

Viewing conditions - for Graphic Technology and Photography

**(Revision of ISO 3664 - 1975, Photography -
Illumination conditions for viewing colour
transparencies and their reproductions)**

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

International Standard ISO 3664 was revised by a joint working group, composed of members of ISO/TC 6, *Paper, board and pulps*; ISO/TC 42, *Photography* and ISO/TC 130, *Graphic technology*.

Annexes A to C of this International Standard are for information only.

Introduction

While colour and density measurements play important roles in the control of colour reproduction, they cannot replace the human observer for final assessment of the quality of complex images. Colour reflection artwork, photographic transparencies, photographic prints, and photomechanical reproductions such as on-press and off-press proofs, or press sheets, are commonly evaluated for their image and colour quality, or compared critically with one another for fidelity of colour matching. Paper and other substrates contribute to the colour appearance and controlling the colour of these is equally critical. However, it should be noted that the paper industry has its own set of International Standards for unprinted paper which differ in illumination conditions from those recommended in this International Standard.

There is no doubt that the best viewing condition for the visual assessment of colour is that in which the product will be finally seen. Where this is known, and it is practical to do so, the various people in the production chain may sensibly agree to use this viewing condition for all evaluation and comparison. However, it is important that this be properly agreed upon in advance and that it be specified that such a viewing condition is NOT ISO-defined.

Unfortunately, such agreement is often not practical. Even if a particular end use condition is known, it may be impractical to provide everybody in the production chain with sufficiently consistent viewing apparatus. Since deficiencies in light sources and viewing conditions, and inconsistencies between colour viewing facilities, can distort the colour appearance of substrates, reproductions and artwork, they are likely to cause miscommunication about colour reproduction and processing. This International Standard provides specifications for illumination and viewing conditions, that when properly implemented, will reduce errors and misunderstandings caused by such deficiencies and inconsistencies. This revision of the 1974 version of the International Standard meets the current needs of the Graphic Technology and Photographic industries and minimizes differences between viewing equipment. It should be noted that this revision contains multiple specifications, each of which is appropriate to specific requirements. Users should ensure that they employ the specification which is appropriate to their application.

The illumination used to view colour photographic prints, photomechanical reproductions, and transparencies needs to provide adequate amounts of radiant power from all parts of the ultraviolet and visible spectrum to avoid distorting their appearance from that observed under commonly used sources of illumination such as daylight. The ultraviolet content is important where fluorescent samples, which are excited in this region, are encountered; a phenomenon associated with many of the paper substrates on which images are reproduced as well as with some of the dyes and pigments themselves.

To ensure consistency with the 1974 International Standard, as well as the majority of equipment in current use, the reference spectral power distribution specified in this International Standard is CIE Illuminant D_{50} . Many of the reasons for the selection of illuminant D_{50} in 1974, as opposed to any other CIE daylight illuminant,

are equally applicable today. Much consideration was given to changing the reference illuminant to be CIE F8, a 5000 Kelvin illuminant more typical of fluorescent lamps. However, it was felt that this would provide only a minimal conformance advantage (as shown in annex B) and the actual goal is for the illumination to simulate natural daylight.

Because it is very difficult to produce artificial sources of illumination which closely match the spectral power distribution of daylight, it is important that the tolerances specified within this International Standard provide a compromise between that required for lamp manufacturing purposes and that for consistent viewing. In this International Standard three constraints which define the colour of the light falling on the viewing plane apply, one directly and two indirectly, and all three must be met simultaneously if a viewing apparatus is to be in compliance.

The chromaticity, which defines directly the colour of the illumination at the viewing surface, is specified as that for illuminant D_{50} and the tolerance by a circle in the CIE 1976 Uniform Chromaticity Scale (UCS) diagram having a specified radius around that value. To establish the compliance of the spectral power distribution of the illumination to that of illuminant D_{50} the methods defined in CIE Publications No. 13.3 and No. 51 are both specified. One defines the colour rendering quality of a lamp; the other its ability to correctly predict metamers. Both requirements are important to the Graphic Technology and Photographic industries.

Because CIE Publication No. 51 does not currently address illuminant D_{50} , additional virtual metamers for this illuminant, for both visible and ultraviolet evaluation, were calculated and are defined in this International Standard. They were derived from those published in CIE Publication No. 51 and are equivalent to them. Also, based on experimental work described in annex B, a practical tolerance of acceptability has been defined, alongside a Colour Rendering Index requirement.

The perceived tonal scale and colours of a print or transparency can be significantly influenced by the chromaticity and luminance of other objects and surfaces in the field of view. For this reason, ambient conditions, which may affect the state of visual adaptation, need to be designed to avoid any significant effects on the perception of colour and tone and immediate surround conditions need to be specified also. Such specifications are provided in this International Standard.

Experience in the industries covered by this International Standard has revealed the need for two levels of illumination; a high level for critical evaluation and comparison, and a lower level for appraising the tone scale of an individual image under illumination levels similar to those under which it will be finally viewed. This International Standard provides these two levels of illumination.

The higher level is essential to graphic technology where comparison is being made; such as between original artwork and proof, or to evaluate small colour differences between proof and press sheet in order to control a printing operation. It is effective in these situations because it enhances the visibility of any differences. The high level of illumination is also appropriate in photography when comparing two, or more, transparencies or when critically evaluating a single image to assess the darkest tones that can be printed.

Since, despite adaptation, the level of illumination has quite a significant effect on the appearance of an image, the lower level is required in order to appraise the image at a level more similar to that in which it will be finally viewed. Although it is recognised that quite a wide range of illumination levels may be encountered in practical viewing situations, the lower level chosen is considered to be fairly representative of the range encountered. For this reason it is applicable to aesthetic appraisal, including the conditions for routine inspection of prints.

The viewing of transparencies is specified both for direct viewing and by projection, and additional conditions where transparencies are to be compared to a print are also specified. A particular surround is specified for transparencies which recognises the way that a transparency should be viewed for optimum visibility of the dark tones, but acknowledges that practical viewing equipment is likely to have ambient conditions that introduce some viewing flare. The combination of surround and flare produce an appearance that is fairly representative of how the transparency will look in a typically lighted room.

Small transparencies are commonly evaluated in graphic technology by direct viewing. When it is necessary to view transparencies directly, they should be viewed according to the conditions specified for that situation. However, for some purposes, smaller transparencies are not viewed directly because the viewing distance for correct perspective and perception of detail is too small for visual comfort. Furthermore, when small transparencies are reproduced for publication or other purposes, they are usually enlarged. To ease comparison, it is helpful to enlarge the transparency image when comparing it to the print. For these reasons, a viewing condition may be required which provides a magnified image when viewed at an appropriate distance.

Colour monitors are increasingly being used to display and view digital images in graphic technology and photography. In order to ensure consistency of assessment in this situation it is important that the viewing conditions in which the monitors are placed are reasonably well specified. However, it should be noted that adherence to these specifications does not ensure that the monitor will match the hardcopy without provision of a defined colour transformation to the displayed image, or use of proper colour management. This aspect of matching is beyond the scope of this International Standard. In practice, even with high quality colour management, an accurate match is difficult to achieve because the luminance levels generally differ significantly between hardcopy (print or transparency) and softcopy (monitor).

Thus, it should be noted that the specifications for images viewed on colour monitors, provided in this International Standard, are for images viewed independently of any form of hardcopy; conditions for direct comparisons between hardcopy and softcopy (even where a suitable colour transformation has been applied) are beyond the scope of this International Standard which can be seen as being primarily relevant where successive viewing of hardcopy and softcopy takes place. ISO 12646, Graphic Technology - Colour proofing using a colour display, currently at Working Draft level in TC 130, is being produced to provide more detailed recommendations where direct comparison is required. In general it may be stated that for such comparisons it is desirable to view the colour monitor under the lower levels of ambient illumination specified in this International Standard and with the maximum level of luminance achievable, and the hardcopy sample at the lower levels of illumination specified for printed matter in this International Standard (and their equivalent for transparencies). However, it should be noted that this will, in turn, affect the perceived tone and colourfulness of the hardcopy.

Viewing conditions - For graphic technology and photography

1 Scope

This International Standard specifies viewing conditions for images on both reflective and transmissive media, such as prints (both photographic and photomechanical) and transparencies, as well as images displayed in isolation on colour monitors. Specifically, it shall be used for:

- critical comparison between transparencies, reflection photographic or photomechanical prints and/or other objects or images;
- appraisal of the tone reproduction and colourfulness of prints and transparencies at illumination levels similar to those for practical use, including routine inspection;
- critical appraisal of transparencies which are viewed by projection, for comparison with prints, objects, or other reproductions;
- appraisal of images on colour monitors which are not viewed in comparison to any form of hardcopy.

This International Standard is not applicable to unprinted papers.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5-2:1991, *Photography - Density measurements - Part 2: Geometric conditions for transmission density*.

ISO 5-3:1995, *Photography - Density measurements - Part 3: Spectral conditions*.

ISO 5-4:1995, *Photography - Density measurements - Part 4: Geometric conditions for reflection density*.

ISO 12646:____¹⁾, *Graphic technology - Colour proofing using a colour display*.

CIE Publication No. 13.3, 1995, *Method of measuring and specifying the colour rendering properties of light sources, 2nd edition*.

CIE Publication No. 15.2, 1986, *Colorimetry*.

CIE Publication No. 51, 1981, *Method for assessing the quality of daylight simulators for colorimetry*.

CIE Publication No. 17.4, 1987, *International lighting vocabulary*.

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 chromaticity: Property of a colour stimulus defined by its chromaticity co-ordinates, or by its dominant or complementary wavelength and purity taken together. [CIE Publication No. 17.4, 845-03-34]

3.2 colour rendering index: Measure of the degree to which the psychophysical colour of an object illuminated by a test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation. [CIE Publication No. 17.4, 845-02-61]

3.3 correlated colour temperature: Temperature of the

1) To be published.

Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions
[CIE Publication No. 17.4, 845-03-50]

3.4 flare: Light falling on an image, in an imaging system, which does not emanate from the subject point. Veiling glare is also sometimes referred to as flare. See image flare, veiling flare, and veiling glare.

3.5 hardcopy: Representation of an image on a substrate which is self sustaining and reasonably permanent. See softcopy, print, and transparency.

NOTE Examples include prints and transparencies.

3.6 illuminance: (at a point of a surface): Quotient of the luminous flux incident on an element of the surface containing the point by the area of that element
[CIE Publication No. 17.4, 845-01-38]

3.7 illuminant: Radiation with a relative spectral power distribution defined over the wavelength range that influences object-colour perception.
[CIE Publication No. 17.4, 845-03-10]

3.8 image flare: Light from a subject point that is scattered by the optical system to areas of the image plane other than the appropriate image point.

NOTE The distribution of image flare light resulting from any subject point is specified by the image point spread function. Point spread functions tend to fall off rapidly as the distance from the image point is increased, are variable for different image point locations and are typically not radially symmetric for image points some distance from the optical system axis.

3.9 luminance: (in a given direction, at a given point of a real or imaginary surface): Quantity defined by the formula:

$$L_v = \frac{d\phi_v}{dA \times \cos\theta \times d\Omega}$$

where $d\phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam.
[CIE Publication No. 17.4, 845-01-35]

3.10 off-press proof print: Print produced by a method other than press printing whose purpose is to show the results of the colour separation process in a way that closely simulates the results on a production press.

3.11 on-press proof print: Print produced by press printing (production or proof press) whose purpose is to show the results of the colour separation process in a way

that closely simulates the results on a production press.

3.12 original: The scene or hardcopy from which image information is obtained, using an image capture device, in a reproduction process.

NOTE As used in graphic technology, the original is typically a print or transparency, and the capture device is usually an input scanner or, occasionally, a process camera. In photography the term original scene is sometimes used.

3.13 print: A two-dimensional hardcopy form of an image intended for viewing. In still photography and graphic technology, the term print is reserved for reflection hardcopy; a medium designed to be viewed by reflected light. See hardcopy, softcopy, transparency.

3.14 relative spectral (power) distribution: Ratio of the spectral (power) distribution of a source or illuminant to a fixed reference value which can be an average value, a maximum value, or an arbitrarily chosen value of this distribution.

3.15 softcopy: Representation of an image produced using a device capable of directly representing different digital images in succession and in a non-permanent form; the most common example being a monitor. See hardcopy.

3.16 source: A primary emitter of electromagnetic radiation.

3.17 surround: The area adjacent to the border of an image which, upon viewing the image, may affect the local state of adaptation of the eye.

NOTE The surround, which can have a significant effect on the perceived tone and colour reproduction of an image, should not be confused with any border immediately surrounding the image such as any unprinted white substrate for reflection copy or the unexposed border present on many transparencies. For a colour monitor the border will normally be dark grey or black, and hence the same as the surround. However, when simulating hardcopy it will be similar to that hardcopy, both in terms of lightness and width.

3.18 transparency: A two-dimensional hardcopy form of an image designed to be viewed by transmitted light. See hardcopy, softcopy, print.

3.19 transparency illuminator: Apparatus used for back illumination of a transparency.

3.20 veiling flare: The relatively uniform but unwanted irradiation in the image plane of an optical system, caused by the scattering and reflection of a proportion of the radiation which enters the system through its normal entrance aperture. The radiation may be from inside or outside the field of view of the system.

NOTE Light leaks in an optical system housing can cause additional unwanted irradiation of the image plane. This

irradiation may resemble veiling flare.

3.21 veiling glare: Light falling on a radiant image surface, such as a back illuminated transparency or monitor, which adds to the luminance of the image. Veiling glare lightens and reduces the apparent contrast of the darker parts of an image. It differs from veiling flare in that it is used exclusively for the perception of images in which no entrance aperture is defined.

3.22 virtual metamer: A set of spectral radiance factors, not based on physical samples, which provide metameric matches for specific standard daylight illuminants.

NOTE Virtual metamers are used to test and classify illumination sources which simulate daylight according to the method provided in CIE Publication 51. This classification is accomplished by calculating the average of the colour differences obtained for these metamers between the illumination source in question and a CIE standard illuminant. Although it may be possible to construct physical realizations of some virtual metamers, the fact that they may not be real allows greater flexibility in their design.

4 Viewing condition requirements

4.1 General requirements

In this clause, the requirements that apply to all of the specified viewing conditions are stated. The requirements specific to each of these viewing conditions are defined in 4.2 (Critical comparison), 4.3 (Practical appraisal of prints) and 4.4 (Projection viewing of small transparencies).

NOTE For ease of reference, each viewing condition described in the International Standard has been given an alpha-numeric designation. This may be useful in describing or specifying conditions: e.g. ISO viewing condition P2 as specified in this International Standard.

4.1.1 Viewing apparatus

To comply with this International Standard, the values specified shall be achieved at the surface of viewing. The specified spectral power distribution applies to the illuminated surface rather than to the source (or lamp) because the light from the source may be modified by reflecting and transmitting components of the apparatus, and the required spectral power distribution may be obtained from a mixture of light from different sources.

The source, image being viewed, and observer's eyes shall be positioned to minimise the amount of light specularly reflected toward the eyes of an observer on or near the normal to the centre of the viewing surface.

The surround of a print or transparency shall have a

diffusing surface and shall have a CIELAB chroma value no greater than 2; i.e. shall appear neutral.

4.1.2 Spectral conditions for the reference illuminant

The relative spectral power distribution of the reference illuminant for both prints and transparencies shall be CIE illuminant D₅₀ as defined in CIE 15.2 (see table 1). This represents a phase of natural daylight having a correlated colour temperature of approximately 5000 K. The chromaticity coordinates of illuminant D₅₀ are $x_{10} = 0,3478$ and $y_{10} = 0,3595$ in the CIE chromaticity diagram and $u'_{10} = 0,2102$ and $v'_{10} = 0,4889$ in the CIE 1976 Uniform Chromaticity Scale (UCS) diagram.

NOTE Chromaticity is specified for the CIE 1964 standard colorimetric observer to ensure compatibility with the method specified in CIE No. Publication 51 which is used to define the degree of compliance of the illumination to the reference illuminant in 4.2.2.

4.1.3 Colour rendering index

The CIE general colour rendering index of the viewing surface shall be measured as specified in CIE Publication No. 13.3 and shall have a value of 90 or higher. In addition, the separate special colour rendering indices for samples 1 to 8 as specified in CIE Publication No. 13.3 shall each have a value of 80 or higher.

4.1.4 Ambient conditions

The visual environment shall be designed to minimise interference with the viewing task. It is important to eliminate extraneous conditions that affect the appraisal of prints or transparencies and an observer should avoid making judgements immediately after entering a new illumination environment because it takes a few minutes to visually adapt to that new environment.

Extraneous light, whether from sources or reflected by objects and surfaces, shall be baffled from view and from illuminating the print, transparency, or other image being evaluated. In addition, no strongly coloured surfaces (including clothing) should be present in the immediate environment.

NOTE The presence of strongly coloured objects within the viewing environment is a potential problem because they may cause reflections which cannot easily be baffled and may influence viewer adaptation.

Walls, ceiling, floors, and other surfaces which are in the field of view shall be baffled or coloured a neutral matt grey, with a reflectance of 60% or less.

Table 1 - Relative spectral power of reference illuminant D₅₀.

Wavelength (nm)	Relative power for illuminant D ₅₀	Wavelength (nm)	Relative power for illuminant D ₅₀
300	0,02	550	102,32
305	1,03	555	101,16
310	2,05	560	100,00
315	4,91	565	98,87
320	7,78	570	97,74
325	11,26	575	98,33
330	14,75	580	98,92
335	16,35	585	96,21
340	17,95	590	93,50
345	19,48	595	95,59
350	21,01	600	97,69
355	22,48	605	98,48
360	23,94	610	99,27
365	25,45	615	99,16
370	26,96	620	99,04
375	25,72	625	97,38
380	24,49	630	95,72
385	27,18	635	97,29
390	29,87	640	98,86
395	39,59	645	97,26
400	49,31	650	95,67
405	52,91	655	96,93
410	56,51	660	98,19
415	58,27	665	100,60
420	60,03	670	103,00
425	58,93	675	101,07
430	57,82	680	99,13
435	66,32	685	93,26
440	74,82	690	87,38
445	81,04	695	89,49
450	87,25	700	91,60
455	88,93	705	92,25
460	90,61	710	92,89
465	90,99	715	84,87
470	91,37	720	76,85
475	93,24	725	81,68
480	95,11	730	86,51
485	93,54	735	89,55
490	91,96	740	92,58
495	93,84	745	85,40
500	95,72	750	78,23
505	96,17	755	67,96
510	96,61	760	57,69
515	96,87	765	70,31
520	97,13	770	82,92
525	99,61	775	80,60
530	102,10	780	78,27
535	101,43		
540	100,75		
545	101,54		

NOTE The wavelength specification has been extended beyond the normal visual range because of the need to consider brighteners or dyes which may fluoresce.

It should be noted that it may be easier to minimise these problems by using a viewing booth, rather than designing an open area for viewing within a room. Such apparatus can also make it easier to meet the specification for surround conditions specified in 4.2.4 and avoid the excessive flare which may otherwise cause problems on transparency illuminators. However, even with such apparatus, adaptation and avoidance of extraneous light still need to be carefully considered.

4.1.5 Maintenance

Manufacturers of viewing apparatus shall specify the average number of hours during which the apparatus is expected to remain within specification. The apparatus should include a time-metering device or some other mechanism for indicating degradation.

However, it is the responsibility of the user, both before and beyond this time limit, to undertake measurements as specified in clause 5 to ensure compliance, unless it can be otherwise demonstrated that the equipment remains within tolerance.

4.2 Conditions for critical comparison (ISO viewing conditions P1 and T1)

4.2.1 Applicability

This subclause specifies viewing conditions for the critical comparison between two (or more) copies of an image. The comparison is usually either between the original and its reproduction or between different copies of a reproduction such as samples from a press run or multiple photographic prints. The images being compared may be on the same media (reflective or transmissive), or on different reflective media (including photographic or photomechanical prints and press proofs or off-press proofs), or even between transmissive and reflective media such as that pertaining when a transparency is compared to a proof of its printed reproduction. The high illumination levels specified permit more critical evaluation of colour and tone gradation in higher density areas which may not be perceived under most practical viewing conditions.

The condition for viewing a print is specified as condition P1; that for viewing a transparency directly on an illuminator having a diffusing screen (compared to viewing by projection) is specified as condition T1. The latter will normally be the case for transparencies larger than 10cm x 10cm and in graphic technology is generally the case for smaller transparencies also.

NOTE In the graphic arts industry the primary viewing application involves comparison, which requires that level P1 be used. However, when it is important that tone reproduction that will be perceived under lower levels of illumination is assessed, it is recommended that P1 be supplemented by level P2, or the

expected actual viewing condition. It should be noted that both P1 and P2 have the same correlated colour temperature of D_{50} .

4.2.2 Illumination

The illumination at the plane of viewing shall approximate that of CIE standard illuminant D_{50} . It shall have u'_{10} , v'_{10} chromaticity co-ordinates within the radius of 0,005 from that specified in 4.1.2 and a colour rendering index as specified in 4.1.3. When assessed using the method defined in CIE Publication No. 51, but using the virtual metamers defined for the visible range in table 2, it shall fall within category C and should fall within category B. For condition P1, when assessed using the method defined in CIE Publication No. 51, but using the virtual metamers defined for the ultraviolet range in table 3, it shall have a metamerism index (MI_{uv}) of less than 4. (See annex B for further explanation of these tolerances).

NOTE No specification is provided for the ultraviolet emission of the illumination for condition T1. In practice fluorescence is not an issue for photographic transparencies and the diffusing surface of the illuminator normally absorbs the majority of any ultraviolet emission from the source.

The categories to which the equipment conforms at the time of manufacture shall be displayed on the equipment. Where the ultraviolet metamerism index is greater than 2, the manufacturer shall specify whether the contribution to visible energy from ultraviolet excitation is greater than or less than the contribution of illuminant D_{50} .

4.2.3 Illuminance (P1)

The illuminance shall be $2000 \text{ lx} \pm 500 \text{ lx}$, and should be $2000 \text{ lx} \pm 250 \text{ lx}$, at the centre of the illuminated viewing surface area. Any departures from complete uniformity shall be gradually diminishing from centre to edge. For a viewing area up to 1 metre square, the illuminance at any point within the illuminated area shall not be less than 75% of the illuminance measured at the centre of the illuminated viewing surface area. For larger viewing areas, the lower limit shall be 60%.

4.2.4 Surround and backing for reflection viewing (P1)

The surround and backing shall be neutral and matt. The surround shall have a luminous reflectance between 10% and 60% with the specific value being selected to be consistent with practical viewing. For many applications a mid-grey of 20% reflectance is very convenient and is recommended where no other condition is defined. However, whatever value is selected it is important when images are being compared that the surrounds for each are similar; and as a result the ratio of the surround luminance shall be 1,0 ($\pm 0,2$):1.

Table 2 - Five sets of spectral reflection radiance factor data providing virtual metamers with the standard data provided in CIE Publication 51. To be used for visible range evaluation for illuminant D₅₀.

Wave length (nm)	Virtual Metamers, Visual range					Wave length (nm)	Virtual Metamers, Visual range				
	Set 1	Set 2	Set 3	Set 4	Set 5		Set 1	Set 2	Set 3	Set 4	Set 5
400	0,029	0,044	0,029	0,403	0,175	600	0,427	0,072	0,102	0,238	0,200
405	0,028	0,056	0,028	0,403	0,177	605	0,473	0,076	0,103	0,240	0,228
410	0,027	0,063	0,028	0,403	0,179	610	0,515	0,083	0,104	0,241	0,258
415	0,026	0,074	0,027	0,403	0,182	615	0,552	0,085	0,104	0,240	0,286
420	0,024	0,081	0,027	0,402	0,184	620	0,582	0,087	0,104	0,237	0,316
425	0,024	0,088	0,026	0,401	0,187	625	0,608	0,087	0,103	0,234	0,342
430	0,024	0,089	0,026	0,398	0,187	630	0,630	0,086	0,103	0,229	0,366
435	0,025	0,088	0,024	0,393	0,186	635	0,646	0,085	0,104	0,228	0,387
440	0,025	0,083	0,025	0,387	0,181	640	0,659	0,084	0,104	0,228	0,405
445	0,026	0,081	0,026	0,375	0,178	645	0,671	0,084	0,106	0,236	0,422
450	0,027	0,076	0,027	0,372	0,174	650	0,683	0,085	0,109	0,245	0,437
455	0,028	0,071	0,029	0,366	0,170	655	0,695	0,086	0,114	0,264	0,451
460	0,031	0,066	0,031	0,360	0,165	660	0,708	0,088	0,120	0,287	0,466
465	0,035	0,059	0,034	0,353	0,160	665	0,722	0,088	0,129	0,320	0,482
470	0,043	0,052	0,037	0,345	0,156	670	0,736	0,088	0,140	0,358	0,502
475	0,054	0,048	0,045	0,336	0,151	675	0,751	0,087	0,154	0,403	0,522
480	0,068	0,045	0,056	0,327	0,148	680	0,766	0,086	0,170	0,449	0,543
485	0,085	0,042	0,067	0,319	0,143	685	0,781	0,086	0,188	0,502	0,564
490	0,103	0,039	0,077	0,311	0,141	690	0,794	0,086	0,206	0,552	0,584
495	0,121	0,037	0,086	0,304	0,139	695	0,806	0,087	0,227	0,600	0,603
500	0,136	0,034	0,092	0,296	0,137	700	0,817	0,088	0,250	0,646	0,621
505	0,148	0,035	0,095	0,289	0,135						
510	0,156	0,033	0,097	0,281	0,135						
515	0,159	0,032	0,095	0,276	0,132						
520	0,160	0,032	0,092	0,271	0,129						
525	0,162	0,032	0,090	0,265	0,125						
530	0,164	0,032	0,089	0,260	0,122						
535	0,167	0,032	0,088	0,255	0,121						
540	0,172	0,033	0,086	0,251	0,121						
545	0,177	0,033	0,084	0,248	0,121						
550	0,182	0,033	0,084	0,246	0,121						
555	0,189	0,032	0,086	0,245	0,119						
560	0,196	0,030	0,087	0,244	0,116						
565	0,209	0,032	0,088	0,243	0,110						
570	0,226	0,036	0,091	0,241	0,108						
575	0,248	0,041	0,094	0,239	0,113						
580	0,275	0,045	0,096	0,236	0,119						
585	0,309	0,049	0,097	0,234	0,131						
590	0,345	0,055	0,097	0,234	0,149						
595	0,384	0,063	0,100	0,235	0,174						

NOTE This data complements that in CIE Publication 51. The standard data, to which the above provides metamers, may be obtained from that document. The above data are NOT available in CIE Publication 51.

Table 3 - Spectral characteristic of non-fluorescent samples providing virtual metamers with the fluorescent samples provided in CIE publication 51 for illuminant D₅₀.

Wave length (nm)	Virtual Metamers ultraviolet range			Wave length (nm)	Virtual Metamers ultraviolet range		
	1	2	3		1	2	3
400	0,662	0,505	0,212	600	0,838	0,838	0,838
405	0,687	0,589	0,293	605	0,839	0,839	0,839
410	0,711	0,668	0,401	610	0,840	0,840	0,840
415	0,742	0,723	0,507	615	0,842	0,842	0,842
420	0,767	0,764	0,613	620	0,844	0,844	0,844
425	0,797	0,805	0,737	625	0,846	0,846	0,846
430	0,822	0,838	0,842	630	0,848	0,848	0,848
435	0,824	0,845	0,868	635	0,850	0,850	0,850
440	0,820	0,843	0,866	640	0,851	0,852	0,852
445	0,816	0,836	0,857	645	0,851	0,854	0,854
450	0,810	0,826	0,845	650	0,852	0,856	0,856
455	0,808	0,822	0,845	655	0,852	0,856	0,857
460	0,807	0,820	0,843	660	0,852	0,856	0,857
465	0,807	0,816	0,837	665	0,853	0,856	0,857
470	0,804	0,813	0,830	670	0,853	0,856	0,858
475	0,806	0,813	0,828	675	0,853	0,858	0,859
480	0,810	0,816	0,827	680	0,853	0,858	0,860
485	0,812	0,817	0,826	685	0,853	0,858	0,861
490	0,814	0,818	0,826	690	0,853	0,858	0,862
495	0,816	0,819	0,825	695	0,853	0,858	0,863
500	0,818	0,821	0,825	700	0,853	0,859	0,864
505	0,822	0,825	0,828				
510	0,826	0,829	0,831				
515	0,830	0,831	0,834				
520	0,831	0,833	0,836				
525	0,832	0,833	0,836				
530	0,832	0,833	0,835				
535	0,832	0,833	0,834				
540	0,833	0,834	0,835				
545	0,833	0,834	0,835				
550	0,834	0,834	0,834				
555	0,835	0,834	0,834				
560	0,835	0,834	0,835				
565	0,835	0,834	0,835				
570	0,836	0,835	0,836				
575	0,836	0,835	0,835				
580	0,836	0,836	0,836				
585	0,837	0,837	0,837				
590	0,837	0,837	0,837				
595	0,837	0,837	0,837				

NOTE This data complements that in CIE Publication 51. The standard data, to which the above provides metamers, may be obtained from that document. The above data are NOT available in CIE Publication 51.

NOTE 1 A wide range of surround reflectances is allowed in this International Standard so that reflection hardcopy images can be evaluated in conditions which are similar to those used in practice. However, extremely light or dark surrounds are not allowed because of their large effect on appearance. Where no practical condition can be specified a mid-grey of 20% reflectance should be used.

The surround shall extend beyond the materials being viewed on all sides by at least 1/3 of their dimension. Where objects are being compared, they may be positioned edge to edge. The backing should have a luminous reflectance of 2 to 4% to be consistent with the definition in ISO 5-4.

NOTE 2 The above requirement may be met by appropriate finishing of the viewing surface or by introduction of masking devices.

4.2.5 Luminance at the surface of the transparency illuminator (T1)

The luminance at the centre of the illuminated surface of the transparency illuminator shall be $1270 \text{ cd/m}^2 \pm 320 \text{ cd/m}^2$ and should be $1270 \text{ cd/m}^2 \pm 160 \text{ cd/m}^2$. Any departures from uniformity shall be gradually diminishing from centre to edge such that the luminance (measured normal to the surface) at any point within the luminous area is not less than 75% of the luminance measured at the centre of the image plane.

4.2.6 Transparency illuminator diffusion characteristics (T1)

The transparency illuminator surface shall provide diffuse light such that the luminance of the surface measured at any angle between 0° and 45° from the normal shall not be less than 90% of the luminance at the same point measured normal to the surface.

4.2.7 Transparency surround (T1)

The surround shall be at least 50 mm wide on all sides. It shall appear neutral compared to the source and shall have a luminance that is between 5% and 10% of that of the surface of the image plane of the illuminator in the direction of observation. A transparency mounted with an opaque border may be viewed without removing the mount.

NOTE This condition is similar to that specified for direct viewing of transparencies in the previous version of this International Standard. However, that version specified an 'illuminated' surround when transparencies were compared to prints. The purpose of this surround was to effect a reduction in transparency contrast to facilitate comparison to prints. Unfortunately, this method of contrast reduction significantly reduces tonal differentiation in the dark tones of the image. With modern imaging systems, contrast reduction can be achieved through a variety of means that maintain shadow contrast. The illuminated surround approach could therefore result in a misleading interpretation of transparency shadow detail, particularly for low-key subjects. The dark surround has therefore

been incorporated for all assessment conditions in this International Standard. In practice this condition may be met by using an opaque black mask; such a mask will appear to have a luminance somewhat above absolute black because of viewing flare and ambient illumination falling on the mask.

4.2.8 Relationship between transparency luminance and print illuminance (P1 and T1)

For critical comparison between transparencies and reflecting materials, the illuminance at the reflecting material surface shall be that specified in 4.2.3 (i.e. $2000 \pm 500 \text{ lx}$). The transparency illuminator shall have a luminance as specified in 4.2.5 (i.e. $1270 \pm 320 \text{ cd/m}^2$). However, the combined tolerances must be such that the ratio of the maximum luminance of the transparency illuminator to the maximum luminance of a perfectly reflecting and diffusing material, at the plane of the reflecting material, shall be $2 (\pm 0,2):1$. The maximum luminance by reflection from the perfectly reflecting and diffusing material is equal to the incident illuminance divided by π .

4.3 Conditions for practical appraisal of prints (including routine inspection). (ISO viewing condition P2)

4.3.1 Applicability

The specifications in this sub-clause are applicable for the appraisal of tone reproduction of individual images, photographic image inspection or the judgement of prints. They are not appropriate for the simultaneous comparison of media, where colour matching is the primary concern, such as any comparison between proof and photo-mechanical print, transparency and proof (or print), or between different photographic prints and transparencies. The only exception is when comparing a print to a colour monitor, because of the low luminance level exhibited by current monitors, but such comparisons are outside the scope of this International Standard which only deals with appraisal of images on a monitor in isolation from hardcopy (see 4.5).

It should be noted that the spectral power characteristics specified for P2 are exactly the same as those specified for condition P1. Therefore, images that match under the conditions of P1 will match under the conditions of P2. However, the reverse is not necessarily true, particularly if there are significant dark tonal areas involved.

Experience has shown that the high levels of illumination specified for ISO viewing condition P1 can give a misleading impression of the tone reproduction and colourfulness of an image which will ultimately be viewed by the consumer in much lower levels of illumination. Images that appear quite acceptable when viewed at the higher levels of illumination may not appear satisfactory when viewed at more typical levels of illumination. To avoid this problem the illumination level for inspection of

photographic prints is often set arbitrarily while many graphic technology users take proofs into unknown conditions of lower illumination level to verify that their tone reproduction will prove acceptable in use. Because neither the level or characteristics of the illumination in these situations are controlled, this practice introduces uncertainties into the process and prevents effective communication.

The viewing conditions specified in this subclause are intended to minimise those problems; the viewing conditions specified are for the appraisal of tone reproduction, for photographic image inspection or judgement of prints, under illumination levels that correspond to an office, library, or a relatively brightly illuminated area in a residence. By appraising images under such conditions it is possible to ensure that they provide a satisfactory tone reproduction; such a judgement cannot be made unambiguously at the higher level of illumination specified for condition P1.

NOTE In the graphic arts industry the primary viewing application involves comparison, which requires that level P1 be used. However, when it is important that tone reproduction that will be perceived under lower levels of illumination is assessed, it is recommended that P1 be supplemented by level P2, or the expected actual viewing condition. It should be noted that both P1 and P2 have the same correlated colour temperature of D_{50} .

4.3.2 Illumination

The illumination at the surface of viewing shall comply with that described in 4.2.2.

4.3.3 Illuminance

The illuminance at the centre of the viewing surface shall be $500 \text{ lx} \pm 125 \text{ lx}$. The illumination uniformity shall comply with that described in 4.2.3.

4.3.4 Surround and backing

The surround and backing shall comply with that described in 4.2.4 except that a white backing may be used where appropriate, e.g. for display purposes. The surround and backing shall be assumed to be in compliance with 4.2.4 unless communicated otherwise to others involved in the production chain, in which case the reflectance of the surround and backing shall be specified.

4.4 Conditions for viewing small transparencies by projection (ISO viewing condition T2)

4.4.1 Applicability

The specifications for the equipment used for viewing a projected image of a slide on a screen are given in the following subclauses. These conditions are not to be confused with those normally used for viewing slides in a commercial projector where the magnification is generally

much greater and there is no intent to compare such images with reflection prints.

4.4.2 Illumination

The light emitted from the screen with an empty slide mount in the gate shall comply with that described in 4.2.2.

4.4.3 Luminance

The luminance at the screen in the direction of the observer shall be $1270 \text{ cd/m}^2 \pm 320 \text{ cd/m}^2$ when measured with an empty slide mount in the projector.

4.4.4 Uniformity of screen luminance.

Any departure from uniformity of screen luminance shall be approximately radially symmetrical about the centre of the screen, the luminance gradually diminishing from the centre to the edges of the projected image of the open slide mount. When the screen is viewed at any angle up to 25 degrees from the perpendicular to its surface, and at the normal viewing distance for the equipment, the luminance of any point within the image of the open slide mount shall be not less than 75% of that at the centre. The screen on which the image is displayed shall exhibit no more speckle, scintillation, or graininess than that exhibited by an untextured flat, matt, front-projection screen.

4.4.5 Surround

The surround shall comply with that described in 4.2.7.

4.4.6 Stray light and flare

Provisions shall be made for shielding the screen from stray light. The surfaces of the stray light shield(s) facing the screen shall be matt black.

Stray light and flare shall be such that, when evaluated with a test transparency conforming to 5.2, the luminance at the centre of the spot image on the screen shall not exceed 1% of the maximum screen luminance for any point in the surrounding field.

4.4.7 Resolution

The resolving power of the optical system shall be such that, when evaluated with a test transparency conforming to 5.3, all patterns having a spatial frequency up to 40 line pairs per millimetre shall be resolved at any point in the projected image.

4.4.8 Distortion

The projection system shall not exhibit noticeable spatial distortion nor cause noticeable chromatic distortion of the projected image.

4.5 Conditions for appraisal of images displayed on colour monitors.

4.5.1 Applicability

In order to ensure consistency of assessment of images viewed on colour monitors it is important that the viewing conditions in which the monitors are placed are reasonably well specified. However, it should be noted that the specifications provided in this International Standard are for images viewed independently of any form of hardcopy; conditions for direct comparisons between hardcopy and softcopy (even where a colour transformation designed to provide a colour match has been applied) are beyond the scope of this International Standard. Thus, these specifications can be seen as being primarily relevant where successive viewing of hardcopy and softcopy takes place. ISO 12646, Graphic Technology - Colour proofing using a colour monitor, currently at Working Draft level in TC 130, is being produced to provide more detailed recommendations where direct comparison is required.

4.5.2 Chromaticity

The chromaticity of the white displayed on the colour monitor should approximate that of D_{65} . It shall have u'_{10} , v'_{10} chromaticity co-ordinates within the radius of 0.025 of $u'_{10} = 0.1979$ and $v'_{10} = 0.4695$ in the CIE 1976 Uniform Chromaticity Scale (UCS) diagram.

NOTE When viewed under the conditions specified in 4.5 the monitor itself will provide the primary adapting stimulus to the eye. The chromaticity of the white of the monitor is not too important in this situation although many users prefer that the chromaticity of that white be close to that of D_{65} . There is some evidence that, at the low luminance levels obtained with monitors, a chromaticity close to that of D_{65} provides a better evocation of white and, furthermore, such a chromaticity permits a higher level of luminance to be achieved with current display technology. However, if the monitor is to be directly compared with prints or transparencies then the chromaticity of the white of the monitor should be close to that of the hardcopy to which it is being compared. This means that a colour monitor used for such a purpose should have a chromaticity close to illuminant D_{50} . Such a chromaticity is within the tolerance specified in this International Standard. The specification for comparing colour monitor to hardcopy is described in greater detail in ISO 12646, Graphic Technology - Colour proofing using a colour monitor.

4.5.3 Monitor luminance

The luminance level of the white displayed on the monitor shall be greater than 75 cd/m^2 and should be greater than 100 cd/m^2 .

NOTE With current display technology the level of luminance that may be achieved depends upon the chromaticity of the white point of the monitor. As the correlated colour temperature is increased the level of screen luminance that may be achieved becomes higher. A level of at least 100 cd/m^2 is recommended for this application but it is accepted that this may be difficult to achieve on some monitors, particularly for older or lower cost

models, or where the monitor white point is set to the chromaticity of illuminant D_{50} .

4.5.4 Ambient illumination

When measured at the face of the monitor, with a cosine corrected photometer and with the monitor switched off, the level of ambient illumination shall be less than, or equal to, 64 lx and should be less than, or equal to, 32 lx . These limits must also be achieved when measured in any plane between the monitor and the observer. The correlated colour temperature of the ambient illumination shall be less than or equal to that of the monitor white point.

NOTE The level of ambient illumination needs to be significantly lower than the luminance level of the monitor white point. This is partly to ensure that the observer is reasonably adapted to the monitor but primarily to ensure that the full contrast range of the monitor is not significantly reduced by the effects of veiling glare. It is for these reasons that the level of ambient illumination needs to be less than 64 lx and, preferably, much lower. This is particularly significant where low luminance monitors are employed. If the level of ambient illumination approaches the higher level specified in this clause, the correlated colour temperature should be approximately the same as the white point of the monitor, in order to minimise chromatic adaptation complications.

4.5.5 Surround condition

The area immediately surrounding the displayed image and its border shall be neutral, preferably dark grey or black to minimise flare, and of approximately the same chromaticity as the white point of the monitor. The luminance of the border should be 20% of the white point luminance, or less, and preferably 3% of the white point luminance, or less.

NOTE When the monitor is being used to visualise images which will be reproduced as hardcopy the recommended lightness of any border displayed around the image will depend upon the comparison. In general, for comparison to prints, which may well be reproduced with a white border consisting of unprinted substrate, the border of the image should be light to simulate this substrate; for comparison to transparencies it should be dark. However, it is generally preferable that any such border be no more than 1 to 2 cm wide, even if it would normally be wider on the hardcopy reproduction.

4.5.6 Environmental conditions

The monitor shall be situated so there are no strongly coloured areas (including clothing) directly in the field of view or which may cause reflections in the monitor screen. Ideally all walls, floors and furniture in the field of view should be grey and free of any posters, notices, pictures, wording or any other object which may affect the vision of the viewer.

4.5.7 Glare

All sources of glare should be avoided since they significantly degrade the quality of the image. The monitor

shall be situated so that no illumination sources such as unshielded lamps or windows are directly in the field of view or are causing discernable reflections from the surface of the monitor.

5. Test methods

5.1 Spectral measurements

To determine the colour rendering index of the illumination, as defined in 4.1.3, and the chromaticity and metameric index as defined in 4.2.2, it is necessary to measure the spectral power distribution of the illumination. This requires measurement over the range 300 to 730 nm for conditions P1 and P2 and over the range 380 to 730 nm for conditions T1 and T2. The bandpass of the measuring instrument (spectroradiometer) shall be 5 nm or narrower. The sampling interval shall not be greater than the bandpass.

NOTE - As in any measurement process, the measuring equipment must be regularly calibrated. In this case the calibration of the spectroradiometer must include assessment of stray light, linearity, wavelength accuracy and spectral power accuracy.

5.2 Illuminance and luminance

All illuminance or luminance measurements shall be made with a photometer having the spectral responsivity of the CIE standard photopic photometric observer, $V(\lambda)$, and measuring an area having a diameter no greater than 1/20 of the shortest linear dimension of the illuminated surface area. For illuminance measurements the photometer shall be cosine-corrected.

For projection viewing apparatus, stray light and flare shall be evaluated with the aid of a test transparency that is clear,

neutral and transparent everywhere except for an opaque central circular spot producing an image having a diameter 1/10 the smallest linear dimension of the projected opening in an open slide mount. Measurement shall be made perpendicular, within 7 degrees, to the spot and 35 cm from the screen.

NOTE The measurement should be made over an area not greater than 30% of the opaque (black) spot diameter, approximately centred on the centre of the spot.

All measurements shall be conducted in the presence of environmental illumination that would normally exist when the apparatus is used.

5.3 Resolution assessment for projection viewing apparatus

A test target shall be used containing square wave resolution patterns varying in spatial frequency and with two mutually perpendicular orientations. The range of frequencies included should be at least 20 to 60 line pairs per millimetre and should include 40 line pairs per millimetre. The dark bars of the test patterns shall have an ISO visual diffuse transmission density, as defined in ISO 5-2 and 5-3, at least 2,0 higher than the density of the transparent background. A pattern having a given spatial frequency shall be considered resolved if the sets of lines of the projected image of that pattern, oriented both radially to the centre of the field and tangentially to a circle about the centre, are clear enough to be counted with reasonable confidence. The concept of "reasonable confidence" is intended to indicate a level of confidence that is somewhere between complete confidence and no confidence at all. All resolution evaluations shall be made with the optical system set at the same focus. A low-power magnifying glass may be used.

Annex A (Informative)

Summary of ISO viewing conditions specified in ISO 3664

This table is deemed to be informative since it is included for convenience and introduces no new specifications. It simply summarises the main normative requirements specified throughout this International Standard.

ISO Viewing condition	Reference Illuminant and chromaticity tolerance (1)	Illuminance/Luminance	Colour Rendering index (according to CIE 13.3)	Metamerism index (according to CIE 51)	Illumination uniformity (min:max)	Surround luminous reflectance/luminance/illuminance
Critical comparison						
Prints (P1)	illuminant D ₅₀ (0,005)	2000 lx ± 500 lx (should be ± 250 lx)	General index: ≥90 Special indices for samples 1 to 8: ≥80	Visual: C or better and should be B or better UV: <4	For surfaces up to 1m x 1m ≥0.75 For surfaces greater than 1m x 1m ≥0.6	<60% (neutral and matt)
Transparencies (Direct viewing) (T1)	illuminant D ₅₀ (0,005)	1270 ± 320 cd/m ² (should be ± 160 cd/m ²) (2)	General index: ≥90 Special indices for samples 1 to 8: ≥80	Visual: C or better and should be B or better	≥0,75	5 - 10% of the luminance level (neutral and extend at least 50mm on all sides)
Practical appraisal of prints (P2)	illuminant D ₅₀ (0,005)	500 ± 125 lx	General index: ≥90 Special indices for samples 1 to 8: ≥80	Visual: C or better and should be B or better UV: <4	≥0,75	<60% (neutral and matt)
Transparencies Projection viewing (T2)	illuminant D ₅₀ (0,005)	1270 ± 320 cd/m ²	General index: ≥90 Special indices for samples 1 to 8: ≥80	Visual: C or better and should be B or better	≥0,75	5 - 10% of the luminance level (neutral and extend at least 50mm on all sides)
Colour Monitors	chromaticity of illuminant D ₆₅ (0,025)	> 75 cd/m ² (should be > 100 cd/m ²)	Not applicable	Not applicable	Not applicable	Neutral, and dark grey or black (3)

Notes

- 1 This specifies the spectral power distribution of the reference illuminant, except for colour monitors in which case it specifies the chromaticity of the white point of the monitor. Permitted tolerances in chromaticity, from that of the reference illuminant, are given in parentheses. These are specified at the plane of viewing, according to the 1976 u'_{10}, v'_{10} UCS system.
- 2 When comparing a transparency to a print the ratio of the luminance of the transparency illuminator to the equivalent illuminance of the print viewing surface shall be 2 (± 0,2):1.
- 3 The ambient illumination for colour monitors should be less than or equal to 32 lx and shall be less than or equal to 64 lx.

Annex B (informative)

Experimental data leading to selection of metamerism indices And reference illuminant for this International Standard

B.1 Introduction

In order to establish a suitable reference illuminant for this International Standard, as well as determining tolerances which are both acceptable and practical, a good deal of experimental work was carried out. The objective of the work was threefold; to determine which reference illuminant would be most appropriate for specifying viewing conditions for the evaluation of hardcopy images for both Graphic Technology and Photography; to define the most appropriate measures of acceptability between this reference illuminant and real sources (together with any other components of the viewing environment); and to establish suitable tolerances for these measures.

Since it was considered important that any tolerances specified were not unreasonably stringent, a small number of practical sources were studied rather extensively. Subsequently the work was extended to verify that a reasonably large number of existing apparatus, in use in industry, were not significantly deviant from these tolerances, although it would not be a concern if many were somewhat outside. Since much of this apparatus had been in use for some time this would not be considered unacceptable. It is inevitable that in such a situation many viewing environments would be due to be updated, or need to have their sources replaced. It would be hoped, and expected, that such a situation would result in apparatus that is more consistent to one another than with older equipment.

B.2 Reference illuminant and acceptability tolerances

In the 1974 version of this International Standard the reference illuminant had been specified as D_{50} and the acceptability tolerances had been specified by a limit on the permitted chromaticity deviation from D_{50} , together with colour rendering indices as defined by CIE publication 13.3. However, in the intervening years various workers had expressed reservations about this specification for quite different reasons. Many practical users had been heard to comment on the wide variation in colour of the illumination they perceived between apparatus that were assumed to meet the 1974 specification; because of this it was considered that the specification of the tolerance in

chromaticity was therefore in need of some reduction. Various research workers had noted that the media encountered in the industries for which this International Standard was appropriate were far more metameric than had previously been the case. The colour rendering index (which simply measures the difference in colour for eight Munsell samples as they would appear under both test and reference illuminants) provided no indication that different apparatus conforming to this specification would render such practical metamers in a similar way. Furthermore, it had been suggested that since most viewing apparatus used fluorescent tubes for simulating the reference illuminant they could not be spectrally similar to D_{50} ; supporters of this position concluded that a new reference illuminant was therefore more appropriate because of the metamerism described earlier.

At the time this revision of the International Standard was started, proposals had already emanated from the USA (though not finally agreed nationally) to reduce the tolerance on chromaticity, replace the reference source with F8 (a spectral power distribution defined by CIE as 'typical' of fluorescent tubes with a chromaticity the same as D_{50}) and add a 'band method' to reduce the incidence of metamerism.

The ISO joint working group felt that there was substantial justification for considering these proposals. However, it was agreed that it was desirable to undertake some experimental work to verify their acceptability. It was also noted that the 'band method' was not supported by CIE who had, in 1981, published a procedure (CIE publication 51) for verifying the acceptability of daylight simulators. This provides a set of theoretical metamers for each of the three reference illuminants D_{55} , D_{65} and D_{75} and specifies a procedure for calculating a Metamerism Index.

B.3 Metamerism index

The CIE method specifies eight theoretical metamers; that is, the relative spectral power for colours which match (thereby giving a colour difference of 0) for a specified illuminant and observer. Five of these are metameric in the visible region of the spectrum, the other three are fluorescent samples which are metameric with respect to the ultra-violet radiation emitted by the source. The

specified procedure requires measurement of the spectral power distribution of the test source and calculation of the tristimulus values for these metamers for both the test and reference source, normalised by area according to equation 1, so that the assessment is independent of the absolute level of illumination.

$$S_n(\lambda) = \frac{100 S(\lambda)}{\sum_{400}^{700} S(\lambda) \bar{y}_{10}(\lambda) \Delta(\lambda)} \quad (1)$$

If the test source has a different spectral power distribution to the reference illuminant the metamers are likely to fail to match under the former; thereby giving rise to a colour difference between each pair of metamers. The magnitude of this difference will depend upon the differences between the test and reference illuminants' relative energies. The CIE procedure then requires that the differences be averaged to produce two indices, one for the visible region and one for the ultra-violet. A category scale is defined which ranks the test source, covering the range from A (best) to E (worst).

Unfortunately, CIE Publication 51 does not provide metamers for D_{50} . To enable this method to be used by the Joint task Force, the necessary metamers were provided by McCamy. He used the same reference data as that in CIE Publication 51 and calculated them from the metamers provided in that publication by extrapolation. The resultant metamers, defined for illuminant D_{50} and the CIE 1964 Supplementary Standard Colorimetric Observer, are given in tables 2 and 3 of this document. It is anticipated that they will be accepted by CIE as an additional data set for CIE Publication 51 in due course. The full details of the derivation can be found in Color Research and Application, Volume 21, Number 3, pp 236-237, June 1996.

B.4 Experimental work

The experimental work undertaken initially was divided into 3 stages. The first was to evaluate whether there was any advantage in using F8 as the reference illuminant. The second was to determine whether the metamers proposed by extrapolation from those published in the CIE document provided reasonable correlation with the differences anticipated for practical metamers found in practice. The third was to determine the effect of the standard colorimetric observer selected. (The CIE 51 method uses the 1964 Supplementary Standard Colorimetric Observer, whereas it is common industry practice to use the 1931 Standard Colorimetric Observer).

In order to achieve this two additional sets of metamers were calculated, derived from practical samples.

For the first set of metamers, the reference consisted of the spectral reflectance data listed in ANSI CGATS TR001-

1995 for the 928 colours defined in ISO 12642. (These are effectively the colours produced when the data set is printed according to the US Specifications for Web Offset Publications - SWOP). The metamers to the SWOP patches were calculated for the cyan, magenta, and yellow dyes of a continuous tone dye diffusion proofing printer, using a tristimulus matching algorithm. Three reference illuminant and observer combinations were used to derive three sets of metameric matches (D_{50} /CIE 1964 Supplementary Standard Colorimetric Observer, F8/CIE 1964 Supplementary Standard Colorimetric Observer, and D_{50} /CIE 1931 Standard Colorimetric Observer). The metamers calculated were defined such that they had a colour difference (ΔE_{ab}^*) of less than 0,02.

The reference for the second set of metamers consisted of spectral reflectances for 8 colour patches printed with offset inks according to ISO 12647-2 (paper type 1). The metamers of these printed patches were calculated using a special matching algorithm with 8 sets of cyan, magenta and yellow colorants belonging to the imaging systems shown in table B.1.

Six commercial fluorescent lamps (labelled A to F), all nominally D_{50} simulators, were measured and evaluated using all three sets of metamers described above (the set provided by McCamy, the set based on the SWOP printing, and the set based on ISO 12647-2). Tables B.2 and B.3 summarise the results of these calculations. The deviation in chromaticity of the lamps from D_{50} , calculated using the CIE 1976 Uniform Chromaticity Scale, is included in the first column of each table. It had been proposed when this revision of this International Standard was started that the tolerance be defined as a circle of radius 0,005 centred on the chromaticity of D_{50} . It should be noted that lamps C and F do not meet the chromaticity recommendation.

Each table contains the CIE visible range metamerism index (MI_{VIS}) based on the McCamy metamers (the average colour difference for the 5 metamers). As described in the CIE publication, the MI_{VIS} is converted to a category scale, in which a 'C' has a value ranging from 0,5 to 1,0, and a 'D' ranging from 1,0 to 2,0. These results show that most lamps fell within the category 'C' (proposed as the minimum in this specification), but that two of them were outside this criteria.

Also shown in tables B.2 and B.3 are the values for the average and maximum ΔE_{ab}^* encountered with each practical data set. Comparing the metamerism index MI_{VIS} with the metamerism differences obtained with different imaging systems, it may be seen that the index values are falling between the average and the maximum colour differences. The "artificial" metamerism pairs used for the index calculation may therefore be regarded as valid indicators of metamerism differences based on the comparison with differences occurring with real imaging systems.

The testing with the metamers based on the 928 SWOP samples was also extended to derive two additional sets of metameric matches for F8 /CIE 1964 Supplementary Standard Colorimetric Observer, and D_{50} /CIE 1931 Standard Colorimetric Observer. Again the metamers calculated were defined such that they had a colour difference (ΔE_{ab}^*) of less than 0,02. Tables B.4 and B.5 show these data. (It should be noted that although the MI_{VIS} and category data are shown in each table, these values are only calculated for D_{50} and the CIE 1964 Supplementary Standard Colorimetric Observer as defined in CIE Publication 51.)

The average ΔE_{ab}^* statistics were similar whether D_{50} or F8 were taken as the reference (with the CIE 1964 Supplementary Standard Colorimetric Observer) and there was no consistent change in deviation between the two sets of results. The magnitude of the values was generally larger for the 1931 Standard Colorimetric Observer, but this was not unexpected; it has been reported before.

However, based on the 928 SWOP samples, the relative ranking between the lamps, was very similar regardless of which illuminant or observer was taken as the reference (see tables B.3, B.4, and B.5). The worst three were lamps $F > A > C$, while D, B, and E's ranking varied slightly. This ranking was the same when the proposed CIE D_{50} metamers were used. For this reason it was decided that we should continue to specify D_{50} as the reference illuminant in this International Standard to enable consistency with existing products and use the CIE method with the metamers proposed by McCamy. It was accepted that the experimental data (despite the fact that it is fairly extensive of itself) was fairly minimal in terms of the possible variations which may be encountered in practice and more data would always be welcome. When the data for the 8 metamers based on the 8 colour patches were subsequently provided, it confirmed the view, as described earlier, that the CIE method (based on illuminant D_{50}) was probably robust enough for application in this International Standard.

On the basis of the proposals made in this International Standard only 3 of the lamps tested would be acceptable. C would fail because of its chromaticity, A because of its metamerism index and F on both counts. However, it is probable that the first of these lamps could easily be made acceptable by suitable design of the apparatus. This 'pass' rate was considered acceptable in the interest of minimising the difference between products, as requested, by many

users and led us to confirm this specification. Support was given to this when we were supplied with data showing a number of Japanese lamps, not tested in this study, all conformed to the specifications proposed.

As a final validation of the proposals made in this specification, 61 viewing apparatuses were measured in situ. It was found that only 11% fully met the chromaticity, colour rendering and metamerism index criteria. Another 17% met the latter two but failed slightly on chromaticity. 13% met the chromaticity and colour rendering specification, but failed slightly on metamerism index. 7% met the metamerism index and chromaticity criteria but failed slightly on colour rendering. The remaining 52% failed on at least 2 criteria but in many cases the deviations in both cases were relatively small.

Given that the maintenance schedule on these units was unknown, it was this data that gave us the final confidence that the specification proposed was about right. Given the requirement by the industry that deviations between the viewing apparatuses be reduced, simply producing a specification that includes all current apparatus that meets the 1974 specification would be rather pointless. By reducing the chromaticity tolerance from that required in 1974, and adding the metamerism index, the industrial requirements should, in part at least, be met. Whilst it is a guess, it seems likely that the number of these existing units fully meeting the specification could be significantly increased by cleaning and replacement of old tubes. Others could be brought into line by suitable modification of the apparatus itself (reflectors, diffusers, etc). But most importantly, knowing that lamps exist with satisfactory properties, it is clear that equipment vendors can be expected to modify their designs to meet the new specification. The only question must be whether the lamp samples measured are taken from batches with large or small distributions of the various criteria but we have no reason to believe that those selected are in any way untypical.

Thus, users who wish to improve communication by reducing the deviation between their units and others can choose to try and modify existing apparatus or purchase new. This must be the compromise between user requirements and practical production so important in an International Standard. Of course, at the next revision we may find that production has improved such that we can reduce the specification yet further; only time will tell!

Table B.1 Imaging systems used to assess the metamerism of light sources

Process	Device
Electrophotography (dry toner)	Canon CLC 800 Xerox DocuColor 40
Electrophotography (liquid toner)	Indigo E-Print 1000
Ink jet (continuous)	Scitex Iris
Ink jet (solid)	HP Design Jet 750
Thermal transfer (dye sublimation)	Tektronix Phaser 440
Silver halide	Fuji Pictography 3000
Photomechanical	Fuji Color-Art

**Table B.2. Matched for D_{50} , CIE 1931 Standard Colorimetric Observer,
8 imaging systems, 8 patches.**

Lamp (chromaticity difference)	CIE51 M_{VIS} (1)	CIE51 Category	Metameric sample difference (2)	
			Average ΔE_{ab}^*	Maximum ΔE_{ab}^*
A (0,003)	115	D	50	145
B (0,005)	88	C	42	91
C (0,008)	97	C	59	133
D (0,001)	73	C	55	134
E (0,002)	89	C	48	120
F (0,007)	242	E	160	387
F8	63	C	29	87

Note
1 Values refer to the CIE 1964 Supplementary Standard Colorimetric Observer
2 Values refer to the CIE 1931 Standard Colorimetric Observer

Table B.3. Matched for D₅₀, CIE 1964 Supplementary Standard Colorimetric Observer, 928 patches

Lamp (chromaticity difference)	CIE51 MI _{VIS} (1)	CIE51 Category	Metameric sample difference (1)	
			Average ΔE_{ab}^*	Maximum ΔE_{ab}^*
A (0,003)	115	D	94	175
B (0,005)	88	C	72	166
C (0,008)	97	C	74	169
D (0,001)	73	C	65	181
E (0,002)	89	C	59	167
F (0,007)	242	E	120	306
F8	63	C	34	167

Note
1 Values refer to the CIE 1964 Supplementary Standard Colorimetric Observer

Table B.4. Matched for F8, CIE 1964 Supplementary Standard Colorimetric Observer, 928 patches

Lamp (chromaticity difference)	CIE51 MI _{VIS} (1)	CIE51 Category	Metameric sample difference (1)	
			Average ΔE_{ab}^*	Maximum ΔE_{ab}^*
A	115	D	97	173
B	88	C	79	166
C	97	C	87	210
D	73	C	60	181
E	89	C	58	167
F	242	E	121	283
D ₅₀			33	178

Note
1 Values refer to the CIE 1964 Supplementary Standard Colorimetric Observer

Table B.5 Matched for D_{50} , CIE 1931 Standard Colorimetric Observer, 928 patches

Lamp (chromaticity difference)	CIE51 MI_{VIS} (1)	CIE51 Category	Metameric sample difference (2)	
			Average ΔE_{ab}^*	Maximum ΔE_{ab}^*
A	115	D	119	291
B	88	C	84	188
C	97	C	94	202
D	73	C	76	226
E	89	C	81	258
F	242	E	138	303
F8	63	C	43	188

Note

1 Values refer to the CIE 1994 Supplementary Standard Colorimetric Observer

2 Values refer to the CIE 1931 Standard Colorimetric Observer

Annex C (informative)

Guidelines for judging and exhibiting photographs

C.1 Introduction

The subjective impression produced by photographs that are judged for contests or juried exhibitions is of particular importance. It follows that photographs intended for such purposes should be optimised for a particular, known viewing condition. The viewing conditions specified in this International Standard are appropriate for this application, but other considerations have led to the use of somewhat wider tolerances in certain directions, and illumination levels that at first glance might seem inappropriate.

The preferred illumination levels for judging and exhibition are conditions P1, T1 and T2. The higher illumination level is chosen to allow maximum utilisation of the density range and colourfulness capabilities of output media, particularly for judging. Prints and transparencies optimised for these illumination levels will appear a bit dark when viewed under typical indoor illumination, but photographers produce the darker images specifically for contests. The feeling is that the increase in "impact" resulting from the larger dynamic range is more important than having the prints look perfect under typical indoor illumination. It is highly desirable, therefore, that illumination levels similar to those specified for ISO viewing conditions P1, T1 and T2 be adhered to for judging. For exhibition, it may be impractical to achieve the high levels of illumination required, and lower levels are acceptable.

Another practical consideration concerns the spectral power distribution of the illumination. The human visual system is excellent at adapting to the correlated colour temperature of illumination sources which approximate a Planckian radiator between 2800 K and 6500 K. Along this locus, typical photographic materials exhibit larger perceptual shifts due to sources failing to approximate a Planckian radiator than from changes in correlated colour temperature. This is particularly true for sources which emit sharp spectral lines. A fluorescent source may have exactly the same chromaticity as a particular Planckian source, but a photographic material may appear substantially different under the two sources.

The purpose of the metamerism and colour rendering index requirements in this International Standard is to minimise the likelihood of substantial changes in appearance due to different source spectral power distributions. If the ISO viewing condition recommendations are adhered to,

metamerism should be minimised and colour rendering should be appropriate. Unfortunately, many small photographic associations do not have access to lighting equipment that meets these strict requirements. The question then becomes: if departure from this International Standard is forced by practical considerations, in which directions can tolerances be extended with minimal impact?

In the photographic community, experience has indicated that the smallest effect on the perception of photographs results from allowing the correlated colour temperature to decrease. Tungsten sources can be filtered to produce excellent 5000 K illumination, but there is a financial cost due to the filters required, and the fact that more powerful sources are needed to produce the same illumination level. Fluorescent sources designed to meet the metamerism and colour rendering index requirements of this International Standard are also expensive, and fluorescent sources tend to be diffuse. The more directional illumination produced by tungsten sources can be positioned to minimise surface reflections, thereby affording the best view of high dynamic range prints.

The result of all these considerations is that the sources preferred for judging photographic prints are moderately directional tungsten or filtered tungsten sources with correlated colour temperatures between 2800 K and 5000 K. The use of filtered tungsten minimises metamerism and colour rendering problems, and differences in correlated colour temperature are dealt with by the adaptation of the human visual system. Tungsten and filtered tungsten sources are also used for projected transparencies. Fluorescent sources which meet the requirements of this International Standard are preferred for the direct viewing of transparencies, where diffuse illumination is desirable.

C.2 Recommendations

Table C-1 summarises the recommendations for the judging and exhibition of photographs. These recommendations assume that comparisons will be made only of similar media under the same illumination, and that observers are adapted to the illumination. If a non-standard correlated colour temperature or illumination level is used, it should remain constant for all evaluations conducted. If prints and transparencies are to be compared, non-standard illumination should be avoided to the greatest extent possible. Any comparisons that involve different effective

correlated colour temperatures or illumination levels should be successive, and observers should be given sufficient time to adapt to the illumination before being allowed to view the photograph. Also, the correlated colour

temperature of any ambient illumination present when transparencies are viewed should be less than or equal to the correlated colour temperature of the viewing illumination.

Table C-1. Recommendations for viewing conditions for judging and exhibiting photographs.

Material	Recommended viewing conditions
Judging:	
photographic prints	ISO condition P1 with 0°/45° viewing geometry, but the correlated colour temperature can be as low as 2800 K if tungsten sources are used ¹ .
transparencies (direct viewing)	ISO condition T1 (diffuse illumination).
transparencies (projection viewing)	ISO condition T2, but the correlated colour temperature can be as low as 2800 K if tungsten sources are used ¹ .
Exhibition	
photographic prints	ISO condition P1 with 0°/45° viewing geometry, but the correlated colour temperature can be as low as 3200 K if tungsten sources are used ¹ , and the illuminance level can be as low as 375 lx.
transparencies (direct viewing)	ISO condition T1 (diffuse illumination), but the correlated colour temperature can be as low as 2800 K if tungsten sources are used ¹ , and the luminance level can be as low as 240 cd/ m ² , or 1000 times the veiling glare luminance, whichever is greater ² .
transparencies (projection viewing)	ISO condition T2, but the correlated colour temperature can be as low as (projection viewing) 2800 K if tungsten sources are used ¹ , and the luminance level can be as low as 40 cd/ m ² , or 1000 times the veiling glare luminance, whichever is greater ³ .
<p>1) With sources at correlated colour temperatures other than 5000 K, the metamerism and colour rendering index qualifications described in this International Standard are not applicable. In such cases, the user must rely on the similarity of the tungsten source spectral power distribution to that of a theoretical Planckian radiator. If the spectral power distributions are sufficiently similar, the chromaticities, metameric differences, and colour rendering will also be similar.</p> <p>2) The veiling glare luminance in a typical direct viewing situation will be approximately 0,0016 times the stray light illuminance incident on the illuminator surface.</p> <p>3) The veiling glare luminance in a typical projection viewing situation will be approximately 0,3 times the stray light illuminance incident on the projection screen.</p>	