
**Imaging materials — Evaluation of
image permanence of photographic
colour prints in consumer home
applications**

*Support d'image — Évaluation de la permanence de l'image de
tirages couleur photographiques dans les applications domestiques
grand public*



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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Reflection colour photographic-indoor stability specifications for consumer home have been discussed (Physical properties and image permanence of photographic materials). Many matters have been discussed about environmental data, psychophysically based end of test, nominal use case conditions, and mechanics of rating system, reciprocity issues, and experimental testing issues in the meetings.

This document describes cumulated information, data and knowledge work over the last 15 years as 'Guidelines for print-life-estimations'. Furthermore, it describes the background and the history of the discussion in TC 42/WG 5.

The purpose of this document provides data, information, and indicating the guidelines for evaluation of image permanence. These data and information were introduced and discussed and were quoted from the papers reported in conferences by TC 42/WG 5 members. Furthermore, detailed information and understanding are available in the references listed in the Bibliography in this paper.

It describes four important environmental stressors (heat, light, atmospheric pollutants, and humidity) in main body of this document. Ozone was chosen as the model system for atmospheric pollutant, but SO_x , NO_x and other atmospheric pollutants are present in the indoor environment. In addition, it includes an [Annex A](#) about accidental stressor (water, abrasion and others), examples of many topics and useful data collections and information.

Information about the stability of colour photographs toward these various factors can be obtained by accelerated stability tests. The starting assumption for indoor use cases is that the various environmental factors (heat, light, atmospheric pollutants, and humidity) each act independently on the photograph, i.e., there are no synergistic interactions taking place between these factors under typical storage and display conditions. While interactions most certainly do take place in the real world, modelling and testing for interactions is extremely difficult. The accelerated tests are therefore designed such that only one factor (heat, light, atmospheric pollutants and humidity) is varied at a time. The other factors not under investigation are controlled or held at a level that will induce only negligible changes in the image during the course of the accelerated test.

In accelerated testing, high levels or "loads" are required for each of the factors in test in order to complete the tests in a reasonable amount of time. The validity of accelerated testing for light and pollutants assumes that equal change will occur for the same cumulative exposure, i.e., one assumes reciprocity for the dose. However, for some systems "reciprocity failure" has been observed. When applied to light-induced fading and staining of colour images, reciprocity failure refers to the failure of many colorants to fade, or to form stain, equally when irradiated with high-intensity versus low-intensity light, even though the total light exposure (intensity $\times$ time) is kept constant through appropriate adjustments in exposure duration. This concept can be applied to any accelerated test where the same cumulative exposure can be obtained by different intensities or concentrations and time. Note, however, that this concept cannot be applied to accelerate testing for heat or humidity where special test procedures are required. This concept does hold for ozone stability testing, where the ozone concentration can be high or low. The extent of colorant fading, colorant migration, and stain formation can be greater or smaller under accelerated conditions, depending on the chemical reactions involved in the colorant degradation, on the kind of colorant 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 layers from the surrounding atmosphere may be restricted in an accelerated test (dry gelatine, for example, is an oxygen barrier). This may change the rate of colorant fading relative to the fading that would occur under normal display conditions. The magnitude of reciprocity failure may also be influenced by the temperature and moisture content of the test specimen. Comparisons between products will more accurately reflect observed differences when accelerated aging conditions are close to actual use conditions.

The following International Standards describe test methods relating to indoor stability. These Standards provide procedures for reporting technical data.

A test method for thermal stability is described in ISO 18936. A test method for humidity fastness is described in ISO 18946. A test method for indoor light stability is described in ISO 18937. A test method

for ozone gas fading stability is described in ISO 18941. A test method for stability under low humidity conditions in ISO 18949.

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Imaging materials — Evaluation of image permanence of photographic colour prints in consumer home applications

1 Scope

This document provides data and information related to evaluation of image permanence of photographic colour prints in consumer home applications. This document characterizes the test methods, the end of test criteria, the environmental factors, and the reporting. It also provides the background and the history of those.

This document describes guidelines and limitations for print life estimates, i.e. translation of the test results to the performance in actual usage as well as limitations of such a translation.

The photographic colour prints printed digitally described in this document can be generated with dyes or pigments by several processes, including ink jet, chromogenic (silver halide), thermal dye transfer processes, and electro photography, excluding lithographic printing, screen printing and other non-digital printing.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18913, *Imaging materials — Permanence — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18913 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

test load

cumulative dose, which is the product of a stress level and exposure time

3.2

specimen aim temperature

controlled aim value temperature of the specimen by configuring the light exposure equipment

4 Overview

4.1 General

This document describes approaches for the evaluation of image permanence of photographic colour prints in consumer home applications. The use profile “consumer home” is defined with two sub-cases i) display and ii) storage. In addition, variants of the use profile due to “partial protection” are introduced.

Then, suitable accelerated test methods representing single factor testing of the four leading environmental factors are described, which are considered important for characterization of image permanence in this use profile. Limitations of these laboratory tests are set into perspective.

Different approaches of collecting and reporting test data are presented. In addition, the advanced reporting level based on eventual translation of test data into print life expectations is introduced together with limitations of such predictions.

The definition of end of test and the interdependence of their meaning with test target design and evaluation metrics are discussed.

4.2 Use case

Within the consumer home use profile, there are two main use cases for colour photographic images, namely display and dark storage, in which the four leading environmental stress factors heat, light, atmospheric pollutants and humidity have different weights. In both, additional (partial) protection against some environmental factors may be introduced by suitable enclosures that create a “micro-environment”, in which the level of one or several environmental factors is reduced. For example, framing of displayed colour prints with glass, plastic, or other materials can introduce additional protection against degradation caused by light or pollutants or both. In dark storage, light-tight enclosures, such as “shoe box” and albums, first of all will help to reduce the level of light exposure as well as help to reduce the level of active atmospheric pollutants due to the lack of air exchange inside the box. Levels of heat and humidity could only be reduced by air-conditioned environments as shown in [Table 1](#).

Table 1 — Major and minor stressors for various storage and display use cases

	Heat	Light	Atmospheric Pollutants	Humidity
Dark Storage Protected	Major	Not a factor	Minor	Major
Dark Storage Unprotected	Major	Not a factor	Major	Major
Display Protected	Major	Major	Not a factor	Minor
Display Unprotected	Major	Major	Major	Major

NOTE 1 Additional protection in storage and display environments can be provided as follows:

- In the dark environment by enclosures which limit air exchange;
- In the light environment by framing with UV absorbing glass which reduces damaging light and also limits air exchange.

NOTE 2 The “Display Protected” category is considered to be “Not a Factor” for atmospheric pollutants only if the protecting frame is sealed to prevent any exchange of air. Atmospheric pollutants, such as ozone, are extremely reactive and are not retained in closed (protected) spaces, while humidity can penetrate into the enclosure and remains for a long period.

NOTE 3 Dark storage protected and display protected provides protection against short-term humidity excursions.

Typical ranges of environmental factors in the use profiles “consumer home” are given in [Clause 8](#).

4.3 Single factor tests and their limitations

A typical approach for image permanence testing for indoor use profiles is based on single factor accelerated test methods that assess the susceptibility of the print to degrade for each of the four leading environmental factors one at a time. Prints are exposed to one of the factors heat, light, humidity and atmospheric pollutants and the other stress factors are set to zero or a 'neutral' level. Ozone was chosen as model system for atmospheric pollutant, acknowledging that SO_x , NO_x and other atmospheric pollutants are also present in the indoor environment and that exposure to these may result in different image fading results^{[1][2]}. A considerable level of acceleration is needed in the test methods for the evaluation of degradation by heat, light, ozone, and humidity, because the degradation of many modern colour print images by these stress factors is too slow to yield timely information about their long-term effects.

For example, in assessing the image degradation of a reflection print due to exposure to light, the accelerated test method in ISO 18937 specifies that the test be conducted under air that contains <2 nl/l ozone at an air temperature and relative humidity of 21 °C to 27 °C for control specimen aim temperature and 50 % ± 5 % RH, respectively. These conditions ensure that any image degradation observed will be due primarily to light exposure and not to ozone, thermal, or humidity. These are designed to minimize the contribution from each other.

An overview of the single factor test methods and their setting for the other environmental factors is described in [Table 2](#). Users can set conditions by controlling their testing equipment.

Table 2 — Test conditions described in test methods International Standards

	Reference ISO	Heat	Light	Ozone	Humidity
Thermal stability	ISO 18936	main factor	dark	<2 nl/l	50 % RH
Light stability	ISO 18937	21 °C–27 °C	main factor	<2 nl/l	50 % RH
Ozone stability	ISO 19841	23 °C	dark	main factor	50 % RH
Humidity resistance	ISO 18946	25 °C	dark	<2 nl/l	main factor

The conditions in the top row (Thermal stability) are not a strictly pure single-factor test of heat; it actually includes the combined stress contributions from both humidity content and temperature. The variation ranges of moisture content of the humidity test conditions listed in the bottom row (Humidity resistance) is a sub-set (within the variation range) of moisture content in the thermal test, but without the involvement of temperature variation.

Some caveats need to be considered, when prints are tested together with some means of protection. For example, testing light stability of framed specimen print with glazing may result in elevated specimen temperature. In addition, material that may outgas during the test could become trapped in the vicinity of the test specimen, and induce additional image degradation. Similarly, test specimens that are laminated may also be subject to interactions that may confound the test results. The user is cautioned to keep such phenomena in mind if unexpected results occur.

This document advises the use of standard test parameter settings with fixed exposure or test load conditions to collect test data for reporting. It is recognized that other test parameter settings may be more representative for particular instances of the use profile or other applications. These other conditions may then be reported in addition and to the standard test parameters settings mentioned before.

The user of this document is advised that the actual image degradation that is observed by the end user or consumer will be a combination of all the degradation modes discussed above. However, complex interactions may exist between these different failure modes, which are not covered by the single stress factor of test approach. For example, the reported photochemical instability of the yellow stain developed during thermal aging^[15] makes simple linear combinations inappropriate.

4.4 Accelerated tests and the concept of reciprocity

An important element of accelerated testing is the level of reliability obtained for the predicted results.

In thermal testing, for example, the underlying model for acceleration is based on a first order thermally activated process. The validity of that assumption is verified by a linear dependence of data in the well-known "Arrhenius-plot" described in ISO 18924.

The accelerated testing of degradation under both, light and ozone, is based on the concept of reciprocity. In the case of light, the principle of reciprocity states that increasing the incident light intensity without changing the spectral distribution of the illumination, while maintaining the same temperature and relative humidity will produce a proportional increase in the rate of photochemical reactions that cause colorant fading and stain formation^[3]. But, different results may be obtained when colour prints are irradiated with high or lower-intensity light, even though the total exposure or test load (intensity × time) is kept constant^{[4][5]}. This is called reciprocity failure and is often related to limitation of effective reaction rates by e.g. slower transport processes or competitive side reactions. Reciprocity failure in a light stability test means, that e.g. the effect of exposure to light of 1 000 lx intensity for 2 h is not the same as the exposure to light of 100 lx for 20 h.

Also in case of ozone testing, a combined transport and reaction process is present and the rate of degradation may not linearly increase with ozone concentration. Reciprocity failure on ozone stability test means, that e.g. the effect of exposure to ozone gas of 10 µl/l¹⁾ intensity for 20 h is not the same as the exposure to ozone gas of 1 µl/l for 200 h. For their information, the interested user may refer to the references listed below^{[6] to [13]}. Because reciprocity law failure can cause serious mis-predictions due to erroneous tests results, the user is strongly encouraged to determine if the system under test obeys the law of reciprocity or if it exhibits reciprocity law failure.

4.5 Concepts and limitations of data reporting

For actual testing of printed images, specific test targets with well-defined patches are prepared. Construction of the test targets depends on the failure modes, for which the changes need to be measured. ISO 18944 provides examples of test targets used for measurement of colour fading. The test target construction (frequency and distribution of test colours in colour space) as well as the approach for statistical data analysis together define the numerical values of the changes observed. Test target design and the actual difference metrics for measurement the change in colour are therefore indispensable elements in the definition of end of test and need to be selected to provide good correlation with visual judgements in view of the use profile.

Raw data collected from the image permanence tests are typically the changes in colour as function of exposure time at a specific stress level, which are then conveniently expressed as cumulative exposure, for example Mlx·h for light tests and µl/l·h for ozone tests. These raw data are sometimes translated in some rating, classification or expected print life supposing the actual usage of the prints.

TC 42/WG 5 initially had made it a goal to translate the test results to print life in "years". However, it has been suspended due to the following reasons.

- a) The "prediction" of print life is inherently difficult because of the reciprocity failure problem, differences of the test conditions from the actual environment, the synergetic effects or other stress factors (e.g. combination of light, thermal and humidity), and others.
- b) The actual environmental conditions within the use profile "consumer home" vary widely. For example, the light level of consumer homes can vary from less than 10 lx to over 1 000 lx, and the ozone level of consumer homes can vary from almost zero or less than 1 nl/l to over 30 nl/l.
- c) Given this, the years generated from the test predictions will likely be much different from the actual performance the consumer may see. Because of all the variables in the consumer environment, the actual performance the consumer will see may be much worse or much better than predicted.

1) 1 nl/l = 1 ppb (1×10^{-9}) and 1 µl/l = 1 ppm (1×10^{-6}). Although the notation "ppb" (parts per billion) and "ppm" (parts per million) are widely used in the measurement and reporting of trace amounts of pollutants in the atmosphere, they are language-dependent and therefore not used in the document.

It became apparent during discussion that it was decided to divide data reporting into three levels and discuss them as follows. The following three levels have been agreed upon for evaluation of image permanence of photographic colour prints in consumer home applications.

Level 1 is Test methods, test conditions and Basic Reporting rule.

Level 2 is End of test criteria.

Level 3 is Environmental conditions of consumer homes and Advanced Reporting.

In Level 1, two Basic Reporting methods were proposed and discussed. One is reporting the changes in graphs and the other is reporting the fade values at a fixed load. Fundamental test results will be reported by using these reporting methods. While Basic Reporting (graphical reporting or a fixed load approach) does not translate directly to a time based response like years, it may still be possible to provide information for customers on whether or not the product meets customer expectations. If a “reference” can be agreed upon, any product that shows less of a change (Delta E or Delta density) in a fixed load response or shows, a curve with a lower slope (rate of change with increasing stress value less than check) can be shown to meet or exceed customer expectations. However, the challenge here is agreeing on an appropriate “reference curve” for graphical reporting or a “spec limit” for fixed load reporting. The committee has discussed this on numerous occasions but has not yet been able to reach a consensus. In Level 2, Total exposures to the end of test will be described. In Level 3, Total exposures will be translated to an “X years”, bins (star-rating, etc.)

In this document, the issues related to level 1 are explained in [Clause 6](#). The details of level 2 are described in [Clause 7](#), and Level 3 is explained in [Clause 8](#).

The purpose of Level 2 and 3 is to provide reporting procedures in order to make it possible to translate the test results obtained from the above-mentioned test methods, which use accelerated exposures to heat, humidity, light, or ozone, to information, which is related to life expectancies of photographic images.

5 Preparation of test targets and analysis

5.1 General

The test targets contain a specific selection of colour patches that sample the colour gamut of the printing system in a representative way. The test colour selection given by a specific test target, together with the colour distance metrics (densitometric, colorimetric) employed, and the figures of merit derived from statistical data analysis (average, percentiles) determine the (range of) values measured as colour change after testing. The meaning for that range of values is then correlated to visual perception by psycho visual testing in order to define end of test. In addition, handling of the specimen is described in this document. The following factors influence the test results for print-life-estimations of photographic colour print images. The outlines are described here.

5.2 Factors influencing the test results

5.2.1 Test design

The test results may be varied depending on the test target, especially the densities and chromaticity of the patches to be measured before and after the image permanence test. The size of the patches is decided based on the geometric restriction of density or chromaticity measurements.

5.2.2 Test conditions

Accelerated tests are carried out under the stress condition for a specific factor, such as light or gas, etc. The other factors than the stress factors influence the test results. In general, temperature and humidity are essential factors. Airflow can also influence the test results.

5.2.3 Measurements

Densities or chromaticities are measured. The geometry of the optical measuring equipment is essential for the accurate and precise measurements. The light source, especially the inclusion or exclusion of the UV components are influential to the test results.

5.3 Test target

5.3.1 General

Test prints can be prepared according to the requirements given in the appropriate test method standards for the four environmental factors of heat, light, ozone and humidity. Test target, measurement, sample handling and preconditioning can be found in ISO 18944 for colour stability testing and ISO 18946 for humidity fastness testing.

ISO 18944 stipulates the details of sample preparation, including dry-down procedures for thermal, light and ozone stability testing, because most printing systems directed to the consumer use case start from sRGB encoded image information, a set of sRGB values has been defined that represents primary (CMYK) and secondary (RGB) colours with systematic variation of CIE L^* along the surface of the colour gamut that can be achieved by the system under test. From these sets, the neighbouring patches encompassing the starting densities of 0,5, 1,0 and 1,5 are identified. The neighbouring patches are used for interpolation as described in detail in ISO 18944.

There are two test targets available in ISO 18944: Test target designs are shown in Figure 1. One is the sRGB linear target shown in Figure 1 a) originally designed, and the other is the CIELAB constant hue target shown in Figure 1 b) uniquely designed. Users can choose either one of two depending on the objective of evaluation. Even though originally designed for densitometric analysis, the colour changes based on these sRGB test targets can also be evaluated using colorimetric analysis.

Image permanence performance of measures can be based on the degradation resulting for each of these initial optical densities. In general, the rate of image fading varies with the initial optical density.

Minimum density patches ($D_{\min}$, usually paper white) also are included for evaluation of stain.

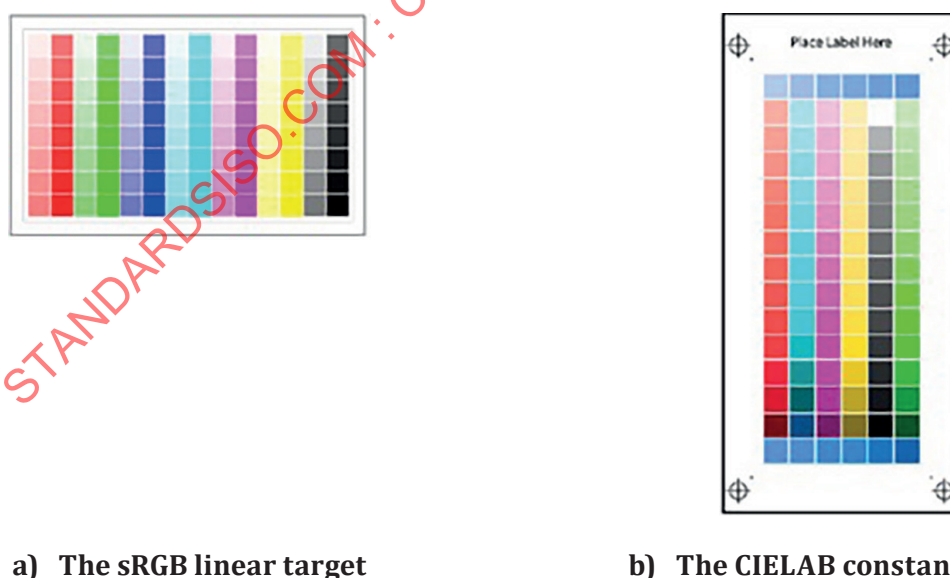
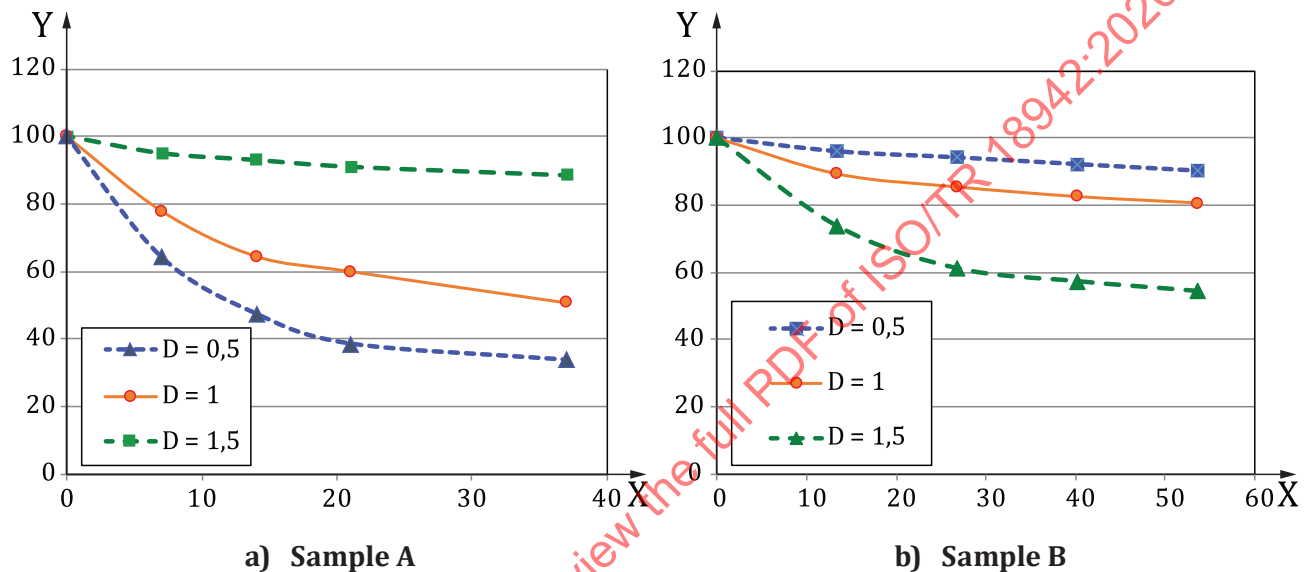


Figure 1 — Test target designs

In ISO 18944, the patch used for the evaluation of print life can be as follows. The initial density is $D_{\min}$, $0,5 \pm 0,05$, $1,0 \pm 0,10$, and $1,5 \pm 0,15$ measured in Status A or T. If the maximum optical density for any

colour is less than the target value, then the highest value possible for that printer system can be used. The colour includes Neutral, Y, M, C, R, G, and B.

Reasons for including the density of 0,5 and 1,5 patches are as follows. In ordinary cases, fading behaviours differ depending on the density range. In many cases the fade rate is faster at lower-density than the higher-density. Examples of fading curves of dependence on the initial density are shown by Sample A in Figure 2. Figure 2 a) shows an example of the density loss as a result of light expressing the stability of colorant itself. On the other hand, in some cases the fade rate is faster at higher-density than lower-density by Sample B. Figure 2 b) shows an example of the density loss because of light fading, observed on the R patches for initial densities of 0,5, 1,0, and 1,5 for an inkjet print. In this case, different colorants are used for the higher-density and lower-density ranges.



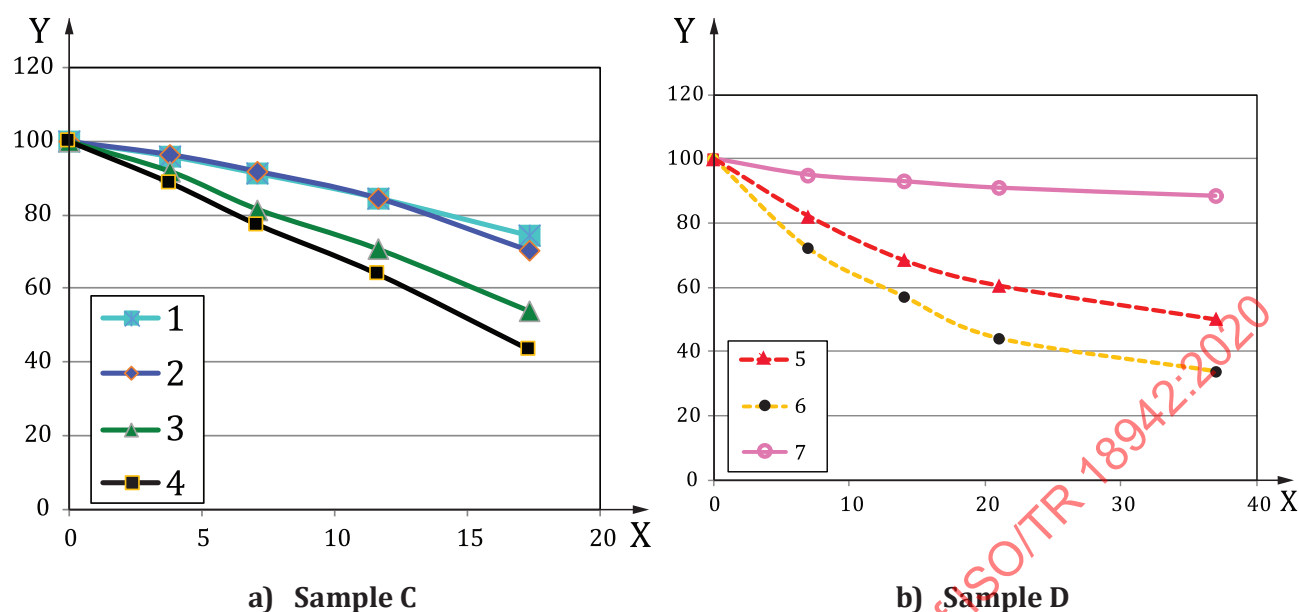
Key

X duration (Mlx·h)

Y residual R density (%)

Figure 2 — Examples of fading curves — Dependence on the initial density

Reasons for including the RGB patches are as follows. In some cases, the fading behaviours of R, G, and B patches differ from those of Y, M, C, or neutral patches. Examples of fading curves of dependence of the colour of the measured patch are shown in Figure 3. An example of the different fading behaviour of primary (cyan), secondary (green and blue), and neutral patches, observed in the density change of a thermal dye transfer process print during a light stability test is shown by Sample C in Figure 3 a). In the case the fading behaviours of R, G, and B patches about same with those of Y, M, C, or neutral patches, it can be evaluated of image permanence by using only Y, M, C, and neutral patches. An example of the same fading behaviour of primary (yellow and magenta), secondary (red), observed in the density change of an inkjet print during a light stability test is shown by Sample D in Figure 3 b).

**Key**

- X duration (Mlx·h)
Y residual R density (%)
- 1 cyan
 - 2 blue
 - 3 green
 - 4 neutral
 - 5 red
 - 6 yellow
 - 7 magenta

Figure 3 — Examples of fading curves — Dependence of the colour of the measured patch

$D_{\min}$ is measured using colorimetry, because it is more appropriate for $D_{\min}$ evaluation, and it is not possible to attain adequate precision with density measurements, especially for Arrhenius analysis of heat stability test.

For the humidity fastness test the checkerboard test target contains all of the combinations of Y, M, C, R, G, and B, white and black as a checkerboard pattern. It includes patterns consisting of solid-fill colour patches, which are used to evaluate changes in colour quality and includes patterns consisting of colour patches with a fine checkerboard of interleaved colour squares, which manifest colour changes that correlate well with loss of line quality caused by lateral migration of colorants.

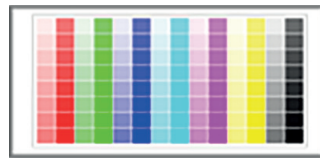
For evaluation of thermal, light and ozone stability testing, the same target is used to compare multiple samples. There are many data of the dependence on the target design for image permanence by several processes, including ink jet, chromogenic (silver halide), thermal dye transfer processes, and electro photography.

For examples, electro photographic prints show significant dependence on the target design for the density change of light stability^[16]. When the sRGB linear target with pure Black (K) and the sRGB linear target with process Black (CMY) are compared, the change in the colour balance is often more obvious for process Black than pure Black. This example shows the influence of the choice of test target on colour changes obtained.

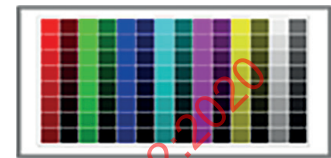
On the other hand, some test data shows almost no dependence of density losses on the selection of the test target. Comparison of three types of target for test are shown in Figure 4. For example, for the density change of light fading, three types of targets are compared, the CIELAB constant hue target in Figure 4 a) Target 1, the sRGB linear target are shown in Figure 4 b) Target 2, and the sRGB linear target process Black in Figure 4 c) Target 3, Target 1 and Target 2 are defined in ISO 18944. In this example, Figure 5 show the fading behaviour of C, M and Y, observed in the density change of two ink jet systems a prints (Sample A and B), where there is almost no dependence on the test target during 34 Mlx·h and 68 Mlx·h for the light stability test.



a) Target 1

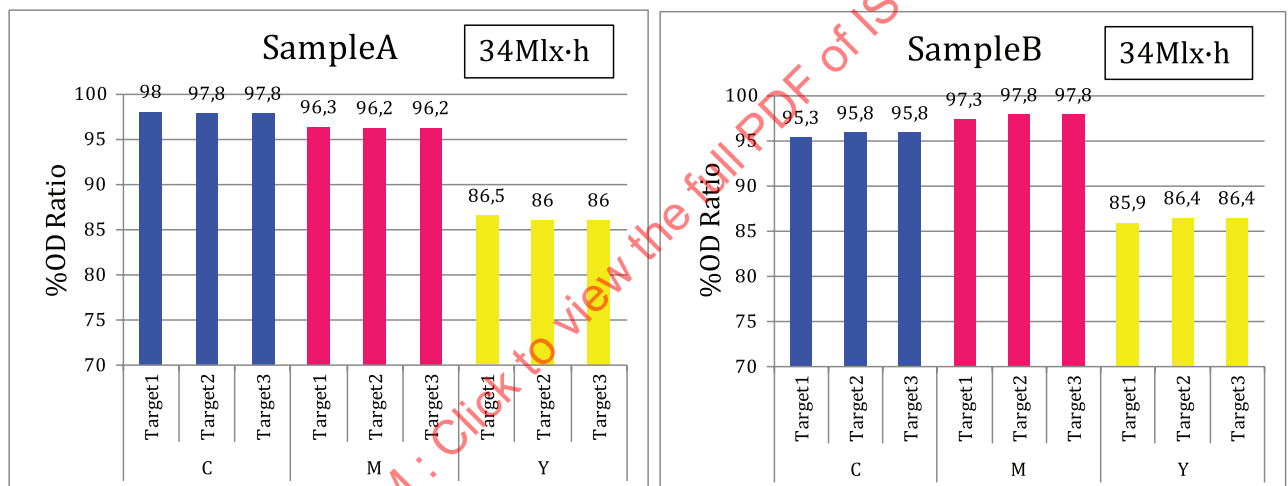


b) Target 2

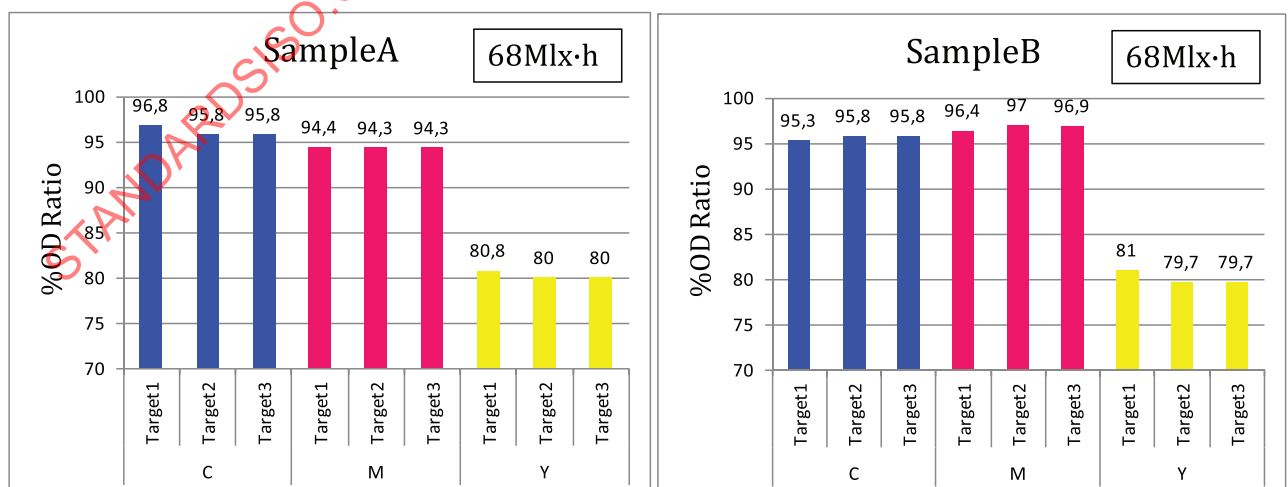


c) Target 3

Figure 4 — Compared three types of target



a) Density loss during 34 Mlx·h on light stability test



b) Density loss during 68 Mlx·h on light stability test

Figure 5 — Density Loss on light stability test

Furthermore, a test target that uses pure C, M, Y, R, G, B, (e.g., B = 255, G = 255, R = 0 for C), and neutral digital values has been widely used for image permanence tests. One problem with this test target is that we cannot attain a high density, such as $D = 1,5$ or sometimes even $D = 1,0$, for cyan or certain other primary colours with some sRGB printers. To attain the density required for the test, a new test target containing mixed-colour digital value patches (e.g., B = 198, G = 191, R = 39) was proposed instead of pure Y, M, C, R, G, and B values. This is justified because pure colours such as pure cyan or pure magenta are rare in the real world, and printers mix colours even if we use a pure colour data target.

We consider that the ultimate goal is a test target with all of the combinations of colours, plus colorimetry analysis that takes into account the importance of each colour. Regarding the importance of each colour, it is shown as follows the frequency of each colour region in photographs recorded in 4 000 pictures taken by several hundred digital still cameras (DSC) users as shown in [Figure 6](#)^[14]. [Figure 6](#) indicates that the frequency near the centre part, which is near to neutral, is relatively high, which means that the colour of the photographic subjects disperse around the neutral colour. The RGB data were converted to Lab values assuming the sRGB colour space.

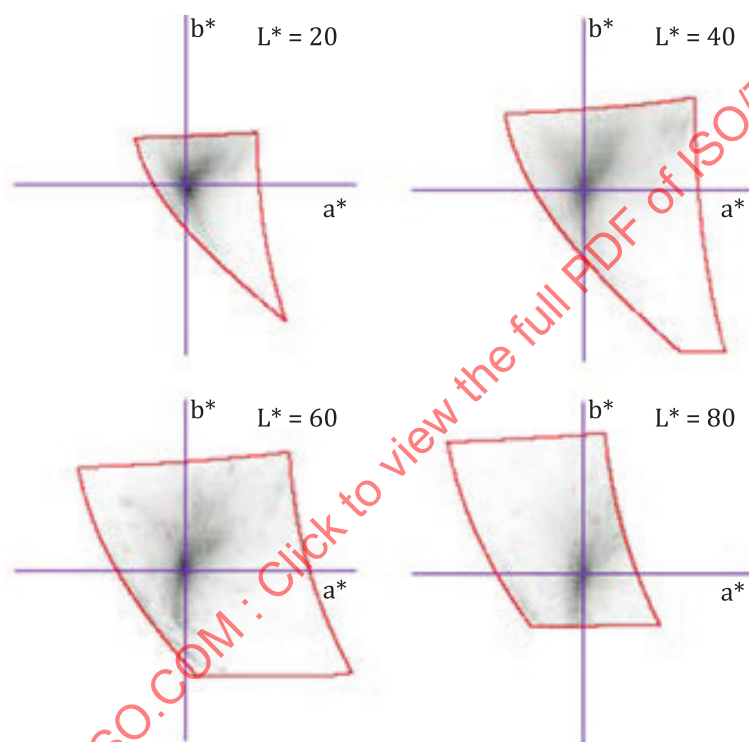


Figure 6 — Frequency of colour regions in photographs recorded by DSC users

5.3.2 Humidity test target (ISO 18946)

ISO 18946 stipulates preparation of the printed test sample, including dry-down procedures for humidity fastness testing. The humidity test target is designed with checkerboard patches and full patches in [Figure 7](#), so that colour changes due to humidity induced, bleeding can be quantified by macroscopic colour measurements. The average colour changes obtained from colorimetric analysis of the test targets have been correlated with visual judgement on pictorial images having undergone the same test conditions.

[Figure 7](#) shows a checkerboard test target in ISO 18946.

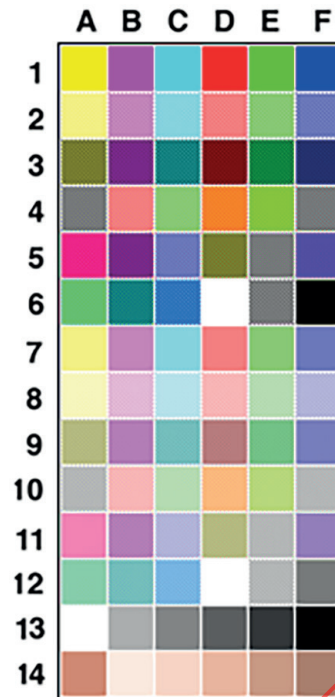


Figure 7 — Checkerboard target

5.4 Measurement (Density and colorimetric values)

5.4.1 General

Colour changes can be measured in terms of status filter densitometry or by means of CIE colorimetry. Status filter densitometry has a long legacy in photography and many results have been published that correlate densitometric changes with perception in consumer home use profile. In the meantime, CIE colorimetry has become more readily available and provides an alternative approach for measurement of colour changes.

5.4.2 Density values to be measured

Status filter of density measurement has been used throughout the modern history of the photographic industry. It is especially convenient for evaluation of silver halide based products, and it is appropriate and convenient for the research and development of photographic prints and their components, because each R (red), G (green) and B (blue) density change corresponds to the fading of the C (cyan), M (magenta) and Y (yellow) colorants, respectively. Due to this history, densitometry is mainly used even now, and TC 42/WG 5 has confirmed that densitometry continues to be used.

The density of the image is measured using the spectral conditions specified as ISO Status A or Status T densitometry as described in ISO 5-3. Reflection density can be measured as described in ISO 5-4.

Status A density is recommended for traditional photographic materials using RGB printing and Status T is recommended for graphic processes using RGB or CMYK printing.

The following densities of the specimens can be measured before and after accelerated testing.

The red density value is taken with respect to the cyan patch, the green density value with the magenta patch, and the blue density value with the yellow patch.

In other words, $dC(R)$ denotes the red density measured through the red filter for a primary cyan patch and $dG(B)$ denotes the blue density measured through the blue filter for a green patch.

a) C, M, Y Patches: $dC(R)t$, $dM(G)t$, $dY(B)t$

These represent the red, green, and blue densities at accelerated test interval t , where t is a value taken from 0 to the end of the test, of cyan, magenta, and yellow image patches.

b) Neutral Patches: $dN(R)t$, $dN(G)t$, $dN(B)t$

These represent the red, green, and blue densities at accelerated test interval t , where t is a value taken from 0 to the end of the test, of neutral image patches.

c) $D_{\min}$ patches: $d_{\min}(R)t$, $d_{\min}(G)t$, $d_{\min}(B)t$

These represent the red, green, and blue minimum densities (in the white patch) of the specimen at accelerated test interval t , where t is a value taken from 0 to the end of the test.

d) R, G, B patches: $dR(G)t$, $dR(B)t$, $dG(R)t$, $dG(B)t$, $dB(R)t$, $dB(G)t$

These represent the red, green, and blue densities at accelerated test interval t , where t is a value taken from 0 to the end of the test, of RGB-composite secondary-colour image patches.

5.4.3 Colorimetric values to be measured

Colorimetric analysis is applied for the evaluation of humidity fastness (ISO 18946 and ISO 18949) and also for measurement of thermal stability of substrate ($D_{\min}$ measurement in ISO 18936).

Furthermore, this colorimetric measurement has been discussed to be used as a general alternative for evaluation of image permanence. The CIE $L^*a^*b^*$ colour coordinates are measured and the colour difference ΔE_{76} or ΔE_{00} , is calculated. TC 42/WG 5 has compared the densitometry approach and colorimetric approach for evaluating colour fading in the context of light, ozone stability and thermal stability testing. The colorimetric approach seems to have some merits but both can be used.

Colorimetric values are measured and calculated as follows. L^* is the measured value for lightness. a^* is the measured value for the red-green colour coordinate, and b^* is the measured value for the blue-yellow colour coordinate as defined in ISO 11664-1 (CIE S 014-1/E) and ISO 11664-4 (CIE S 014-4/E).

Measurement condition: M1 (ISO 13655), Geometry: 450/00 with a 20 observer for the detector

Illuminant: CIE Illuminant D50. Parameter: CIE 1976 ΔE_{76} or CIE 2000 ΔE_{00}

ΔE , the change in colour differential from prior to the test, with the equation below:

Measure the $L^*a^*b^*$ (L_1^* , a_1^* , b_1^*) colour values of the specimen prior to the accelerated test.

Measure the $L^*a^*b^*$ (L_2^* , a_2^* , b_2^*) colour values of the specimen after the accelerated test, and find

$$\Delta E = \sqrt{\Delta L^* \cdot \Delta L^* + \Delta a^* \cdot \Delta a^* + \Delta b^* \cdot \Delta b^*}$$

where

$$\Delta L^* = L_2^* - L_1^*$$

$$\Delta a^* = a_2^* - a_1^*$$

$$\Delta b^* = b_2^* - b_1^*$$

The image permanence of photographic colour prints was evaluated based mainly on CIEDE1976 formula (ΔE_{76}). Future evaluations will also include CIEDE2000 formula (ΔE_{00}).

5.4.4 Discussion of densitometric and colorimetric approaches

The advantage of the colour density approach is that densitometry often directly correlates with the amount of colorant per area. This advantage has led to the widespread use of densitometric analysis in the photographic industry.

The downside of density approach is that there are cases in which the density data is difficult to correlate directly with human perception.

The advantages of the colorimetric approach are:

- ΔE can be directly related to human perception, even though ΔE is still not yet perfectly visually equidistant.
- It is possible to calculate the average ΔE value for several patches comprising colours with different densities.
- For example, the graphic printing industries have adopted colorimetric measurements.

The downsides of the colorimetric approach are:

- ΔE itself does not show the direction of change in the colour space. It describes only the distance between two chromaticity points: although if one looks into the changes in each component of ΔE , one may obtain some insight regarding the leading cause of the fading.
- The criteria for determining print end of test based on colour differences have not achieved wide recognition.

For example, the ΔE (colorimetric values) approach by graph as follows is shown in Figure 8. When there are many samples measured using this approach, it is possible to express results with one graph. In this example, for ΔE change of light fading, twenty samples of various types are compared.

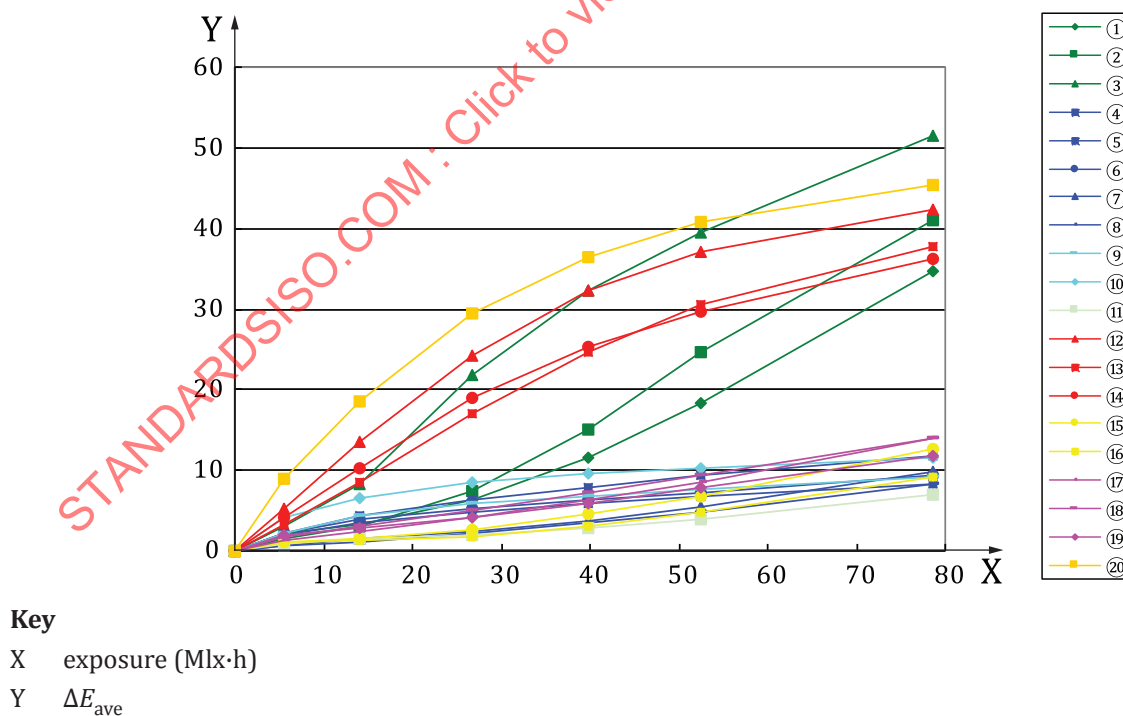
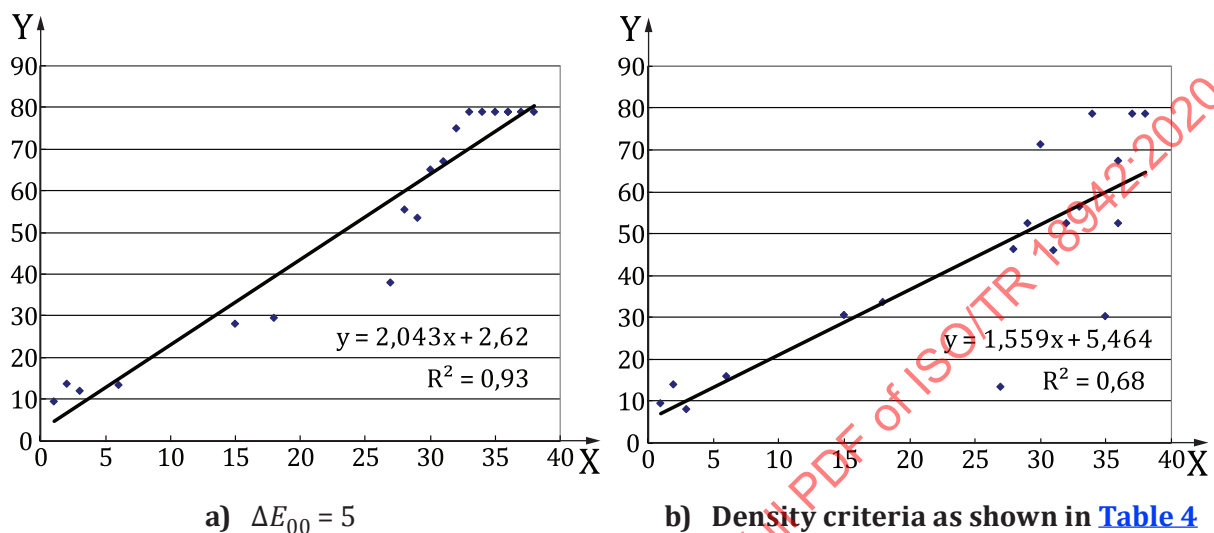


Figure 8 — Example of colorimetric approach

An example of comparison with a) the colorimetric approach and b) the density approach correspondence to the visual assessment is shown in Figure 9. Twenty faded images were visually assessed by two professional observers. The optical densities and chromaticities of the samples were

measured before and after exposure to different amounts of light. The values of the density changes and colour differences, E_{76} and E_{00} , were calculated for each set of fresh and faded samples. In this example, average ΔE_{76} and ΔE_{00} were better criteria. On the other hand, in TC 42/WG 5, it has been pointed out that visual assessment is very difficult. That is, the using Colorimetric for visual assessment may have lower correlation when using maximum Colorimetric than when using average or some percentile of Colorimetric. On the other hand, when using density for visual assessment, the difference in correlation is small. Furthermore, it has been pointed out that for robust visual comparison of dark colours, the illumination level would have to be increased.



Key

- X visual assessment score
Y light exposure (Mlx·h)

Figure 9 — Correspondence between visual assessment score and light dose to reach end of test

5.5 Preconditioning

Printed samples are stored at 23 °C and 50 % RH for 14 days before the accelerated test, in order to differentiate short term drying-down and long-term stability effects. This pre-conditioning is not mandatory if it does not affect the test results. For example, aqueous inkjet needs pre-conditioning, whereas silver halide and thermal dye transfer do not.

6 Test methods

6.1 General

The test method Standards ISO 18936 (thermal), ISO 18937 (light), ISO 18941 (ozone), ISO 18946 (humidity) and ISO 18949 (Low humidity) provide several options for test methods, conditions and reporting. To provide comparability of test results for the use profile “consumer home” specific options and conditions are selected.

6.2 Thermal stability

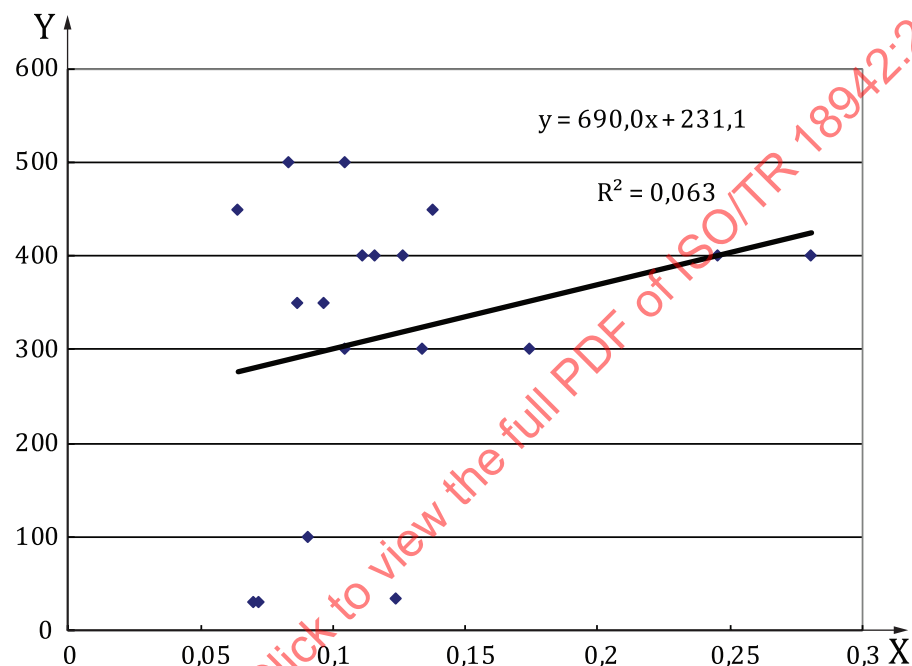
There are following two cases for thermal stability:

- Stability at high temperature, for example leaving the image in a vehicle;
- Stability at ordinary temperature for a long time.

For case a), the high temperature short-term tests are effective.

Case b) is very important and essential for photographic prints. For case b), the Arrhenius test is indispensable.

It is sometimes misunderstood that the higher temperature test results correspond to long-term stability somehow, even if it is a short-term test. [Figure 10](#) shows that there is not necessarily a correlation between short-term high temperature tests and the Arrhenius test. The latter has a protocol to crosscheck that the results may be extrapolated to the actual storage condition. A short term test at one high temperature may trigger failure modes not representative for low temperature long term use conditions, for example when testing a photographic material above the glass transition temperature of any of its polymeric components.



Key

X $D_{\min}$ increase/85 °C 50 % RH 8 W

Y Arrhenius prediction (years)

Figure 10 — $D_{\min}$ change — Arrhenius versus one-point high temperature test

Information for testing low glass transition temperature products is described in ISO 18936, and it points out the problems of conducting a thermal test above the glass transition temperature of a product^[10].

The humidity of the thermal stability tests is critical. 50 % RH is selected as the standard humidity for the test. 50 % RH is close to average relative humidity of consumer homes in the world is shown [Table 5](#) in [Clause 7](#).

Additionally, 20 % RH and 70 % RH can also be selected. 20 % RH is the lowest recommended RH for colour film storage in ISO 18911. While 30 % RH is the lowest recommended RH for colour prints in ISO 18920. However, 20 % RH (or lower) is commonly found in some climates (deserts, cold climates during heating season). On the other hand, from survey in Japan, 70 % RH is sometimes typical humidity of storage space like inside of albums are shown [Figures 23, 24 and 25](#) of [Clause 8](#).

There are two options to control the humidity or moisture content of the samples for the thermal stability test. One is the free hanging method and the other is the sealed bag method. The free hanging method at constant relative humidity can be used (see ISO 18936:—, 9.2.4). The sealed bag method is also a very good method, which can simulate the closed storage environment. The sealed bag method

is a constant moisture method (assume it is airtight during the entire test), which is quite different from constant RH method. If there is no additional hazardous species released during the test, then the sealed container method will yield less damage from moisture vs. the free hanging method (at 85 °C, the RH inside a sealed container is only up to 3,3 % RH, if it starts at 50 % RH at 25 °C). However, the free hanging method is recommended to obtain thermal stability data for specifications, because the free hanging method is more stable and free from variation as compared to the sealed bag method.

6.3 Light stability (Indoor display)

The light stability test follows ISO 18937 and illumination intensity, spectral power distribution, temperature and humidity need to be tightly controlled to not confound the single factor light fading test with thermal or humidity induced degradation. Acceleration in this test is based on the principle of reciprocity.

The illumination intensity is 80 klx or lower. The relative humidity of the air circulating the test chamber is 50 % RH. The Black Panel Temperature (BPT) and Chamber air temperature (CAT) set points are intended to result in a photographic print sample exposed under these conditions to be indirectly controlled at a specimen aim temperature.

For simulating indoor display condition, filtered Xe arc light source is preferably used. The justification is shown in [8.3](#).

The spectral power distribution of the test illumination source can be modified by the use of optical filters in order to simulate a particular usage condition. To control the sample surface temperature at the desired aim value, IR-reducing filters may be employed to reduce infrared energy above 800 nm. The window glass filter and UV cut-off filter with half cut wavelength (λ at $T = 50\%$) of 370 nm to 375 nm may be used for simulating indoor daylight typical home display. IR-reducing filter can be used as needed to meet the Black Panel Temperature and chamber air temperature of requirements.

Two specimen aim temperature are proposed as follows:

- a) 25 °C is preferred to avoid thermal interactions and is used if 25 °C can be reached without introducing humidity effects from the cooling equipment.
- b) 30 °C is allowable to avoid humidity variations induced by use of localized cooling equipment near ambient temperatures.

For specimen aim temperate calibration, one or more neutral patches with Status A or Status T density of $0,75 \pm 0,10$ are used in the light stability test. Specimen aim temperature exposed varies according to colour and colour density. An example of measurement is shown in [Figure 11](#), three types of filter system (non IR-cut filter, one IR-Cut filter and two IR Cut filters are used) are modified. Test conditions are 80 klx, air 23 °C 50 % RH using xenon-arc light source. These are compared with BPT, Bk and colour patches, paper, and WPT (White Panel Temperature). In this measurement, patches (Bk1 = dye, Bk2 = Pigment and Dye C, M, Y of Ink jet prints) with density 0,75 are used.

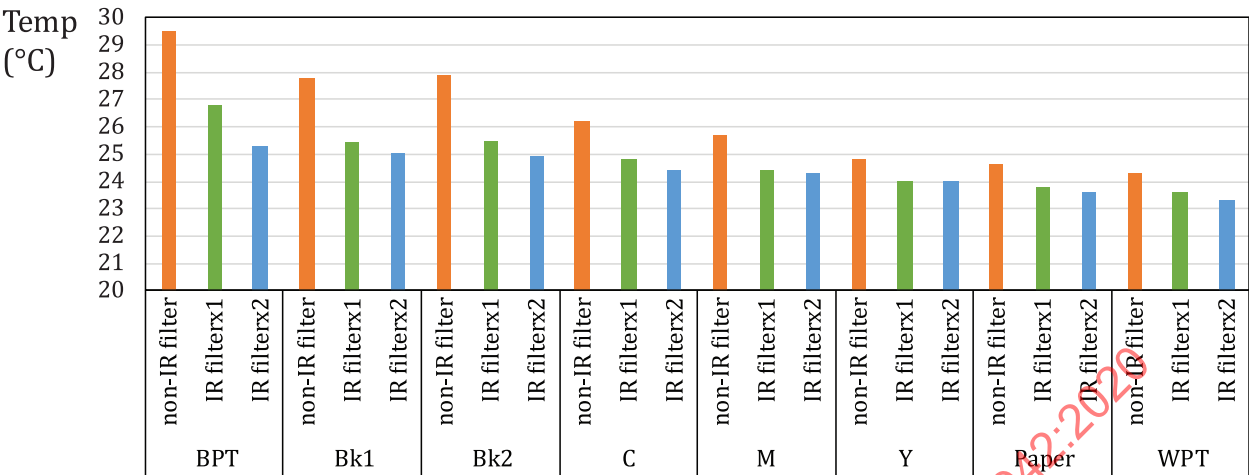
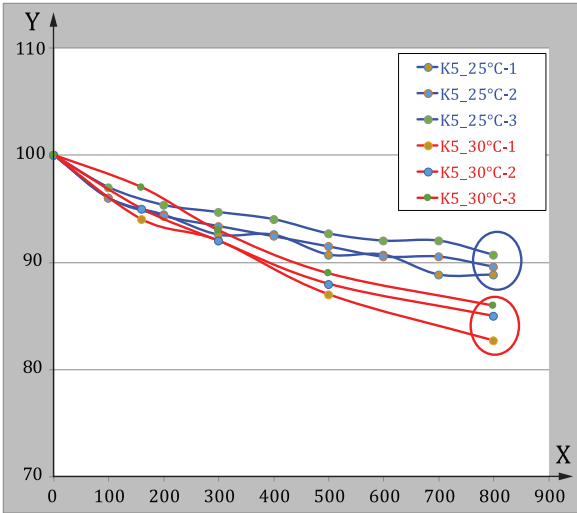
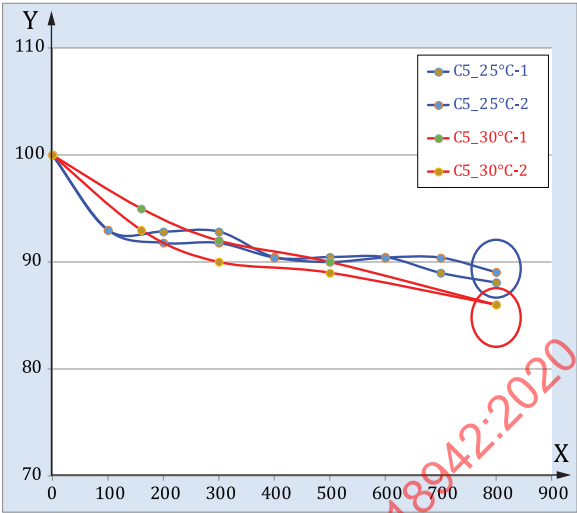


Figure 11 — Sample surface temperature exposed xenon-arc light source with IR filter

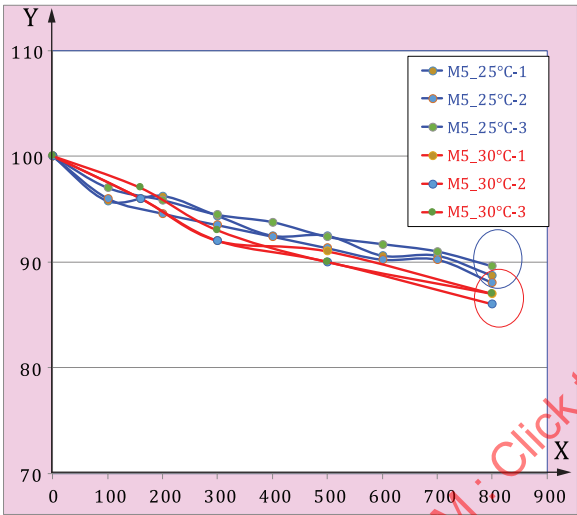
The temperature influences the results of density change of the light stability test. An example of the density dependence of light fading, observed in the K, C, M, Y density change for initial densities of 0,5, 1,0, and 1,5 (or maximum density) at specimen aim temperature 25 °C and 30 °C in an inkjet print is shown in [Figure 12](#). In this result, the blue circle is the change of density at 25 °C and red circle is change of density at 30 °C. In some cases, temperature dependence is large and the density change can be sensitive to the temperature. This tendency was observed in some ink jet prints.



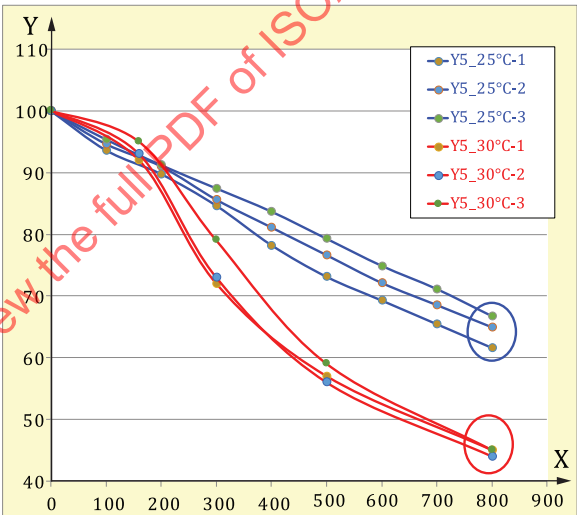
a) K density change



b) Cyan density change



c) Magenta density change



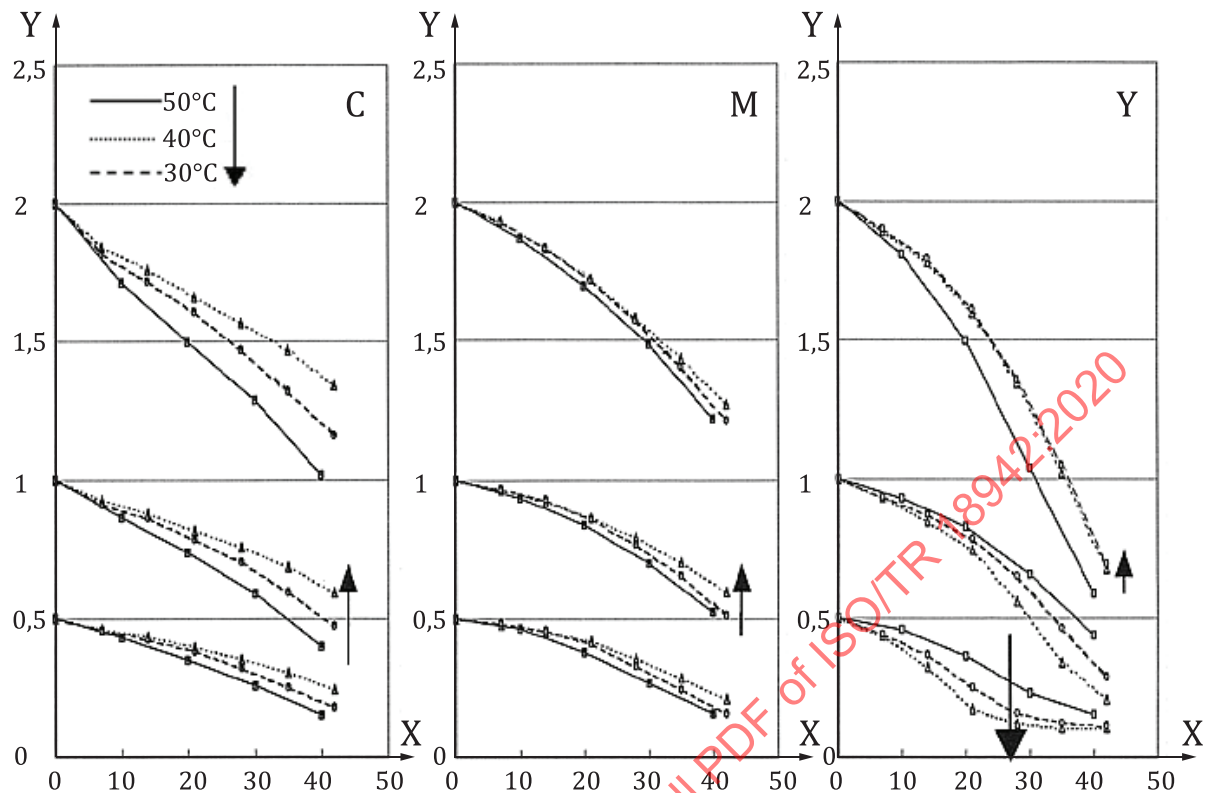
d) Yellow density change

Key

X duration (Mlx·h)
Y % OD Ratio

Figure 12 — Temperature dependence on density change

An example of the colour balance dependence of light fading, observed in the C, M, Y density change for initial densities of 0,5, 1,0, and 2,0 at specimen aim temperatures 35 °C from 50 °C in an inkjet print is shown in [Figure 13](#). Temperature dependence is large and the density changes and colour balance can be sensitive to the temperature.



Key

X time (d)
Y density

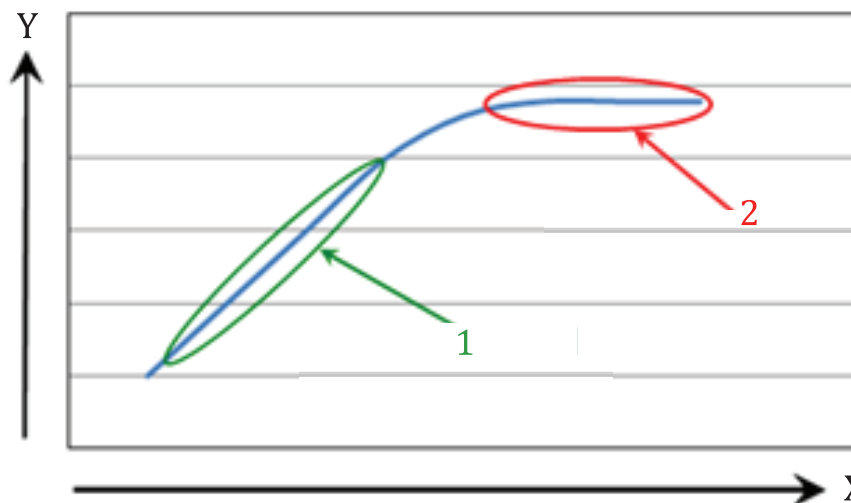
Figure 13 — Temperature dependence on colour balance

6.4 Ozone gas stability

Ozone gas stability is tested according to ISO 18941 and concentration, humidity and temperature need to be tightly controlled during the test to not confound this single factor gas fading test with thermal or humidity induced degradation.

The method used for the accelerated testing of ozone gas stability is based on the concept of reciprocity. Additionally, to avoid the confounding of factors, only a single accelerating factor is used in this test. On ozone gas concentration, the test is carried out at 1,0 µl/l as specified in ISO 18941:—, 9.4. Other optional concentration, such as 0,5 µl/l or 5,0 µl/l, may be useful for testing. If concentrations other than 1,0 µl/l are used, evaluating the materials for ozone reciprocity behaviour is required before any tests results can be evaluated, and before tests, results can be compared from one sample to another. The relative humidity of the air circulating the test chamber is 50 % and the temperature is 23 °C.

For inkjet prints, in particular those on porous media, it is known that the flow rate over the sample can have a significant impact on the results, especially for fast fading systems in [Figure 14](#).

**Key**

- X ozone concentration, flow rate or agitation, arbitrary units (AU)
 Y rate of change, (AU)
 1 dependent portion
 2 independent portion

Figure 14 — Effect of concentration, flow or agitation on rate of fade

An example of reciprocity failure on ozone gas concentration, observed in the C, M and neutral blue, neutral red, neutral green density loss for initial densities at five ozone concentration on one porous photo paper is shown in [Figure 15](#). Significant reciprocity failure is seen especially at the higher ozone concentration and especially in the cyan and magenta layers. In this example, temperature is 22 °C and the test chamber is relative humidity 50 %. Ozone concentrations of 1,0, 1,5, 2,1, 3,0 and 5,0 ppm (µl/l) were tested, with durations per [Table 3](#). As before, all test targets were equality spaced off impingement plenums using fixed position target mounts. A total of 18 targets were positioned in the centre six rows and centre three columns of the chamber and were impinged with ozone-enriched air from a plenums of orifice jets at 90° to the target. Another ten targets were positioned in the two outermost rows using the centre five columns but, in this case, the plenums were blocked so that these targets had no direct impingement.

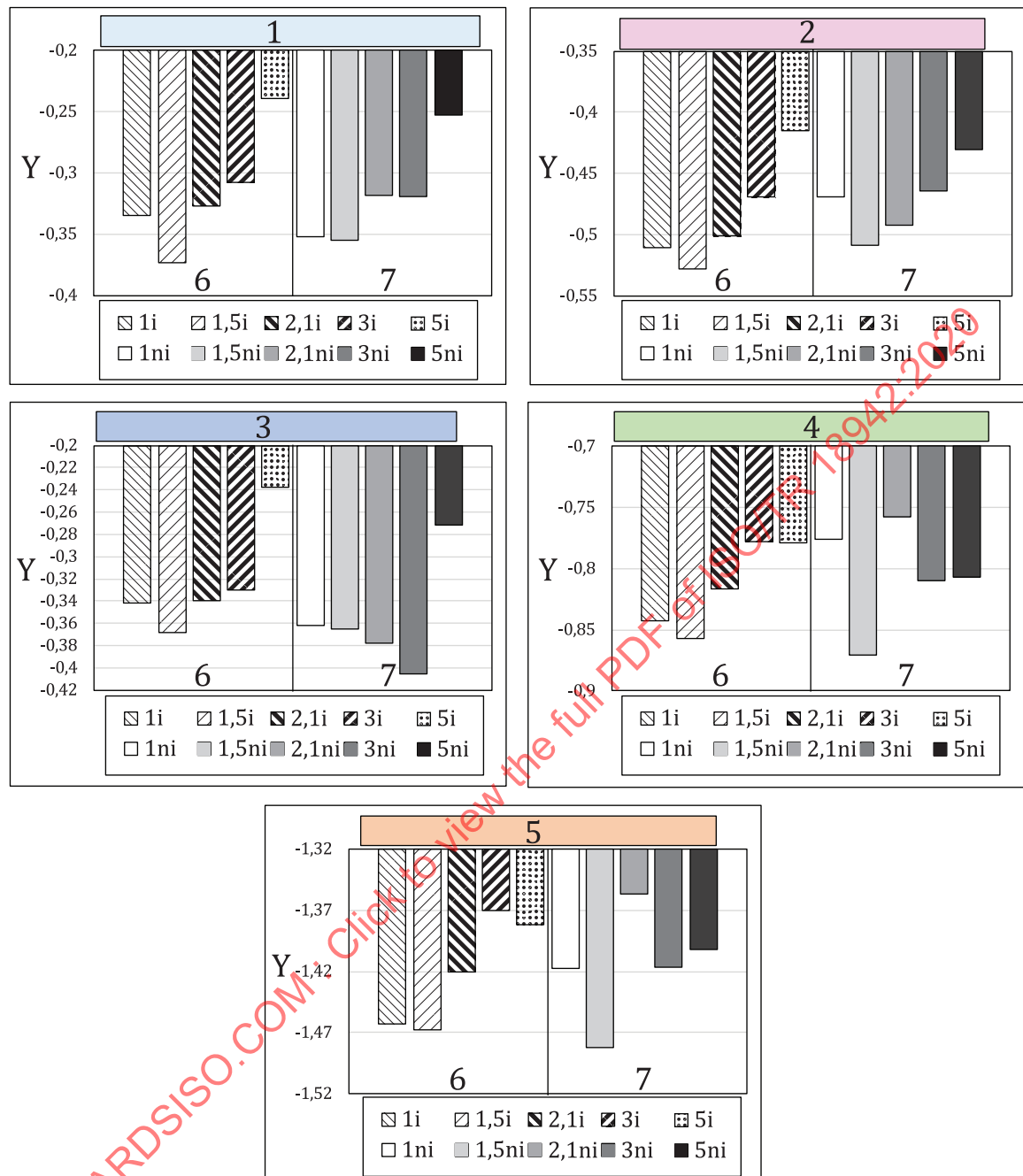
The impinged results obtained in these experiments did not allow for a clear differentiation between impinged and non-impinged testing. The impinged results showed a fairly consistent trend for all colour records. The non-impinged results don't exhibit that same consistency. There was no significant differentiation between using impinged and non-impinged exposure to ozone.

For accurate testing we operate

- at a high enough flow rate so that fade is independent of flow rate, and
- at a low enough concentration that fade does not become independent of concentration.

Table 3 — Ozone concentration versus test duration

Test phase	#1	#2	#3	#4	#5
ppm	1,0	1,5	2,1	3,0	5,0
504	504	336	240	168	101
days	21	14	10	7	4,2
ppm·h	504	504	504	504	504



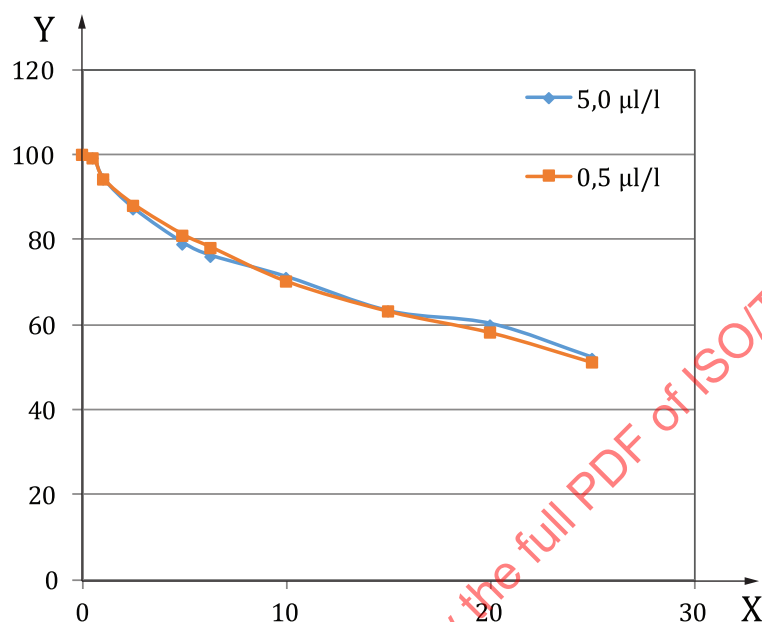
Key

Y density loss

- 1 cyan reciprocity — 72 F/50 % RH @ 504 ppm·h
- 2 magenta reciprocity — 72 F/50 % RH @ 504 ppm·h
- 3 neutral blue reciprocity — 72 F/50 % RH @ 504 ppm·h
- 4 neutral green reciprocity — 72 F/50 % RH @ 504 ppm·h
- 5 neutral red reciprocity — 72 F/50 % RH @ 504 ppm·h
- 6 impinged
- 7 non-impinged

Figure 15 — C, M, neutral Red, neutral Green and neutral Blue reciprocity results for impinged and non-impinged target

On the other hand, no reciprocity failure has been shown in tests between samples exposed to 0,5 µl/l ozone and those exposed 5,0 µl/l^{[17][18]}. An example is shown in [Figure 16](#). The inkjet samples tested in [Figure 16](#) tend to have no reciprocity failure with density degradation having little influence from ozone concentrations. In this example, ozone density dependence for dye-based inkjet printed on porous inkjet media is reported. There is no reciprocity failure only for fast fading prints such as non-ozone resistant dye on porous media, but reciprocity failure can occur in slow fading prints. Furthermore, reciprocity failure, or lack thereof, is highly dependent on the inkjet system being tested, including both ink type (dye or pigment) and media type (swellable or porous).

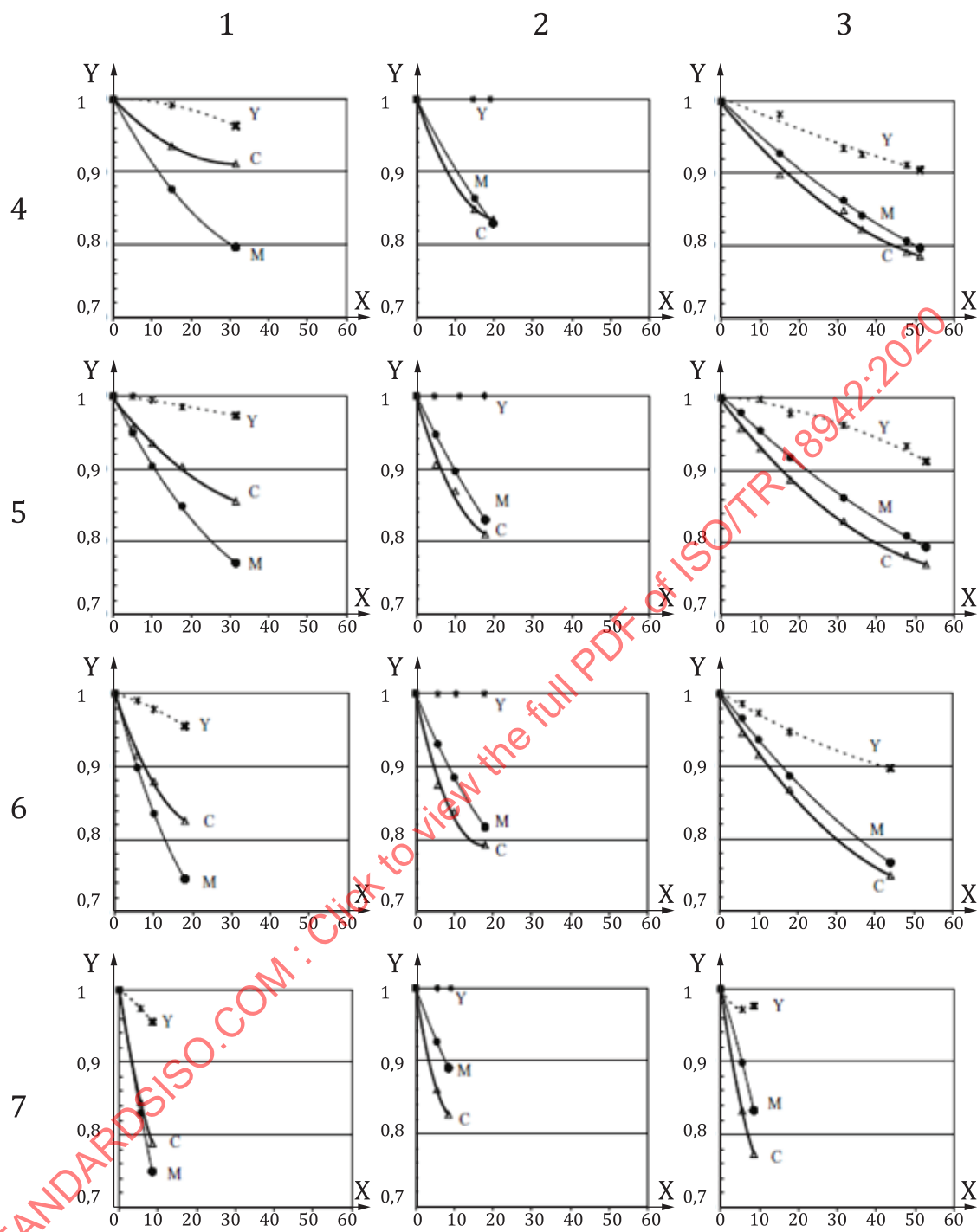


Key

X ozone exposure (µl/l-h)
Y residual R density (%)

Figure 16 — An example of fading curve — Ozone level dependence

The relative humidity of the environment can have a major impact on the rate of ozone fading in density change. An example of humidity dependence on density change for dye-based inkjet printed on porous inkjet media is reported in [Figure 17](#). Three OEM dye Ink jet printers (A, B and C) and porous paper combined in this test. In this example, temperature is 23 °C and relative humidity is arranged 40 % through 70 % in 10 % increments.



Key	
X	ozone exposure (ppm·h)
Y	neutral scale optical density
1	OEM Mfg. A (dye ink/porous paper)
2	OEM Mfg. B (dye ink/porous paper)
3	OEM Mfg. C (dye ink/porous paper)
4	40 % RH @23 °C
5	50 % RH @23 °C
6	60 % RH @23 °C
7	70 % RH @23 °C

Figure 17 — Humidity dependence on density change

6.5 Humidity fastness

Two types of high humidity tests (Method A and Method B in ISO 18946) and one type of low humidity test (ISO 18949) are proposed.

Temperature and exposure time are important for humidity fastness.

Method A tests the degree of the deterioration (average ΔE of the printed image) quantitatively in a fixed humidity condition, i.e. 25 °C and 85 % RH for 1, 2, 4, or 8 weeks. Method A is most useful for research and development of printing systems or printing materials where humidity fastness of many samples can be screened and closely compared.

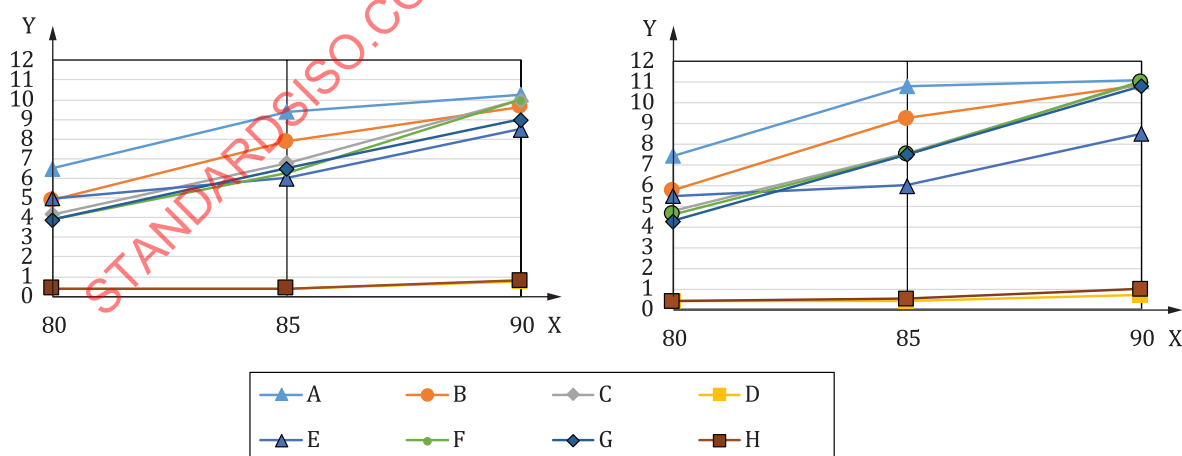
Method B tests the limitations of printing systems and materials by analysing data from tests at various levels of humidity, i.e. 25 °C for two weeks at three or more humidity levels chosen from 60 %, 65 %, 70 %, 75 %, 80 %, 85 %, 90 % and 95 % RH, and showing where each sample starts to deteriorate. Method B is especially useful for communicating with end users who will be able to recognize the high humidity limitations for each product tested.

Low humidity exposure is required for testing the $D_{\min}$ stability of the imaging substrate, as well as physical properties of the substrate.

ISO 18949 tests the propensity of the image-receiving layer or underlying substrate to yellow upon exposure to low relative humidity, i.e. 25 °C at 20 % RH for up to six months

Method A and ISO 18949 were recommended for specification of humidity fastness test.

Examples of three humidity conditions and exposure time, on 80 % RH, 85 % RH and 90 % RH for two weeks and four weeks on eight System IJ prints samples are shown in Figures 18 and 19. System A, B, C and D are OEM dye Ink jet printers 1, 2, 3 and one pigment Ink jet printer 4 and porous paper combined in this test. System E, F, G and H are OEM dye Ink jet printers 1,2,3 and one pigment Ink jet printer 4 and polymer coating paper combined in this test. In this example, on 80 % RH after two weeks the yellowing and the colorimetric change of most samples change are done. Porous and polymer coating paper do not show significant differences. Pigment prints are quite stable. On 85 % RH, after four week the colorimetric change of the some samples are ongoing. Furthermore, it is shown that 90 % RH is a high enough condition for comparing of humidity fastness. Because 90 % RH may be observed in the room etc. on high humidity conditions, material differences corresponding to market complaints can be detected in 90 % RH condition.

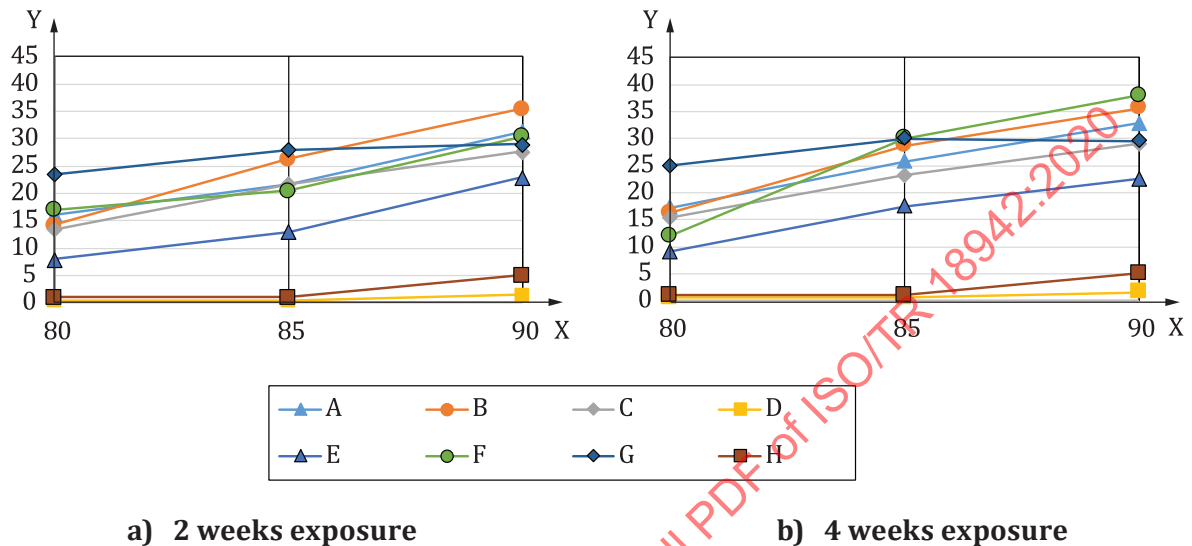


a) 2 weeks exposure

b) 4 weeks exposure

Key

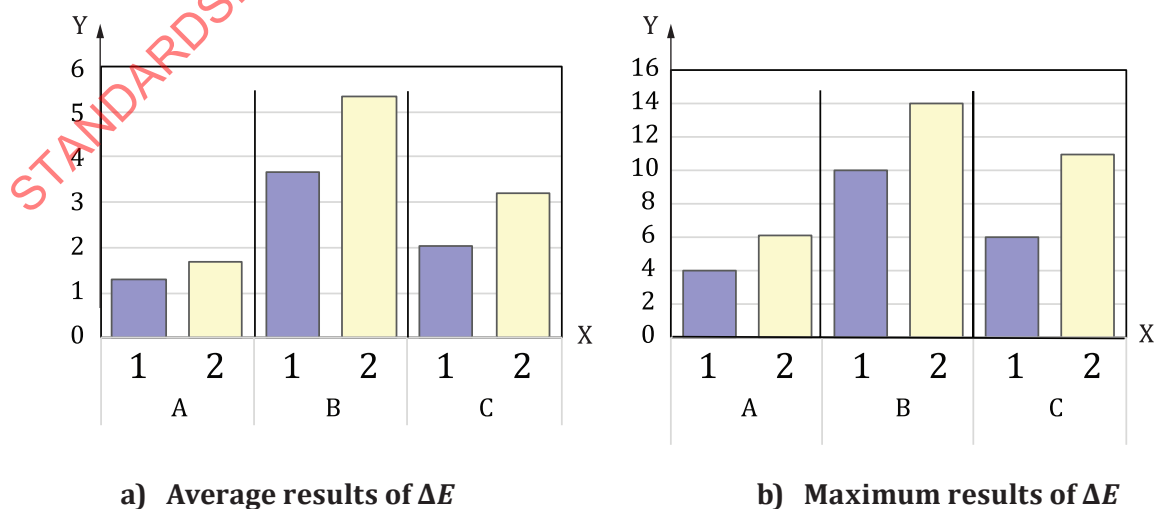
X humidity (% RH)

Y ΔE **Figure 18 — Average results of ΔE on humidity fastness test****Key**

X humidity (% RH)

Y ΔE **Figure 19 — Maximum value results of ΔE on humidity fastness test**

Airflow rate and flow direction against the sample are important for humidity fastness test (see [Figure 20](#)). Three OEM dye Ink jet printers (A, B and C) and porous paper combined in this test. Two test conditions 1 and 2 are compared. Air flow 1 condition is direct flow on the surface of print. Air flow 2 condition is indirect flow on the surface of an enclosed print. Air flow 2 condition showed the larger ΔE change than Air flow 1 condition. This example shows the influence of the circulation of air in the test chamber.



Key

X air flow

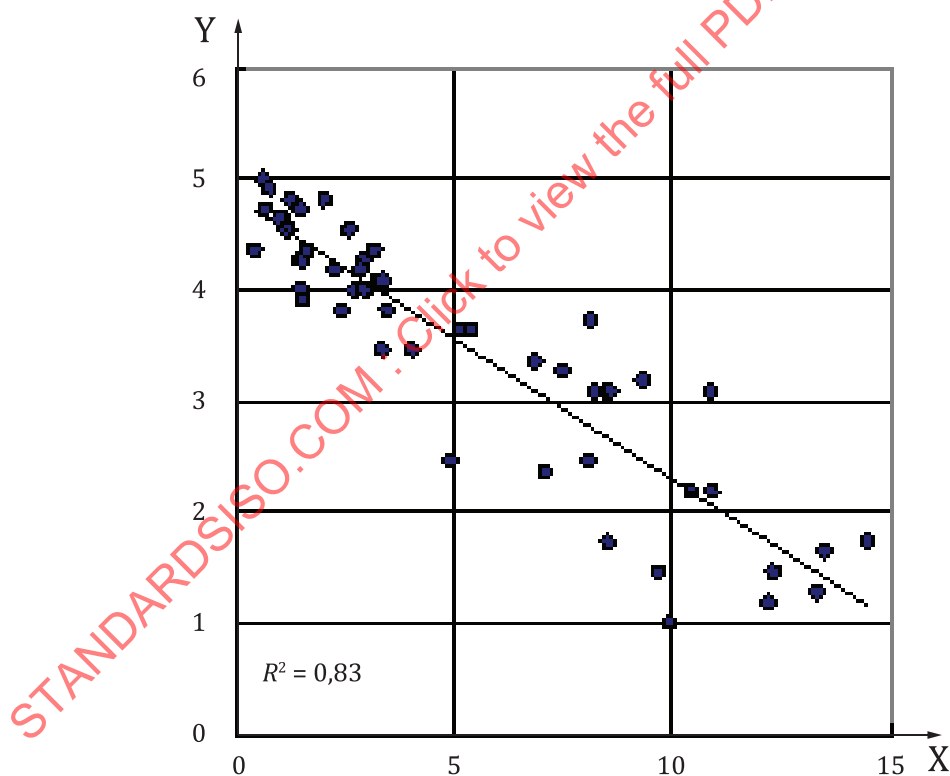
Y ΔE **Figure 20 — Dependence of airflow on Humidity fastness test**

The test methods described in this document provides average ΔE as the test results. An example of the correlation between this value and the psychophysical evaluation is shown as follows in see [Figure 21](#).

In this evaluation, the humidity test target and photo images of a portrait, a landscape, and a snapshot were printed with 14 inkjet materials. Those prints were exposed to humidity in several different conditions. The psychophysical evaluation was performed by 10 people with experience in evaluating printed images.

Example of criteria is as follows:

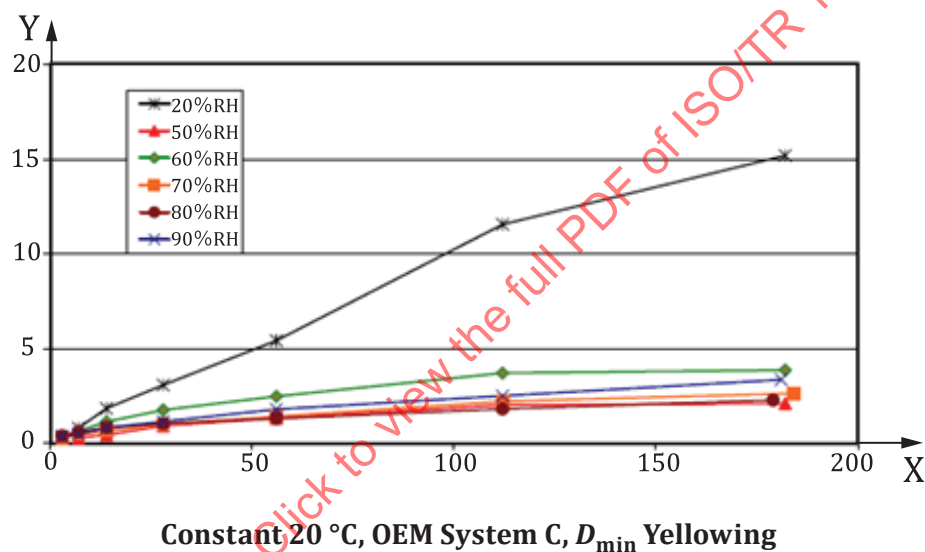
- 5: No change
- 4: Slight change, but little effect of the value of the photo
- 3: Change which influence the value of the photo
- 2: Significant change
- 1: No value at all

**Key**X average ΔE

Y psychophysical score

Figure 21 — Correlation between psychophysical evaluations to average ΔE

During development of the ISO 18946 humidity test standard, ISO 18949 was added because low humidity is a storage condition that can be encountered in many consumer homes in many parts of the world. There are environments of low humidity in conjunction with high temperatures such as desert conditions. However, low humidity and the low temperatures conditions also are noted. In many areas around the world, cold temperatures are common, especially in winter. In general, cold air cannot hold as much moisture as warm air and therefore the dew points of cold air are low. However, consumer homes are not maintained at cold temperatures and this presents the key problem. Cold dry air with low dew points enters the home and it is warmed to room temperature. The dew point remains constant and the relative humidity drops. Relative humidity has been recorded as low as 10 % to 20 % in the winter months in many areas. An example of $D_{\min}$ yellowing for porous media accelerated at low humidity is shown in Figure 22. As has been mentioned in 6.2, the highest moisture content in this test range at 25 °C is well within the moisture level in the thermal test if it follows the "free hanging method" at a constant 50 % RH and 85 °C. The print sample is held at 25 °C at 10 % RH for 12 months in ISO 18949. In general, the contamination (ex. some kinds of amine compounds) in the chamber may cause the yellowing of the substrate in case of specific material. The effect of the contamination is also considered in discussion on substrate yellowing.



Key

X time (days)

Y ΔE

Figure 22 — $D_{\min}$ yellowing for porous media accelerated at low humidity

7 End of test criteria

7.1 General

The primary meaning of "End of test" is the dividing point where the image is useful or no longer useful. However, the judgment of useful or not useful depends on the purpose of the images, contents of the images, the necessity of the images, emotion or viewpoints of the observers.

The judgment is completely different between the single stimulus, i.e. no comparison with the referenced images, to the double stimulus, i.e. the comparison with the referenced images, usually undamaged images.

7.2 Initial optical density and colour

The patches used for the evaluation of print life can be as follows:

The initial density is $D_{\min}$, $0,5 \pm 0,05$, $1,0 \pm 0,10$, and $1,5 \pm 0,15$, with Status A or T. Interpolation is also allowed if a single density value is not within the range. If the maximum optical density for any colour is less than the target value, then the highest value possible for that printer system can be used. The colour can include Neutral, Y, M, C, R, G, and B defined by ISO 18944.

7.3 List of several sets of end of test criteria for background explanation

The summary end of test criteria that have been reported are shown in [Table 4](#).

Extensive psychophysical publications correlating the densities and colour balance changes have been reported in two studies^{[19] to [21]}. As shown in [Table 4](#), these two studies arrived at different conclusions about the criteria for the end of test. In the discussions of TC 42/WG 5, it was pointed out Study1 used the comparison of the faded images with the initial images, while Study2 used single stimuli after memorizing the initial images. Furthermore, some end of test criteria have already been proposed for the print life predictions of consumer printers. For example, JEITA CP-3901A^[22] and WIR Visually-Weighted end of test criteria set v3.0^[23] have been used. After considerable discussion, the proposed values by TC 42/WG 5 are, as shown in [Table 4](#).

Table 4 — Summary of end of test criteria reported

		TC 42/WG 5 Discussion	ISO 18909	WIR 3.0	JEITA CP-3901	Study 1	Study 2
Pure Colour	Density loss	40 %	30 %	25 % to 30 %	30 %	40 % (39 % to 60 %)	50 %
Neutral patch	Density loss	40 %	30 %	25 % to 30 %	30 %	23 %	50 %
	Colour balance	20 %	15 %	12 % to 18 %	15 %	15 % (12 % to 19 %)	25 %
$D_{\min}$ patch	Density loss		0,1	0,15 (toY)	0,06(R/G) 0,1(B)	0,2	
	Colour balance	$\Delta E = 10$	0,06	0,1 (B/G,R)	0,05(R/G) 0,1(R,G/B)	0,13 (B/G,R)	
OD patch used		0,5,1,0,1,5 MaxOD	1,0	0,6,1,0	0,5,1,0,1,5 MaxOD	0,5,1,0,1,5	0,5,1,0,1,5

Furthermore, the end of test criteria for ΔE , " $\Delta E_{76} = 10$ " or " $\Delta E_{00} = 5$ " were proposed^[24]. This proposal is based on the psychophysical study in which the fading images were observed, the ΔE_{76} and ΔE_{00} were measured in light-fading tests using 20 consumers photographic, and production prints (See [Figure 9](#)).

8 Environmental conditions

8.1 General

The service lifetime of a photo print depends on the environmental conditions, in which the photo prints are stored or displayed. These conditions may vary considerably in terms of temperature, humidity, intensity and spectral power distribution of the illuminating light, and concentration of atmospheric pollutants. These vary greatly from place-to-place, nation-to-nation, season-to-season, etc. as a result of climatological, individual and sociocultural factors. Because of potential synergistic interactions between the four environmental conditions in their combined impact on print degradation, one would have to run combined tests at different levels of the stresses, but this is impractical. As a minimum, the degradation of the prints has to be assessed for all four environmental factors independently, i.e. "single factor assessments" of print life performance for heat, light, ozone, and humidity, each as described in [4.3](#).

Depending on the actual use case within the use profile "consumer home" the effective level or range of some of these four environmental stress factors is reduced as presented in [Table 1](#) and therefore

depends on the degree of (partial) protection provided in final use, with the main sub-uses “display” and “storage” as examples.

The following sections give an overview of the continuum of stress factors observed in various instances of use case in consumer home environments. Up to now, there is no agreement about the consistent definition of a set of representative stress factor levels that would be regarded as “typical environmental condition”. This has been extremely difficult because such levels would still vary by 2× to 5× depending on location in the world, sociocultural background, and user perspective. The user perspective is also influenced by range of expectations for retained image quality (end of test) which depends on the purpose of the photographic print in the use context.

Furthermore, when the translation of the test data to the expected print life is required, it is necessary to define the “typical environmental condition”.

8.2 Temperature and humidity

The data for temperature and humidity of consumer homes corrected world-wide throughout the year are reported in Table 5^{[25][26]}. The table a) shows the data collection in Phase I and the table b) shows the data collection in Phase II. For these data collection, in Phase II of study, temperatures and humidity were monitored for 6 to 12 months in eight homes in each of four cities (Rochester, London, Los Angeles, and Melbourne). For Phase, eight homes in each of four additional cities (Atlanta, Shanghai, Sao Paulo, Tokyo) were monitored for 10 to 12 months.

Table 5 — Temperature, dew point, and relative humidity of consumer homes

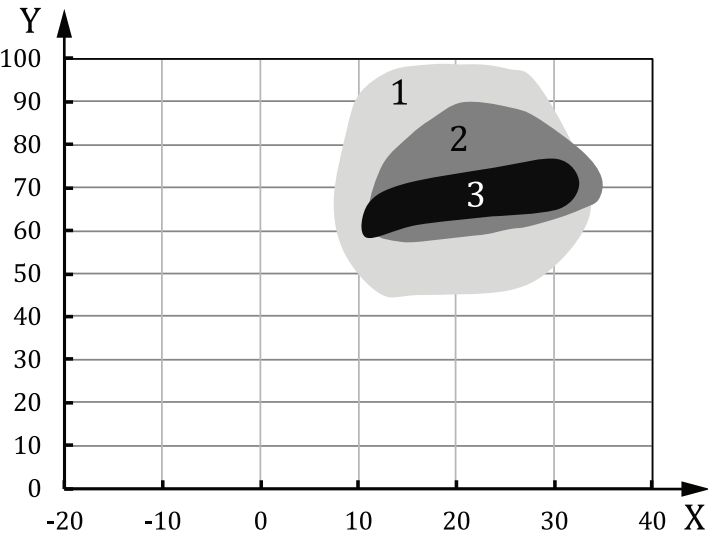
a) Phase I

	Mean Temp °C	σ °C	Mean Temp °C	σ °C	Mean RH %	σ °C
Rochester	20	3,3	1,2	6,2	44	11
London	20	2,4	5,8	4,7	53	8,8
Los Angeles	21	2,4	4,1	6,7	49	13
Melbourne	20	2,8	7,6	3,8	56	7,9
Overall	20	3,5	4,7	5,9	51	11

b) Phase I and Phase II

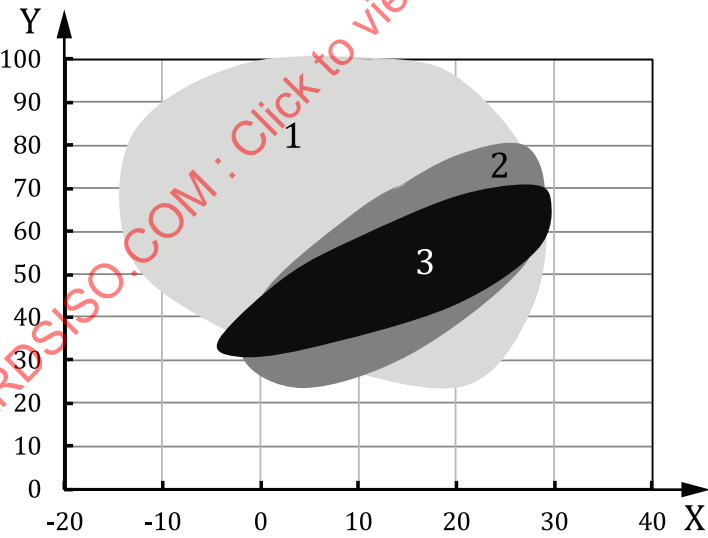
	Mean Temp °C	σ °C	Mean Temp °C	σ °C	Mean RH %	σ °C
Atlanta	22	3,2	10,7	5,8	51	13
Shanghai	23	6,0	14,0	6,9	60	12
Sao Paulo	23	3,3	15,7	3,4	63	10
Tokyo	20	5,3	9,9	6,4	55	12
Phase II	22	4,6	12,6	6,1	57	13
Phase I + II	21	3,9	11,1	5,5	54	13

The range of the variation in humidity of the storage space is smaller than the meteorological (outdoor) observatory. For example, the temperature and humidity of outdoor, indoor and the inside of albums had been measured for a year at Okinawa (the south semi-tropical regions of Japan), Sapporo (the north regions of temperate zone of Japan) and Kanagawa (the centre of Japan). The results are shown in Figures 23, 24 and 25.



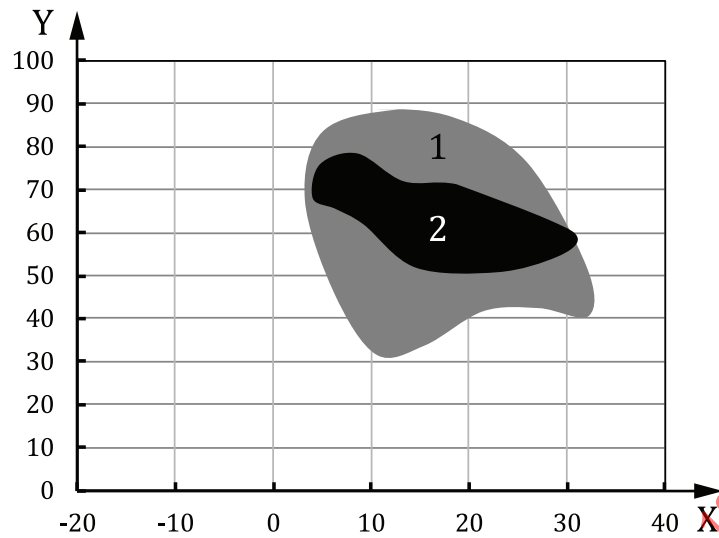
- Key**
- X temperature (°C)
 - Y humidity (% RH)
 - 1 outdoor
 - 2 indoor
 - 3 album

Figure 23 — Ranges of year-round temperature and humidity drift at storage area of photographs compared with that provided by meteorological agency, Okinawa ('86/10-'88/2)



- Key**
- X temperature (°C)
 - Y humidity (% RH)
 - 1 outdoor
 - 2 indoor
 - 3 album

Figure 24 — Range of year-round of temperature and humidity drift ('86/9- '88/7) of a personal house in Sapporo (the study)

**Key**

- X temperature (°C)
 Y humidity (% RH)
 1 indoor
 2 album

Figure 25 — Range of year-round of temperature and humidity drift ('86/9-'88/7) of a personal house in Kanagawa

8.3 Light

An example of the relative spectral power distribution in consumer homes is shown in [Figure 26](#). For comparison, spectral data of Xenon-arc light source with several optical filters are also shown. The data is normalized at 550 nm.

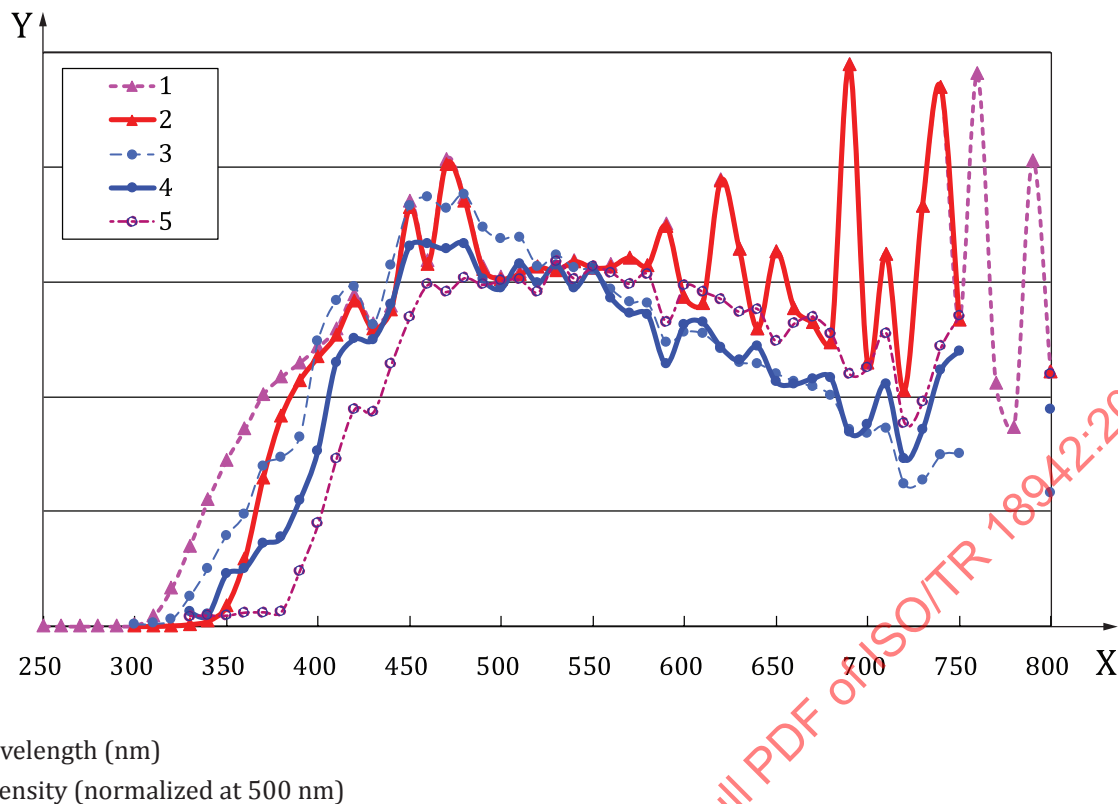
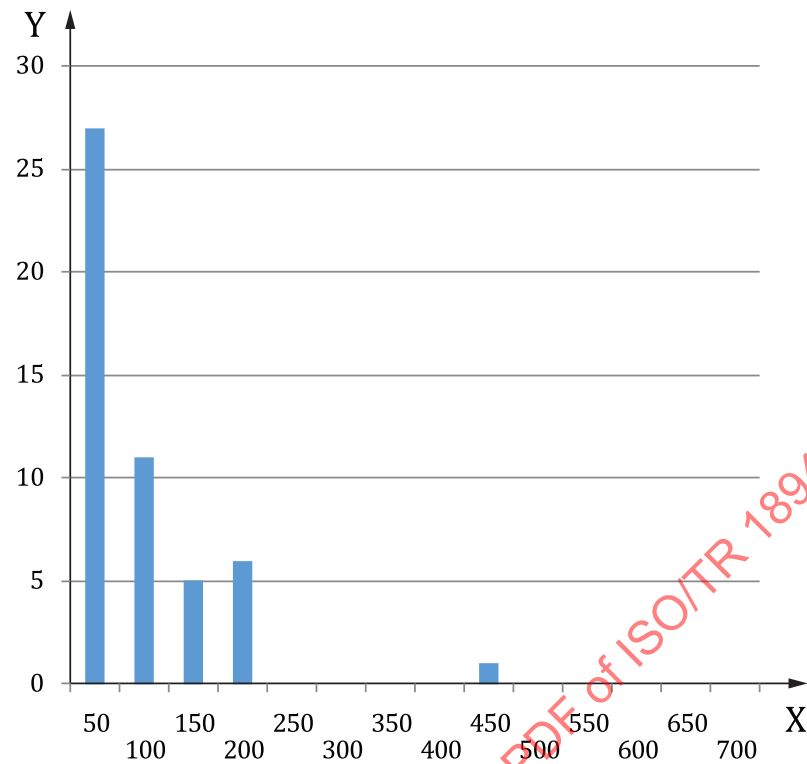


Figure 26 — Example of relative spectral power distribution in consumer homes and Xe light with several optical filters

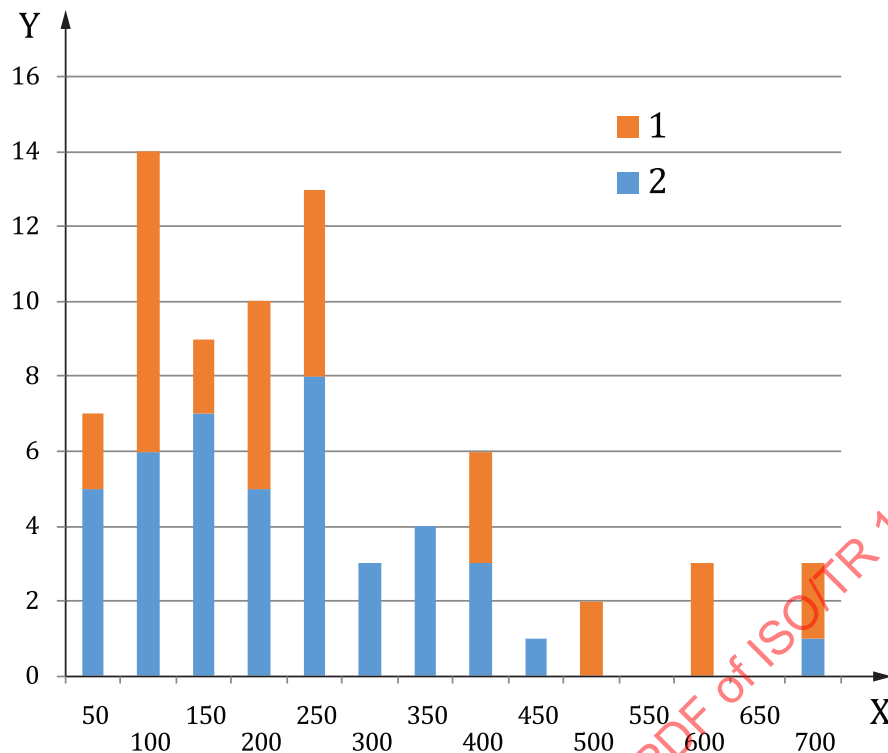
One-year average daytime light levels for 48 homes in the USA, UK and Australia are shown in [Figure 27](#)^[24]. The median is 22 lx and the mean is 64 lx. Somewhat surprising were the relatively low light levels found in Atlanta, given its location in the “sun belt”, which means the design of the houses, more specifically the sizes of the windows, are determining factors rather than the geographical factors.

**Key**

X light level (lx)
 Y number of places

Figure 27 — Histogram of one-year average daytime light levels for each of the 48 homes

The light levels of 19 homes were also measured in Japan and in the Netherlands in one day near the Autumnal Equinox. The results are shown in [Figure 28](#)^[24].



Key

- X light level (lx)
 Y number of places
 1 Japan
 2 Netherlands

Figure 28 — Histogram of average daytime light levels for each of the 19 homes in Japan and in the Netherlands in one day near the Autumnal Equinox

Some available known consumer home indoor light levels have been shown and discussed. The typical light levels proposed are 125 lx and 250 lx, 500 lx. 500 lx is based on anecdotal, single spot measurements taken in brightly lit display areas.

8.4 Ozone

Ozone gas is mainly generated outdoors due to the reaction of UV irradiation from the sun. The concentration of ozone outdoors depends on the following:

- Level of the sun light (stronger with stronger the sun light), therefore the weather, latitude of the region, day or night^[27];
- Air pollution (higher with higher air pollution concentration).

The ozone gas enters the room and decomposes when it reacts with something in the room. Therefore, the concentration of ozone at indoors depends on the following:

- outdoor ozone (higher with higher outdoor ozone concentration);
- air ventilation, i.e. inflow of air from outdoor (higher with higher inflow);
- size of the room (lower with the smaller room);
- materials of the surface of the room (lower with soft materials which react with ozone).

Ozone levels vary between place-to-place, nation to nation and season to season etc. Some available known consumer home indoor ozone levels are shown in [Figures 29, 30](#) and [31](#). Ozone levels are calculated with average and 95th percentile. Furthermore, it is important to gather available direct ozone level and also to know as a function of outdoor ozone level^[28]. Measurement of ozone concentrations were by using of passive sampler measurement or direct measurement. Two examples of outdoor ozone levels in Japan and USA are shown in [Figure 29](#). The typical ozone levels proposed are 4,6 nl/l and 9 nl/l.

The details of measurement are as follows. Outdoor ozone levels are as follows shown in [Figure 29](#). At 1 192 places in Japan (from Hokkaido to Okinawa), ozone levels have been measured by direct measurement in [Figure 29 a](#)). Ozone levels were calculated with 29,4 nl/l on average and 42,0 nl/l at the 95th percentile. In [Figure 29 b](#)) ozone levels for the USA are calculated with 45,3 nl/l on average and 53,5 nl/l at the 95th percentile. The outdoor ozone levels in the USA tend to be higher than in Japan.

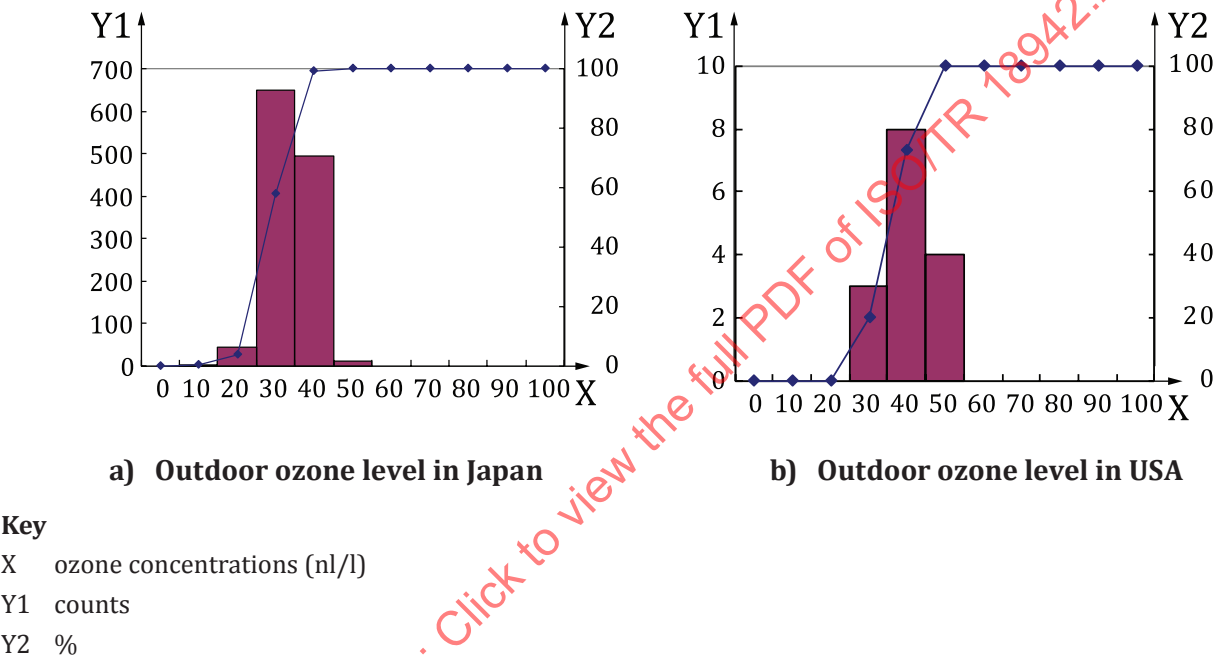


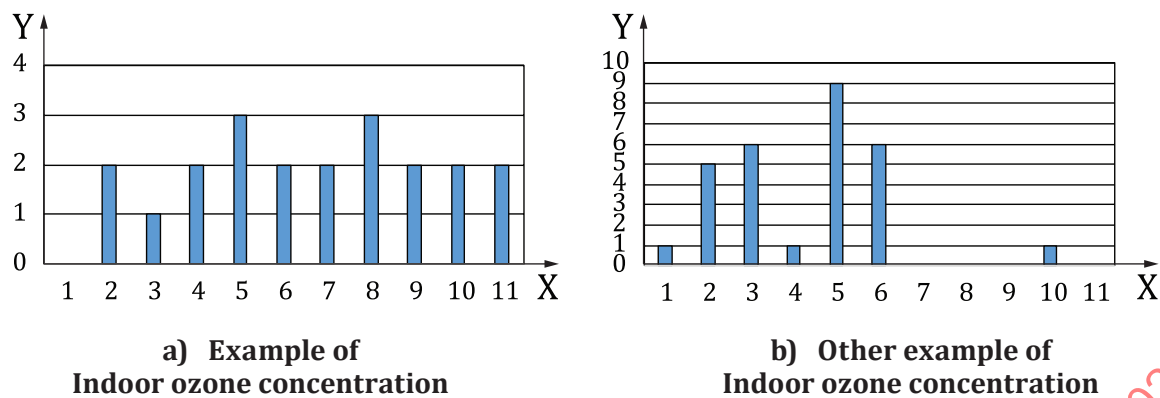
Figure 29 — Outdoor ozone level in Japan and USA

Indoor ozone levels are shown as follows in [Figure 30](#):

At 15 places, (Japan 1) ozone levels were measured by using of passive sampler measurement. In this example, ozone levels were calculated with 6,2 nl/l on average and 10,4 nl/l at the 95th percentile.

At 19 places, (Japan 2) ozone levels were measured by using of passive sampler measurement. In this example, ozone levels were calculated with 4,1 nl/l on average and 6,0 nl/l at the 95th percentile.

Furthermore, it was reported that ozone levels in the USA were calculated with 9 nl/l at the 95th percentile and ozone level in other Japanese reporting are calculated with 4,6 nl/l on average in TC 42/WG 5.

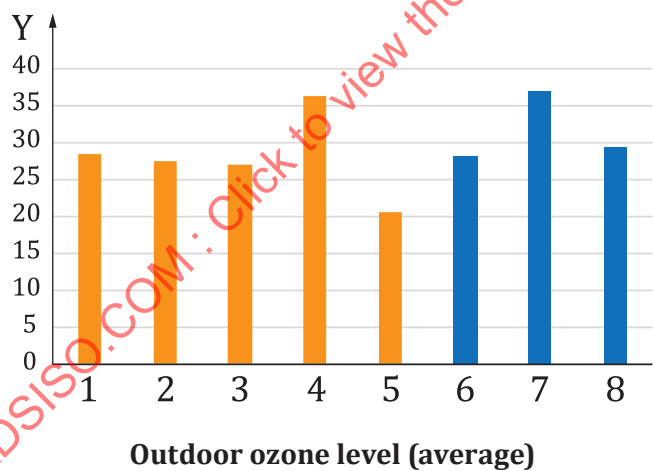


Key
X concentrations (µl/l)
Y counts

Figure 30 — Indoor ozone level in Japan

Further calculations, outdoor to indoor conversion are from 14 % to 24 %.
Japan1: 10 nl/l (indoor)/42 nl/l (outdoor) = 24 %
Japan2: 6 nl/l (indoor)/42 nl/l (outdoor) = 14 %
USA: 9 nl/l (indoor)/54 nl/l (outdoor) = 17 %

Measurements of outdoor ozone level including Europe area are shown as follows in [Figure 31](#).



Key
Y ozone concentrations (nl/l)
1 Switzerland
2 Germany
3 France
4 Italy
5 United Kingdom
6 USA, NY/LA
7 USA, NV
8 Japan

Figure 31 — Outdoor ozone level including Europe area

Opening a window increases indoor ozone levels because outside air containing higher levels of ozone enters the room^[29].

For example, for all test locations as described in [Figure 31](#), the indoor/outdoor ratio have been determined.

Location O3 ratio are as follows,

Outdoor = 100 %

Air conditioned, supplying outdoor air = 57 % to 90 %

No air conditioned, windows closed = 4 % to 19 %

8.5 Conclusion

As the data above has shown, there is an extremely large variation in environmental conditions for all factors. The variation is large within a home, within a city, within a region, and around the world^[27] to^[30]. For this reason, creating a standard to predict print life has been much difficult. Because of the variation in environmental conditions, it is virtually impossible to make an accurate prediction that will have direct meaning to the end consumer. Despite trying various ways to try to avoid this issue, for example using fixed dosage loads to determine a performance rating, this technical standard has been elected not to pursue the several determinations.

8.6 General

Starting from the basic reporting in Level1 of the test methods results as stipulated in [4.5](#), there is the advanced reporting in Level 3 for translating the image permanence performance into user language. This holds for dose related responses (ozone & light via reciprocity, thermal via Arrhenius), whereas humidity represents fixed stress loads, for which test results may be translated into binning, but cannot be translated into “years” life expectancy.

Two basic reporting methods in graph reporting and fixed load reporting in Level 1 have been proposed in this document. Graph reporting shows the changes in graphs and fixed load-reporting reports the faded values at a fixed load. Examples of “Graph reporting” are shown in [8.7.1](#). Examples of “Fixed load reporting” are shown in [8.7.2](#).

Two advanced reporting methods in “years” of rating and in “star” rating reporting in Level3 proposed in TC 42/WG 5 can be described for the reporting of the predicted life of photographic prints. “Year rating” is reporting method expressed in “years” with some remarks relating to the proposition. The estimated print life is calculated using the “typical environmental conditions” and based on the presupposition that there is no reciprocity failure. “Star rating” is reporting method expressed by the number of star marks. Calculations for “Year rating” are shown in [8.8.2](#). An example of “Star rating” is shown in [8.8.3](#).

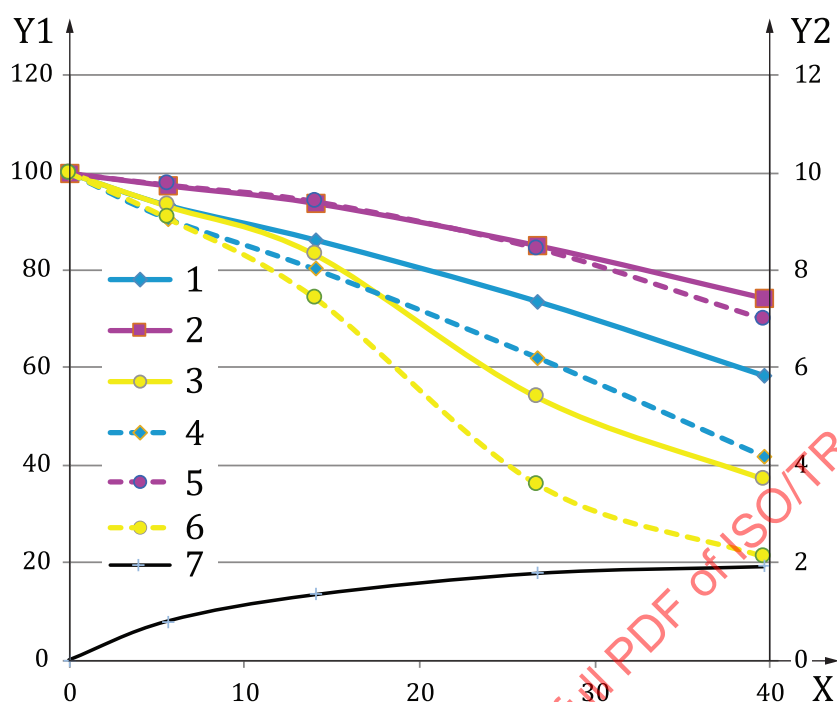
8.7 Basic reporting

8.7.1 Graph reporting

The results of image permanence tests are usually plotted in graphs. The Y-axis can be the residual density (percentage of the initial density) or the colour difference (ΔE) from the initial chromaticity. The X-axis can be the total exposure of the stress. The graphs indicate the results objectively including the variation with time. It is visually understandable. The downside is it is not simple compared to “one number reporting” described in the next sub-clause. An example of reporting with graph is shown in [Figures 32](#) and [33](#).

[Figure 32](#) is the abridged version which illustrates the residual density changes of the gray, yellow, magenta and cyan patches with 1,0 density and the colour difference changes of the $D_{\min}$ patch.

Figure 33 is the detailed version which illustrates the residual density changes of the gray, yellow, magenta, cyan, red, green and blue patches with 0,5, 1,0, and 1,5 densities and the colour difference changes of the $D_{\min}$ patch.



Key

- X light exposure (Mlx·h)
- Y1 residual density (%)
- Y2 ΔE_{00} for $D_{\min}$
- 1 gray (R)
- 2 gray (G)
- 3 gray (B)
- 4 cyan (R)
- 5 magenta (G)
- 6 yellow (B)
- 7 $D_{\min}$

Figure 32 — Example of reporting with graph — Abridged version for density changes of gray, yellow, magenta and cyan patches with $D = 1,0$ and $D_{\min}$ change

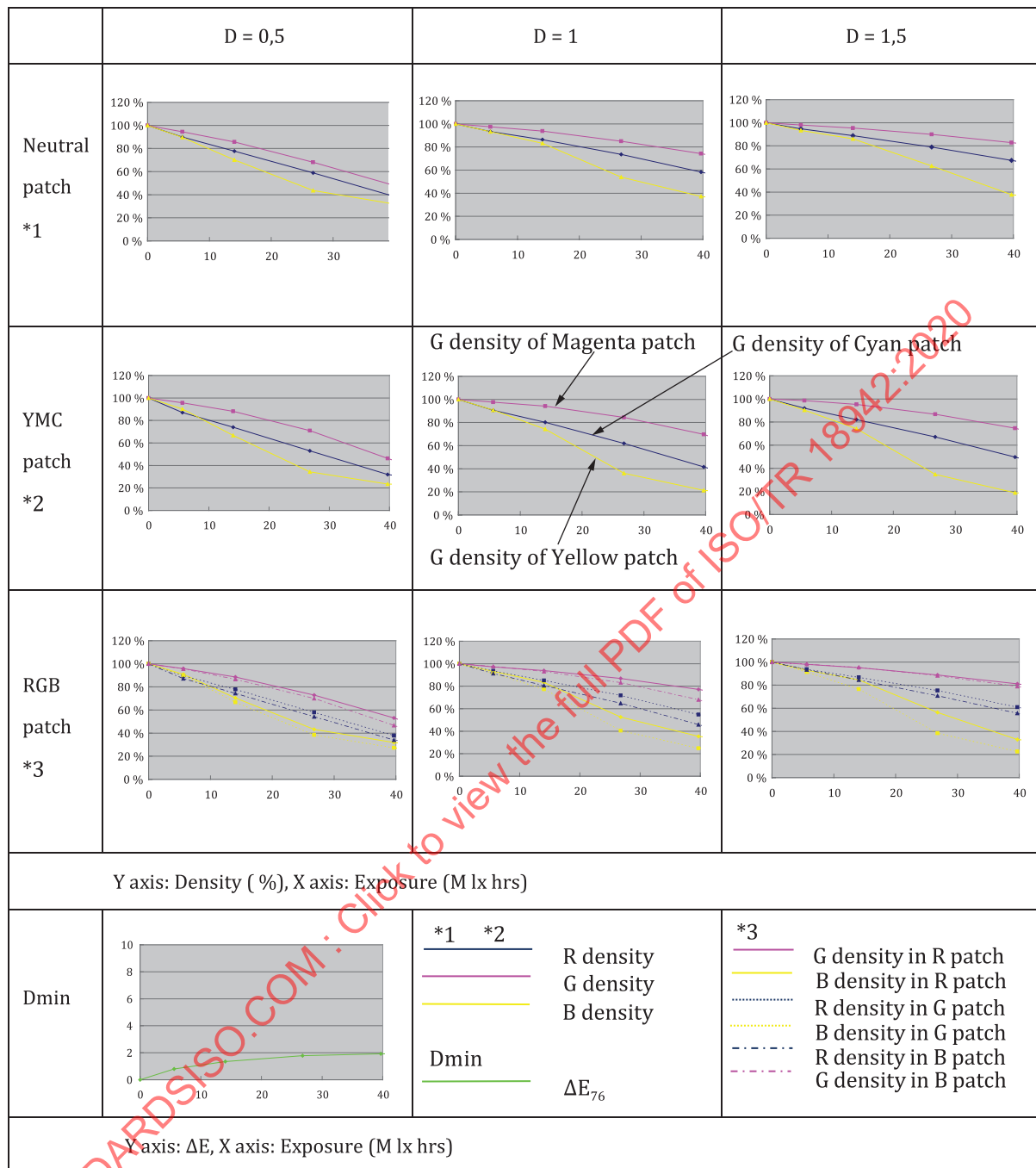


Figure 33 — Example of reporting with graph — Detailed version for density changes of gray, yellow, magenta, cyan, red, green and blue patches with $D = 0,5, 1,0$ and $1,5$ and D_{min} change

8.7.2 Fixed-load reporting

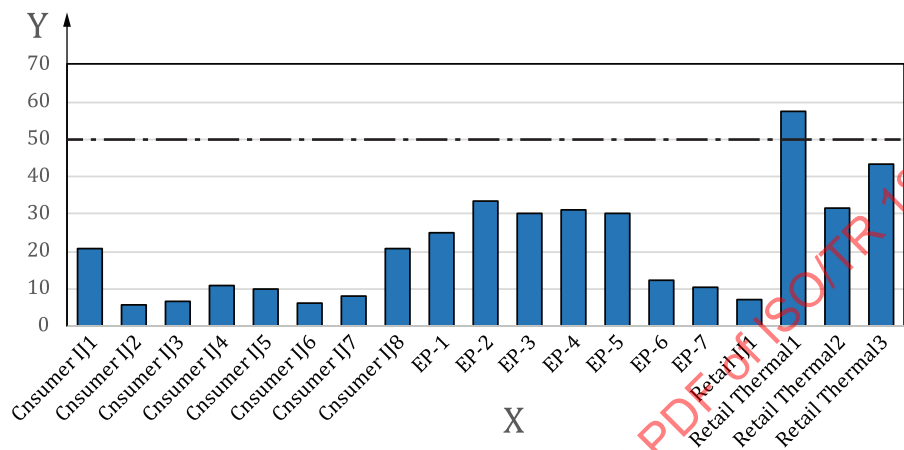
The fixed-load reporting method reports the amount of the change at a certain fixed exposure level. The advantage of the fixed-load reporting is the test results can be reduced to one simple number.

The following load was proposed for each test. Examples of loads are as follows and results for light fade and ozone fade are shown in [Figure 26](#).

- Light: 20 Mlx·h (4 weeks at 50 Klx) – Xe + Glass + L37
- Ozone: 1 450 $\mu\text{l/l}$ h (12 weeks at 1 $\mu\text{l/l}$)

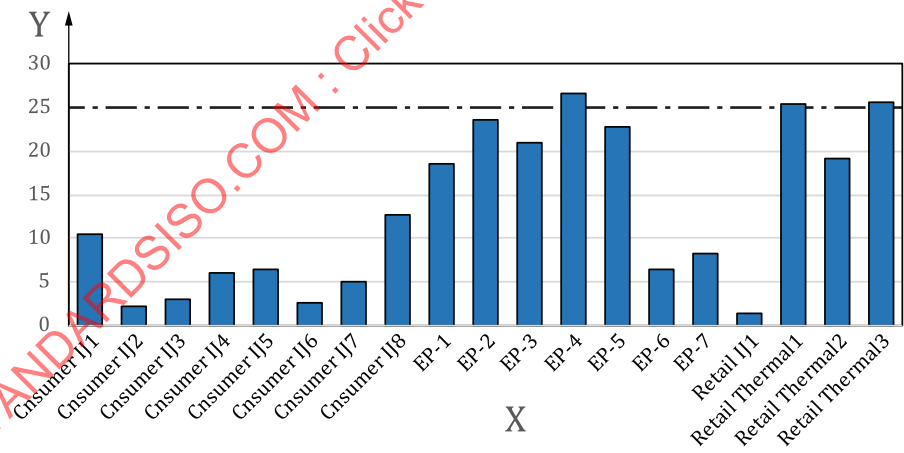
- Humidity: 4 weeks at 25 °C/85 % RH for Method A, 6 months 25 °C/20 % RH for Method C
- Thermal: 85 °C/50 % RH for 28 days. For image-bearing layers with $T_g \leq 55$ °C, the 85 °C test condition cannot be used, and the test condition of 50 °C/50 % RH for 32 weeks is mandatory instead. In this load, the only high temperature short-term tests are effective (for example leaving the prints in a vehicle). Otherwise, the Arrhenius test is indispensable for stability in ordinary temperature for long term.

Some examples of test results for light and ozone evaluated at each fixed load are shown in [Figures 34 to 37](#).



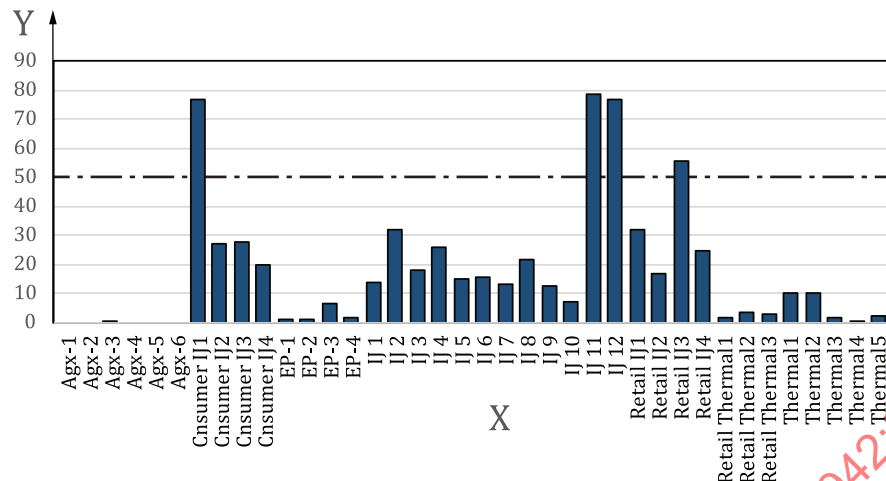
Key
X system
Y density loss (%)

Figure 34 — Density Loss from 1,0 after 33,6 klx·h for light stability test



Key
X system
Y colour balance

Figure 35 — Colour balance shift after 33,6 klx·h for light stability test

**Key**

X system

Y density loss (%)

Figure 36 — Density Loss from 1,0 after 2 016 µl/l·h for ozone stability test**Key**

X system

Y colour balance

Figure 37 — 1,0 Colour balance shift after 2 016 µl/l·h for ozone stability test**8.7.3 Discussion of graph reporting and fixed-load reporting**

The advantages of the graph reporting are:

- Technically correct and objective without translation.
- Visual and easy to understand the feature.
- Variation with time (amount of exposure) is indicated.
- Not only the fading, but also colour balance can be indicated.

The downsides of the graph reporting are:

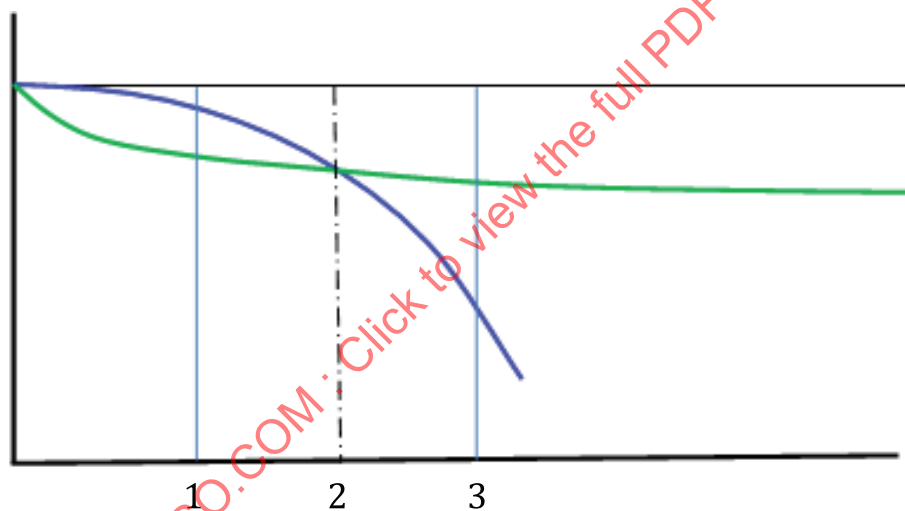
- For non-technical people detailed explanation will be required.
- Many lines and many graphs are needed to express the feature of each colour and each density and colour patches.
- Difficult to compare multiple products.

The advantages of the fixed-load reporting are:

- Easy to communicate even to end-consumers.
- Easy to compare multiple products.
- Easy to do the test, because measurement is required at only one point.

The downsides of the fixed-load reporting are:

- The requirements of users are variable, and it may be difficult for only one load to be sufficient for the variable requirements of users.
- Variations with time (amount of exposure) are not shown. For example, the two completely different products are indicated “equal” at one fix load as follows (see [Figure 38](#)).

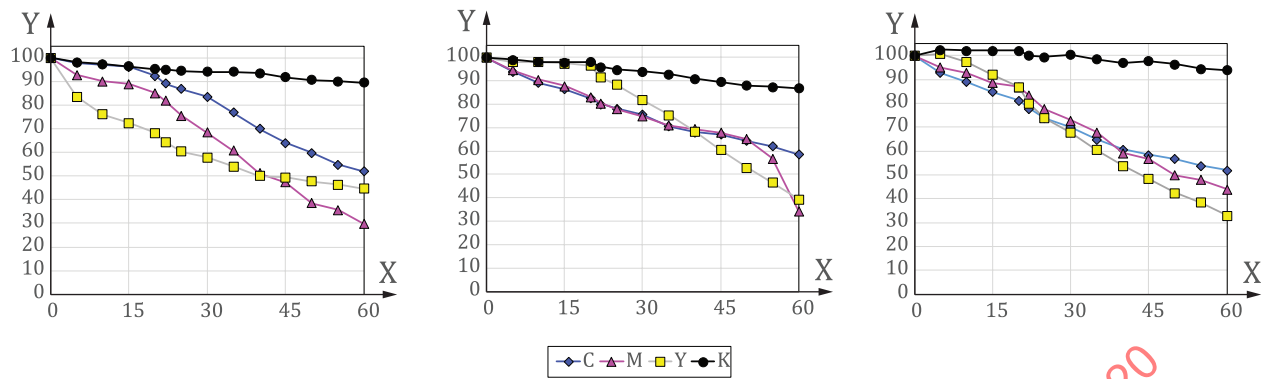


Key

- 1 1st fix point
- 2 2nd fix point
- 3 3rd fix point

Figure 38 — Two types of fading curves

An example of various fading light stability tests are shown in [Figure 39](#). One load may not lead to definitively even simple binning, because fade curves vary. It is understood there are various fading curves, and appropriate loads must be selected.



a) Result of Sample A

b) Result of Sample B

c) Result of Sample C

Key

X duration (Mlx·h)

Y % OD Ratio

Figure 39 — Various fading example of graph for light stability test (Initial OD = 0,5, Xe 50 klx, sample Temp: 23 °C, exposure: 15, 30, 45 and 60 Mlx·h)

Furthermore, fixed-load reporting without consideration of end of test criteria is difficult to correspond to the human perception. For example, the colour balance change is more critical than the fading rate.

NOTE We have had continued discussion on reporting based on graphical reporting adding advice for interpretation of graphs for level 1 in TC 42/WG 5. After many discussions, it is concluded, that level 1 works for relative comparison, but level 3 is required for some expression of service life expectation. Professional users might be happy with cumulative exposure information (level 2), but for consumer's performance is translated into something that is related to user experience. The discussion ultimately resulted in a suggested motion to completely stop work on the consumer home level 1 project.

8.8 Advanced reporting

8.8.1 Two advanced reporting methods

Two advanced reporting methods in "Years" of rating, in "Star" of rating reporting proposed in this document can be described for the reporting of the predicted life of photographic prints.

8.8.2 Reporting "year rating"

8.8.2.1 Thermal stability

The life expectancy relating to thermal stability can be estimated using the Arrhenius prediction described in ISO 18924 using the data obtained with the test of 4.2.

The calculated time necessary to reach the end of test listed in Table 4, at 23 °C and 50 % RH can be applied.

8.8.2.2 Light stability

The life-expectancy range of a print image exposed to light is calculated according to normal conditions in a consumer home, where Light Level is the chosen light intensity in lx with the following equation: The accelerated exposure (klx·h) factor is the required accelerated light exposure to reach the first end of test in [Table 4](#).

$$E_{\text{an, light}} = L_{\text{light}} (\text{year}) \cdot 12 \frac{\text{h}}{\text{day}} \cdot 365 \frac{\text{day}}{\text{year}} \cdot \frac{\text{klx}}{1000 \text{ lx}}$$

$$S_{\text{cons, in}} (\text{years}) = \frac{E_{\text{acc}} (\text{klx} \cdot \text{h})}{E_{\text{an, light}} (\text{klx} \cdot \text{h}/\text{year})}$$

NOTE In order to compare the life-expectancy estimates due to light-induced image degradation of various print images, it is necessary to assume a standard set of nominal conditions. For example, JEITA CP-3901A published for standard of print life in Japan defines 250 lx. While indoor light levels have been found to vary widely, both geographically and as a function of time, three nominal indoor levels have been proposed e.g. 120 lx, 250 lx and 500 lx.

8.8.2.3 Ozone stability

The life expectancy ranges of a print image exposed to ozone gas is calculated according to normal condition in consumer home, where the ozone Level is the chosen ozone concentrations in nl/l with the following equation.

The accelerated exposure (µl/l·h) factor is the required accelerated ozone gas exposure to reach the first end of test in [Table 4](#).

$$E_{\text{an, oz}} = L_{\text{oz}} (\text{nl/l}) \cdot 24 \frac{\text{h}}{\text{day}} \cdot 365 \frac{\text{day}}{\text{year}} \cdot \frac{1 \mu\text{l}}{1000 \text{ nl/l}}$$

$$S_{\text{cons, in, oz}} = \frac{E_{\text{acc}} (\mu\text{l/l} \cdot \text{h})}{E_{\text{an, oz}} (\mu\text{l/l} \cdot \text{h}/\text{year})}$$

NOTE In order to compare image life estimates due to image degradation by ozone or other atmospheric pollutants, it is necessary to define a standard set of nominal conditions of ozone level. For example, JEITA CP-3901A defines 4,6 nl/l (Annual Ozone Exposure is 40 µl/l·h/year). While indoor ozone levels have been found to vary widely, both geographically and as a function of time, for the purposes of this standard two nominal indoor level have been proposed e.g. 4,6 nl/l and 9 nl/l.

8.8.2.4 Humidity fastness

Due to the nature of the humidity test method, ISO 18946, and the fact that there is no accelerated exposure factor determined in the method, it is not possible to calculate and report a life expectancy. Only the fixed stress loads and direct output from the humidity test method, Methods A, B, and ISO 18949 (Low humidity test method) may be reported.

8.8.3 Reporting “Star rating”

Discussions of any type of a rating system need to begin with a fundamental explanation of the expectations and knowledge limitations of the end consumer. The concept of consumer usage cases, specifically storage and display as described in [Clause 4](#) is generally understood by the end consumer. Within those usage cases, there is protected and unprotected storage and display as detailed in [Table 1](#). Depending on the knowledge level of the consumer, the concept that providing protection to the print in display or in storage will increase print life may or may not be understood. More advanced consumers can easily understand this but to many the expectation is that a print will last forever regardless of how it is displayed or stored. However, for virtually all end consumers, the concept of what caused a print