STANDARDS AND STANDARDIZATION IN OPTICAL RADIATION MEASUREMENTS

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Abstract: The concept of the National Measurement System will be discussed in general, with special emphasis on color science and densitometry. Current trends in the system are a shift towards independently realizable physical standards, i.e., to collaborative efforts by industry, academia and the National Bureau of Standards to provide a broader standards base. In densitometry, one is concerned to control and to standardize the photometric scale, spectral response, and geometry of illumination and collection. This paper will address these items and concepts.

Background

Quality and acceptance in the world market dictate that quality control operations be sound and based on physical standards that are traceable to a national standards laboratory. While the maintenance of traceability to nationally recognized standards through reference standards is an essential step to a unified national measurement system, no company can realize maximum benefits unless its measurement process involves and directly influences product quality and/or performance. Metrology and calibration functions play an ever increasing role in the overall quality assurance programs which provide the necessary control over product quality. However, a strong effort must be made to properly interface the key elements of the overall measurement control system. This involvement can be most effective when recognized as a requirement by management, and supported by company policy and procedures.

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The evolution of calibration control systems designed for periodic recall and calibration of test and measuring equipment has forced rigorous control of measurement standards and working level instrumentation. Unfortunately, in most cases neither the product nor the product test equipment is significantly influenced by the overall calibration control system.

An examination of the calibration control process will yield a general system overview similar to that shown in Figure 1.

The interaction necessary for an effective overall measurement system represents a significant challenge to the metrologist, especially in the area that most directly influences product testing and/or quality -- active participation during product design. A good metrologist has spent much of his time questioning such things as unnecessary echelons of standards, unrealistic accuracy demands and unsupported product tolerances, absolute methods of testing and calibrating that can lead to ineffective test equipment control, and poor utilization of manpower and facilities. The metrologist, therefore, has much to contribute during the initial product design and development phases.

Continuous participation by measurement oriented personnel in the development and design stages is essential. At least, the original goal set for standards needed for the new product must be updated as the requirements and specifications are better defined. Even better results can be achieved, however, if the metrologists continue to participate fully in the total effort, particularly in the areas where the manufacturing procedures, test methods, and standards must interact. More efficient, or more comprehensive, testing may be made possible by suitable rearrangement of manufacturing sequences, or by the development of special standards to be used in prototype or pre-production test activities. The key areas of a total measurement system is outlined in Figure 2.

Effective measurement control can only be achieved if sufficient attention is focused on all elements of the industrial process, from product design to product completion. Some more important areas included in this total measurement system, or "cradle to grave" concept are shown in Figure 3.

While the maintenance of traceability to nationally recognized reference standards is an essential step to a unified material measurement system, no company can realize maximum benefits unless its measurement process involves, and directly influences, product quality and/or performance. Over the past several years the metrology and calibration functions have played an ever increasing role in the overall quality assurance programs which provide the necessary control over product quality to assume delivery of supplies that conform to contractural requirements. However, a strong effort must be exerted to properly interface all the key elements of the overall control system. This involvement can be most effective when recognized as a requirement by management and is supported by company policies and procedures.

Total Measurement System

The pressures of social, economic, and industrial environment are continuing to place tremendous demands on all levels of management and technical personnel to achieve and maintain high quality products with improved reliability and performance characteristics. All of this action is demanded with lower costs than ever before (Figure 3).

Intermediate Standard Laboratories

The National Bureau of Standards (NBS) has a policy to focus on more stringent requirements and encourages the remainder of the national measurement system to extend services to lower levels of accuracy. It provides those services that are necessary to make the overall system function. Many of the standards are not available through the NBS and must be developed by the intermediate standards laboratories in collaboration with NBS. A scheme for a national measurement standardization system for spectrophotometry is outlined in Figure 4. The hierarchy of documentary standards is given in Figure 5. The required stages of standardization are outlined in Figure 6 and are self explanatory.

The intermediate standards laboratory uses transfer standards and conducts measurement assurance programs with NBS to maintain its performance and traceability.

Type of Standards

Standards can be divided into two types, physical standards and documentary standards. The documentary standards are normally produced by national or international standardizing bodies, i.e., ANSI, ISO, etc. They normally define procedures and/or mathematical formulations. The characteristics of physical standards are outlined below.

1) Primary Standard is the basic standard for any scale and is often established by international convention to be a fundamental property of matter. Example: In the case of spectral reflectance, this basic standard was established by the CIE in 1969 to be a perfect reflecting diffuser. Since such a material does not exist, it is the task of material standardizing laboratories to provide calibrations of other material standards in terms of the primary (basic) standard.

2) Transfer Standards are materials calibrated in terms of the primary standard. They should provide accurate scales of, e.g., reflectance on any instrument, that is, of transferring the reflectance scale to any desired instrument.

3) Instrument Standards are materials that are more durable and more easily used than transfer standards. These are devised (calibrated) from transfer standards.

The Concept of Standards "Traceability"

The national standardizing laboratory (NBS) has the responsibility for maintaining and realizing a material standard. Continuing the use of reflectance-scale standards as an example, this is the primary standard of reflectance as defined by the CIE by international agreement. When a user laboratory needs a working standard of reflectance, one of several paths may be used to supply it. In one, illustrated below, the NBS or NBS equivalent lab calibrates a transfer standard and supplies it to an intermediate laboratory or directly to the users lab, which in turn uses it to calibrate a working standard for the user laboratory's instrument. In any case, at least two calibration steps are involved.

Laboratory	Standard	
NBS or Equivalent	Primary	
Intermediate	Calibration	
	Transfer	
User	Working	Measurements

Table 1: Standards Traceability

Measurement Consistency

The cability of each laboratory to make accurate measurements must be established through a measurement assurance program (MAP). Depending on the application, measurements made in such laboratories would be for the accurate analysis of an unknown or the accurate measurement of a reference sample. It is recognized that the capability to make accurate measurements requires more than just the provision of a calibrated standard. There is the obvious need for standard procedures, and additional technical and institutional elements essential to the system.[1]

Reflection Densitometry

Since no national standard exists for reflection color densitometry, these can be developed using appropriate materials for the purpose and following the recommendations and methodologies specified by ANSI and for ISO. As in spectrophotometry for accurate performance of densitometers one needs to control the following parameters. The spectral response, photometric scale, linearity, and geometry. These instrumental parameters can be controlled by suitable reference materials. An example for such a set of standard reference materials can be a set of yellow, cyan, magenta, and neutral ink patches of small areas to minimize location variability, and printed on a suitable substrate. The spectral reference data of such a set is given in Figure 7. Status T spectral responses used for reflection materials such as printing inks on paper are given in Figure 8 and the spectral power distribution of

illuminant A_2 in Figure 9. These are defined by ANSI, PH2.18-1984.

Let us now define reflectance and status T densities.

Reflectance is the ratio of the reflected light to the incident light, R = I/Io. Density is the logarithm of the reciprocal of reflectance, D = log 1/R or Log Io/I. Quantities of I and Io are determined by the energy from a source, $S(\lambda)$, and a detector response, $s(\lambda)$.

Then,

$$D = \log \frac{\int_\lambda S(\lambda)s(\lambda)d\lambda}{\int_\lambda S(\lambda)R(\lambda)s(\lambda)d\lambda} \quad (1)$$

ANSI PH2.18-1984 defines the source for reflection densitometry as CIE illuminant A. The measuring response is defined as Status T, the density, D, becomes:

$$D = \log \frac{\int_\lambda S(\lambda)s_T(\lambda)d\lambda}{\int_\lambda S(\lambda)R(\lambda)s_T(\lambda)d\lambda} \quad (2)$$

Determining the density of a cyan ink film $C_R(\lambda)$ with the red status T response $s_{TR}(\lambda)$ gives:

$$D_R = \log \frac{\int_\lambda S(\lambda)s_{TR}(\lambda)d\lambda}{\int_\lambda S(\lambda)C_R(\lambda)s_{TR}(\lambda)d\lambda} \quad (3)$$

D_G and D_B are computed in a similar manner using $s_{TG}(\lambda)$ and $s_{TB}(\lambda)$ for responses and $M(\lambda)$ and $Y_B(\lambda)$ for reflectances, respectively.

When a densitometer reads a reference cyan ink patch and agrees with the calibrated values the following is achieved:

$$D_R = \log \frac{\int_\lambda S(\lambda)s_{TR}(\lambda)\,d\lambda}{\int_\lambda S(\lambda)C_R(\lambda)s_{TR}(\lambda)d\lambda} = \log \frac{\int_\lambda S(\lambda)s_R(\lambda)d\lambda}{\int_\lambda S(\lambda)C_R(\lambda)s_R(\lambda)d\lambda} \quad (4)$$

Where $s_R(\lambda)$ is the red response of the densitometer which consists of a detector response and filtration. Ideally, $s_R(\lambda)$ would be identical to $s_{TR}(\lambda)$.

Equation (4) is in essence a definition of instrument metamerism. For a given $C_R(\lambda)$ function there is an equality between the status T value and the densitometer's response. However, because $s_R(\lambda)$ will probably never exactly equal $s_{TR}(\lambda)$, given a different $C_R(\lambda)$ function (that is reading a different cyan ink sample) the equality in Equation (4) may no longer hold. This would mean the densitometer's response is metameric to the status T response.

Status T Reference

The status T response is used to determine status T density as defined by ANSI Standard PH2.18-1984 Par. 4.4 which states in part (to evaluate the modulation produced by an image on which a color separation process is to be performed involving processes in which the primaries are to be printed separately).

To evaluate a densitometer's response the reference material should be measured according to the prescribed procedures and the difference between the densitometer values and the calibrated values is an estimate of the compliance of the densitometer to the ANSI standard.

Procedures for using Status T Reference

1) On the white position of the reference, adjust the densitometer to read the values of the reference on all three color filter positions. (This sets the intercept).

2) On the black position of the reference, adjust the densitometer to read the value of the reference on all three color filter positions. (This sets the slope).

3) With the densitometer in the red filter position, read the cyan patch of the reference. Compare this reading to the reference value for the cyan patch and determine the difference, if any.

4) With the densitometer in the green filter position, read the magenta patch of the reference. Compare this

reading to the reference value for the magenta patch and determine the difference, if any.

5) With the densitometer in the blue filter position, read the yellow patch of the reference. Compare this reading to the reference value for the yellow patch and determine the difference, if any.

The differences in the densitometer values compared to those of the reference for the cyan, magenta and yellow patches is an approximation of the departure of the densitometer from status T response. Small differences are to be expected in accordance with the manufacturer's stated values for the instrument's precision and accuracy. The greater the difference, the more the densitometer's response departs from that of status T. A user would need to determine for his own circumstances what differences should be of concern.

Because it is not a complete spectroradiometric analysis, matching the values on the reference does not technically assure a status T response. However, because the patches of the status T reference are ink on paper similar to those encountered in practice by the user, and if the densitometer's values are within the manufacturer's stated accuracy values the true response of the densitometer would not be expected to vary significantly from that of status T.

Summary

Given the status T reference patches, ink on paper similar to that encountered in practice, and that the densitometers are doing a good job of approaching status T response; two densitometers which agree within accepted tolerance limits, with status T reference, should not have significantly different spectral responses and should read ink on paper with reasonably good agreement.

Literature Cited

1. ANSI PH2.18-1984

2. F. Grum, Paper Presented at CORM Annual Meeting 1982

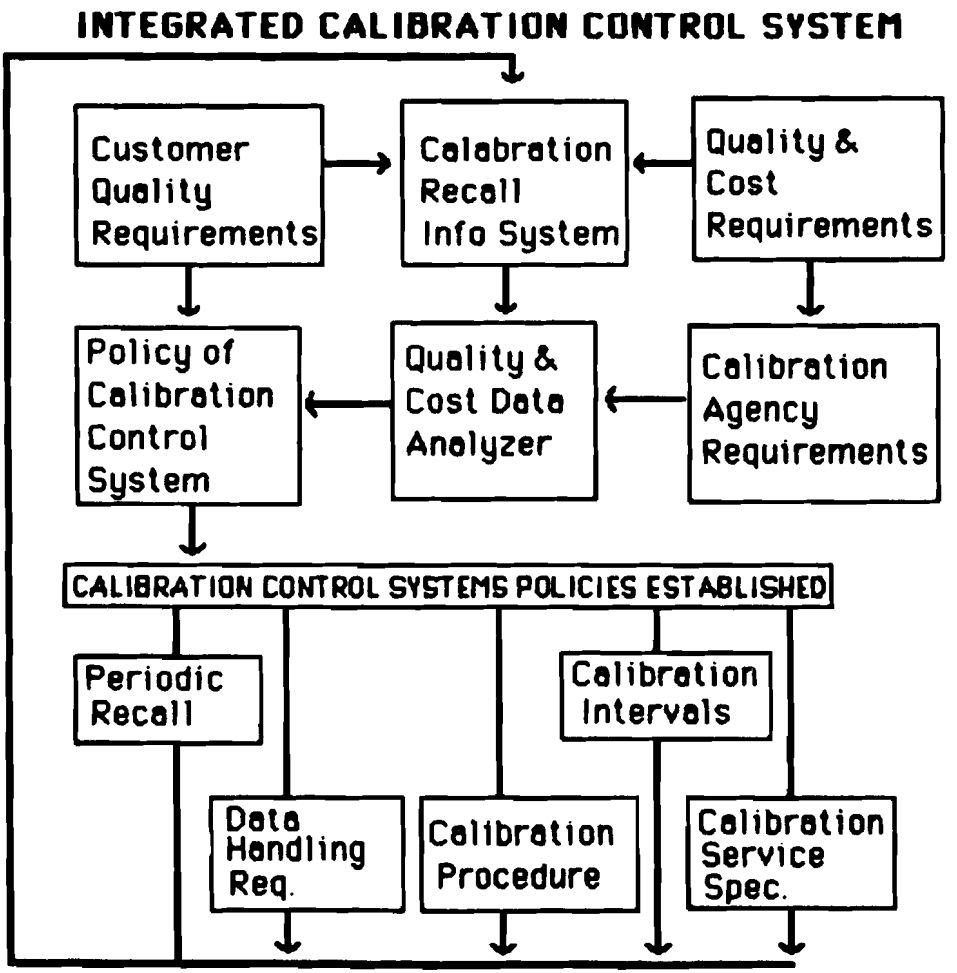

FIGURE 1. INTEGRATED CALIBRATION CONTROL SYSTEMS.

KEY AREAS OF TOTAL MEASUREMENT SYSTEM

- Product design & test requirements
- Test equipment acquisition & utilization
- Measurement standards & traceability
- Test equipment calibration & maintenance
- Test equipment replacement/disposal
- Measurement system quality requirements

FIGURE 2. KEY AREAS OF TOTAL MEASUREMENT SYSTEM.

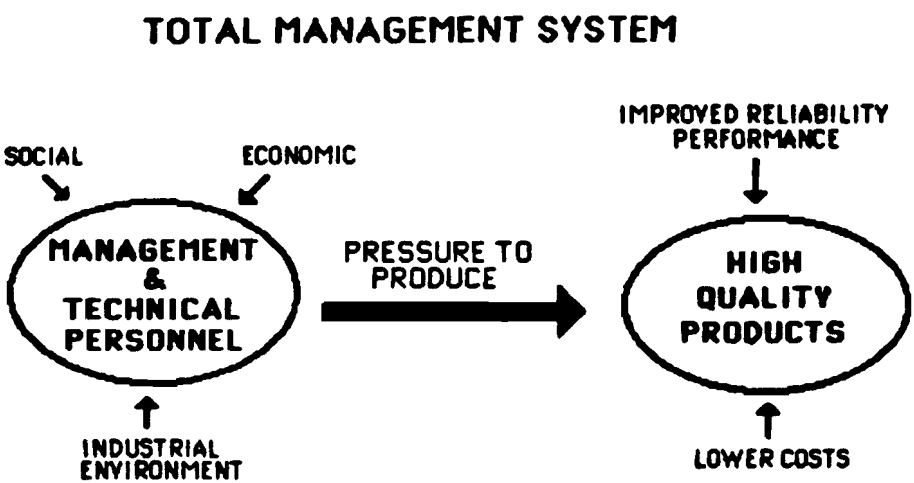

FIGURE 3. TOTAL MANAGEMENT SYSTEM.

NATIONAL MEASUREMENT STANDARDIZATION SYSTEMFOR SPECTROPHOTOMETRY (CORM 1983)

OBJECTIVES

-Establish intermediate calibration laboratories
-Design and test SRM's that can be used as transfer standards
-Provide guideline on methodologies for measurement

IMPLEMENTATION

-A MAP service in spectrophotometry
-SRM's for instrument standardization for routine spectrophotometry
-New methodology for spectrophotometry

FIGURE 4. NATIONAL MEASUREMENT STANDARDIZATION SYSTEM FOR SPECTROPHOTOMETRY.

HIERARCHY OF DOCUMENTARY STANDARDS

NATIONAL LABORATORIES SPECIFY PHYSICAL STANDARD

- Wavelength Tables
- Publication of Methodology
- Consultation

MAJOR STANDARDS ORGANIZATIONS WRITE GENERAL DOCUMENTARY STANDARDS

- CIE, ISO
- ANSI, ASTM

TRADE ASSOCIATIONS AND OTHERS ADAPT DOCUMENTARY STANDARDS FOR SPECIALIZED APPLICATIONS

- AACC, AATCC, ACS, ACS, ADA, AIA, AOCS, ...
- Instrument Manufactures
- BRH, CPS, DOD, DOE, DOT, FDA, GSA, NASA, ...

FIGURE 5. HIERARCHY OF DOCUMENTARY STANDARDS.

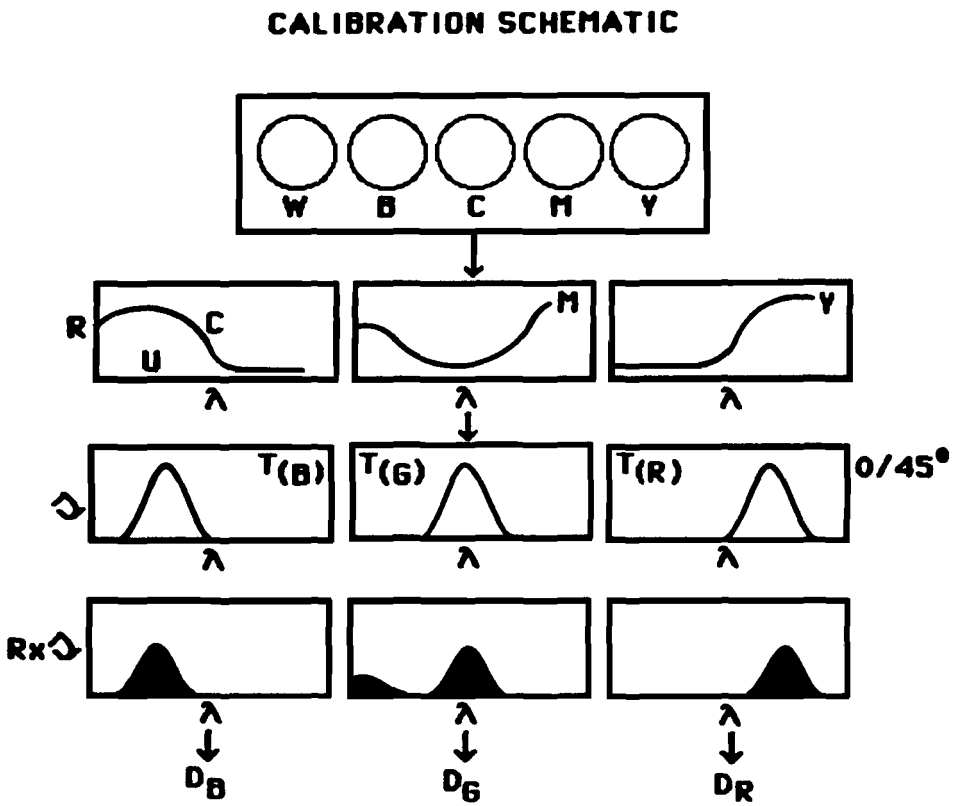

FIGURE 6. CALCULATION SCHEME FOR STATUS DENSITY.

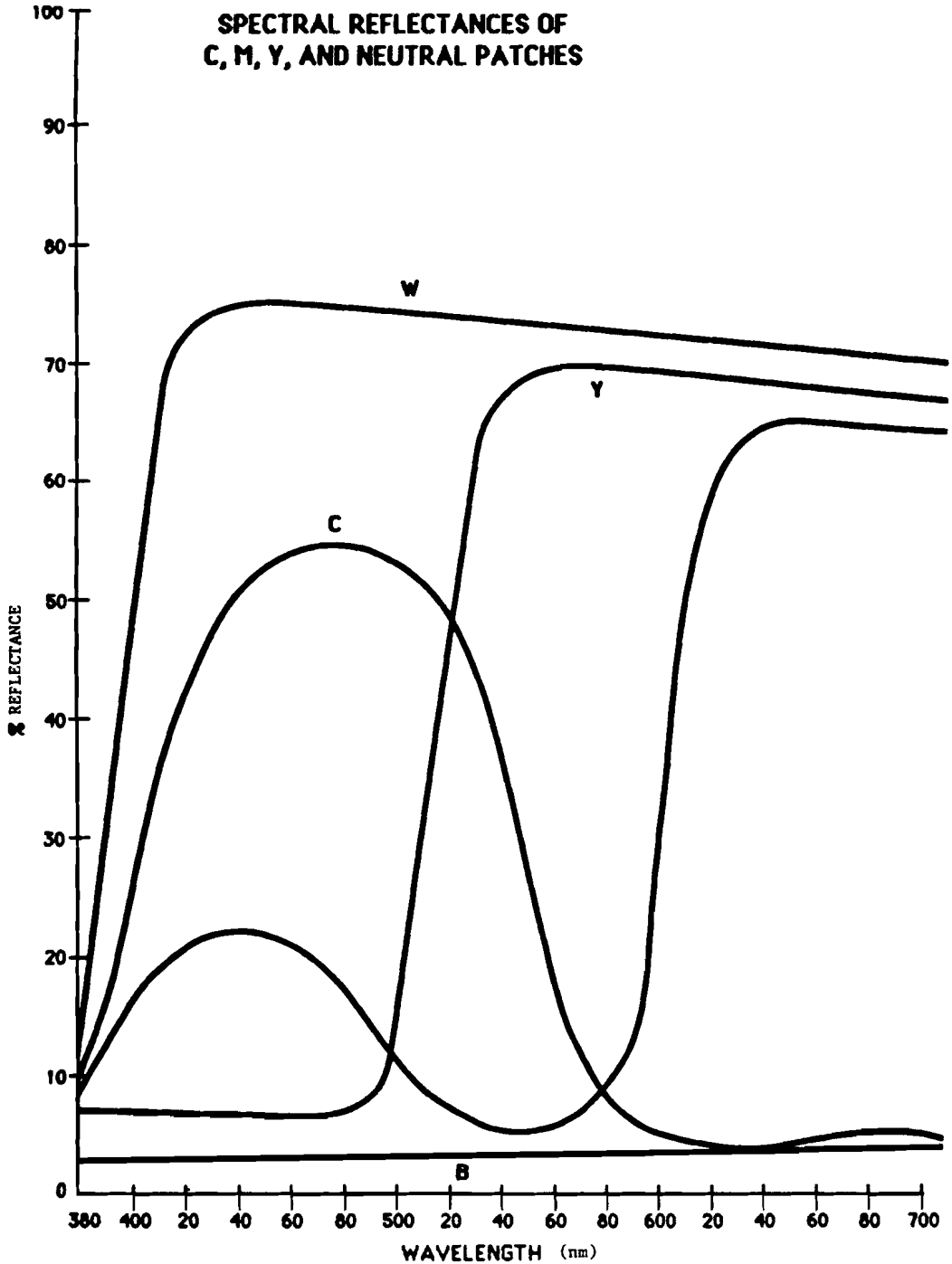

FIGURE 7. SPECTRAL REFLECTANCES OF A SET OF CYAN, MAGENTA AND YELLOW INK PATCHES.

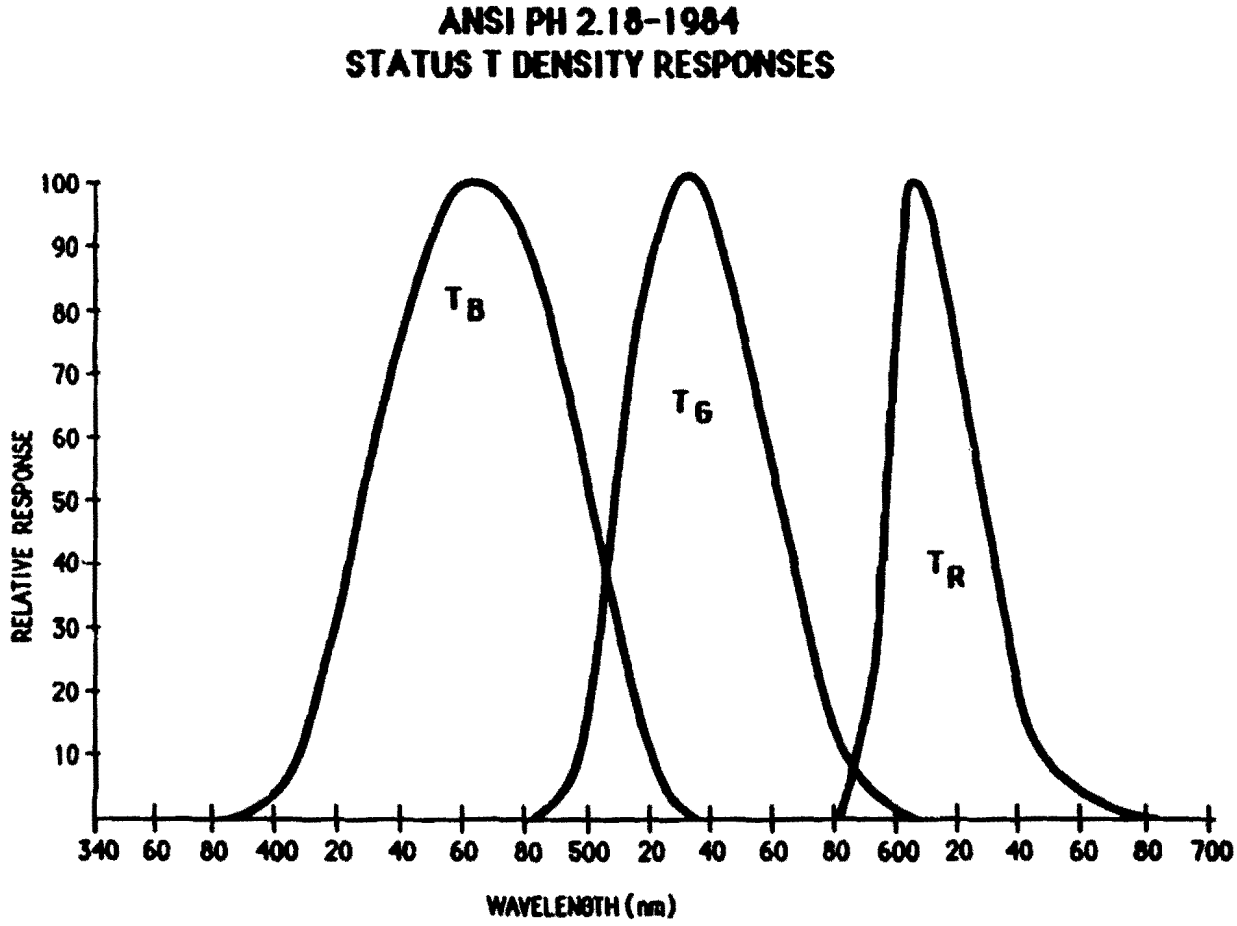

FIGURE 8. ANSI PH2.18 STATUS T SPECTRAL RESPONSE FUNCTIONS.

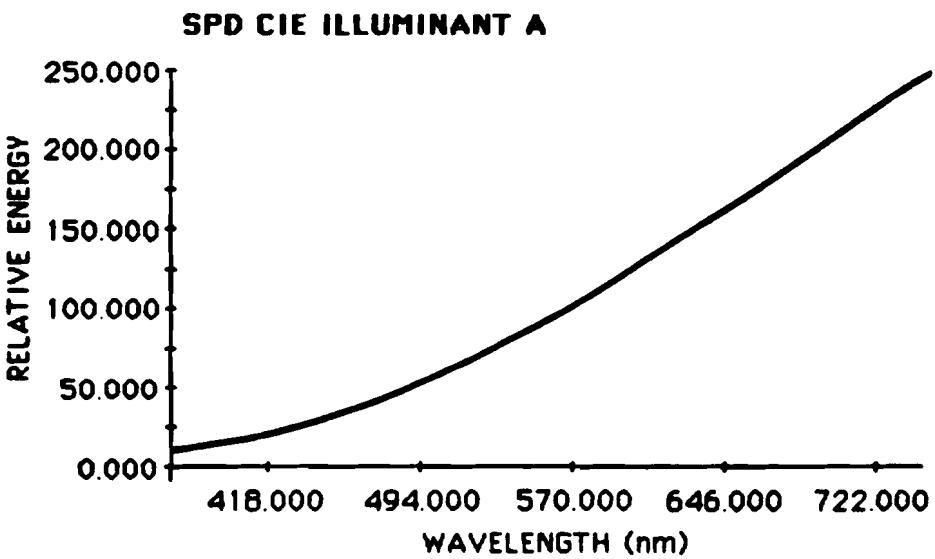

FIGURE 9. SPECTRAL POWER DISTRIBUTION OF CIE ILLUMINANT A.