NATIONAL BUREAU OF STANDARDS REPORT

6413

BACKGROUND AND OBJECTIVES
OF THE U.S. STANDARD FOR THE
COLORS OF SIGNAL LIGHTS

By

F. C. Breckenridge

Optics and Metrology Division

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Technical Report
to
Bureau of Aeronautics

NBS

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NATIONAL BUREAU OF STANDARDS

FOREWORD

The U. S. Standard for the Colors of Signal Lights is being developed by the U. S. National Committee on the Colors of Signal Lights which is sponsored by the U. S. National Committee of the International Commission on Illumination. Technical studies essential to the development of this standard are provided by the National Bureau of Standards with the financial collaboration of the Bureau of Aeronautics in the Department of the Navy. The present report was presented at the 1959 meeting of the Highway Research Board. It will be published in their Bulletin 226. It is being issued also as an NBS Report primarily for the information of the Bureau of Aeronautics and because it will be of interest to many signal lighting engineers and executives who are responsible for aeronautical and marine lights and railroad signal lighting, as well as to those who are concerned with signal lights on highways.

Background and Objectives of the U. S. Standard for the Colors of Signal Lights

F. C. Breckenridge

The U. S. Standard for the Colors of Signal Lights has four objectives. (1) It is designed to advance international cooperation thru bringing the United States into harmony with the recommendations of the International Commission on Illumination. (2) It aims at the elimination of wasteful differentiation. (3) It will accomplish technical improvements in the specifications. (4) It will contribute towards the maximum possible reliability for the recognition of the colors of signal lights.

Background of U. S. Standard

The International Commission on Illumination (C.I.E.) is one of those organizations that have been set up for the dual purpose of coordinating scientific and engineering activities across international boundaries and sharing the results of technical work carried out at the more active centers with localities which can not carry out such work themselves. In the United States the C.I.E. is represented by the U. S. National Committee of the C.I.E. This committee in turn carries on its work through individuals and committees which specialize in the various aspects of lighting that together comprise the work of the C.I.E.

At the 1948 plenary session of the International Commission on Illumination, Mr. John G. Holmes of Great Britain presented a paper reviewing some of the more important specifications for signal light colors in use in different countries and pointing out the unreasonable variations in these specifications. Since signal lights in different countries are being more and more used by citizens of other countries, there was a strong consensus of those present that the C.I.E. should look into the possibility of bringing more order into the situation. A technical committee was set up by the Commission for this purpose. This committee was comprised of representatives from the interested countries including the United States.

The C.I.E. Committee on Color Specifications for Signal Lights was faced with an urgent assignment because the International Civil Aviation Organization (I.C.A.O.) had requested guidance in establishing standards for aeronautical use. As soon as it had been constituted under the chairmanship of Mr. Holmes, the committee proceeded to survey prevailing practices in the use of colors for aviation lights by all the countries which were affiliated with the C.I.E. These included all the countries which were at that time important in international aviation. On the basis of the reports received from these countries, recommendations were sent to the I.C.A.O. in November 1949. The Aerodromes, Air Routes and Ground Aids Division of

I.C.A.O. (AGA) met that same month and adopted recommendations for standards governing aviation signal colors. These were largely based upon the aviation practices of the U.K. and the U.S.

The C.I.E. committee then proceeded to carry out a more complete study of all signal light color specifications in the cooperating countries. When this had been completed, it prepared its own recommendations for the chromaticity boundaries for signal light colors. These were discussed at the C.I.E. plenary session in 1951, and a standard set of recommendations for chromaticity boundaries were adopted. Most of these differed from the I.C.A.O. boundaries. These differences resulted from taking into account experience in fields other than aviation and in most cases they were small. In 1952 the AGA Division of I.C.A.O. met again and considered the C.I.E. boundaries and adopted nearly all of the overall boundaries.

In addition to the overall boundaries the C.I.E. had recommended some more restrictive boundaries for signal lights which were designed to provide more certainty of recognition at the cost of a reduced visual range. These found little interest in the I.C.A.O. as they were not sufficiently correlated with specific conditions of use. The C.I.E. 1951 recommendations for restricted boundaries were also unsatisfactory as a basis for bringing specification practices in the United States into a more consistent relationship for the same reason.

In 1955 the C.I.E. again considered its recommendations in the light of experience between meetings and made minor changes in the position of one green and one blue boundary. The yellow-white region was reconsidered, and within an overall region that was substantially the same as that defined to represent the two colors in 1951, a series of successively more restrictive definitions based upon the conditions of use were recommended. This principle appears to be constructive, and it is hoped that restrictive red and green definitions can be developed upon this basis at the 1959 plenary session of the C.I.E.

International Cooperation

The U.S. National Committee on the Colors of Signal Lights was appointed in 1952 to assist the U.S. Representative in preparing for the 1955 meeting and to provide a liaison with those organizations and government agencies which are responsible for the specification and regulation of signal light colors used in this country. It is the responsibility of this committee to introduce the C.I.E. Recommendations to the organizations and agencies represented on it. The C.I.E. has, of course, no compulsory authority and whatever actions are taken by American interests will be voluntary ones. Should any case be found in which it would be seriously contrary to our interests to follow the C.I.E. recommendations, we would not be expected to do so. There is however, no reason to anticipate such a situation since the American practices have been carefully considered in the formulation of the C.I.E. Recommendations.

Elimination of Waste

To understand the possibilities of eliminating wastes through correlating the different specifications for signal light colors which manufacturers are asked to meet it is necessary to compare the different specifications now in use. To do this for all the colors would be beyond the scope of this paper, but we may look at the case for the reds and yellows. Since for the types of glass generally used the hue and saturation of these colors vary together, we may represent the significant limits of these specifications in a single dimension. Figure 1 compares the U.S. and international specifications by means of such representation. For this purpose the y" coordinate in the RUCS system has been used as the best available index of the chromaticity differences to be represented. The extension of the heavy vertical lines across the light horizontal lines indicates changes suggested to eliminate unnecessary differences.

We are not in a position to determine how much, if any monetary saving can be achieved through making it possible to use the same melts of glass for different types of equipment, but it seems fairly evident that there would be at least some simplications in shop and inspection practices.

Clarity of Specifications

As one studies the specifications now in use it becomes evident that there is considerable confusion between the functions of the definitions stated in terms of the C.I.E. chromaticity coordinates and of the limit glasses. Some specifications, or parts of specifications, read as if the equations were the legal controls on what is acceptable. On the other hand, some of the duplicates of the limit glasses give chromaticities that are outside of these boundaries. Moreover, the limit glasses locate the boundary lines in only a few well separated points, and there is no way of interpolating the boundaries between these points except by spectrophotometric or colorimetric difference measurements neither of which is at present feasible for the inspection of large numbers of pieces of signal ware.

The usual practice, and we believe the universal practice, is to test the ware against duplicates of the limit standards, that is, against carefully measured filters combined with incandescent lamps operated at specified color temperatures. So long as the ware has the same colorant as the limit glasses and differences in chromaticity are due to variations in the thickness of the ware and the concentration of the colorant, the chromaticity limit glasses provide limits that are both practically and theoretically sound. This is because the locus of chromaticities that can be obtained by varying the thickness of ware or the concentration of colorant in ware is a line, and these lines are sufficiently straight that the defining of a single point serves to divide all the chromaticities available with a given colorant into two distinguishable classes. The defining of two points defines a specific range of acceptable chromaticities. In practice these conditions have been nearly realized, the ware furnished having chromaticities that are repre-

sented by points close to the straight or mildly curving lines which represent the change of chromaticity with the change of concentration of the colorants used in the limit standards, and the inspection is carried out by comparing light transmitted by the ware with light transmitted by the limit standards. Since this practice of purchasing ware on the basis of limit standards is both well established and theoretically sound, it is desirable that the specifications be clearly based upon it.

It is one of the purposes of the U.S. Standard for Signal Light Colors to facilitate the writing of specifications on the basis of limit standards and at the same time correlate their requirements with the basic chromaticity definitions. This is accomplished by requiring that the ware be made from materials having chromaticity characteristics similar to those of the standard filters. The meaning of this is illustrated in Figure 2 in which the dotted line extending upward from the point representing the chromaticity of an ordinary gas-filled tungsten lamp at 2854°K into the green region of this RUCS diagram represents the chromaticities resulting from the combination of such a lamp with filters of different thicknesses all made from the same type of glass. The curves, one on each side of this dotted line, are the present tolerances for green ware purchased on the basis of this standard.

The adoption of a set of limit filters and the requirement that ware furnished have chromaticity characteristics similar to those of the adopted filters does not limit the chromaticities as seen by the user to those represented by the standard filters with the standard light source. In the case of the green especially, the narrow band of chromaticities defined by these requirements is broadened into a substantial area on the chromaticity diagram by the variations of chromaticity that result from variations in the color temperature of the source of light. Figure 3 illustrates this compound variation. In this figure, as in Figure 2, the dotted lines represent the variations resulting from changes in the thickness or colorant concentration in the ware but in this figure the full lines represent changes in chromaticity caused by variations in the color temperature of the light source.

In the case of red signal lights, the variations in the color temperature of the filament merely result in an extension of the variations allowed by the limit filters. The chromaticities of the yellow, white, and blue signal lights are also extended by the color temperature variations, but with these colors there may also be some broadening of the band of chromaticities of the signals as produced in service.

Nearly all systems of signal lights are affected by these variations in the light source, and it is the responsibility of the specification writer to take them into account and make sure that the overall variations in chromaticity come within the basic chromaticity definitions.

It has been suggested that photoelectric colorimeters will soon be available and that with them inspections can be carried out with direct reference to the basic definitions without the need for limit filters. This practice would not be sound since it ignores the variations introduced by the differences in the light source. Allowances for these still have to be made, and when the acceptable areas of chromaticity have been reduced to make these allowances, it is probable that we shall not have much more area of acceptable chromaticity left in some systems than is allowed under the requirement for similar chromaticity characteristics. On the other hand, basing procurement specifications upon limit standards does not make it impracticable to use photoelectric colorimeters for inspection of the ware furnished under such specifications. On the contrary it makes the use of such instruments simpler since the limit standards would serve as necessary calibration standards for such photoelectric colorimeters without which the results at present attainable are not sufficiently precise and dependable for the work.

Reliability of Recognition

The recognition of signal light colors is a matter of education. No one is born with a capacity to catalog colors as red, yellow, green, and blue. Those who are not abnormal in their color vision learn to use the color adjectives according to a general pattern, but the precise limits of what is blue or green differ not only from person to person but even for the same person depending upon the environment and the recent history of the use of his eyes. These effects are even larger for colors seen as signal lights than for the colors of surfaces.

There are nine conditions which affect the probability that a signal-light color will be correctly recognized. These are listed in the Report of Secretariat 1.3.3, for Colors of Signal Lights, to the 13th Session of the C.I.E., 1955, as follows:

"(1) the number of colors in the system
(2) the normality of the observer's vision
(3) the state of his visual adaptation
(4) the solid angle subtended by the signal at the observer's eye
(5) the illuminance, or the fixed-light equivalent illuminance, at his eye
(6) the luminance of the background
(7) the observer's familiarity with the system of colors
(8) the opportunity to compare colors if such is present, and
(9) the degree of concentration which the observer can devote to the recognition of the color."

It should be clear from a consideration of these conditions that the separation between the colors is of great importance, and that since many observers will be using the signals of more than one system, it is highly advantageous to have as much uniformity between the different systems as the limitations of their use will permit.

In determining the boundaries for a system of signal-light colors there are four sources of guidance, namely:

(1) the theory of color perception
(2) experiments to determine the recognizability of signal-light colors.
(3) experience with the use of lights conforming to known specifications.
(4) the practicability of obtaining desired chromaticities with the available colorants.

It is not feasible here to examine any of these in detail. It must suffice to point out that theory has contributed to the determination of the direction of boundaries, the results of experiments show that our several colors are centered in favorable parts of the chromaticity diagram, practical limitations dictate the extent of the acceptable color variations, and experience, in some fields at least, altho not demonstrating perfection, encourages confidence in the conclusions we have reached on the basis of theory and experiment.

USCOMM-NBS-DC
February 12, 1959

COMPARISON OF LIMITS FOR RED AND YELLOW SIGNAL LIGHT COLORS

U. S. and INTERNATIONAL SPECIFICATIONS

R-U-C-S DIAGRAM

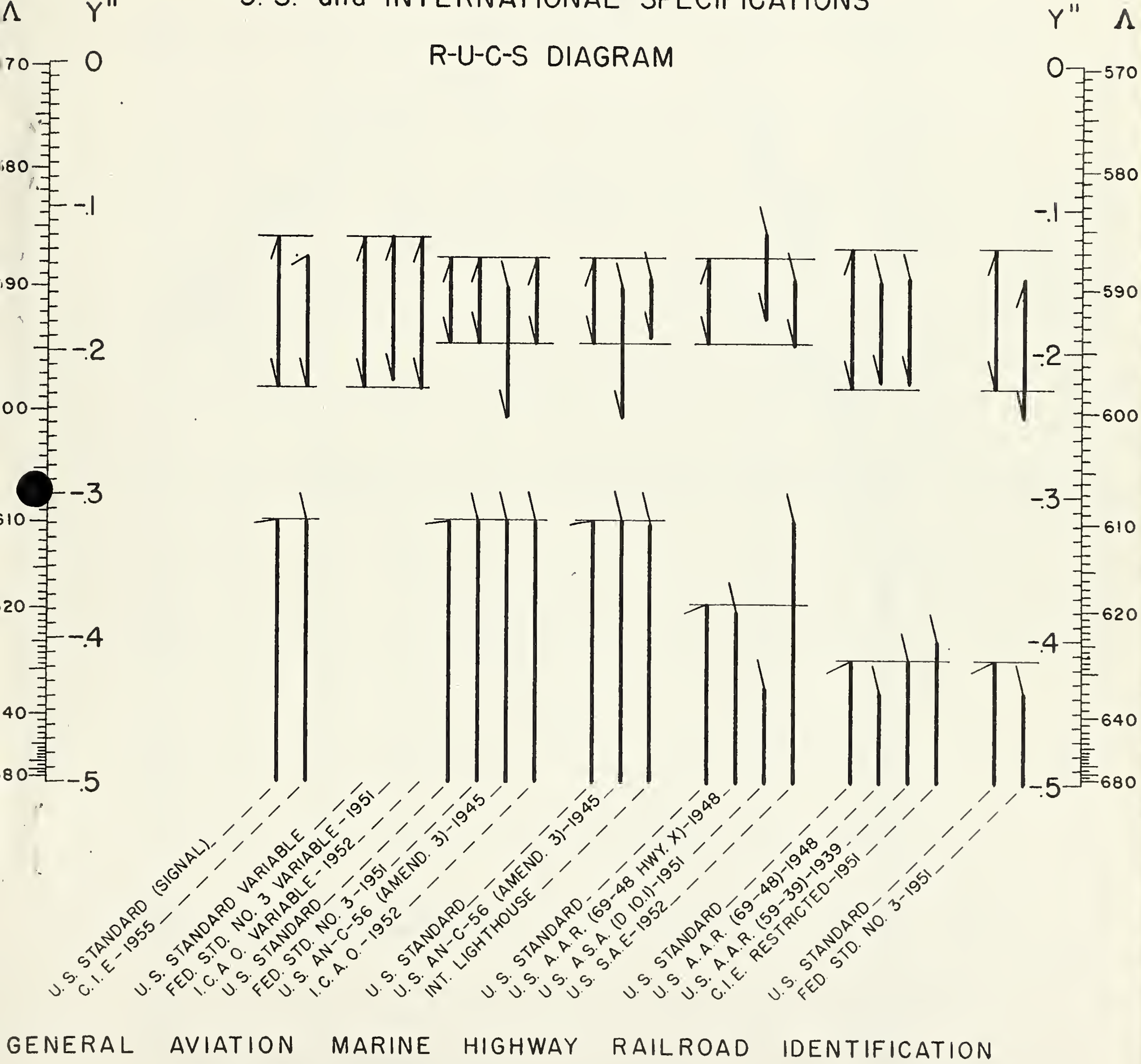

FIGURE 1

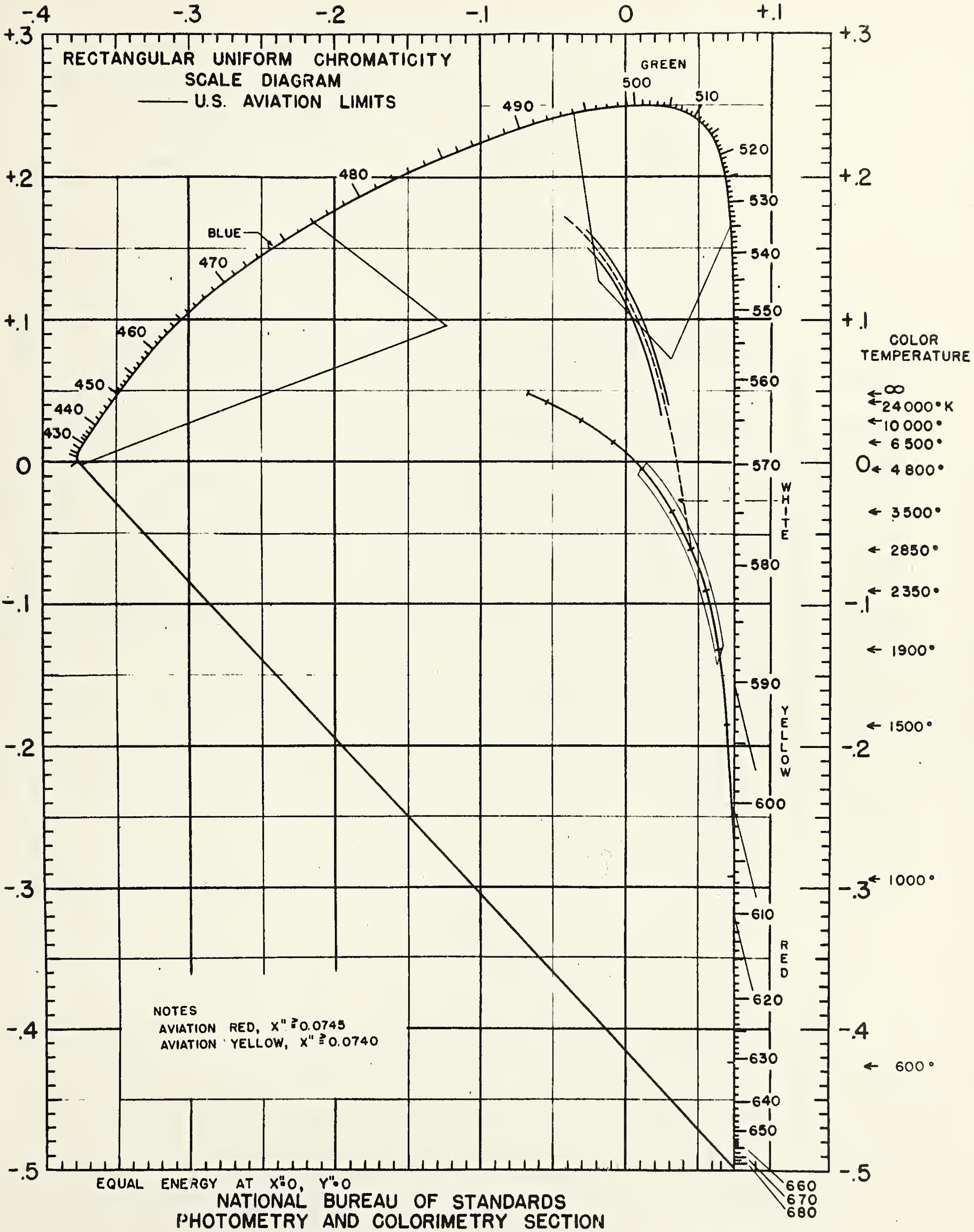

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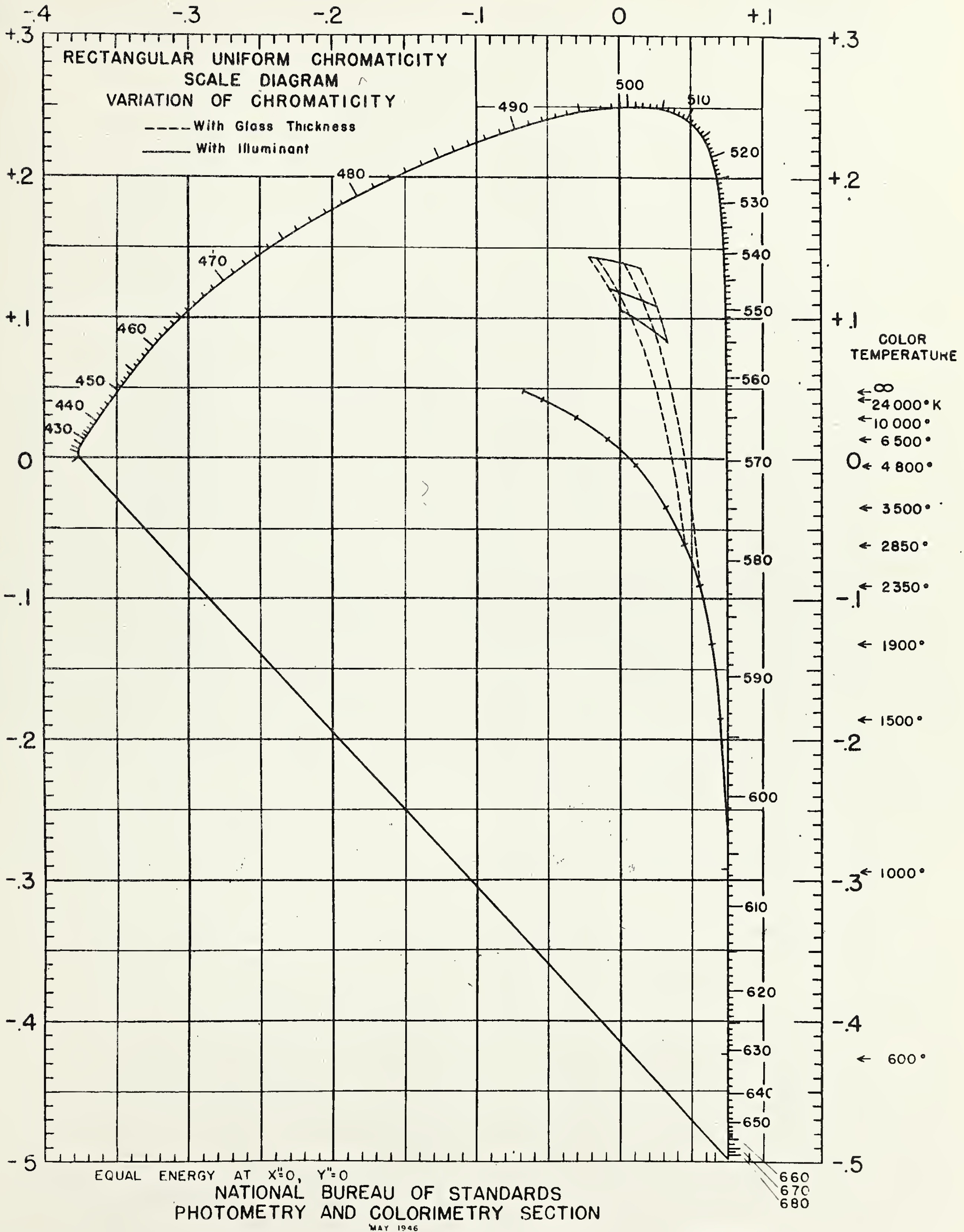
FIGURE 2


RECTANGULAR UNIFORM CHROMATICITY
SCALE DIAGRAM
VARIATION OF CHROMATICITY
----With Glass Thickness
——With Illuminant
-.4
-.3
-.2
-.1
0
+.1
+.3
+.2
+.1
0
-.1
-.2
-.3
-.4
-.5
430
440
450
460
470
480
490
500
510
520
530
540
550
560
570
580
590
600
610
620
630
640
650
660
670
680
COLOR TEMPERATURE
∞
24 000°K
10 000°
6 500°
4 800°
3500°
2850°
2350°
1900°
1500°
1000°
600°
EQUAL ENERGY AT X"=0, Y"=0
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MAY 1946

FIGURE 3

U. S. DEPARTMENT OF COMMERCE
Lewis L. Strauss, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major laboratories in Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside front cover.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Anolog Systems. Application Engineering.

- Office of Basic Instrumentation.
- Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Ionospheric Communication Systems.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio-Meteorology.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.


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