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Photography — Processed photographic colour films and paper prints — Methods for measuring image stability

Photographie — Films et papiers photographiques couleur traités — Méthodes de mesure de la stabilité de l'image

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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 10977 was prepared by Technical Committee ISO/TC 42, *Photography*.

Annexes A, B, C, D, E and F of this International Standard are for information only.

Introduction

This International Standard addresses the stability of colour photographic images and is divided into two sections. The first section covers the methods and procedures for predicting the long-term, dark storage stability of colour photographic images. The second section covers those for measuring the colour stability of such images when exposed to light of specified intensities and spectral distribution, at specified temperatures and relative humidities.

Today, the majority of continuous-tone photographs are made with colour photographic materials. The length of time that such photographs are to be kept can vary from a few days to many hundreds of years, and the importance of image stability can be correspondingly small or great.

Often the ultimate use of a particular photograph is not known at the outset. Knowledge of the useful life of colour photographs is important to many users, especially since stability requirements often vary depending upon the application. For museums, archives and others responsible for the care of colour photographic materials, an understanding of the behaviour of these materials under various storage and display conditions is essential if they are to be preserved in good condition for long periods of time.

The images of most modern colour photogaphs are formed by organic cyan, magenta and yellow dyes that are dispersed in transparent binder layers coated onto transparent or white opaque supports. Colour photographic dye images typically fade during storage and display; they will usually also change in colour balance because the three image dyes seldom fade at the same rate. In addition, a yellowish (or occasionally other colour) stain can form and physical degradation can occur, such as embrittlement and cracking of the support and image layers. The rate of fading and staining can vary appreciably and is governed principally by the intrinsic stability of the colour photographic material and by the conditions under which the photograph is stored and displayed. The quality of chemical processing is another important factor. Post-processing treatments, such as application of lacquers, plastic laminates and retouching colours, can also affect the stability of colour materials.

The two main factors that influence storage behaviour, or dark stability, are the temperature and relative humidity of the air that has access to the photograph. High temperature, particularly in combination with high relative humidity, will accelerate the chemical reactions that can lead to degradation of one or more of the image dyes. Low-temperature, low-humidity storage, on the other hand, can greatly prolong the life of photographic colour images. Other potential causes of image degradation are atmospheric pollutants (such as oxidizing and reducing gases), micro-organisms and insects.

The stability of colour photographs when displayed indoors or outdoors is influenced primarily by the intensity of the illumination, the duration of exposure to light, the spectral distribution of the illumination and the ambient environmental conditions. (However, the normally slower dark fading and staining reactions also proceed during display periods and will contribute to the total change in image quality.) Ultraviolet radiation is particularly harmful to some types of colour photographs and can cause rapid fading as well as degradation of plastic layers such as the pigmented polyethylene layer of resin-coated (RC) paper supports.

In practice, colour photographs are stored and displayed under varying combinations of temperature, relative humidity and illumination, and for different lengths of time. For this reason, it is not possible to predict precisely the useful life of a given type of photographic material unless the specific conditions of storage and display are known in advance. Furthermore, the amount of change that is acceptable differs greatly from viewer to viewer and is influenced by the type of scene and the tonal and colour qualities of the image.

After extensive examination of amateur and professional colour photographs that have suffered varying degrees of fading and/or staining, no consensus has been achieved on how much change is acceptable for various image quality criteria. For this reason, this International Standard does not specify "acceptable" end-points for fading and changes in colour balance. Generally, however, the acceptable limits are twice as wide for changes in overall image density as for changes in colour balance. For this reason, different criteria have been used as examples in this International Standard for predicting changes in image density and in colour balance.

The actual determination of such changes is made with test strips that have been exposed and carefully processed according to the manufacturer's recommendations to produce at least:

a) an area of minimum density, $d_{\min}$;

b) patches of uniform, neutral density of 1,0 above $d_{\min}$; and

c) uniform density patches of cyan, magenta, or yellow dyes having red, green, or blue densities of 1,0 above $d_{\min}$.

To simplify the preparation of test samples and the handling of data, a starting density of 1,0 above $d_{\min}$ is specified for both dark- and light-stability tests; although it is recognized that the two types of fading generally have dissimilar visual characteristics [1]. The effects of light fading, both visually and when expressed as a percentage density change, tend to be proportionally much greater in lower density portions of an image (e.g. in the range of 0,1 to 0,5 above $d_{\min}$) than in high density areas. Conversely, in dark fading the visual effects of fading are generally more noticeable in higher densities than in low densities. Density losses in dark fading, expressed as a percentage density change, tend to be more or less equal throughout the entire density range (see annex A). The user may adopt different end-points for light- and dark-stability tests to take into account the visual differences manifested by these two types of fading.

Pictorial tests can be helpful in assessing the visual changes that occur in light- and dark-stability tests, but are not included in this International Standard because no single scene is representative of the wide variety of scenes actually encountered in photography.

In dark storage at normal room temperatures, most modern colour films and papers have images that fade and stain too slowly to allow evaluation of their dark storage stability simply by measuring changes in the samples over time. In such cases, too many years would be required to obtain meaningful stability data. It is possible, however, to assess in a relatively short time the probable long-term fading and staining behaviour at moderate or low temperatures by means of accelerated ageing tests carried out at high temperatures. The influence of relative humidity also can be evaluated by conducting the high-temperature tests at two or more humidity levels.

Similarly, information about the light stability of colour photographs can be obtained from accelerated light-stability tests. These require special test units equipped with high-intensity light sources in which test strips can be exposed for days, weeks, months or even years, to produce the desired amount of image fading (or staining). The temperature of the samples and their moisture content are controlled throughout the test period and the types of light sources are chosen to yield data that can be correlated satisfactorily with those obtained under conditions of normal use.

Accelerated light-stability tests for predicting the behaviour of photographic colour images under normal display conditions can be complicated by "reciprocity failure". When applied to light-induced fading and staining of colour images, reciprocity failure refers to the failure of many dyes to fade, or to form stains, equally when irradiated with high-intensity versus low-intensity light, even though the total light exposure (intensity × time) is kept constant through appropriate adjustments in exposure duration [2]. The extent of dye fading and stain formation can be greater or smaller under accelerated conditions, depending on the photochemical reactions involved in the dye degradation, on the kind of dye dispersion, on the nature of the binder material and on other variables. For example, the supply of oxygen that can diffuse into a photograph's image-containing emulsion layers from the surrounding atmosphere can be restricted in an accelerated test (dry gelatin is an excellent oxygen barrier). This can change the rate of dye fading relative to that which would occur under normal display conditions. The magnitude of reciprocity failure is also influenced by the temperature and moisture content of the test sample. Furthermore, light fading is influenced by the pattern of irradiation (continuous versus intermittent) as well as by light/dark cycling rates.

For all of these reasons, long-term changes in image density, colour balance and stain level can be estimated reasonably closely only for conditions similar to those employed in the accelerated tests or when good correlation has been confirmed between accelerated tests and actual conditions of use.

Density changes induced by the test conditions and measured during and after the tests include those in the film or paper support and in the various auxiliary layers that are included in a particular product. With most materials, however, the major changes occur in the dye image layers.

This International Standard is based on American National Standard IT9.9[1] which was the result of 11 years of testing activity in the United States in which there was active participation from Canada, Germany, Japan, Switzerland and the United Kingdom.

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[1] ANSI IT9.9:1990, *Imaging media — Stability of Color Photographic Images — Methods for Measuring.*

Photography — Processed photographic colour films and paper prints — Methods for measuring image stability

1 Scope

1.1 General

This International Standard describes test equipment, test procedures and analytic methods for predicting the long-term dark storage stability of colour photographic images and measuring the colour stability of such products when subjected to certain illuminants at specified temperatures and humidities.

Because of the problems outlined in the Introduction, this International Standard does not specify limits of acceptability for the stability of colour products. Instead, it provides means for measuring image changes that takes place during the ageing of colour photographs and indicates the critical image-change parameters that should be calculated. This International Standard does not specify which of the several light-stability tests is the most important.

Throughout this International Standard, densities are expressed in dimensionless units.

1.2 Dark stability

The tests for predicting the stability of colour photographic images in dark storage are based on an adaptation of the Arrhenius method described by Bard *et al.* [3] [4] and earlier references by Steiger and others [5] [6] [7]. Although this method is derived from well-understood and proven theoretical precepts of chemistry, the validity of its application to predicting changes of photographic images rests on empirical confirmation. Although many chromogenic-type colour products yield image fading and staining data in both accelerated and non-accelerated dark ageing tests that are in good agreement with the Arrhenius relationship, some other types of products do not[2].

1.3 Light stability

The methods of testing light stability in this International Standard are based on the concept that increasing the light intensity without changing the spectral distribution of the illuminant or the ambient temperature and relative humidity should produce a proportional increase in the photochemical reactions that occur at typical viewing or display conditions, without introducing any undesirable side effects.

However, because of "reciprocity failures" that were discussed previously, this assumption does not always apply. Thus, the accelerated light-stability test methods described in this International Standard are valid at the specified accelerated test conditions but it is possible that they do not reliably predict the behaviour of a given product in long-term display under normal conditions.

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 in-

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[2] For example, integral-type instant colour print materials often exhibit atypical staining at elevated temperatures; treatment of some chromogenic materials at temperatures above 80 °C and 60 % relative humidity can cause loss of incorporated high-boiling-point solvents and abnormal image degradation; and the dyes of silver dye-bleach images deaggregate at combinations of very high temperature and high relative humidity, causing abnormal changes in colour balance and saturation [8]. In general, photographic materials tend to undergo dramatic changes at relative humidities above 60 % (especially at the high temperatures employed in accelerated tests) owing to changes in the physical properties of gelatin.

dicated 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 5-3:1984, *Photography — Density measurements — Part 3: Spectral conditions*.

ISO 5-4:1983, *Photography — Density measurements — Part 4: Geometric conditions for reflection density*.

3 Test methods — General

3.1 Sensitometric exposure

The photographic material shall be exposed and processed in accordance with the manufacturer's recommendations to obtain areas (patches) of uniform density of at least 5 mm × 5 mm. The changes in colour densities shall be measured in areas of minimum density, $d_{\min}$, and in areas with a density of 1,0 ± 0,05 above $d_{\min}$. These changes are to be monitored in neutral areas, i.e. where the initial red, green and blue densities are all approximately equal (above their respective values of $d_{\min}$), as well as in areas selectively exposed to produce the purest possible cyan, magenta and yellow dye scales. These shall be made with the aid of appropriate filters (see table 1). The desired density may be obtained from a single precise exposure or from a continuous wedge exposure. Alternatively, if it is more convenient (e.g. with automated densitometry), the starting densities of 1,0 above $d_{\min}$ may be interpolated from other densities (one way to do this is described in annex B).

Table 1 — Suitable filters for exposing test samples

Type of material[1)]	Filters to generate[2)]		
	Cyan dye	Magenta dye	Yellow dye
Reversal and direct positive	Minus red 44	Minus green 32	Minus blue 12
Negative working	Red 29	Green 99	Blue 47 B

1) If materials to be tested have unusual spectral sensitivity characteristics, consult the manufacturer for recommendations.

2) Numbers in table refer to Kodak Wratten Filters, described in *Kodak Filters for Scientific and Technical Uses*, Kodak Publication No. B-3, Eastman Kodak Company, Rochester, New York (1985).

3.2 Processing

The sensitometrically-exposed samples shall be processed using the processing system of primary interest. The processing chemicals and processing procedure can have a significant effect on the dark keeping and/or light keeping stability of a colour photographic material. For example, a chromogenic colour negative print paper processed in a "washless" or "plumbingless" system with a stabilizer rinse bath instead of a water wash probably has different stability characteristics than the same colour paper processed in a "conventional" chemistry and a final water wash. Therefore, the specific processing chemicals and procedure shall be listed along with the name of the colour product in any reference to the test results; stability data obtained from a colour material processed in certain processing chemicals shall not be applied to the colour material processed in different chemicals, or using a different processing procedure.

Likewise, data obtained from test specimens shall not be applied to colour materials that have been subjected to post-processing treatments (e.g. application of lacquers, plastic laminates or retouching colours) that differ from the treatments given to the test specimens.

3.3 Densitometry

Image density shall be measured with the spectral conditions specified for ISO status A densitometry (for transparencies and reflection prints) and for ISO status M densitometry (for negatives) as specified in ISO 5-3.

ISO standard transmission density, D_T (90°*opal*; S_H: $\leqslant$ 10°; s), shall be measured with an instrument complying with the geometric conditions as specified in ISO 5-2.

ISO standard reflection density, D_R (40° to 50°; S: 5°; s) shall be measured as specified in ISO 5-4.

One of the problems encountered in densitometry is the instability of the measuring device, especially during the course of long-term tests. Some of the components of densitometers that can change appreciably with age, as well as from one unit or batch to another, are the optical filters, the light sensors and the lamps. For example, the filters in many modern densitometers deteriorate with age and sometimes need to be replaced every 2 years. However, replacement filters of the same type frequently do not exactly match the original filters in spectral transmittance characteristics. Such changes in transmittance will cause unequal changes in the measured density values of dyes having different spectral absorption properties.

One way of dealing with such problems in a densitometer system is to keep standard reference samples of each test product sealed in vapour-proof containers and stored at − 18 °C or lower. These samples can be used to check the performance of the system periodically and to derive correction factors for different products, as required (the calibration standards supplied with a densitometer are not adequate for this purpose).

3.4 Density values to be measured

The following densities of the samples prepared as described in 3.1 shall be measured before and after the treatment interval (refer to figure 1):

a) $d_{\mathrm{min}}(\mathrm{R})_t$, $d_{\mathrm{min}}(\mathrm{G})_t$ and $d_{\mathrm{min}}(\mathrm{B})_t$ being the red, green and blue minimum densities, respectively, of samples that have been treated for time t;

b) $d_{\mathrm{N}}(\mathrm{R})_t$, $d_{\mathrm{N}}(\mathrm{G})_t$ and $d_{\mathrm{N}}(\mathrm{B})_t$ being the red, green and blue densities, respectively, of neutral patches that initially had densities of 1,0 above d_{min} and that have been treated for time t;

c) $d_{\mathrm{C}}(\mathrm{R})_t$, $d_{\mathrm{M}}(\mathrm{G})_t$ and $d_{\mathrm{Y}}(\mathrm{B})_t$ being the red, green and blue densities of cyan, magenta and yellow colour patches, respectively, that initially had densities of 1,0 above d_{min} and that have been treated for time t.

3.5 Correction of density for d_{min} changes

The areas of minimum density of many types of colour photographs change with time during dark storage and, generally to a lesser extent, also change on prolonged exposure to light during display or projection. Such changes most commonly take the form of density (stain) increases, usually yellowish in colour. However, some materials, under certain conditions, can exhibit a loss in minimum density e.g. colour negatives in dark storage.

For the purposes of this International Standard, changes in d_{min}, as measured in the minimum density patches, whether increases or losses, are assumed to have occurred equally at all density levels. Therefore, in order to determine accurately the amount of dye fading that has taken place during testing or during storage and display, it is necessary to take the change in d_{min} into account.

Different methods of d_{min} correction are specified for transmission and reflection materials because multiple internal reflections affect the d_{min} density values obtained with reflection materials, but not those of transmission materials [9] [10]. Specifically, the multiple reflections within the image and auxiliary layers of a reflection material cause an increase in the measured value of the stain density, but have much less effect on the measured values of reflection densities in the range of 0,7 to 1,0 above d_{min}. It was determined empirically by the working group that half the change in the measured value of d_{min} for reflection materials provides a reasonable approximation of the actual d_{min} contribution to dye densities in the range of 0,7 to 1,0 above d_{min}. The above information is summarized in table 2.

Two examples are described in 3.7.1.1 and 3.7.1.2 (illustrated in figures 1 and 2) to help clarify the d_{min} correction procedures.

Table 2 — Correction of density measurements for d_{min} changes

Type of material	Correction
Transmission	d_{min}
Reflection	$0{,}5\ d_{\mathrm{min}}$

NOTES

1 The correction applies for a starting density of 1,0 above d_{min} and for both dark and light stability tests.

2 No correction is made for d_{min} changes when determining colour balance changes of neutral patches.

3.6 Symbols

For the purposes of the following calculations, d is used to represent the measured density and D to represent the density corrected for d_{min}.

3.7 Calculation of image-stability parameters

From the measured density values, the following parameters are calculated (see figures 1 and 2).

3.7.1 Densities corrected for d_{min}

3.7.1.1 Transmission density

a) $D_{\mathrm{N}}(\mathrm{R})_t = d_{\mathrm{N}}(\mathrm{R})_t - d_{\mathrm{min}}(\mathrm{R})_t$

b) $D_{\mathrm{N}}(\mathrm{G})_t = d_{\mathrm{N}}(\mathrm{G})_t - d_{\mathrm{min}}(\mathrm{G})_t$

c) $D_{\mathrm{N}}(\mathrm{B})_t = d_{\mathrm{N}}(\mathrm{B})_t - d_{\mathrm{min}}(\mathrm{B})_t$

d) $D_{\mathrm{C}}(\mathrm{R})_t = d_{\mathrm{C}}(\mathrm{R})_t - d_{\mathrm{min}}(\mathrm{R})_t$

e) $D_{\mathrm{M}}(\mathrm{G})_t = d_{\mathrm{M}}(\mathrm{G})_t - d_{\mathrm{min}}(\mathrm{G})_t$

f) $D_{\mathrm{Y}}(\mathrm{B})_t = d_{\mathrm{Y}}(\mathrm{B})_t - d_{\mathrm{min}}(\mathrm{B})_t$

EXAMPLE

See figure 1.

A colour transparency material tested for dark stability had a neutral patch with a starting blue density, $D_{\mathrm{N}}(\mathrm{B})_0$, of 1,0, calculated as follows:

$$d_{\mathrm{N}}(\mathrm{B})_0 = 1{,}1$$

$$d_{\text{min}}(\text{B})_0 = 0{,}1$$

and so

$$D_\text{N}(\text{B})_0 = d_\text{N}(\text{B})_0 - d_{\text{min}}(\text{B})_0 = 1{,}1 - 0{,}1 = 1{,}0$$

After incubation for time t, the blue density $D_\text{N}(\text{B})_t$ was 0,72, because the measured density values had changed as follows:

$$d_\text{N}(\text{B})_t = 0{,}90$$

$$d_{\text{min}}(\text{B})_t = 0{,}18$$

and so

$$D_\text{N}(\text{B})_t = d_\text{N}(\text{B})_t - d_{\text{min}}(\text{B})_t = 0{,}90 - 0{,}18 = 0{,}72$$

Hence, the blue density of the neutral patch decreased by 0,28 whereas that of the minimum density patch increased (due to formation of yellowish stain) by 0,08. If the d_{min} value had increased by less, or even decreased (as can occur with colour negative films, for example), the value of $d_\text{N}(\text{B})_t$ would have changed by a different, commensurate amount.

However, by subtracting the d_{min} density from the density of the neutral patch, both before and after incubation, the actual change in density of the neutral patch is determined. Similar procedures are employed to correct the cyan, magenta and yellow patches for changes in d_{min}.

3.7.1.2 Reflection density[3]

a) $D_\text{N}(\text{R})_t = d_\text{N}(\text{R})_t - d_{\text{min}}(\text{R})_t + 0{,}5[d_{\text{min}}(\text{R})_t - d_{\text{min}}(\text{R})_0]$

b) $D_\text{N}(\text{G})_t = d_\text{N}(\text{G})_t - d_{\text{min}}(\text{G})_t + 0{,}5[d_{\text{min}}(\text{G})_t - d_{\text{min}}(\text{G})_0]$

c) $D_\text{N}(\text{B})_t = d_\text{N}(\text{B})_t - d_{\text{min}}(\text{B})_t + 0{,}5[d_{\text{min}}(\text{B})_t - d_{\text{min}}(\text{B})_0]$

d) $D_\text{C}(\text{R})_t = d_\text{C}(\text{R})_t - d_{\text{min}}(\text{R})_t + 0{,}5[d_{\text{min}}(\text{R})_t - d_{\text{min}}(\text{R})_0]$

e) $D_\text{M}(\text{G})_t = d_\text{M}(\text{G})_t - d_{\text{min}}(\text{G})_t + 0{,}5[d_{\text{min}}(\text{G})_t - d_{\text{min}}(\text{G})_0]$

f) $D_\text{Y}(\text{B})_t = d_\text{Y}(\text{B})_t - d_{\text{min}}(\text{B})_t + 0{,}5[d_{\text{min}}(\text{B})_t - d_{\text{min}}(\text{B})_0]$

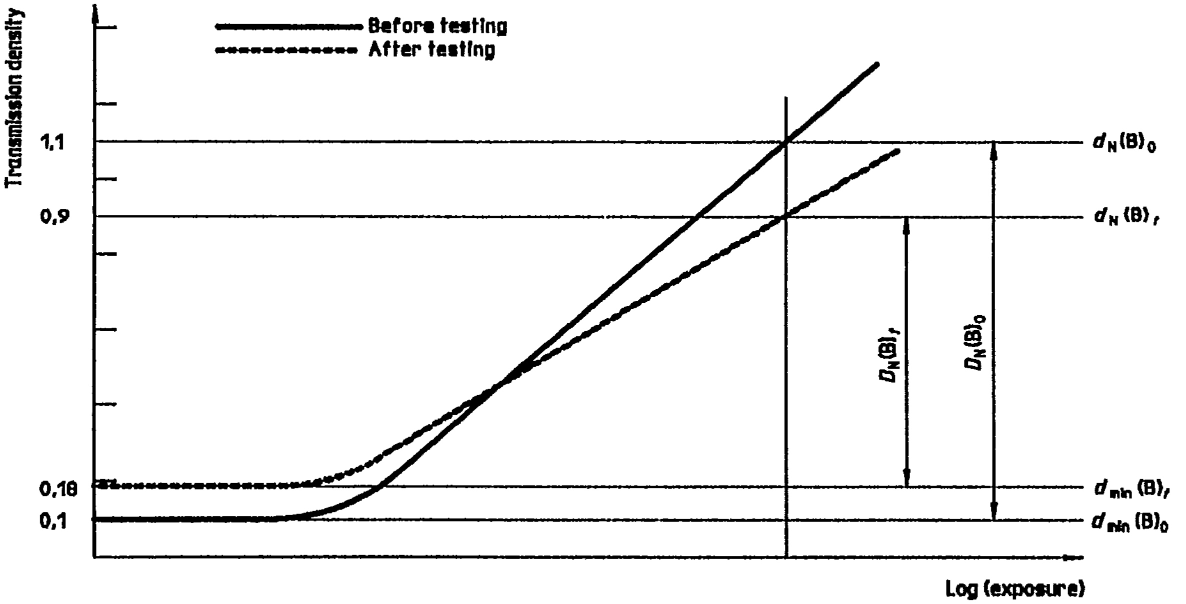

Figure 1 — Blue transmission density of a neutral patch of a transparency-type colour material

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[3] The d_{min} correction for reflection density includes an extra back correction equal to half of the d_{min} gain with respect to the d_{min} correction for transmission density.

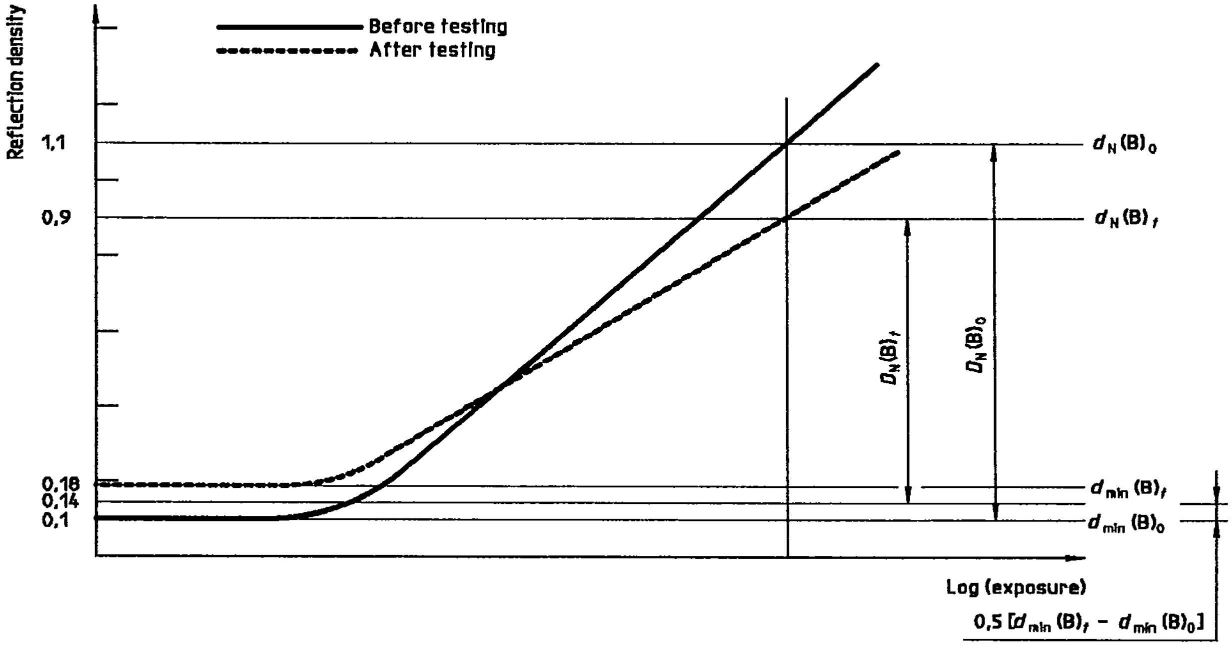

Figure 2 — Blue reflection density of a neutral patch of a reflection-type colour material

EXAMPLE

See figure 2.

A colour reflection print material tested for dark stability had a neutral patch with a starting blue density, $D_N(B)_0$, of 1,0, calculated as follows:

$$d_N(B)_0 = 1,1$$

$$d_{min}(B)_0 = 0,1$$

and so

$$D_N(B)_0 = d_N(B)_0 - d_{min}(B)_0 = 1,1 - 0,1 = 1,0$$

After incubation for time t, the blue density $D_N(B)_t$ was 0,76, because the measured density values had changed as follows:

$$d_N(B)_t = 0,90$$

$$d_{min}(B)_t = 0,18$$

and so

$$\begin{aligned} D_N(B)_t &= d_N(B)_t - d_{min}(B)_t + 0,5[d_{min}(B)_t - d_{min}(B)_0] \\ &= 0,90 - 0,18 + 0,5(0,18 - 0,10) \\ &= 0,72 + 0,04 = 0,76 \end{aligned}$$

Hence, the blue density of the neutral patch decreased by 0,24, whereas that of the minimum density patch increased (due to formation of yellowish stain) by 0,08. However, this increase in measured d_{min} value was due in part to the effects of multiple internal reflections, as explained in 3.5. Therefore, a correction was made equal to half of the measured change of 0,08. Such a correction of half of the change in d_{min} would also have to be made if the d_{min} value had decreased rather than increased. Similar procedures are employed to correct the cyan, magenta and yellow patches for changes in d_{min}.

3.7.2 Colour balance in the neutral density patch

These are calculated as percentages of average density.

a) $\% \, d_N(R\text{-}G)_t = \dfrac{d_N(R)_t - d_N(G)_t}{0,5[d_N(R)_t + d_N(G)_t]} \times 100$

b) $\% \, d_N(R\text{-}B)_t = \dfrac{d_N(R)_t - d_N(B)_t}{0,5[d_N(R)_t + d_N(B)_t]} \times 100$

c) $\% \, d_N(G\text{-}B)_t = \dfrac{d_N(G)_t - d_N(B)_t}{0,5[d_N(G)_t + d_N(B)_t]} \times 100$

3.7.3 d_{min} changes

a) $d_{min}(R)_t - d_{min}(R)_0$

b) $d_{min}(G)_t - d_{min}(G)_0$

c) $d_{min}(B)_t - d_{min}(B)_0$

3.7.4 $d_{\min}$ colour balance

a) $d_{\min}(\text{R-G})_t = d_{\min}(\text{R})_t - d_{\min}(\text{G})_t$

b) $d_{\min}(\text{R-B})_t = d_{\min}(\text{R})_t - d_{\min}(\text{B})_t$

c) $d_{\min}(\text{G-B})_t = d_{\min}(\text{G})_t - d_{\min}(\text{B})_t$

4 Test methods — Dark stability

4.1 Number of specimens

Two or more specimens are required for each of at least four temperatures (i.e. a minimum of eight specimens) for a prediction at a single humidity. The specimens should be representative of the products and modes of processing to be tested. It is suggested that additional tests with identical specimens be repeated at different times to provide an indication of the repeatability of the test procedures and testing equipment.

4.2 Test conditions

Long-term dark stability is evaluated by a series of tests carried out at several elevated temperatures at a particular humidity, (50 ± 3) % R.H. being recommended. At least four different temperatures shall be used at any one humidity level. The temperature range shall be at least 20 °C, preferably wider, and the temperature intervals shall be approximately equally spaced, e.g. 55 °C, 65 °C, 75 °C and 85 °C. The tolerance shall be ± 0,5 °C. The lower the temperature, the closer the approximation to normal storage conditions but the longer the time to reach the specified end points of the test.

Because the effects of humidity on image stability can differ markedly from one product to another, it is useful to evaluate its effect. This is done by means of a temperature test series carried out at different relative humidities. If the relative humidity during storage is expected to be significantly lower than 50 % R.H., such as in an arid climate, or significantly higher, as in a tropical climate, the relative humidity selected for the test should correspond to the climate. However, at relative humidities above 60 %, especially at the high temperatures employed in accelerated tests, misleading results can be obtained because of difficulties in maintaining constant moisture levels and because of abrupt changes in the physical properties of some components of photographic image layers, such as gelatin. Furthermore, the combination of high temperature and high relative humidity can cause changes that are not typical of a photograph's behaviour under normal storage conditions. The relative humidity shall be maintained within ± 3 % of the aim values.

4.3 Test equipment and operation

Strips shall be free-hanging in air of controlled temperature and relative humidity. Recirculating forced-air environment chambers shall be used.

The use of desiccators containing aqueous solutions as humidity chambers was not investigated because this method of humidity control has several practical difficulties and because the aqueous solutions could lead to chemical contamination of the test specimens. Sealed envelopes for maintaining constant relative humidity were investigated, but inconsistent fading data were obtained. For these reasons, desiccators and sealed envelopes shall not be used for the tests specified in this International Standard. The atmospheric requirements stated can be obtained with temperature- and humidity-controlled environment chambers of the type in which the relative humidity maintained by controlled contact of recirculated air with humidifying water.

4.4 Computation of dark stability

The image life shall be estimated by using the Arrhenius method. One example is illustrated in annex C.

5 Test methods — Light stability

5.1 General

Five different light stability tests are described in 5.6 to 5.10. These tests are intended to simulate common-use situations. Selection of the appropriate test(s) should be based on the conditions of intended use. In most homes, for example, indirect daylight through window glass is the principal illumination causing displayed photographs to fade.

NOTE 1 The low-intensity illumination provided by incandescent tungsten lamps in homes usually contributes very little to the deterioration of colour photographs. Fluorescent lamps, however, which generally provide more intense illumination than tungsten lamps, are increasingly found in homes. When fluorescent lamps are present, they can make a significant contribution to the fading of displayed prints.

In offices and public buildings, fluorescent lamps are usually the primary source of illumination. Photography exhibits in galleries, museums and archives are most often illuminated with standard incandescent tungsten lamps or quartz-halogen tungsten lamps. Exposure to direct sunlight is the principal cause of fading in colour print materials used outdoors, e.g. billboards, outdoor displays and identification badges.

Colour materials generally exhibit at least some degree of reciprocity failure in high-intensity light-stability tests. That is, a material can fade or stain a different amount when exposed to high-intensity illumination for a short period than it does when exposed to lower-intensity illumination for a longer period even though the total light exposure (intensity × time) and the temperature and relative humidity are the same in both cases. The illumination level of 6 klx specified for the indoor indirect daylight test in 5.6 and the fluorescent room illumination test in 5.7 and the 3 klx level specified for the incandescent tungsten test in 5.8, were chosen because they are of sufficient intensity to produce meaningful results within a reasonable length of time (i.e. about 1 year) with most colour materials. Tests performed with illumination levels that more closely approximate normal indoor display conditions (e.g. 0,6 klx) would be more meaningful but would require test periods of many years for most materials.

To determine if a material has a tendency to exhibit reciprocity failures in fading and staining behaviour in high-intensity tests, parallel tests should be conducted at a lower intensity (e.g. 1 klx) with at least one of the specified indoor illumination sources.

When certain types of colour prints are displayed for long periods, it has been found that whether or not the prints are framed (enclosed) under glass or plastic sheets can have a significant effect on rates of dye fading and stain formation [2]. This "enclosure effect", which is described in annex D should be considered when selecting light exposure test conditions.

5.2 Number of specimens

Two or more identical specimens are required for each of the tests to be performed. It is suggested that additional tests with identical specimens be repeated at staggered intervals to provide an indication of the repeatability of the test procedures and test equipment.

5.3 Irradiance measurements and normalization of results

Irradiance levels shall be measured with a radiometer with a spectral response that falls within ± 5 % of the given CIE relative photopic luminosity curves. Wavelength distributions for the irradiance sources specified in this International Standard are defined in each test.

NOTE 2 The ultraviolet component of the radiation should conform as closely as possible to that specified for the spectral distribution of the relevant standard light source. However, this International Standard does not require the ultraviolet radiation levels to be adjusted to conform to the specified spectral distributions within fixed limits, because there is no simple way to make such adjustments without also affecting the intensity of the visible radiation. It is important to note that ultraviolet radiation is considerably more harmful to some types of colour photographs than to others and, therefore, variations in the level (and spectral distribution) of the ultraviolet radiation in the illumination will affect some materials more than others. The test conditions specified in 5.9 for simulated outdoor sunlight are particularly noteworthy in this regard, because the ultraviolet component of this illumination is large and the test specimens are not protected by an ultraviolet-absorbing glass filter.

The intensity of the irradiance shall be monitored and recorded daily with a radiometer (or integrating radiometer) and maintained within ± 10 % of the specified starting value throughout the test period, but the deviations shall be taken into account when determining the accumulated irradiation. The times reported to reach the test end-points shall be normalized to the standard illumination called for by the particular test.[4] The times to reach the end-points shall be reported in the units of time that are deemed most appropriate for a particular test (i.e., minutes, days or years). The tests specified in 5.9 and 5.10 use cycling conditions that alternate between periods of light and dark; the times reported to reach the selected end-points shall include the illumination time only.

5.4 Backing of specimens during light-stability test

Prints shall be backed with a non-reactive and non-yellowing white material such as 100 % cotton cellulose mount board (100 % "rag" board) or metal (e.g. flame-sprayed, ceramic-coated steel plate). Specimen positions in the light-stability test apparatus that are not occupied with actual test prints shall be filled with dummy samples that have a reflectance approximately equal to that of the test specimens. Transparencies shall have a black backing[5] under all test conditions.

In high-intensity tests, where thermal heating of the sample and black backing material could be significant, it is essential that temperature and relative humidity specifications be maintained.

Translucent print materials, designed for viewing by either reflected or transmitted light (or a combination of reflected and transmitted light), shall be

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4) Data can be normalized to a standard illumination level (e.g. 6 klx) using:

$$\text{Corrected time} = \text{Actual time} \times \frac{1}{6}\ \text{Measured source intensity in klx.}$$

5) Kodak Black Aero Leader 5986, Kodak Catalog Number 159-9455, is recommended for backing transparencies.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

evaluated as transparencies or as reflection prints, depending on how they will be used. Data shall be reported for each condition of intended use.

5.5 Specification for "standard" window glass

The window glass specified in the tests below shall be a soda lime float glass with a thickness of approximately 6,5 mm ± 0,5 mm and shall have spectral transmission characteristics that closely conform to the values given in table 3. In order to maintain conformance, it is recommended that the glass be cleaned as needed and replaced yearly (or sooner if the glass develops a visually detectable haze).

5.6 Simulated indoor indirect daylight through window glass

The surface temperature of the sample shall be 24 °C ± 2 °C, maintained by an adequate airflow across the samples; the ambient relative humidity shall be (50 ± 5) %.

The test unit shall consist of a xenon high-pressure arc lamp (or its equivalent) with a quartz burner tube assembly giving an illuminance of 6 klx. In addition, a standard window-glass filter (see 5.5) shall be inserted between the lamp unit and the test specimens to yield a spectral distribution that conforms closely to the CIE ID65 Illuminant spectral distribution given in table 4.

Table 3 — Relative spectral transmittance of float glass to be used as window glass

Source: Japanese Industrial Standard JIS Z8902-1984, *Xenon Standard White Light Source*

Wavelength nm	Relative spectral transmittance	Wavelength nm	Relative spectral transmittance	Wavelength nm	Relative spectral transmittance	Wavelength nm	Relative spectral transmittance	Wavelength nm	Relative spectral transmittance
300	0,0	400	98,5	500	100,5	600	97,5	700	91,2
305	0,0	405	98,7	505	100,6	605	97,2	705	90,8
310	0,0	410	98,3	510	100,7	610	96,9	710	90,5
315	0,1	415	97,9	515	100,7	615	96,6	715	90,1
320	0,9	420	97,8	520	100,7	620	96,3	720	89,6
325	4,6	425	97,8	525	100,6	625	95,9	725	89,3
330	13,5	430	97,8	530	100,6	630	95,6	730	88,5
335	27,6	435	97,7	535	100,5	635	95,2	735	88,4
340	43,9	440	97,7	540	100,5	640	94,9	740	87,9
345	59,2	445	98,0	545	100,5	645	94,6	745	87,6
350	71,7	450	98,4	550	100,4	650	94,2	750	87,1
355	80,4	455	98,8	555	100,2	655	94,0	755	86,6
360	86,7	460	99,3	560	100,0	660	93,7	760	86,1
365	90,8	465	99,6	565	99,8	665	93,4	765	85,8
370	92,7	470	99,8	570	99,6	670	93,2	770	85,3
375	91,2	475	99,9	575	99,2	675	92,9	775	84,9
380	89,7	480	100,0	580	98,9	680	92,6	780	84,4
385	92,3	485	100,2	585	98,5	685	92,3		
390	95,6	490	100,4	590	98,1	690	92,0		
395	97,5	495	100,4	595	97,7	695	91,5		

NOTE — Data are normalized to 100 % at 560 nm.

Table 4 — Relative spectral power distribution for simulated indoor indirect daylight ID65

Source: Clarke, F.J.J, *Proceedings for the 19th Session of the CIE*, Kyoto, Japan 1979, p. 75

Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power
300	0,0	500	108,7	700	64,3
310	0,0	510	107,3	710	61,3
320	0,4	520	106,7	720	60,2
330	9,8	530	105,5	730	59,8
340	21,3	540	105,1	740	59,9
350	32,6	550	102,3	750	52,6
360	41,9	560	99,3	760	49,6
370	45,6	570	96,3	770	48,9
380	49,1	580	92,2	780	53,3
390	59,6	590	89,6	790	50,8
400	73,8	600	87,0	800	47,2
410	86,5	610	86,1	810	44,9
420	87,7	620	83,4	820	44,7
430	89,1	630	80,9		
440	100,4	640	77,8		
450	111,4	650	76,2		
460	115,7	660	75,1		
470	115,8	670	73,9		
480	113,0	680	70,1		
490	111,3	690	66,2		

NOTE — Data are smoothed by a piecewise running mean, taking each 10 nm interval value with its immediate neighbours (*ibid.*, p. 76).

5.7 Glass-filtered fluorescent room illumination

"Cool White" fluorescent lamps giving an illuminance of 6 klx are specified for this test. Other types of fluorescent lamps may be used to simulate a particular display condition; however, to satisfy the reporting requirements of this International Standard, only data obtained from tests using "Cool White" lamps are acceptable. A standard window-glass filter (see 5.5) shall be placed between the fluorescent lamps and sample plane.

NOTE 3 Most bare-bulb fluorescent lamps have a strong ultraviolet emission at 313 nm which has an adverse effect on the image stability of some types of colour photographs; ordinary window glass effectively absorbs this potentially harmful emission.

To simulate display situations where prints or transparencies are subjected to direct, bare-bulb fluorescent illumination, the glass sheet may be omitted. However, to satisfy the reporting requirements of this International Standard, only data obtained from tests with glass-filtered fluorescent lamps are acceptable.

The spectral energy distribution of the lamp between 300 nm and 780 nm should conform closely to the values given in table 5.

The surface temperature of the sample shall be 24 °C ± 2 °C, maintained by an adequate airflow across the sample; the ambient relative humidity shall be (50 ± 5) %.

Half of the lamps shall be replaced after each 2 000 h of operation of test equipment.

Table 5 — Relative spectral power distribution for F-6 "Cool White" fluorescent lamps

Source: Toshiba Corporation (300 nm to 375 nm); Japanese Industrial Standard, JIS Z8719-1984, *Evaluation Method of Degree of Metamerism for Change in Illuminants* (380 nm to 780 nm)

Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power
300	0,03	465	6,41	625	8,95
305	0,03	470	6,52	630	7,74
310	0,78	475	6,58	635	6,69
315	1,71	480	6,59	640	5,71
320	0,03	485	6,56	645	4,87
325	0,03	490	6,56	650	4,16
330	0,03	495	6,42	655	3,55
335	0,31	500	6,28	660	3,02
340	0,06	505	6,20	665	2,57
345	0,10	510	6,19	670	2,20
350	0,13	515	6,30	675	1,87
355	0,24	520	6,60	680	1,60
360	0,68	525	7,12	685	1,37
365	5,61	530	7,94	690	1,29
370	2,34	535	9,07	695	1,05
375	0,94	540	10,49	700	0,91
380	1,05	545	25,22	705	0,81
385	1,31	550	17,40	710	0,71
390	1,63	555	15,63	715	0,61
395	1,90	560	17,22	720	0,54
400	3,11	565	18,53	725	0,48
405	14,80	570	19,43	730	0,44
410	3,43	575	21,97	735	0,43
415	3,30	580	23,01	740	0,40
420	3,68	585	19,41	745	0,37
425	4,07	590	18,56	750	0,38
430	4,45	595	17,42	755	0,35
435	32,61	600	16,09	760	0,39
440	10,74	605	14,64	765	0,41
445	5,48	610	13,15	770	0,33
450	5,78	615	11,68	775	0,26
455	6,03	620	10,25	780	0,21
460	6,25				

5.8 Incandescent tungsten room illumination

The surface temperature of the sample shall be 24 °C ± 2 °C, maintained by an adequate airflow across the sample; the ambient relative humidity shall be (50 ± 5) %. Standard 75R30/FL or 150R/FL tungsten incandescent reflector-flood lamps giving an illuminance of 3 klx shall be used. The lamp shall have a CIE illuminant A spectral distribution as given in table 6. The voltage shall be adjusted to maintain an illumination colour temperature of 2 856 K ± 100 K. A standard window-glass filter (see 5.5) shall be placed between the lamps and the sample plane. Lamps shall be replaced after 2 000 h. To meet the reporting requirements of this International Standard, only data obtained from tests using standard incandescent tungsten lamps are acceptable.

Table 6 — Relative spectral power distribution for incandescent tungsten CIE Illuminant A

Source: CIE Standard 15.2, *Colorimetry*, 1986, second edition, pp. 47-49

Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power
300	0,93	450	33,09	600	129,04	750	227,00
305	1,13	455	35,41	605	132,70	755	229,59
310	1,36	460	37,81	610	136,35	760	232,12
315	1,62	465	40,30	615	139,99	765	234,59
320	1,93	470	42,87	620	143,62	770	237,01
325	2,27	475	45,52	625	147,24	775	239,37
330	2,66	480	48,24	630	150,84	780	241,68
335	3,10	485	51,04	635	154,42	785	243,92
340	3,59	490	53,91	640	157,98	790	246,12
345	4,14	495	56,85	645	161,52	795	248,25
350	4,74	500	59,86	650	165,03	800	250,33
355	5,41	505	62,93	655	168,51	805	252,35
360	6,14	510	66,06	660	171,96	810	254,31
365	6,95	515	69,25	665	175,38	815	256,22
370	7,82	520	72,50	670	178,77	820	258,07
375	8,77	525	75,59	675	182,12	825	259,86
380	9,80	530	79,13	680	185,43	830	261,60
385	10,90	535	82,52	685	188,70		
390	12,09	540	85,95	690	191,93		
395	13,35	545	89,41	695	195,12		
400	14,71	550	92,91	700	198,26		
405	16,15	555	96,44	705	201,36		
410	17,68	560	100,00	710	204,41		
415	19,29	565	103,58	715	207,41		
420	20,99	570	107,18	720	210,36		
425	22,79	575	110,80	725	213,27		
430	24,67	580	114,44	730	216,12		
435	26,64	585	118,08	735	218,92		
440	28,70	590	121,73	740	221,67		
445	30,85	595	125,39	745	224,36		

NOTE — Data are normalized to 100 % at 560 nm.

NOTE 4 With most colour photographic materials, the light fading and staining effects of glass-filtered quartz tungsten-halogen lamps are similar, but not identical, to those of standard incandescent lamps. Bare-bulb quartz tungsten-halogen lamps emit comparatively high levels of ultraviolet radiation, which will adversely affect the stability of some types of colour photographs.

5.9 Simulated outdoor sunlight (xenon arc)

The test unit shall be a xenon high-pressure arc lamp (or its equivalent) giving an illuminance of 100 klx containing a quartz burner tube assembly with inner and outer borosilicate (e.g. Pyrex) glass filters of 1,5 mm and 2,5 mm thickness, respectively. The lamp shall have a CIE D65 spectral distribution as given in table 7[6]. An additional borosilicate glass filter of 6,0 mm thickness shall be positioned in front of the lamp, but the test samples shall not be covered with glass.

Table 7 — Spectral power distribution for outdoor daylight CIE Illuminant D65

Source: CIE Standard 15.2, *Colorimetry*, 1986, second edition, pp. 47-49

Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power	Wavelength nm	Relative spectral power
300	0,03	450	117,01	600	90,01	750	63,59
305	1,66	455	117,41	605	89,80	755	55,01
310	3,29	460	117,81	610	89,60	760	46,42
315	11,77	465	116,34	615	88,65	765	56,61
320	20,24	470	114,86	620	87,70	770	66,81
325	28,64	475	115,39	625	85,49	775	65,09
330	37,05	480	115,92	630	83,29	780	63,38
335	38,50	485	112,37	635	83,49	785	63,84
340	39,95	490	108,81	640	83,70	790	64,30
345	42,43	495	109,08	645	81,86	795	61,88
350	44,91	500	109,35	650	80,03	800	59,45
355	45,78	505	108,58	655	80,12	805	55,71
360	46,64	510	107,80	660	80,21	810	51,96
365	49,36	515	106,30	665	81,25	815	54,70
370	52,09	520	104,79	670	82,28	820	57,44
375	51,03	525	106,24	675	80,28	825	58,88
380	49,98	530	107,69	680	78,28	830	60,31
385	52,31	535	106,05	685	74,00		
390	54,65	540	104,41	690	69,72		
395	68,70	545	104,23	695	70,67		
400	82,75	550	104,05	700	71,61		
405	87,12	555	102,02	705	72,98		
410	91,49	560	100,00	710	74,35		
415	92,46	565	98,17	715	67,98		
420	93,43	570	96,33	720	61,60		
425	90,06	575	96,06	725	65,74		
430	86,68	580	95,79	730	69,89		
435	95,77	585	92,24	735	72,49		
440	104,86	590	88,69	740	75,09		
445	110,94	595	89,35	745	69,34		

NOTE — Data are normalized to 100 % at 560 nm.

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6) This combination was chosen in an attempt to simulate D65; it is recognized, however, that the spectral match in the UV region is not ideal.

Suitable commercial test units are available that have the specified xenon-arc assembly and the controls for regulating the temperature and relative humidity of the air in the test chamber.[7] However, the temperature of the samples rises well above the air temperature when the samples are illuminated continuously. This causes the moisture content of the samples to fall and stay at very low levels throughout the test period. Test results obtained in this manner tend to be misleading, because photographs displayed outdoors are cycled between light and dark periods (i.e. day and night) and usually attain high moisture levels during the cooler dark intervals.

The sample temperature during periods of light exposure shall be at least 35 °C but shall not exceed 60 °C; 40 °C is recommended.[8] After the light periods, the sample shall be cooled to 25 °C ± 5 °C within 15 min.

It is possible to simulate the effects of some outdoor conditions by designing the xenon-arc test to have light/dark cycles as defined in table 8. Although the cycle pattern shown in table 8 has longer light periods than dark periods, it has been found to provide good correlation with results obtained in some outdoor tests.

Table 8 — 100 klx test conditions

	Light	Dark
Light/dark cycle duration	3,8 h	1 h
Chamber temperature	40 °C ± 5 °C	25 °C ± 5 °C
Chamber relative humidity	(40 ± 10) %	(80 ± 5) %
Black panel temperature	65 °C ± 10 °C	—

5.10 Intermittent tungsten-halogen lamp slide projection

A slide projector equipped with a quartz tungsten-halogen lamp and infrared-transmitting mirror and infrared-absorbing glass filter should be used for this test[9]. Projectors equipped with xenon arc lamps shall not be used.

Because the intensity of illumination tends to fall off somewhat in the corner areas of a slide projector film gate, the area of the film samples to be measured shall be restricted to a square, 10 mm × 10 mm, in the centre of the slides.

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[7] Suitable xenon-arc test equipment is available from several companies, including Atlas Electric Devices Company, 4114 North Ravenswood Avenue, Chicago, Illinois 60613, USA. If other equipment is used, it can be necessary to modify the conditions given in table 8.

[8] One way to determine the sample temperature is with Reatec temperature indicator strips placed on the front side of the sample. Reatec temperature indicator strips, manufactured in Switzerland, are supplied in the US by MRC Inc., The Woods, Suite A-514, 985 Old Eagle School Road, Wayne, Pennsylvania 19087, USA.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

[9] An Eastman Kodak Ektagraphic III Projector, equipped with a 300 W, 82 V ANSI code EXR lamp is suitable for this test.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

The illumination level at the film plane may be measured with a selenium barrier-layer cell; the selenium cell should be placed in the centre of the film gate during measurements[10]. Lamps shall be operated at the nominal voltage level specified by the manufacturer with a tolerance of 10 %.

NOTE 5 Light output of quartz tungsten-halogen projector lamps of a given type can vary significantly from one lamp to another, even when the lamps are made by the same manufacturer. To maintain a uniform light level when lamps are changed, the average light output of a representative group of at least five lamps operated at the nominal voltage should be determined. To make individual lamps conform to this average output level, the voltage should be adjusted as necessary with a variable transformer.

A constant-voltage regulator shall be used if line voltage fluctuation during the test period is greater than ± 3 %. Sample temperature at the film plane shall not exceed 70 °C once the temperature has stabilized after at least 30 min of test-equipment operation.

Precision timing equipment (instead of a built-in projector timer) shall be used to control illumination periods, and to measure the interval required for the test equipment mechanism to move from one film sample to the next. Film samples shall be illuminated for one 15 s period each hour (i.e. a total of 6 min of illumination each 24 h).

Equipment shall be arranged so that between illumination periods the film samples are protected from light and are surrounded by air having a temperature of 24 °C ± 2 °C and a relative humidity of (50 ± 5) %.

Reported data shall be normalized to the standard 1 000 klx illumination level, computed from the measured illumination level of the particular equipment and lamp used for this test (see 5.3).

5.11 Computation of light stability

Treatment of densitometric data for light-stability tests is illustrated in annex E.

6 Test report

6.1 Image life parameters

The data obtained in the various tests are reported in terms of the times required for the photographic images to reach the chosen end-point values for the following fading and/or staining parameters, called image life parameters:

a) 30 % change in neutral patches D_N(R), D_N(G), D_N(B) (d_{min}-corrected);

b) 30 % change in colour patches D_C(R), D_M(G), D_Y(B) (d_{min}-corrected);

and the following end-points which do not apply to colour negative materials:

c) 15 % change in colour balance of neutral patch % d_N(R-G), % d_N(R-B), % d_N(G-B) (not d_{min}-corrected);

d) 0,10 change in d_{min}(R), d_{min}(G), d_{min}(B) in the d_{min} patch;

e) 0,06 change in colour balance d_{min}(R-G), d_{min}(R-B), d_{min}(G-B) in the d_{min} patch.

NOTE 6 The image-life parameters listed are the critical characteristics that have practical significance for the visual degradation of colour images; however, the numerical end-points given here are only illustrative. The working group that produced this International Standard was not able to specify broadly applicable "acceptable" end-points because the amount of image change that can be tolerated is subjective and will vary with the product type and specific consumer or institutional requirements. Each user of this International Standard shall select end-points for the listed parameters which, in that user's judgment, are appropriate for the specific product and in-

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[10] A suitable instrument for measuring the illumination level at the film plane is the United Detector Technology Model 81 Photometer, available from United Detector Technology Inc., 12525 Chardon Avenue, Hawthorne, California 90250, USA.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Users of equivalent products should note that the relevant components of the above are:

a) Model 81 Control Module;

b) Model 248 Uniprobe, which includes a P/N 1228 Detector, P/N 111 Photopic filter and P/N 112 Cosine Diffuser;

c) Model 1343 P/C Module.

For use in a slide projector, a special fixture to hold the detector should be constructed by the user. This fixture mounts in the lens barrel vacated by removing the lens of the projector. The rack-and-pinion track intended for changing the position of the lens can be used to register the fixture.

tended application. Selected end-points may be different for light and dark stability tests.

The relative importance of each of the above image-life parameters (and their respective end-points) will vary depending on the intended use of the film or print material, the subject matter of the photograph, and the requirements of the viewer. In most cases, it is only necessary to continue the tests long enough to determine the end-points for just a few of the parameters listed above. In any event, the time to reach the first end-point, the parameter to which that end-point applies and the end-point values chosen for all of the other parameters listed above shall be reported.

6.2 Dark-stability tests

The results of the tests are predictions of times required for the photographic images to reach the specified fading and/or staining end-points for the image-life parameters listed in 6.1 when the images are stored at particular conditions of temperature and humidity (e.g. 24 °C and 50 % R.H.). The starting densities (i.e. 1,0 above $d_{\min}$) of the neutral and colour patches, the particular end-point values chosen for all of the image-life parameters listed in 6.1, and the relative humidity employed for the tests shall be included in the report of test results.

6.3 Light-stability tests

The report of test results shall include the following:

a) type of test (e.g. simulated indoor indirect daylight; glass-filtered fluorescent room illumination; incandescent tungsten room illumination, etc.);

b) if glass is used, the distance of the glass from the print and whether or not the glass and print are taped together along the edges to form a sealed enclosure;

c) the starting densities (i.e. 1,0 above $d_{\min}$) of the neutral and colour patches in the test sample;

d) the particular values chosen for all of the end-points listed in 6.1 and the time required for the sample to reach the limiting end-point;

e) for transparencies or translucent print materials intended for viewing with either reflected or transmitted light, whether the base or emulsion side of the material was facing toward the light used in the test;

f) the temperature and relative humidity at the sample plane during the test [for the simulated outdoor sunlight test (see 5.9), if the temperature and relative humidity fall within the ranges specified, they need not be included in the test report].

Annex A
(informative)

The importance of the starting density in dye fading and colour balance changes in light-stability tests

To simplify preparation of test samples and the handling of data, this International Standard specifies a starting density of 1,0 above d_{min} for both light-stability and dark-stability tests. This International Standard requires that dye fading endpoints be expressed as a "percentage change". As is shown in table A.1, the starting density is of little significance in dark-stability tests — the chromogenic colour negative print paper tested here shows practically the same percentage density loss regardless of the starting density. (It should be noted, however, that with typical chromogenic print materials in dark-stability tests, the contribution of stain to measured density is proportionally greater in low densities than in high densities and this generally causes colour balance changes to be greater in low density areas of an image than in high densities.)

Table A.1 — Dark fading of cyan dye (red density) with a chromogenic colour-negative paper in an accelerated dark-stability test (from neutral patches)

Starting density above d_{min}	Density change at end of test	Percentage density change %
0,30	− 0,14	− 47
0,40	− 0,19	− 48
0,50	− 0,24	− 48
0,60	− 0,28	− 47
1,00	− 0,46	− 46
1,50	− 0,72	− 48

In light fading, dye fading behaviour is very different as the percentage density losses measured are characteristically much larger in low densities than in high densities. In table A.2 it can be seen that the percentage density loss measured in a patch that had a starting density of 0,50 is twice that of a patch that had a starting density of 1,0; with a starting density of 0,30, the percentage loss is more than three times that of a starting density of 1,0.

With many types of pictorial scenes, starting densities of 0,50 or 0,60 are visually the most critical in assessing changes caused by light fading. In some images, very low density "detailed highlight" areas (such as the rendering of texture in a white fabric, in the facial highlights of a portrait or the pale coloration of a late afternoon sky), densities as low as 0,10 above d_{min} can be very important. In light fading, these low-density dye images can fade completely while high-density portions of the images can show little, if any, visually perceptible change. In dark fading, highlight detail is not lost in a corresponding manner.

Table A.2 — Light fading of magenta dye (green density) with a chromogenic colour-negative paper in an accelerated light-stability test (from neutral patches)

Starting density above d_{min}	Density change at end of test	Percentage density change %
0,30	− 0,14	− 47
0,40	− 0,15	− 38
0,50	− 0,15	− 30
0,60	− 0,15	− 25
1,00	− 0,15	− 15
1,50	− 0,14	− 9

For these reasons, with many types of pictorial scenes, light-faded images will appear visually more faded than dark-faded images when both have suffered the same relative amount of dye loss (e.g. 30 %) when measured in areas with a starting density of 1,0. The light-faded images will have lost a disproportionate amount of density and usually also exhibit greater colour balance changes in visually critical medium- and low-density areas.

Test prints of portraits and other common pictorial subjects can be useful in assessing fading and colour balance changes at various starting densities and, based on observations made with such prints, the user of this International Standard may adopt different density change and colour balance endpoints for light-stability and dark-stability tests.

Annex B
(informative)

An interpolation method for step wedge exposures

If a step wedge is used to make the sensitometric exposure for the sample, generally there will not be a step that is of exactly the desired density. For example, the densities of the two steps nearest to $d_{\min} + 1{,}0$ may be used to calculate the desired density by linear interpolation. After each fading time, the same coefficient α is used for interpolating the density after fading.

First, on the unfaded strip, the step with the density $d_{1,\,t=0}$ just below $d_{\min} + 1{,}0$ and the step with the density $d_{2,\,t=0}$ just above $d_{\min} + 1{,}0$ are chosen. (See figure B.1.)

After fading, these two steps will have reached the densities $d_{1,\,t}$ and $d_{2,\,t}$. The density d_t of the initial $d_{t=0} = d_{\min} + 1{,}0$ is then estimated through linear interpolation as:

$$d_t = d_{1,\,t} + [d_{2,\,t} - d_{1,\,t}] \times \alpha$$

where

$$\alpha = \frac{(d_{\min} + 1{,}0) - d_{1,\,t=0}}{d_{2,\,t=0} - d_{1,\,t=0}}$$

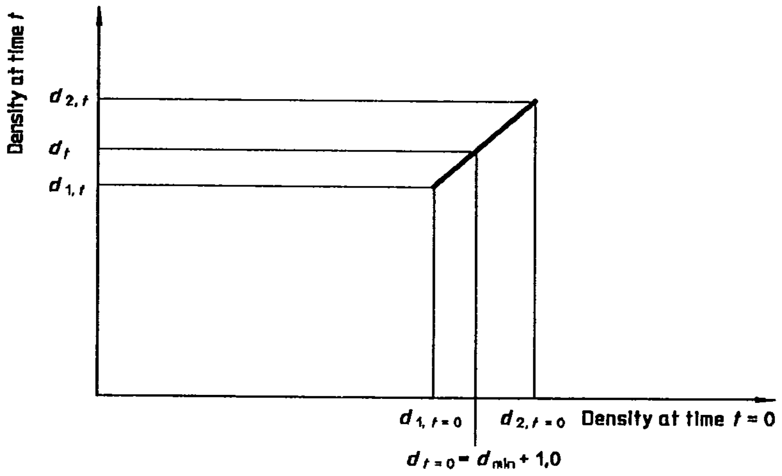


Figure B.1

Annex C
(informative)

Illustration of Arrhenius calculation for dark stability

C.1 Plot of colour fading

This annex illustrates the Arrhenius calculation using as an example the fading of a yellow colour patch in a transparency and the resulting densities after incubation at 60 °C and 50 % R.H. The required values of the density parameters can be found in table C.1 for generating the fading curve at 60 °C. The given parameters are as follows:

a) $d_{\min}(\mathrm{B})_t$, the measured blue $d_{\min}$ at t, the time spent in the oven which ranged from 0 to 266 days;

b) $d_\mathrm{Y}(\mathrm{B})_t$, the measured density of the yellow colour patch to blue light at time t.

Densitometry of the yellow patches gives densities to blue light at each time t, $d_\mathrm{Y}(\mathrm{B})_t$. These densities include both the density due to the presence of the yellow dye and also the blue density of the support and other miscellaneous colourants. To correct for the densities of the miscellaneous colourants at each time t, the $d_{\min}$ densities are substracted from the densities of the test patches to give $D_\mathrm{Y}(\mathrm{B})_t$, i.e.

— for transmission materials:
$D_\mathrm{Y}(\mathrm{B})_t = d_\mathrm{Y}(\mathrm{B})_t - d_{\min}(\mathrm{B})_t$.

— and for reflection print materials:
$D_\mathrm{Y}(\mathrm{B})_t = d_\mathrm{Y}(\mathrm{B})_t - d_{\min}(\mathrm{B})_t + 0{,}5[d_{\min}(\mathrm{B})_t - d_{\min}(\mathrm{B})_0]$

The initial density (before fading) of the yellow colour patch was chosen experimentally so that $D_\mathrm{Y}(\mathrm{B})_0 = 1{,}0$.

$D_\mathrm{Y}(\mathrm{B})_t$ is plotted in figure C.1 against the time, t, in days. A smooth curve is then drawn manually through the points. The same procedure is applied to the data from all temperatures. From these plots one can interpolate the times required for the original density $D_\mathrm{Y}(\mathrm{B})_0$ to fall by a specified value, such as 0,3 for each of the temperatures. In this example, the values of the time, $t_{-0,3}$ [at which $D_\mathrm{Y}(\mathrm{B})_t = 0{,}70$], are determined from the plot. These times are estimated from figure C.1 to be as shown in table C.2.

These times, $t_{-0,3}$, at each temperature are then used to make the Arrhenius plot.

Table C.1 — Densitometry data for transmission material in a 60 °C/50 % RH oven

Time, t days	$d_{\min}(\mathrm{B})_t$ [1]	$d_\mathrm{Y}(\mathrm{B})_t$ [1]	$D_\mathrm{Y}(\mathrm{B})_t$ [1] [2]
0	12	112	100
14	19	118	99
28	20	118	98
42	21	117	96
56	22	117	95
70	23	117	94
90	24	114	90
112	25	114	89
133	26	111	85
161	26	108	82
196	27	103	76
231	28	99	71
266	28	95	67

1) Densities are given in hundredths.

2) $D_\mathrm{Y}(\mathrm{B})_t = d_\mathrm{Y}(\mathrm{B})_t - d_{\min}(\mathrm{B})_t$

Table C.2 — Estimate of times $t_{-0,3}$

Temperature (°C)	85	77	68	60
$t_{-0,3}$ [1], (days)	18	40	95	240

1) Time to lose 0,30 in density from an initial $d_{\min}$-corrected density of 1,00 [or from figure C.1, the time required for $D_\mathrm{Y}(\mathrm{B})_t = 0{,}70$].

C.2 The Arrhenius plot

An Arrhenius plot is now made from the $t_{-0,3}$ and temperature data in table C.2. This requires that the times be plotted logarithmically against the reciprocal of the thermodynamic temperature[11] as shown in figure C.2. If the Arrhenius relationship is followed, the result will be a linear graph.

A best-fit straight line, approximated by eye, is manually drawn through the points in the Arrhenius plot and an extrapolation of the straight line is made to 23 °C. For the product used in this example, the yellow dye is predicted to lose 0,3 from the initial $d_{\min}$-corrected density of 1,0 after 60 years when kept in the dark at 23 °C and 50 % R.H.

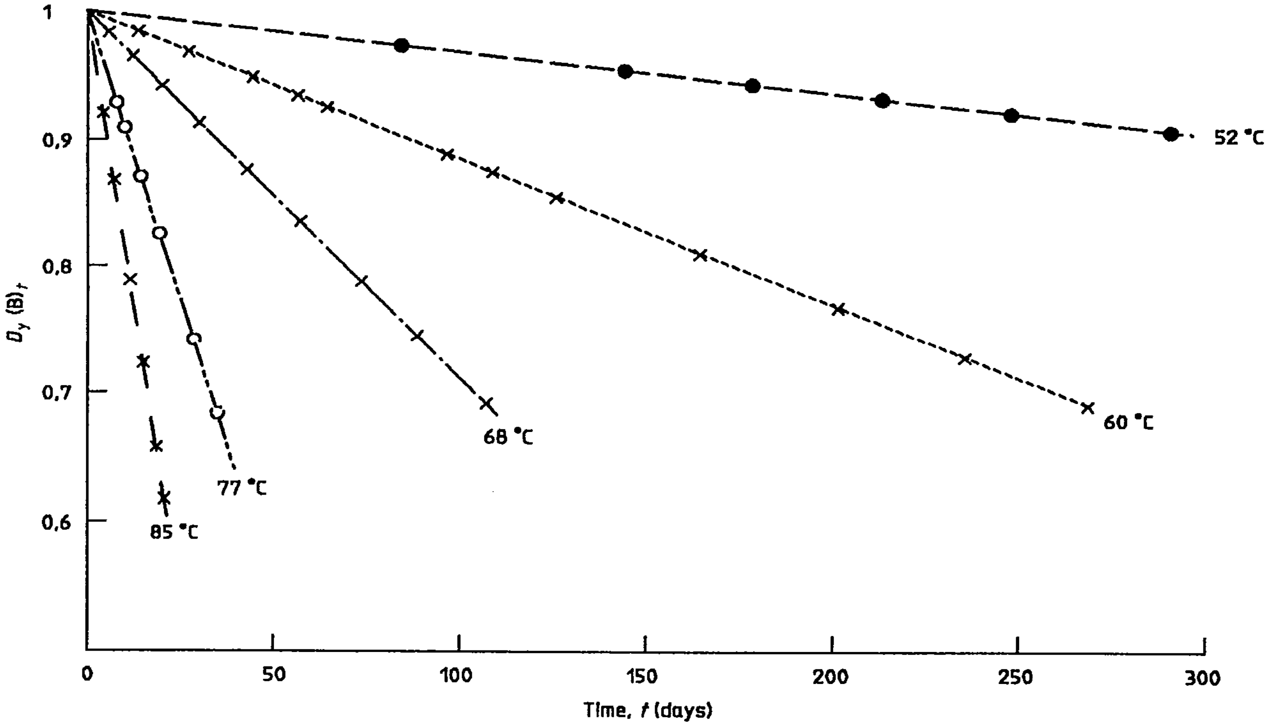
In an analogous manner, an Arrhenius plot can also be made for any other density loss.

C.3 Computerization of the Arrhenius method

When large numbers of photographic materials are subjected to this Arrhenius method for predicting the stabilities of colour photographs, the burden of handling the very large number of density values becomes a serious impediment to the usefulness of the method. Computerization is a remedy for this problem.

Generation of the values needed for the fading plot (see figure C.1) is readily handled by a computer, i.e. by calculation of the density decrease with time $[D_Y(B)_t - D_Y(B)_0]$. Programs are readily available for fitting such groups of data points.

After the computer calculates the optimum fit, the time taken to lose any particular amount of density can then be determined by the computer. Programs are also available to fit the best straight line to the Arrhenius plot. These programs, however, are not the simple regression programs used in fitting straight lines to a series of points. In an Arrhenius plot, a non-linear transformation of the raw data has occurred; i.e. taking the logarithm of the time to lose a given amount of density is a non-linear transformation. Therefore, considerably more complex curve-fitting methods (e.g. the non-linear least-squares methods) are required.



NOTE — Initial $d_{\min}$-corrected blue density was 1,0, i.e. $D_Y(B)_0 = 1{,}0$.

Figure C.1 — $d_{\min}$-corrected blue density of the yellow colour patch of a transmission material

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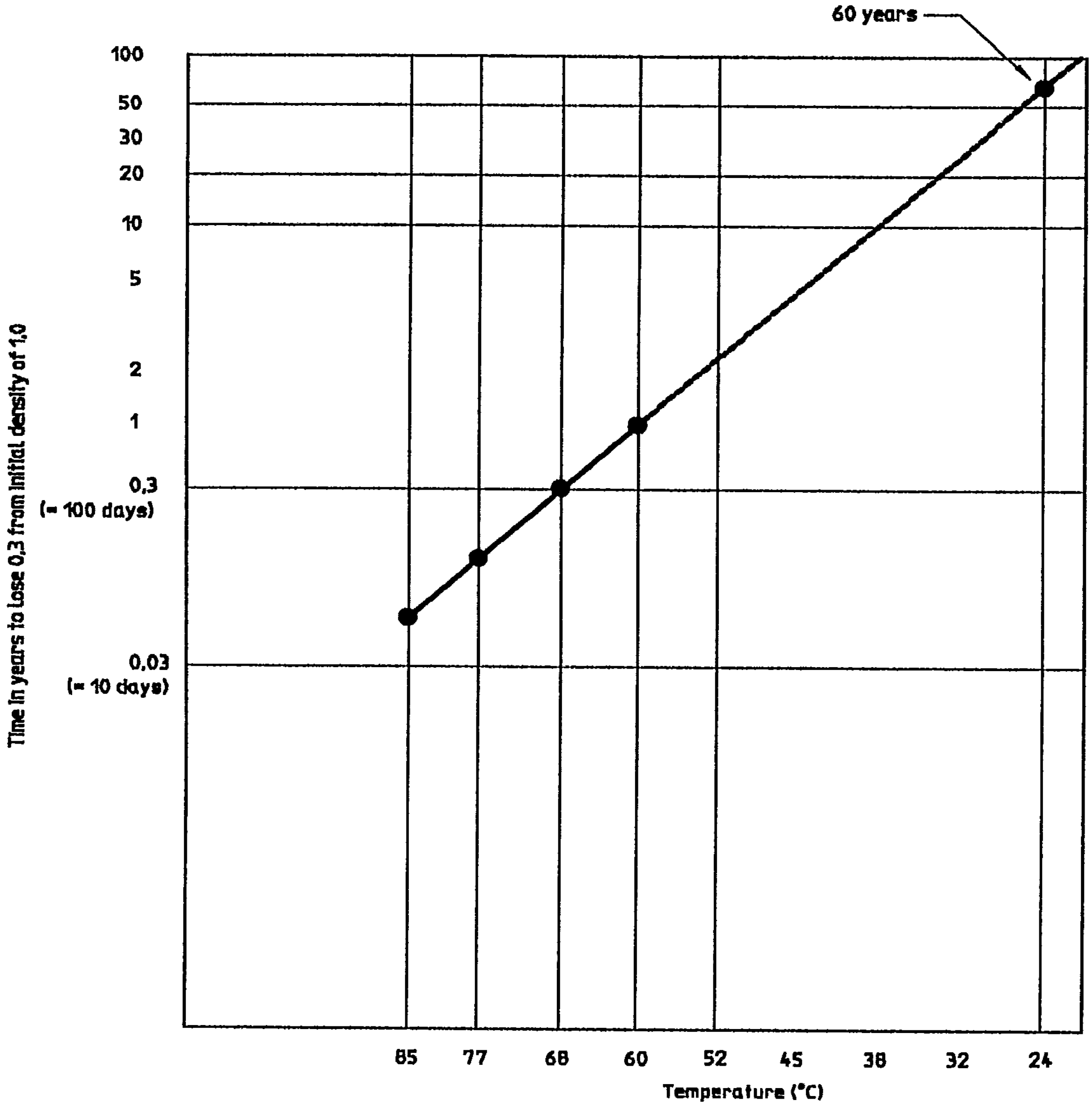
[11] The thermodynamic temperature T, in kelvin, is related to the temperature Θ, in degrees Celsius by the following: $T = \Theta + 273$



NOTE — Temperatures have been plotted as reciprocals of corresponding thermodynamic temperatures.

Figure C.2 — Arrhenius plot of blue density

Annex D
(informative)

"Enclosure effects" in light-stability tests with prints framed under glass or plastic sheets

Studies with a variety of chromogenic print materials have shown that when certain of these materials are displayed for long periods under typical indoor illumination levels, framing or enclosing these prints with glass or plastic sheets can have a significant effect on fading and stain formation. The manner of processing (e.g. a water wash, use of a low-pH stabilizer, etc.) can have a pronounced influence on the rate of dye fading of these framed and displayed print materials. Most commonly, the "enclosure effect" in chromogenic prints is manifested by an increase in yellow dye fading in particular and, unlike what is generally observed with light fading, is most noticeable in high- and maximum-density areas of an image. The disproportionate loss of yellow dye eventually causes the image to suffer a pronounced blue shift in colour balance. The "enclosure effect" has been observed both in prints framed directly against glass and in prints that are separated from the framing glass by a cardboard overmat.

Experience has shown that the "enclosure effect" generally is subject to large reciprocity failures in high-intensity light-stability tests; therefore, to meaningfully evaluate this phenomenon, long-term test with illumination intensities of 1,0 klx or lower should be employed.

Although the "enclosure effect" has been studied principally in chromogenic prints, other types of materials are possibly affected similarly.

A test frame that can be used to evaluate the "enclosure effect" is illustrated in figure D.1.

To prepare a test frame, the glass, mount board and backing sheet are cut to the same size, approximately 50 mm longer in both dimensions than the test area of the print sample. The glass should be carefully cleaned with a mild, neutral pH detergent, rinsed thoroughly with warm water and dried with clean paper towels. Backing boards and overmats should be made of white 4-ply 100 % cotton fibre non-buffered photographic mount board with an approximately neutral pH.12)

A stable and non-reactive pressure-sensitive tape13) should be used to attach the backing board, print and overmat to the cover glass. The tape should completely cover the edges of the test unit, with no vacant areas present through which air could circulate.

Print samples should be prepared to the same size as the cover glass and backing board, with the test area at least 50 mm shorter in both dimensions than the print sample.

Print samples should be tested in direct contact with the frame cover glass; if desired, identical samples should also be tested in units with an overmat to maintain a separation between the print and the glass. Print-mounting adhesives should not be used. The test frame should not be opened except for short periods when density measurements are made.

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12) A suitable material for backing sheets and overmats is Rising Photomount 4-ply white mount board, manufactured by the Rising Paper Company, Housatonic, Massachusetts 01236, USA.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

13) A suitable tape is 3M Magic Transparent Tape No. 810, manufactured by the 3M Company, Commercial Tape Division, 3M Center, St Paul, Minnesota 55144, USA.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

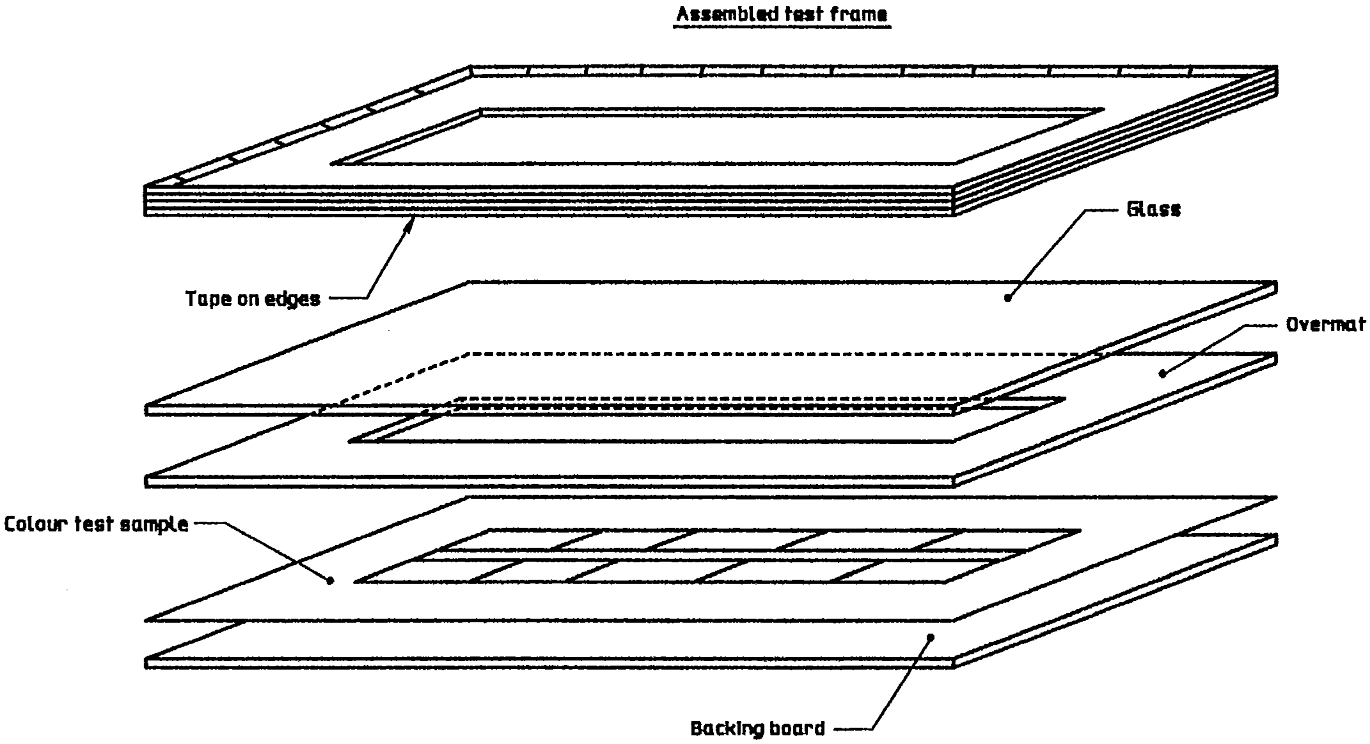

Figure D.1 — Print test frame

Annex E
(informative)

Data treatment for the stability of light-exposed colour images

E.1 General

This annex is a supplement for 6.3 and is intended to demonstrate the procedure of manipulating density data for determining the stability of colour images exposed to light.

The example cited below corresponds to colour paper exposed to fluorescent illumination of 6,0 klx (see 5.7). Reflection-density data necessary for obtaining image-life parameters are measured after each period of light exposure. The stabilities derived from various parameters are expressed in number of days required for the test sample to reach the chosen end-points.

NOTE 7 The end-points in each category have comparative meaning only. Development of a predictive method for long-term display under normal conditions awaits further investigation.

E.2 Data handling procedures

E.2.1 Density measurement

In this example, red, green and blue reflection-density measurements were made at d_{min}, 1,0 above d_{min} for the neutral patch and 1,0 above d_{min}, for the cyan, magenta and yellow separation patches at 0 days (i.e. before illumination), 28 days, 56 days, 84 days, 140 days, 224 days and 308 days (see table E.1).

E.2.2 Graphic determination of stability parameters

a) Using the procedure described in 3.7, calculate the d_{min}-corrected densities for the neutral patch and colour patches and the neutral density patch colour balance, the d_{min} changes and the d_{min} colour balance (see table E.2).

b) Plot the data from table E.2 on a graph. (Figures E.1 to E.5 illustrate five of the fifteen necessary plots.)

c) From the graphs, determine the number of days to reach the chosen end-points for each of the stability parameters and identify which fails first.

E.2.3 Results

Report the results in accordance with 6.3.

In this example, the results obtained are shown in table E.3.

Table E.1 — Reflection densitometry data

Time, t (days)		0	28	56	140	224	308
d_{min}	$d_{\mathrm{min}}(\mathrm{R})_t$	0,09	0,09	0,08	0,08	0,08	0,08
	$d_{\mathrm{min}}(\mathrm{G})_t$	0,12	0,12	0,12	0,13	0,13	0,14
	$d_{\mathrm{min}}(\mathrm{B})_t$	0,12	0,14	0,16	0,21	0,22	0,23
Neutral patch	$d_{\mathrm{N}}(\mathrm{R})_t$	1,09	1,00	0,93	0,76	0,69	0,44
	$d_{\mathrm{N}}(\mathrm{G})_t$	1,12	1,08	1,06	0,89	0,64	0,47
	$d_{\mathrm{N}}(\mathrm{B})_t$	1,12	1,12	1,08	1,00	0,86	0,66
Colour patches	$d_{\mathrm{C}}(\mathrm{R})_t$	1,09	1,00	0,92	0,68	0,40	0,19
	$d_{\mathrm{M}}(\mathrm{G})_t$	1,12	1,08	1,02	0,45	0,24	0,21
	$d_{\mathrm{Y}}(\mathrm{B})_t$	1,12	1,00	0,96	0,79	0,49	0,41

Table E.2 — Density data calculations

Time, t (days)		0	28	56	140	224	308
Neutral patch (d_{min}-corrected)	$D_N(R)_t$	1,00	0,91	0,84	0,67	0,60	0,35
	$D_N(G)_t$	1,00	0,96	0,94	0,77	0,52	0,34
	$D_N(B)_t$	1,00	0,99	0,94	0,84	0,69	0,49
Colour patch (d_{min}-corrected)	$D_C(R)_t$	1,00	0,91	0,83	0,59	0,31	0,10
	$D_M(G)_t$	1,00	0,96	0,90	0,33	0,12	0,08
	$D_Y(B)_t$	1,00	0,87	0,82	0,63	0,32	0,24
Neutral patch percentage colour balance (not d_{min}-corrected)	% $d_N(R\text{-}G)_t$	− 2,7	− 7,6	− 13	− 16	+ 8	− 6,6
	% $d_N(R\text{-}B)_t$	− 2,7	− 11	− 15	− 27	− 22	− 40
	% $d_N(G\text{-}B)_t$	0	− 3,6	− 1,8	− 12	− 29	− 34
d_{min} changes	$d_{min}(R)_t - d_{min}(R)_0$	0,00	0,00	− 0,01	− 0,01	− 0,01	− 0,01
	$d_{min}(G)_t - d_{min}(G)_0$	0,00	0,00	0,00	+ 0,01	+ 0,01	+ 0,02
	$d_{min}(B)_t - d_{min}(B)_0$	0,00	+ 0,02	+ 0,04	+ 0,09	+ 0,10	+ 0,11
d_{min} colour balance	$d_{min}(R\text{-}G)_t$	− 0,03	− 0,03	− 0,04	− 0,05	− 0,05	− 0,06
	$d_{min}(R\text{-}B)_t$	− 0,03	− 0,05	− 0,08	− 0,13	− 0,14	− 0,15
	$d_{min}(G\text{-}B)_t$	0,00	− 0,02	− 0,04	− 0,08	− 0,09	− 0,09

Table E.3

Parameter	Days to reach the end-point
30 % change in 1,0 neutral patch	120 (red density)
30 % change in 1,0 colour patch	103 (red density)
15 % change in colour balance from 1,0 neutral	56 (red-blue)
0,10 change in d_{min}	225 (blue density)
0,06 change in d_{min} colour balance	40 (red-blue)

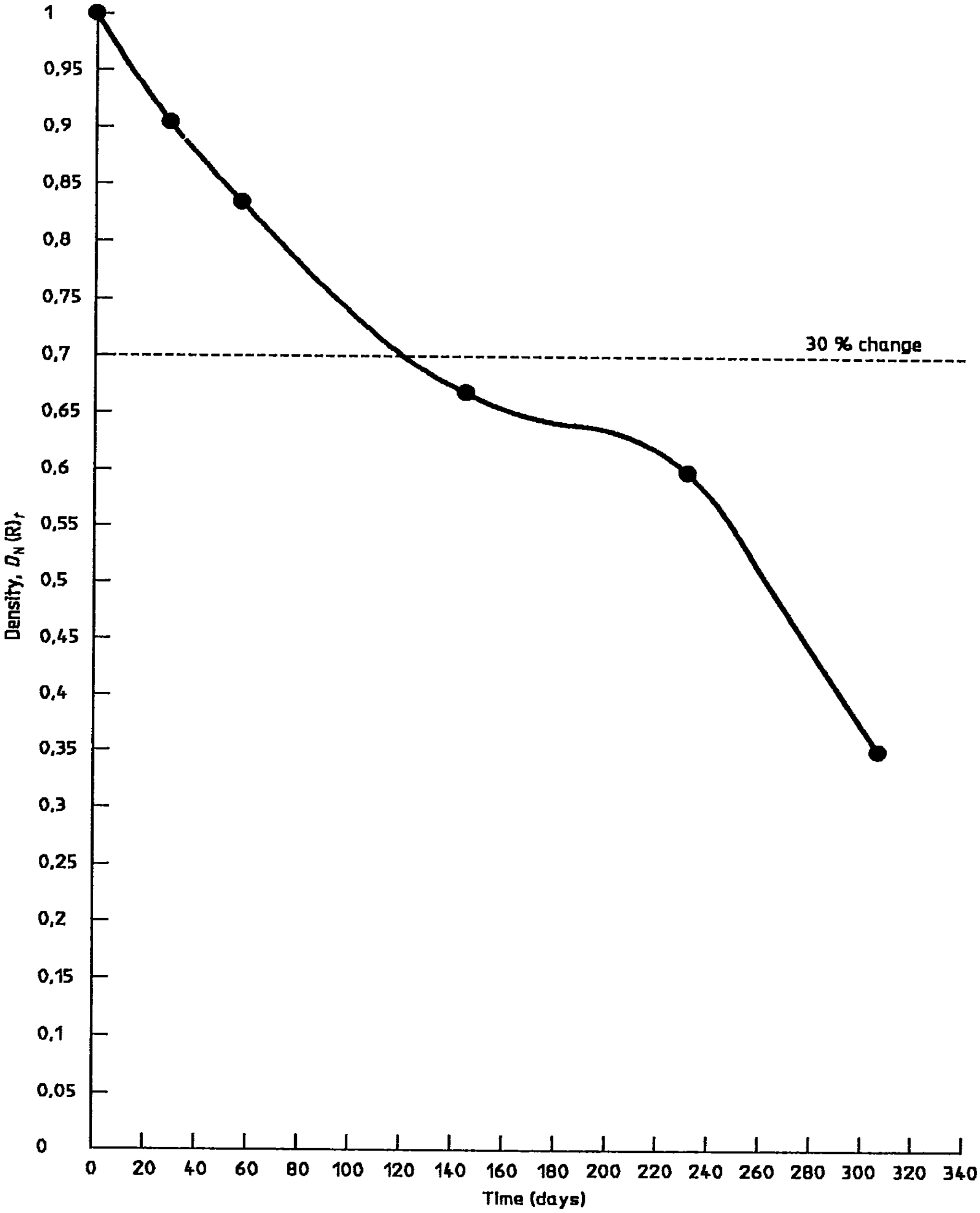

Figure E.1 — Red density of neutral patch vs time

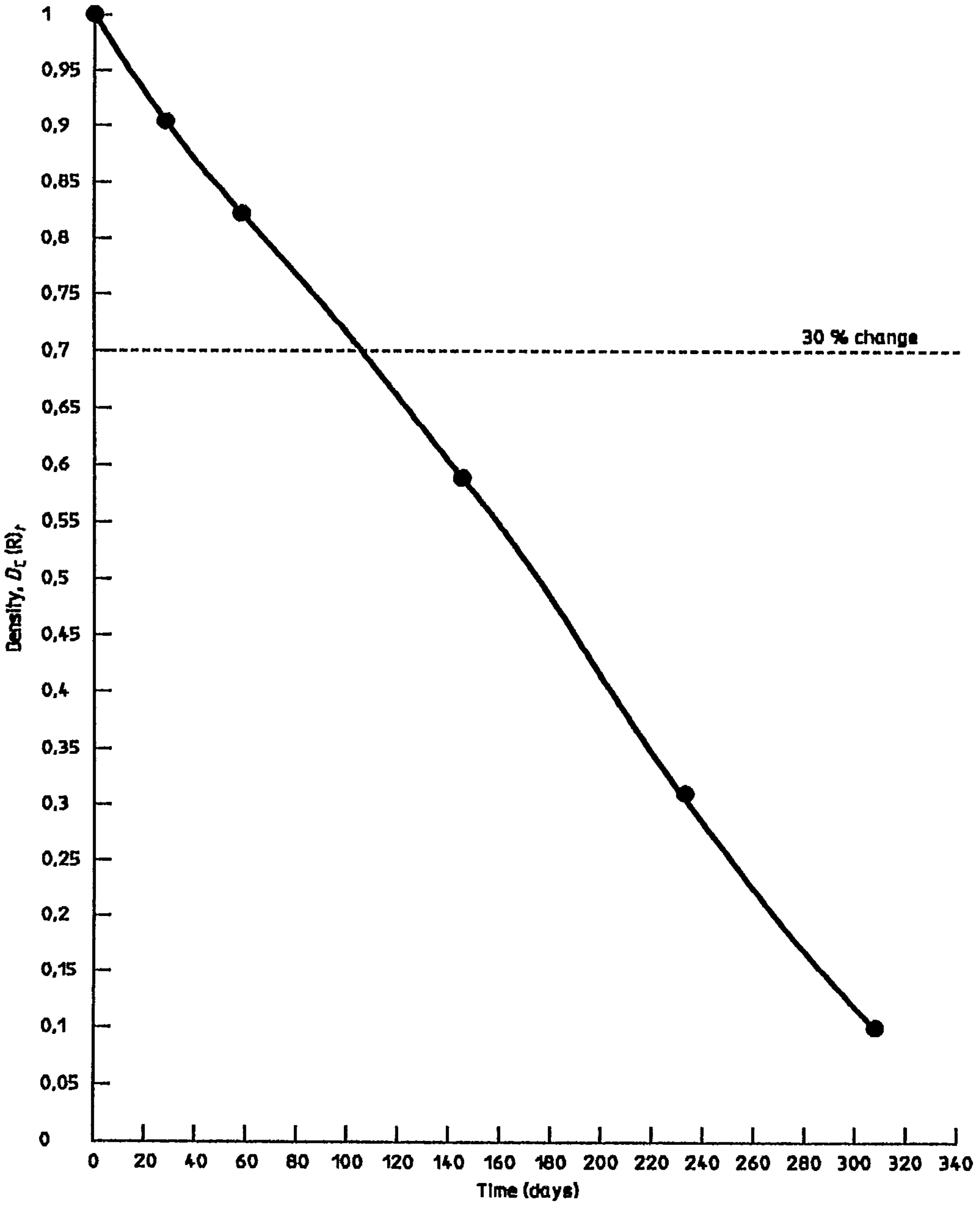

Figure E.2 — Red density of cyan patch vs time

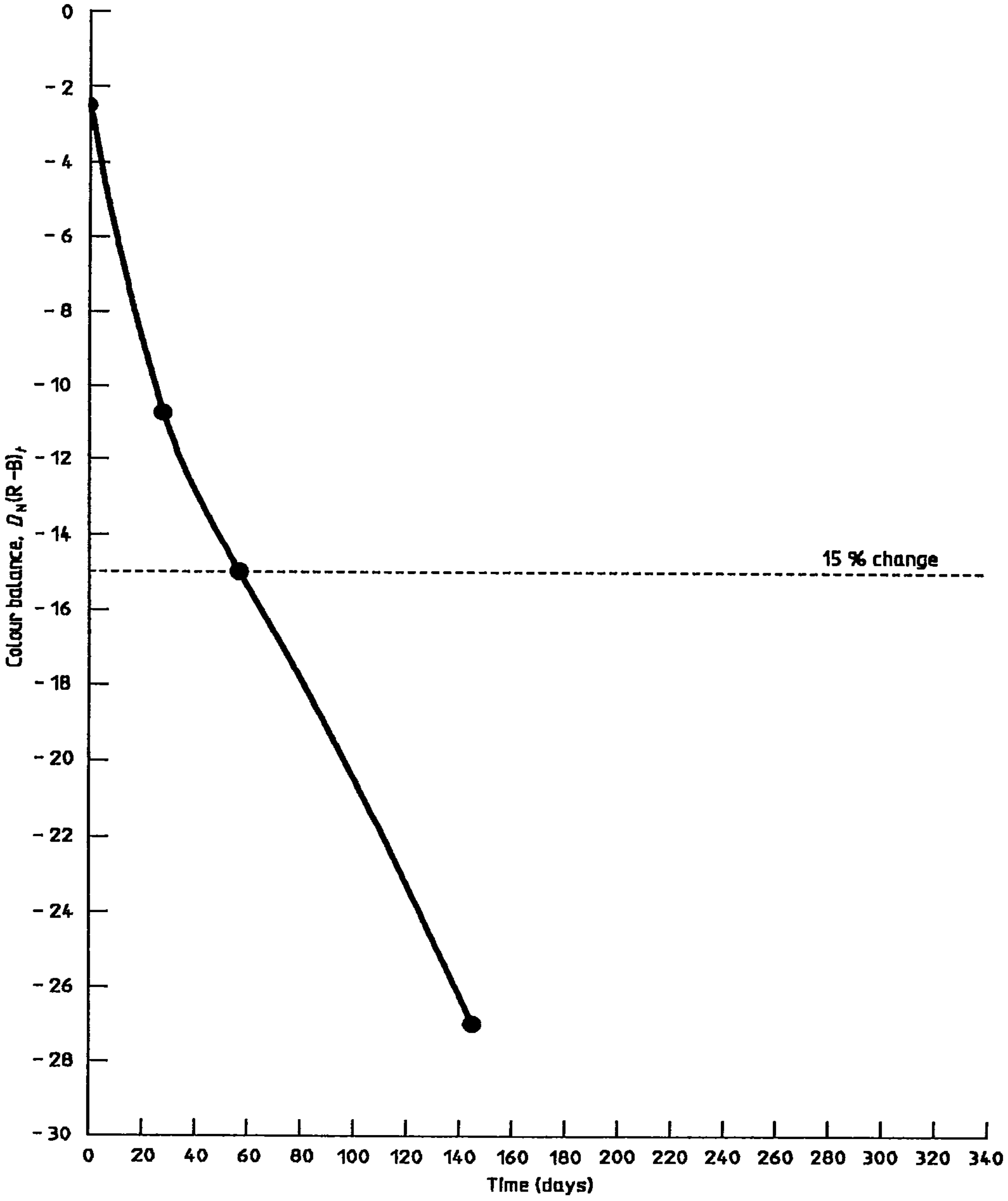

Figure E.3 — Colour balance of neutral patch vs time

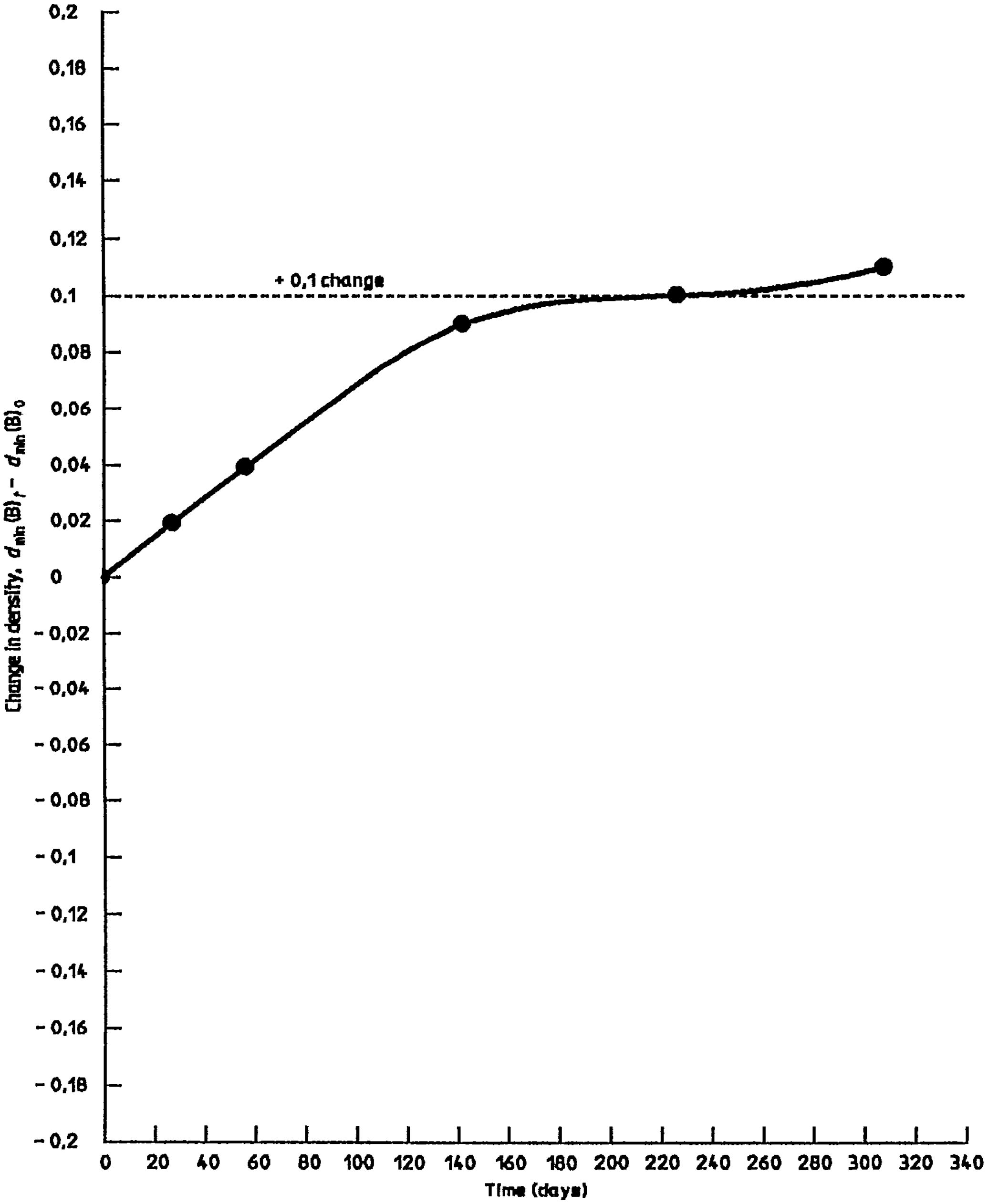

Figure E.4 — Change in blue d_{min} vs time

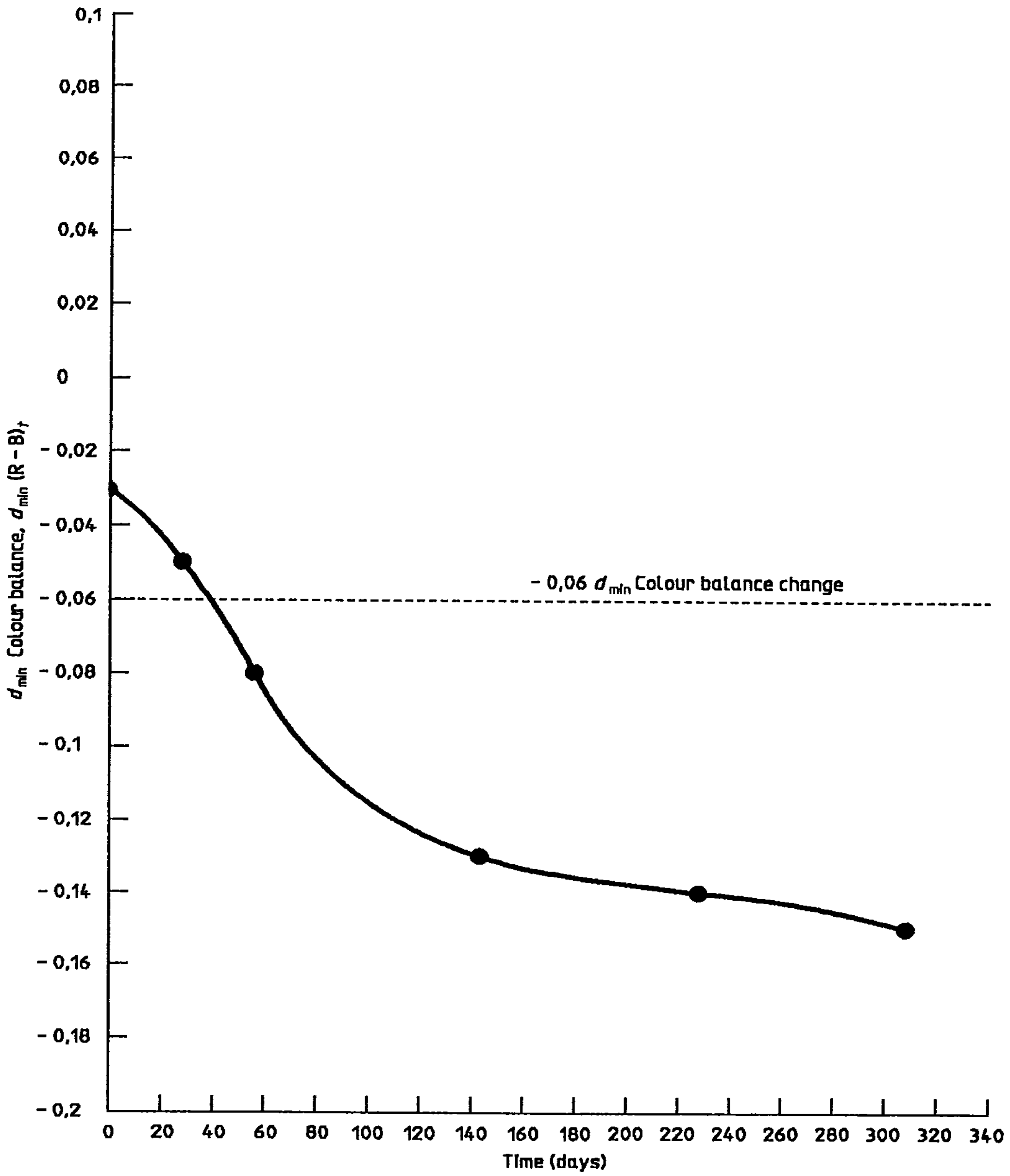

Figure E.5 — d_{min} colour balance vs time

Annex F
(informative)

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