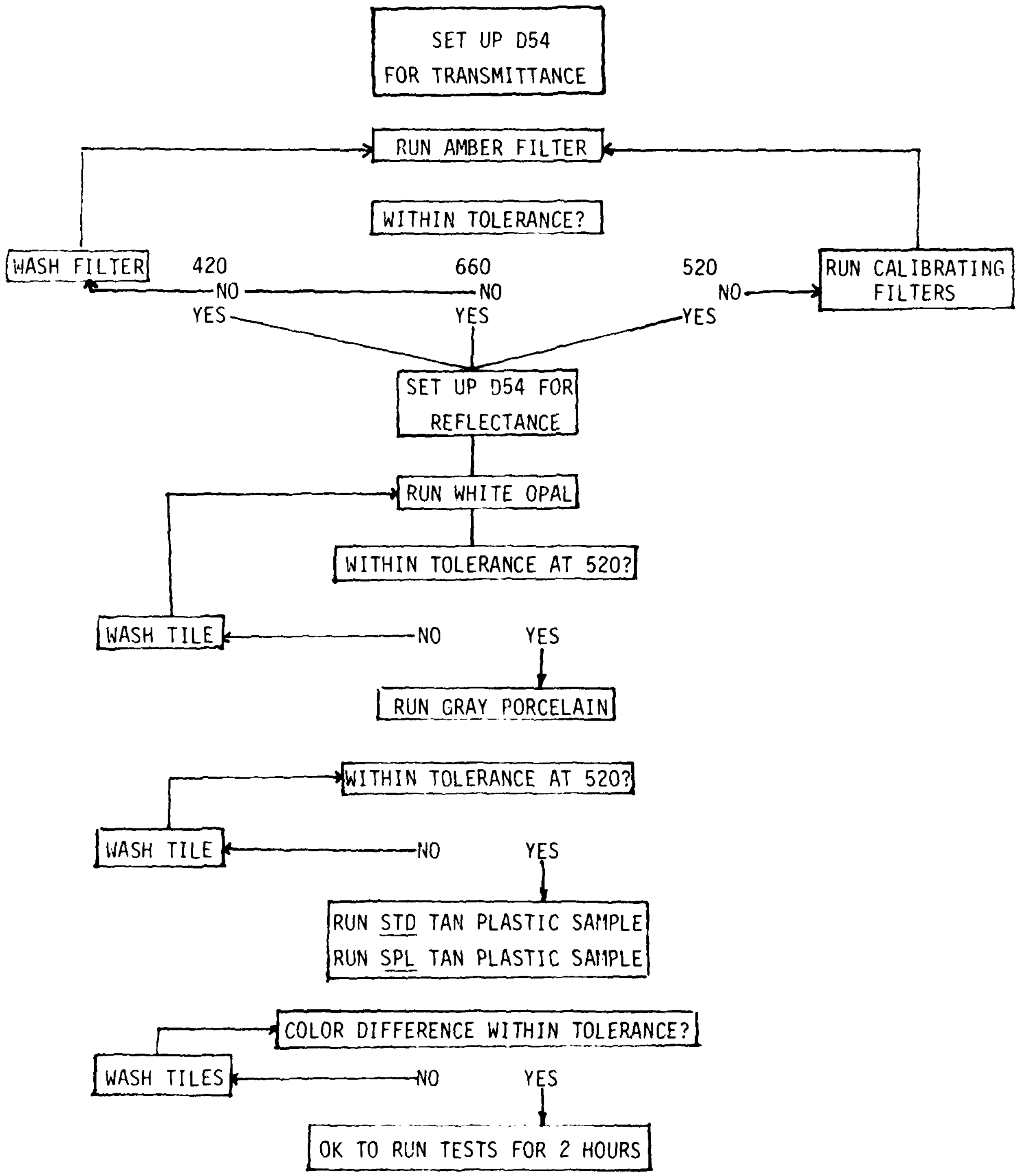


Figure 14. Schematic of standardization of Hunter D54.

```
DATE:  1/25/81
 BEGIN WITH SAMPLE NO.?(1-5)        1

MEASURE: WHITE TILES        INSERT SAMPLE THEN HI~ RETURN AFTER PAUSE
AT 540 NM UPPEv LIMIT  99.62 LOWER LIMIT  99.48
PAUSE --


W/L      FIRST     AVG OF 2
 540      99.54      99.53

MEASURE: AMBER FILTER       INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
AT 420 NM UPPER LIMIT   3.53 LOWER LIMIT   3.47
AT 520 NM UPPER LIMIT  39.27 LOWER LIMIT  38.93
AT 660 NM UPPER LIMIT  80.09 LOWER LIMIT  79.85
PAUSE --


W/L      FIRST     AVG OF 2
 420       3.49       3.49
 520      39.15      39.16
 660      80.00      79.96

MEASURE: GRAY PORCELAIN    INSERT SAMPLE THEN HIT RE~URN AFTER PAUSE
AT 540 NM UPPER LIMIT  44.00 LOWER LIMIT  43.80
PAUSE --


W/L      FIRST     AVG OF 2
 540      43.92      43.94

MEASURE: STD TAN PLASTIC   INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
COLOR DIFF. UPPER LIMIT   1.94 LOWER LIMIT   1.84
PAUSE --


MEASURE: SPL TAN PLASTIC   INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
PAUSE --


AVG OF 2  DL=   1.60 DC=   0.97 DE=   1.87
STOP --
```

**Figure 15. Standardization test for Match-Scan, typical output from QMSTAN computer program.**

```
?$QSTANH
 DATE:  1/27/81
 BEGIN WITH SAMPLE NO.? (1-5)
?1

  1. ON D54 PRESS "ASCII OUT", THEN "O", THEN "TRANS"
       PUT WHITE PORCELAIN OVER PORT,
       BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54
  4. PRESS "ASCII", THEN "2",
  5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: AMBER FILTER      INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "1ONM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L     FIRST    AVG OF 2
   420      3.49      3.49
   520     38.76     38.74
   660     80.20     80.20
 *** REMOVE AMBER FILTER***
  1. ON D54, PRESS "ASCII",THEN "O",THEN "R-SIN"/      PUT ZERO TRAP
  2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
  3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT
  4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54,
  5. PRESS "ASCII", THEN "2"
  6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: WHITE TILE        INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "1ONM" AND "RETURN" AT SAME TIME
  AT 540 NM UPPER LIMIT 98.46 LOWER LIMIT 98.26
 PAUSE
?
 PAUSE
?
  W/L     FIRST    AVG OF 2
   540     98.40     98.40
```

**Figure 16. Standardization test for Hunter D54, typical output from QSTANH computer program.**

```
 MEASURE: GRAY PORCELAIN    INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
 AT 540 NM UPPER LIMIT 43.06 LOWER LIMIT 42.86
PAUSE
?
PAUSE
?
 W/L      FIRST    AVG OF 2
  540      42.92      42.92
 MEASURE: STD TAN PLASTIC  INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
 COLOR DIFFERENCE: UPPER LIMIT  1.93 LOWER LIMIT  1.83
PAUSE
?
PAUSE
?

 MEASURE: SPL TAN PLASTIC  INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
PAUSE
?
PAUSE
?

ONE  DL=    1.63 DC=    0.88 DE=    1.85.

AV2  DL=    1.62 DC=    0.87 DE=    1.84

***OK TO MAKE MEASUREMENTS***
STOP
```

**Figure 16. Standardization test for Hunter D54 (continued).**

```
?$OSTANH
  DATE:  1/27/81
  BEGIN WITH SAMPLE NO.? (1-5)
?1

  1. ON D54 PRESS "ASCII OUT", THEN "O", THEN "TRANS"
       PUT WHITE PORCELAIN OVER PORT,
       BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54
  4. PRESS "ASCII", THEN "2",
  5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: AMBER FILTER      INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L      FIRST    AVG OF 2
   420       3.76       3.77
 ***READING AT  420NM IS OUT OF SPECS FOR:AMBER FILTER
     WASH SAMPLE, THEN

  MEASURE: AMBER FILTER      INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L      FIRST    AVG OF 2
   420       3.48       3.48
   520      38.74      38.74
   660      80.14      80.15

 *** REMOVE AMBER FILTER***
  1. ON D54, PRESS "ASCII",THEN "O",THEN "R-SIN",      PUT ZERO TRAP
  2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
  3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT
  4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54,
  5. PRESS "ASCII", THEN "2"
  6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
```

**Figure 16. Standardization tests for Hunter D54 (continued).**

## APPENDICES

## Appendix A

### Computer Program QMSTST for Match-Scan Statistical Study.

```
      PROGRAM QMSTAT
C     --- TO CALCULATE STATISTICAL DATA FOR A STANDARDIZATION
C     PROCEDURE APPLICABLE TO THE MATCH-SCAN
C
C     LINK INSTRUCTIONS:
C     ASS DX1 DK
C     R LINK
C     *QMSTAT=QMSTAT,DXO:MSLIB,FISNOV.NEW
C
C
      DIMENSION AVGNO(4),CMF(3,32),D65(32),FAC(32,3),FACT(32),PLAS
      DIMENSION R(32,10),RC(32,13,2),RG(32),STAR(3,13,2),SPL(4,5)
      DIMENSION TRI(3,13,2),TRIO(3),VAL(3),DSQ(3),AVG(3),CD(3,13)
     DATA CMF/0.0191,0.0020,0.0860
     X,  0.0847,0.0088,0.3894
     X,  0.2045,0.0214,0.9725
     X,  0.3147,0.0387,1.5535
     X,  0.3837,0.0621,1.9673
     X,  0.3707,0.0895,1.9948
     X,  0.3023,0.1282,1.7454
     X,  0.1956,0.1852,1.3176
     X,  0.0805,0.2536,0.7721
     X,  0.0162,0.3391,0.4153
     X,  0.0038,0.4608,0.2185
     X,  0.0375,0.6067,0.1120
     X,  0.1177,0.7618,0.0607
     X,  0.2365,0.8752,0.0305
     X,  0.3768,0.9620,0.0137
     X,  0.5298,0.9918,0.0040
     X,  0.7052,0.9973,0.0000
     X,  0.8787,0.9556,0.0000
     X,  1.0142,0.8689,0.0000
     X,  1.1185,0.7774,0.0000
     X,  1.1240,0.6583,0.0000
     X,  1.0305,0.5280,0.0000
     X,  0.8563,0.3981,0.0000
     X,  0.6475,0.2835,0.0000
     X,  0.4316,0.1798,0.0000
     X,  0.2683,0.1076,0.0000
     X,  0.1526,0.0603,0.0000
     X,  0.0813,0.0318,0.0000
     X,  0.0409,0.0159,0.0000
     X,  0.0199,0.0077,0.0000
     X,  0.0096,0.0037,0.0000
     X,  0.0046,0.0018,0.0000/
      DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1080
     X,  1094.,1078.,1049.,1077.,1044.,1040.,1000.,[illegible]4.,957.,886.
     X,  900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./

      DATA SPL/'WHIT','E TI','LES ','    ','AMBE','R FI','LTER','
     X  'GRAY',' FOR','CELA','IN  ','STD ','TAN ','PLAS','TIC ','SPL ',
     X  'TAN ','PLAS','TIC '/
      DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG','STD ','SPL '/
100   FORMAT(' DATE: 'I2,2('/',I2))
150   FORMAT('$ BEGIN WITH SAMPLE NO.?(2-5)',6[illegible]
```

```
200     FORMAT('OMEASURE: '4A4,' INSERT SAMPLE THEN HIT RETURN'/)
300     FORMAT(I5,3F10.2,F10.3)
400     FORMAT(1HO,2(2X,A4),' X=',F7.4,' Y=',F7.4,' Z=',F7.4)
450     FORMAT(1HO,2(2X,A4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500     FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2',2X,'AVG OF 10',4X,'SIGMA
600     FORMAT(1HO,2(2X,A4),' L*=',F7.2,' A*=',F7.2,' B*=',F7.2)
650     FORMAT(1HO,2(2X,A4),' L*=',F7.3,' A*=',F7.3,' B*=',F7.3)
700     FORMAT(1HO,A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
750     FORMAT(1HO,A4,' DL=',F7.3,' DC=',F7.3,' DE=',F7.3)
        CALL IDATE(IM,ID,IY)
        WRITE(5,100) IM,ID,IY
        WRITE(5,150)
        READ(5,300) NSAM
        DO 2000 II=1,5
        IF(II.EQ.1) GOTO 960
        IF(II.LT.NSAM) GOTO 2000
960     I=II
        WRITE(5,200) (SPL(M,I),M=1,4)
        PAUSE
        DO 1000 N=1,10
        DO 980 L=1,32
980     FACT(L)=1.
        CALL GMSR(4000,7100,100,1,0,5,0,1,FACT,RG,IER)
        DO 990 L=1,32
990     R(L,N)=RG(L)
        CALL IDLE(1000)
1000    CONTINUE
        IF(I.LT.4) WRITE(5,500)
        IF(I.GT.1) GOTO 1100
        DO 1040 L=1,32
        FAC(L,2)=0.
        FAC(L,3)=0.
        DELSQ=0.
        DO 1020 N=1,10
        IF(N.EQ.1) FAC(L,1)=R(L,N)
        IF(N.LE.2) FAC(L,2)=R(L,N)*0.5 + FAC(L,2)
        FAC(L,3)=R(L,N)*0.1 + FAC(L,3)
1020    CONTINUE
        DO 1030 N=1,10
1030    DELSQ=(R(L,N)-FAC(L,3))*(R(L,N)-FAC(L,3)) - DELSQ
        SIGMA=SQRT(DELSQ*0.1111)
        WRITE(5,300) 390+L*10,(FAC(L,M),M=1,3),SIGMA
        DO 1035 M=1,3
1035    FAC(L,M)=FAC(L,M)*0.01
1040    CONTINUE
        GOTO 2000
1100    DO 1140 L=1,32
        VAL(2)=0.
        VAL(3)=0.
        DELSQ=0.
        DO 1120 N=1,10
        IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
        IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
        IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
```

```
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
      R(L,N)=R(L,N)/FAC(L,3)
      VAL(3)=R(L,N)*0.1 + VAL(3)
      IF(I.GE.4) RC(L,3,I-3)=VAL(3)
      IF(I.GE.4) RC(L,3+N,I-3)=R(L,N)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      DO 1130 N=1,10
1130  DELSQ=(R(L,N)-VAL(3))*(R(L,N)-VAL(3)) + DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      WRITE(5,300) 390+L*10,(VAL(M),M=1,3),SIGMA
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      J1=1
      J3=3
      DO 2970 I=1,3
2970  AVG(I)=0.
2980  DO 3050 J=J1,J3
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K) + RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
      IF(J1.GT.3) GOTO 3030
      WRITE(5,400) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
      GOTO 3050
3030  DO 3040 I=1,3
      AVG(I)=AVG(I) + TRI(I,J,K)*0.1
3040  CONTINUE
3050  CONTINUE
      IF(J1.EQ.4) GOTO 3060
      J1=4
      J3=13
      GOTO 2980
3060  DO 3068 I=1,3
      DSQ(I)=0.
      DO 3065 J=4,13
3065  DSQ(I)=(TRI(I,J,K)-AVG(I))*(TRI(I,J,K)-AVG(I)) + DSQ(I)
      DSQ(I)=SQRT(DSQ(I)*0.1111)
3068  CONTINUE
      WRITE(5,450) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,13
      DO 3080 K=1,2
```

```
3080    TRI(I,J,K)=TRI(I,J,K)**TH
        DO 3170 K=1,2
        J1=1
        J3=3
        DO 3100 I=1,3
3100    AVG(I)=0.
3110    DO 3150 J=J1,J3
        STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
        STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
        STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
        IF(J1.GT.3) GOTO 3130
        WRITE(5,600) PLAST(K),AVGNO(J),(STAR(M,J,K),M=1,3)
        GOTO 3150
3130    DO 3140 I=1,3
3140    AVG(I)=AVG(I)+STAR(I,J,K)*0.1
3150    CONTINUE
        IF(J1.EQ.4) GOTO 3160
        J1=4
        J3=13
        GOTO 3110
3160    DO 3168 I=1,3
        DSQ(I)=0.
        DO 3165 J=4,13
3165    DSQ(I)=(STAR(1,J,K)-AVG(I))*(STAR(I,J,K)-AVG( )) +DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3168    CONTINUE
        WRITE(5,650) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3170    CONTINUE
        J1=1
        J3=3
        DO 3175 I=1,3
3175    AVG(I)=0.
3180    DO 3250 J=J1,J3
        DO 3200 I=1,3
3200    STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
        CD(1,J)=SQRT(STAR(1,J,1))
        CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1) + STAR(3,J,1)*STAR(3,J,1))
        CD(3,J)=SQRT(CD(1,J)*CD(1,J) + CD(2,J)*CD(2,J))
        IF(J1.GT.3) GOTO 3230
        WRITE(5,700) AVGNO(J),(CD(M,J),M=1,3)
        GOTO 3250
3230    DO 3240 I=1,3
3240    AVG(I)=AVG(I) + CD(I,J)*0.1
3250    CONTINUE
        IF(J1.NE.1) GOTO 3260
        J1=4
        J3=13
        GOTO 3180
3260    DO 3268 I=1,3
        DSQ(I)=0.
        DO 3265 J=4,13
3265    DSQ(I)=(CD(I,J)-AVG(I))*(CD(I,J)-AVG(I)) + DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3268    CONTINUE
        WRITE(5,750) AVGNO(4),(DSQ(M),M=1,3)
4000    STOP
        END
```

## Appendix B.

**Computer program QMSTAT for Hunter D54 statistical study.**

```
?$COPY,DS(QMSTAT),TY
C       PROGRAM QMSTAT
C       ---TO CALCULATE STATISTICAL DATA FOR A STANDARDIZED PROCEDURE
C       APPLICABLE TO THE HUNTER D54P SPECTROPHOTOMETER
        DIMENSION AVGNO(4),CMF(3,32),D65(32),FAC(32,3),PLAST(2)
        DIMENSION R(32,10),RC(32,13,2),RG(32),STAR(3,13,2),SPL(4,5)
        DIMENSION TRI(3,13,2),TRIO(3),VAL(3),DSQ(3),AVG(3),CD(3,13)
        DIMENSION NWL(32)
        DATA CMF/0.0191,0.0020,0.0860,0.0847,0.0088,0.3894
     -,0.2045,0.0214,0.9725,0.3147,0.0387,1.5535
     -,0.3837,0.0621,1.9673,0.3707,0.0895,1.9948
     -,0.3023,0.1282,1.7454,0.1956,0.1852,1.3176
     -,0.0805,0.2536,0.7721,0.0162,0.3391,0.4153
     -,0.0038,0.4608,0.2185,0.0375,0.6067,0.1120
     -,0.1177,0.7618,0.0607,0.2365,0.8752,0.0305
     -,0.3768,0.9620,0.0137,0.5298,0.9918,0.0040
     -,0.7052,0.9973,0.0000,0.8787,0.9556,0.0000
     -,1.0142,0.8689,0.0000,1.1185,0.7774,0.0000
     -,1.1240,0.6583,0.0000,1.0305,0.5280,0.0000
     -,0.8563,0.3981,0.0000,0.6475,0.2835,0.0000
     -,0.4316,0.1798,0.0000,0.2683,0.1076,0.0000
     -,0.1526,0.0603,0.0000,0.0813,0.0318,0.0000
     -,0.0409,0.0159,0.0000,0.0199,0.0077,0.0000
     -,0.0096,0.0037,0.0000,0.0046,0.0018,0.0000/
        DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.,
     -1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.,
     -900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
        DATA SPL/'WHIT','E TI','LES ','    ','AMBE','R FI','LTER','    ',
     -'GRAY',' POR','CELA','IN  ','STD ','TAN ','PLAS','TIC','SPL ',
     -'TAN ','PLAS','TIC '/
        DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG','STD ','SPL '/
100     FORMAT(' DATE: ',I2,2('/',I2))
150     FORMAT(' BEGIN WITH SAMPLE NO.?(1-5)',6X)
200     FORMAT(// MEASURE: '4A4,' INSERT SAMPLE,PRESS READ ON HUNTER,THEN
     - 10NM')
300     FORMAT(I5,3F10.2,F10.3)
350     FORMAT(I3,F11.2)
400     FORMAT(/2(2XA4),' X=',F7.4,' Y=',F7.4,' Z=',F7.4)
450     FORMAT(/2(2XA4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500     FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2',2X,'AVG OF 10',4X,'SIGMA')
600     FORMAT(/2(2XA4),' L*=',F7.2,' a*=',F7.2,' b*=',F7.2)
650     FORMAT(/2(2XA4),' L*=',F7.3,' a*-',F7.3,' b*=',F7.3)
700     FORMAT(/A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
750     FORMAT(/A4,' DL=',F7.3,' DC=',F7.3,' DE=',F7.3)
        CALL DATE$B(IY,IM,ID)
        WRITE(5,100) IM,ID,IY
        WRITE(5,150)
        READ(5,350) NSAM
        IF(NSAM.GT.1) GOTO 950
        WRITE(5,150)
950     DO 2000 II=1,5
```

```
      IF(II.LT.NSAM) GOTO 2000
960   I=II
      WRITE(5,200) (SPL(M,I),M=1,4)
      DO 1000 N=1,10
      PAUSE
      DO  980 L=1,32
      READ(14,350) NWL(L),RG(L)
980   CONTINUE
      DO 935 L=1,32
      R(L,N)=RG(L)
935   CONTINUE
1000  CONTINUE
      IF (I.LT.4) WRITE(5,500)
      IF(I.GT.1) GOTO 1100
      DO 1040 L=1,32
      FAC(L,2)=0
      FAC(L,3)=0
      DELSQ=0.
      DO 1020 N=1,10
      IF(N.EQ.1) FAC(L,1)=R(L,N)
      IF(N.LE.2) FAC(L,2)=R(L,N)*0.5+ FAC(L,2)
      FAC(L,3)=R(L,N)*0.1 + FAC(L,3)
1020  CONTINUE
      DO 1030 N=1,10
1030  DELSQ=(R(L,N)-FAC(L,3))*(R(L,N)-FAC(L,3)) +DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      NM=390+L*10
      WRITE(5,300) NM,(FAC(L,M),M=1,3),SIGMA
      DO 1035 M=1,3
1035  FAC(L,M)=FAC(L,M)*0.01
1040  CONTINUE
      GOTO 2000
1100  DO 1140 L=1,32
      VAL(2)=0.
      VAL(3)=0.
      DELSQ=0.
      DO 1120 N=1,10
      IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
      IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
      IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
      R(L,N)=R(L,N)/FAC(L,3)
      VAL(3)=R(L,N)*0.1+VAL(3)
      IF(I.GE.4) RC(L,3,I-3)=VAL(3)
      IF(I.GE.4) RC(L,3+N,I-3)=R(L,N)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      DO 1130 N=1,10
1130  DELSQ=(R(L,N)-VAL(3))*(R(L,N)-VAL(3))+DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      NM=390+L*10
```

```
      WRITE(5,300)NM,(VAL(M),M=1,3),SIGMA
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      J1=1
      J3=3
      DO 2970 I=1,3
2970  AVG(I)=0.
2980  DO 3050 J=J1,J3
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K)+RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
      IF(J1.GT.3) GOTO 3030
      WRITE(5,400) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
      GOTO 3050
3030  DO 3040 I=1,3
      AVG(I)=AVG(I)+TRI(I,J,K)*0.1
3040  CONTINUE
3050  CONTINUE
      IF(J1.EQ.4) GOTO 3060
      J1=4
      J3=13
      GOTO 2980
3060  DO 3068 I=1,3
      DSQ(I)=0.
      DO 3065 J=4,13
3065  DSQ(I)=(TRI(I,J,K)-AVG(I))*(TRI(I,J,K)-AVG(I))+DSQ(I)
      DSQ(I)=SQRT(DSQ(I)*0.1111)
3068  CONTINUE
      WRITE(5,450) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,13
      DO 3080 K=1,2
3080  TRI(I,J,K)=TRI(I,J,K)**TH
      DO 3170 K=1,2
      J1=1
      J3=3
      DO 3100 I=1,3
```

```
3100    AVG(I)=0.
3110    DO 3150 J=J1,J3
        STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
        STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
        STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
        IF(J1.GT.3) GOTO 3130
        WRITE(5,600) PLAST(K),AVGNO(J),(STAR(M,J,K),M=1,3)
        GOTO 3150
3130    DO 3140 I=1,3
3140    AVG(I)=AVG(I)+STAR(I,J,K)*0.1
3150    CONTINUE
        IF(J1.EQ.4) GOTO 3160
        J1=4
        J3=13
        GOTO 3110
3160    DO 3168 I=1,3
        DSQ(I)=0.
        DO 3165 J=4,13
3165    DSQ(I)=(STAR(I,J,K)-AVG(I))*(STAR(I,J.K)-AVG(I))+DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3168    CONTINUE
        WRITE(5,650) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3170    CONTINUE
        J1=1
        J3=3
        DO 3175 I=1,3
3175    AVG(I)=0.
3180    DO 3250 J=J1,J3
        DO 3200 I=1,3
3200    STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
        CD(1,J)=SQRT(STAR(1,J,1))
        CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1)+STAR(3,J,1)*STAR(3,J,1))
        CD(3,J)=(CD(1,J)*CD(1,J)+CD(2,J)*CD(2,J))
        IF(J1.GT.3) GOTO 3230
        WRITE(5,700)AVGNO(J),(CD(M,J),M=1,3)
        GOTO 3250
3230    DO 3240 I=1,3
3240    AVG(I)=AVG(I)+CD(I,J)*0.1
3250    CONTINUE
        IF(J1.NE.1) GOTO 3260
        J1=4
        J3=13
        GOTO 3180
3260    DO 3268 I=1,3
        DSQ(I)=0.
        DO 3265 J=4,13
3265    DSQ(I)=(CD(I,J)-AVG(I))*(CD(I,J)-AVG(I))+DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3268    CONTINUE
        WRITE(5,750) AVGNO(4),(DSQ(M),M=1,3)
4000    STOP
        END
```

## Appendix C

**Computer Program QMSTAN for Standardization Program of Match-Scan.**

```
      PROGRAM QMSTAN
C     ---TO PROVIDE A STANDARDIZATION
C     PROCEDURE APPLICABLE TO THE MATCH-SCAN
C
C     LINK INSTRUCTIONS:
C     ASS DX1 DK
C     R LINK
C     *QMSTAN=QMSTAN,DX0:MSLIB,FISNOV.NEW
C
C
      DIMENSION CMF(3,32),D65(32),FAC(32,3),FACT(32)
      DIMENSION R(32,10),RC(32,2,2),RG(32),STAR(3,2,2),SPL(4,5)
      DIMENSION UL(6),OW(6),NM(5),AC(6)
      DIMENSION TRI(3,2,2),TRIO(3),VAL(3),CD(3,2)

   DATA CMF/0.0191,0.0020,0.0860
 X,   0.0847,0.0088,0.3894
 X,   0.2045,0.0214,0.9725
 X,   0.3147,0.0387,1.5535
 X,   0.3837,0.0621,1.9673
 X,   0.3707,0.0895,1.9948
 X,   0.3023,0.1282,1.7454
 X,   0.1956,0.1852,1.3176
 X,   0.0805,0.2536,0.7721
 X,   0.0162,0.3391,0.4153
 X,   0.0038,0.4608,0.2185
 X,   0.0375,0.6067,0.1120
 X,   0.1177,0.7618,0.0607
 X,   0.2365,0.8752,0.0305
 X,   0.3768,0.9620,0.0137
 X,   0.5298,0.9918,0.0040
 X,   0.7052,0.9973,0.0000
 X,   0.8787,0.9556,0.0000
 X,   1.0142,0.8689,0.0000
 X,   1.1185,0.7774,0.0000
 X,   1.1240,0.6583,0.0000
 X,   1.0305,0.5280,0.0000
 X,   0.8563,0.3981,0.0000
 X,   0.6475,0.2835,0.0000
 X,   0.4316,0.1798,0.0000
 X,   0.2683,0.1076,0.0000
 X,   0.1526,0.0603,0.0000
 X,   0.0813,0.0318,0.0000
 X,   0.0409,0.0159,0.0000
 X,   0.0199,0.0077,0.0000
 X,   0.0096,0.0037,0.0000
 X,   0.0046,0.0018,0.0000/
      DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.
 X,    1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.
 X,    900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
      DATA SPL/'WHIT','E TI','LES ','    ','AMBE','R FI','LTER','    '.
 X    'GRAY',' FOR','CELA','IN  ','STD ','TAN ','PLAS','TIC ','SPL ',
 X    'TAN ','PLAS','TIC '/
```

```
C       1=OPAL@540;2=AMBER@420;3=AMBER@520;4=AMBER@660;5=GRAY@540;6=COL DIF
        DATA NM/540,420,520,660,540/
        DATA UL/99.62,3.53,39.27,80.09,44.00,1.94/
        DATA OW/99.48,3.47,38.93,79.85,43.80,1.84/
        DATA    AC/'UPPE','R LI','MIT ','LOWE','R LI','MIT '/
100     FORMAT(' DATE: 'I2,2('/',I2))
150     FORMAT('$ BEGIN WITH SAMPLE NO.?(1-5)',6X)
160     FORMAT(' AT',I4,' NM',2(1X3A4,F6.2))
170     FORMAT(' COLOR DIFF.',2(1X3A4,F6.2))
D175    FORMAT('$   CHANGE LIMITS? 0=NO; 1=YES',4X)
180     FORMAT(2X3A4,'?')
190     FORMAT(F7.2)
200     FORMAT('OMEASURE: '4A4,
     X' INSERT SAMPLE THEN HIT RETURN AFTER PAUSE')
210     FORMAT('0***READING AT',I5,' NM IS OUT OF SPECS FOR: ',4A4,/
     X'     WASH SAMPLE, THEN')
220     FORMAT('*** COLOR DIFFERENCE IS OUT OF SPECS'/
     X'       WASH PLASTIC TILES, THEN')
300     FORMAT(I5,3F10.2,F10.3)
500     FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2')
700     FORMAT(1HO,'AVG OF 2  DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
        CALL IDATE(IM,ID,IY)
        WRITE(5,100) IM,ID,IY
        WRITE(5,150)
        READ(5,300) NSAM
950     DO 2000 I=1,5
        IF(I.NE.1.AND.I.LT.NSAM) GOTO 2000
960     WRITE(5,200) (SPL(M,I),M=1,4)
        IF(I.EQ.5) GOTO 975
        IF(I.LE.2) K=0
        IF(I.GE.3) K=2
        IF(I.EQ.4) GOTO 970
965     WRITE(5,160) NM(I+K),(AC(M),M=1,3),UL(I+K),(AC(M),M=4,6),OW(I+K)
970     IF(I.EQ.4) WRITE(5,170) (AC(M),M=1,3),UL(6),(AC(M),M=4,6),OW(6)
D       WRITE(5,175)
D       READ(5,300) ICH
D       IF(ICH.EQ.0) GOTO 972
D       WRITE(5,180) (AC(M),M=1,3)
D       READ(5,190) UL(I+K)
D       WRITE(5,180) (AC(M),M=4,6)
D       READ(5,190) OW(I+K)
972     IF(I.NE.2) GOTO 975
        IF(K.LT.3) K=K+1
        IF(K.LT.3)GOTO 965
975     CONTINUE
        PAUSE
        DO 1000 N=1,2
        DO 980 L=1,32
980     FACT(L)=1.
        CALL GMSR(4000,7100,100,1,0,5,0,1,FACT,RG,IER)
        DO 990 L=1,32
990     R(L,N)=RG(L)
        CALL IDLE(1000)
1000    CONTINUE
```

```
      IF(I.LT.4) WRITE(5,500)
      IF(I.GT.1) GOTO 1100
      DO 1040 L=1,32
      FAC(L,2)=0.
      DO 1020 N=1,2
      IF(N.EQ.1) FAC(L,1)=R(L,N)
      IF(N.LE.2) FAC(L,2)=R(L,N)*0.5 + FAC(L,2)
1020  CONTINUE
      IF(L.NE.15) GOTO 1030
              WRITE(5,300) 390+L*10,(FAC(L,M),M=1,2)
      IF(FAC(15,2).LT.UL(1).AND.FAC(15,2).GT.OW(1)) GOTO 1030
      WRITE(5,210) 540,(SPL(M,1),M=1,4)
      GOTO 960
1030  DO 1035 M=1,2
1035  FAC(L,M)=FAC(L,M)*0.01
1040  CONTINUE
      GOTO 2000
1100  DO 1500 L=1,32
      VAL(2)=0.
      DO 1120 N=1,2
      IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
      IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
      IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
1120  CONTINUE
      LL=L/10+2
      IF(I-3) 1140,1160,1500
1140  IF(L.EQ.3.OR.L.EQ.13.OR.L.EQ.27) GOTO 1150
      GOTO 1500
1150  WRITE(5,300) 390+L*10, (VAL(M),M=1,2)
      IF(VAL(2).LT.UL(LL).AND.VAL(2).GT.OW(LL)) GOTO 1500
      WRITE(5,210) 390+L*10,(SPL(M,I),M=1,4)
      GOTO 960
1160  IF(L.NE.15) GOTO 1500
      WRITE(5,300) 540,(VAL(M),M=1,2)
      IF(VAL(2).LT.UL(5).AND.VAL(2).GT.OW(5)) GOTO 1500
      WRITE(5,210) 540,(SPL(M,3),M=1,4)
      GOTO 960
1500  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3050 K=1,2
      DO 3050 J=1,2
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
```

```
3000    TRI(I,J,K)=TRI(1,J,K) + RC(L,J,K)*CMF(I,L)*D65(L)
3020    TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
3050    CONTINUE
        DO 3080 I=1,3
        DO 3080 J=1,2
        DO 3080 K=1,2
3080    TRI(I,J,K)=TRI(I,J,K)**TH
        DO 3150 K=1,2
        DO 3150 J=1,2
        STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
        STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
3150    STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
        J=2
        DO 3200 I=1,3
3200    STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
        CD(1,J)=SQRT(STAR(1,J,1))
        CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1) + STAR(3,J,1)*STAR(3,J,1))
        CD(3,J)=SQRT(CD(1,J)*CD(1,J) + CD(2,J)*CD(2,J))
        WRITE(5,700) (CD(M,J),M=1,3)
        IF(CD(3,2).LT.UL(6).AND.CD(3,2).GT.OW(6)) GOTO4000
        WRITE(5,220)
        NSAM=4
        GOTO 950
4000    STOP
        END
```

## Appendix D

**Computer program QSTANH for standardization program of Hunter D54.**

```
C       PROGRAM QSTANH
C       ---TO PROVIDE A STANDARDIZATION PROCEDURE
C       APPLICABLE TO THE HUNTER D54P SPECTROPHOTOMETER
        DIMENSION AV(6),AVGNO(4),CD(3,13),CMF(3,32),D65(32)
        DIMENSION NM1(5),NML(32),PLAST(2)
        DIMENSION R(32,10),RC(32,13,2),RS(32),SPL(4,5),ST(6)
        DIMENSION STAR(3,13,2),TRI(3,13,2),TRIO(3),VAL(3)
        DATA CMF/0.0191,0.0020,0.0860,0.0847,0.0088,0.3894
     -,0.2045,0.0214,0.9725,0.3147,0.0387,1.5535
     -,0.3337,0.0621,1.9673,0.3707,0.0895,1.9948
     -,0.3023,0.1282,1.7454,0.1956,0.1852,1.3176
     -,0.0805,0.2535,0.7721,0.0162,0.3391,0.4153
     -,0.0038,0.4608,0.2185,0.0375,0.6067,0.1120
     -,0.1177,0.7618,0.0607,0.2365,0.8752,0.0305
     -,0.3768,0.9620,0.0137,0.5298,0.9918,0.0040
     -,0.7052,0.9973,0.0000,0.8787,0.9556,0.0000
     -,1.0142,0.8689,0.0000,1.1185,0.7774,0.0000
     -,1.1240,0.6583,0.0000,1.0305,0.5280,0.0000
     -,0.8563,0.3981,0.0000,0.6475,0.2835,0.0000
     -,0.4316,0.1793,0.0000,0.2683,0.1076,0.0000
     -,0.1526,0.0603,0.0000,0.0813,0.0318,0.0000
     -,0.0409,0.0159,0.0000,0.0199,0.0077,0.0000
     -,0.0076,0.0037,0.0000,0.0046,0.0018,0.0000/
        DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.,
     -1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.,
     -900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
        DATA SPL/'AMBE','R FI','LTER','    ',
     -           'WHIT','E TI','LE  ','    ',
     -           'GRAY',' POR','CELA','IN  ',
     -           'STD ','TAN ','PLAS','TIC ',
     -           'SPL ','TAN ','PLAS','TIC '/
        DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG ','STD ','SPL '/
C   1=AMBER@420;2=AMBER@520;3=AMBER@660;4=OPAL@540;5=GRAY@540;6=COL DIFF.
        DATA ST/3.48,38.68,80.20,98.36,42.96,1.88/
        DATA AV/0.03,0.18,0.12,0.10,0.10,0.05/
        DATA NM1/420,520,660,540,540/
100     FORMAT(' DATE: ',I2,2('/',I2))
120     FORMAT(' 1. ON D54 PRESS "ASCII OUT", THEN "O", THEN "TRANS"'/
     -'          PUT WHITE PORCELAIN OVER PORT,'/
     -'          BLOCK BEAM WITH BLACK CARDBOARD'/
     -' 2. PRESS "ZERO". REMOVE CARDBOARD'/
     -' 3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54'/
     -' 4. PRESS "ASCII", THEN "2",'/
     -' 5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER')
150     FORMAT(' BEGIN WITH SAMPLE NO.? (1-5)')
170     FORMAT('*** REMOVE AMBER FILTER***'/
     -' 1. ON D54, PRESS "ASCII",THEN "O",THEN "R-SIN"'/
     -'          PUT ZERO TRAP OVER PORT'/
     -' 2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT'/
     -' 3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT'/
     -' 4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54,'/
     -' 5. PRESS "ASCII", THEN "2"'/
     -' 6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER')
200     FORMAT(' MEASURE: '4A4' INSERT SAMPLE IN D54:'/
```

```
     -'   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54'/
     -'   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME')
210   FORMAT(//'***READING AT'I5'NM IS OUT OF SPECS FOR:'4A4/
     -'      WASH SAMPLE, THEN')
220   FORMAT(' AT',I4,' NM UPPER LIMIT',F6.2,' LOWER LIMIT',F6.2)
230   FORMAT(' COLOR DIFFERENCE: UPPER LIMIT'F6.2' LOWER LIMIT'F6.2)
240   FORMAT(//'*** COLOR DIFFERENCE IS OUT OF SPECS FOR: ',4A4/
     -'      WASH TILES, THEN')
250   FORMAT(V)
300   FORMAT(I5,3F10.2,F10.3)
350   FORMAT(I3,F11.2)
450   FORMAT(/2(2XA4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500   FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2')
700   FORMAT(/A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
800   FORMAT(///'***OK TO MAKE MEASUREMENTS***')
      CALL FRMAT
      CALL DATE$B(IY,IM,ID)
      WRITE(5,100) IM,ID,IY
      WRITE(5,150)
      READ(5,250) NSAM
      IF(NSAM.GT.1) GOTO 950
      WRITE(5,120)
      PAUSE
950   DO 2000 II=1,5
      IF(II.LT.NSAM) GOTO 2000
960   I=II
      IF(I.NE.2) GOTO 970
      WRITE(5,170)
      PAUSE
970   WRITE(5,200) (SPL(M,I),M=1,4)
      K=1
      IF(I.NE.1) K=I+2
      IF(I.EQ.5) GOTO 978
975   UL=ST(K)+AV(K)
      OW=ST(K)-AV(K)
      IF(I.EQ.4) WRITE(5,230) UL,OW
      IF(I.EQ.4) GOTO 978
      WRITE(5,220) NM1(K),UL,OW
      IF(I.NE.1) GOTO 978
      IF(K.EQ.3) GOTO 978
      K=K+1
      GOTO 975
978   CONTINUE
      DO 1000 N=1,2
      PAUSE
      DO 980 L=1,32
      R(L,N)=RG(L)
      READ(14,350) NWL(L),RG(L)
980   CONTINUE
      DO 985 L=1,32
      R(L,N)=RG(L)
985   CONTINUE
1000  CONTINUE
      IF(I.LT.4) WRITE(5,500)
```

```
      K=1
      IF(I.NE.1) K=I+2
1100  DO 1140 L=1,32
      VAL(2)=0.
      DO1120 N=1,2
      IF(N.EQ.1) VAL(1)=R(L,N)
      IF(N.EQ.1.AND.I.GE.4) RC(L,1,I-3)=VAL(1)
      IF(N.LE.2) VAL(2)=R(L,N)*0.5+VAL(2)
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      NM=390+L*10
      IF(NM.NE.NM1(K)) GOTO 1140
      WRITE(5,300) NM,(VAL(M),M=1,2)
      IF(ABS(VAL(2)-ST(K)).LT.AV(K)) GOTO 1135
      WRITE(5,210) NM1(K),(SPL(M,I),M=1,4)
      GOTO 970
1135  IF(I.EQ.1.AND.K.LT.3) K=K+1
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      DO 3070 J=1,2
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K)+RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
C     WRITE(5,450) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,2
      DO 3080 K=1,2
3080  TRI(I,J,K)=TRI(I,J,K)**TH
      DO 3170 K=1,2
      DO 3170 J=1,2
      STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
      STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
      STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
3170  CONTINUE
3180  DO 3250 J=1,2
      DO 3200 I=1,3
3200  STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
      CD(1,J)=SQRT(STAR(1,J,1))
      CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1)+STAR(3,J,1)*STAR(3,J,1))
```

```
      CD(3,J)=SQRT(CD(1,J)*CD(1,J)+CD(2,J)*CD(2,J))
      WRITE(5,700) AVGNO(J),(CD(M,J),M=1,3)
3250  CONTINUE
      IF(ABS(CD(3,2)-ST(6)).LT.AV(6)) GOTO 3300
      NSAM=4
      WRITE(5,240) (SPL(M,4),M=1,4)
      GOTO 950
3300  WRITE(5,800)
4000  STOP
      END
?
```