TECHNICAL SPECIFICATION

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Imaging materials — Photographic prints — Effect of light sources on degradation under museum conditions

Matériaux pour l'image — Épreuves photographiques — Effet des sources de lumière sur la dégradation dans des conditions de musée

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Contents

Page

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

One of the typical uses of prints in museums is their display in a permanent or temporary exhibition under ambient light or artificial illumination. In general, prints may fade due to various environmental stresses, such as light, heat, humidity, pollutants, or biological attack, and the combination of these factors. A museum can fully or partially control and suppress most of those factors. However, light is necessary for display and will cause some degradation over time[1].

This document will provide guidance on how to assess light exposure-related damage to analogue and digital photographic prints under museum display conditions for particular print materials sets. The choice of the light source with the lowest damage potential depends on the specific material types in the mix and the spectral irradiance of the light source.

The document can be of benefit to curators, conservators and lighting designers to select the display lighting with the lowest possible damage potential to an exhibition. It can serve the manufacturers for lighting materials to develop particular solutions for the museum.

Depending on the use case, material type and conditions, a two-tier evaluation may be possible.

Tier I evaluation is useful for comparison of different light sources, namely, to identify the light source that will result in smallest image fading (ΔE) under a given exposure level (lx-h).

Tier II evaluation is useful to estimate appropriate illumination levels (lx) to reach intended display duration, if the following conditions are met (see Annex A for detailed discussion):

a) the museum is able to display the work with a light source having the same relative spectral irradiance (RSI) as the one used for the testing; and

b) a set of representative test samples is available that have the same types of colourant and substrate material as the display work, and

c) the assumption of linearity of image fading in response to different levels of light intensities (reciprocity) is verified, for which test results under different combinations of illumination intensity (lx) and duration (hours) are compared.

A test method of light stability for simulated daylight in indoor display is described in ISO 18937. Future ISO 18937-1 is a description of a general test method and future ISO 18937-2 is a test method with xenon light but which does not cover the particular museum display use case. Therefore, the covered range of environmental conditions and wavelength of light is broader than what is required for this document. It would be difficult to translate the test results following ISO 18937-1 into a specification for museum print display requiring practically no degradation.

This document follows the recommendations of ISO/TS 21139-1:2019, Clause 4[2] for the definition of a museum use profile and specifications, although the museums use case is not in the scope of ISO/TS 21139-1.

Imaging materials — Photographic prints — Effect of light sources on degradation under museum conditions

1 Scope

The test method in this document is intended to be used to characterize and compare the degradation of a set of print materials under exposure to particular light sources, eventually including optical filter combinations, under museum environmental conditions. The document covers typical types of indoor light sources commonly found in a museum including indoor daylight, LED, and incandescent light.

This document is applicable to analogue and digital reflection photographic prints.

NOTE Examples of photographic prints covered by this document are prints made with digital printing technologies such as inkjet, electrophotography, and thermal dye transfer, as well as prints made on silver halide colour paper but not prints made on black and white silver halide paper.

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*

ISO 18937:2020, *Imaging materials — Photographic reflection prints — Methods for measuring indoor light stability*

ISO 18944, *Imaging materials — Reflection colour photographic prints — Test print construction and measurement*

3 Terms, definitions, and abbreviated terms

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

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

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

NOTE SAA also maintain a terminological database:

— SAA online glossary available at https://www2.archivists.org/glossary

3.1
Mlx-h
abbreviated from Mega lux hour, a unit of light exposure, product of illuminance and time

3.2
spectral irradiance
SI
spectral power distribution
SPD
power per unit area per unit wavelength of an illumination

3.3
relative spectral irradiance
RSI
relative distribution of irradiance power per unit area per unit wavelength, across (and normalized in) a given range of wavelengths. In this document, the wavelength range of interest is from 300 nm to 800 nm

3.4
duplicate
one of multiple copies of an object made at the same time from the same master

3.5
limiting exposure
accumulated exposure level in *Mlx-h* (3.1) or kJ/cm^2 which causes unacceptable level of deterioration

3.6
safe display duration
estimated accumulated display duration that will not cause a change exceeding the level accepted by the user

Note 1 to entry: Generally, accumulated intermittent exposures will have the same effect as one long exposure to the same overall level. The safe display duration can be split into several periods.

3.7
Planckian radiator
ideal thermal radiator that absorbs completely all incident radiation, whatever the wavelength, the direction of incidence or the polarization

Note 1 to entry: This radiator has, for any wavelength and any direction, the maximum spectral concentration of radiance for a thermal radiator in thermal equilibrium at a given temperature

Note 2 to entry: A Planckian radiator is sometimes called "black body".

3.8
print material set
defined mix of print materials comprising types of print technology and historic period representative for a collection of print materials to be displayed under a specific display light

4 Use profile

4.1 General

This document describes how to evaluate the light stability of a set of photographic print materials on display under museum environmental conditions. The prints are displayed either framed or un-framed, continuously or intermittently lit, mounted on a wall or in an exhibition case. The use profile requires that the indoor environmental conditions are monitored and precisely controlled.

4.2 Stress factors in museum use profile

Most museum standards require light levels to be adapted to the light fading sensitivity of the colour print, in order to avoid any visible change. However, for light sources such as LED or OLED, that cannot be described as Planckian radiators, the illumination level is no longer sufficient to characterise the irradiance on a print. The use of illumination level and RSI in the 300 nm to 800 nm range is required to characterize a display condition.

Table 1 shows the set of stress factors to be considered in order to decide whether this document may be used. This document shall only be applied to prints intended for display under museum conditions, where the stress factors apart from light are within the recommended range of Table 1.

Table 1 — Assessment of stress factors

Stress factor	Permitted level
temperature	typical day-night cycle of temperature in the range 18 °C to 24 °C
relative humidity	30 % to 55 %
ozone	low ozone level (<2nl/l)[3]
other pollutants	as indicated in reference[4]
biological agents	absent

NOTE The acceptable level of pollutants depends on the types of materials in the collection, some of which can exhibit a particular sensitivity to certain types of pollutants. For example, dye based inkjet prints can be very sensitive to ozone. Sensitivity to ozone can be tested as per ISO 18941[3].

Throughout this document, the term degradation means degradation due to light exposure only. Apart from stress during display, colour prints can suffer damage from shipping, handling, and mounting. The sensitivity to bending, folding and abrasion may vary widely among materials and should be taken into consideration when preparing the display. However, mechanical stress such as abrasion and folding are not part of the display conditions and thus not considered in the document.

5 Test method

5.1 General

The material set is tested by exposure to a single light source with a particular relative spectral irradiance (RSI). An additional test shall be run with the light source of a different RSI. The test specimens from the set are exposed to light for a certain duration under well-defined spectral conditions and controlled humidity and temperature. The colour change from the initial state is measured after the exposure. Potential other changes are visually assessed. The test duration shall be determined in accordance with ISO 18937:2020, 5.6.

Museums usually apply additional UV filtering through the use of special window glass, shades, framing or other protections. For assessing the safe display duration for an actual display with a filtered light source, all filters shall be included. A typical museum long-pass UV cut-on filter is described under 5.4.2.

NOTE One definition of museum-grade UV-filter, sometimes referred to as Thomson specification, requires transmission of the optical filter to be 0 % at 320 nm, <1 % at 380 nm, and <50 % at 400 nm.

5.2 Sample specimen preparation

5.2.1 Outline

Manufacturers interested in knowing how their contemporary materials perform under museum display conditions can apply the test method of this document to contemporary materials and freshly made prints as described in 5.2.2.

However, in the museum environment, the possibility of being able to make new prints with the materials of interest is the exception. Most museum objects are older than 20 years and the print materials they were made with may no longer be available. The choice of an appropriate print material set will require some research and evaluation.

NOTE References and institutions that help to identify unknown print materials, or that maintain an on-line identification database, are given in References [5][6][7].

In spite of considerable effort, it may be difficult or impossible to find a good match of materials. In this case, a meaningful test cannot be done.

5.2.2 Contemporary materials

If a contemporary photographic work comes with a detailed record of how it was printed including media material, set of inks, method of printing (equipment and settings used), and post-printing finishing, and all the above are still available on the market, the exact same settings shall be used to make test prints.

The standard test pattern for printing as described in ISO 18944 shall be used. Other test patterns may be used if required by the application. A minimum requirement of the test target is to have two levels of YMCK values as well as a grey wedge with at least 4 levels and the minimum density of the print. Optional levels of Y, M, C, R, G, B, Grey (Y+M+C, or K), and other important colours, such as skin colour, can be included.

Printing and conditioning of samples shall be done in accordance with ISO 18944.

One set of printed sample specimens serves as control and needs to be stored in a dark, cool or cold place with pollutant levels as specified in Table 1. This set can be used as a reference to compare with the test print to track the visual impact of image fading and other changes to the materials after light exposure (such as physical damage, or edge bleeding/diffusion, or loss of glossiness, etc.). At least one set of replicate sample prints is required for the exposure to understand and mitigate the variability of exposures.

5.2.3 Historic materials

Museum objects are unique and there is often no possibility to utilize samples of real art colour prints for testing purposes. Destructive testing cannot be done on original art objects. Expendable duplicate originals or other duplicates of real museum materials made with material from the same manufacturer at the same time can be used to determine the safe display duration (see Annex A).

The usual case is that there are no duplicates and that the exact same material is not available. If the print technology and the time period of when the object was printed is known, the light degrading potential of new light sources on a particular type of historic material can be assessed with a selection of expendable prints made with the same print technology from the same historical time period. If the type of print material was made by several different manufacturers, the test set should include at least the major manufacturers at the time. However, this approach only allows one to make a relative ranking of the degrading potential of light sources and shall not be used to estimate the safe display duration for an actual museum object.

5.2.4 Selection of suitable test patches on historic materials

In the case of duplicates or expendable historical materials, colour patches have to be selected from the image itself, which is not the usual test pattern. A selection of suitable test patches should contain all colorants that were used in the print technology on three levels of lightness, light (L^* about 70), medium (L^* about 50) and dark (L^* about 30 or darker). Typical analogue photographic colour print materials for example have 3 colorants, digital colour prints may have up to 12 different colorants that can make up an image. Mixtures of colours on one patch are acceptable. Grey areas or skin tone areas are often suitable patches with two or three colorants present. In addition, one patch with very little or no colourant - possibly at the edge - should be selected to represent the minimum density of the print.

A magnifier with 50 times to 200 times enlargement can be used to identify the colorants in the patches. For a spectrophotometer with a 3 mm aperture, the patches should have a diameter of at least 4 mm and be mapped on the print with a precision at least 1 mm to allow the exact positioning and re-positioning after each test.

NOTE One way to obtain the required positioning precision is to prepare a mask with punch holes.

The precision of re-positioning shall be verified before the exposure test by measuring the selected spots multiple times and demonstrating that the standard deviation of the measurements is less than $\Delta E_{76} \leq 2$.

For duplicates, at least two sets of patches should be chosen as described above, either on the same print or on two similar prints. Due to the selection of not fully identical print patches, a much greater variability of the results is to be expected compared to tests done on a printed test pattern. Other patches on the same samples can be used as a reference if exposure is avoided by a light tight cover material.

5.2.5 Reference sample specimens

Reference specimens can be colour prints with known light stability or other colour materials with known light stability.

Museums often use the Blue Wool Scale (BWS) as defined in ISO 105-B04[9] as a dosimeter and as a scale to express light stability in terms of “Blue Wool Scale” with level 1 marking “fugitive” to level 8 “exceptional”. The BWS is exposed together with the specimen under test. This document does not recommend using the BWS as a dosimeter. State-of-the art test equipment has calibrated UV and visible light dosimeters that measure cumulative doses with much smaller uncertainty than BWS cards. In addition, the response of BWS cards to the combined stress factors of light, temperature and humidity is not the same as for the various printing technologies. However, BWS ratings are still very common in museums for various objects. Therefore, it might be desirable to also express colour fastness of digital prints in BWS ratings. For that purpose, one may refer to CIE 157[9]. Users should be aware that BWS ratings depend on RSI of the light source and are highly susceptible to the level of relative humidity during the test (see ISO 105-B02[7]).

5.2.6 Backing of the specimens

The sample and reference specimens are usually backed during the exposure test. Suitable backing materials include non-reactive and non-yellowing white material such as 100 % cotton rag board or metal (white-painted aluminium or stainless-steel plate).

5.2.7 Dummy sample

In a light exposure chamber, all sample positions shall be filled with samples, or with dummy samples which are equivalent in average density or reflectance to the actual test samples, for both light exposure tests and for the calibration of light, temperature, and humidity. Dummy samples maintain the same air flow pattern and reflected light conditions in the test chamber independent of the number of real samples.

5.3 Light exposure

5.3.1 Outline

Test results obtained for a given material set using one light source cannot predict the behaviour under a light source with a different RSI. To predict degradation for light sources with different RSI, the individual action spectra of colorants in the print have to be known[11]. However, measuring action spectra is time consuming. In many cases, it may be preferable to measure the light fastness of the particular print material set for each type of light source. Results and the predictions made for that material set are only valid for the light source that was used in the exposure test, for example for filtered daylight, incandescent illuminant A, or a certain LED with a particular RSI. The type of light source shall be an integral part of any reporting of data and of safe display duration for the print material set.

As the actual museum display lighting may not be known or it may change over time, it is helpful to know the light stability of colour print materials to different standardized light sources typical for museum display. This does not allow one to predict a safe display duration, but it allows one to choose the light source with the lowest damage potential among the tested light sources. This document stipulates several typical museum light sources for testing degradation damage potential: Xenon-arc lamp, incandescent light, and LED light. Equipment that can achieve the test conditions stipulated in 5.3.3, 5.3.4 and 5.3.5 shall be used.

In principle, the test method may also be used for museum display under a fluorescent light source; however, the method details of that test light source are outside the scope of this document.

NOTE 1 For cases where testing with fluorescent lamps is necessary users are referred back to the 1st edition of ISO 18937:2014. There is a long legacy of published data on the subject, some of which refers to materials that will not be longer available or relevant today.

Temperature and humidity control equipment shall be used to attain the chamber temperatures and the relative humidity range stipulated in this document.

If the exposure test is done at low light levels, a chamber may not be required, and an exposure unit open to a conditioned lab environment could be used. Care shall be taken to verify that the humidity, temperature and pollutant levels close to the sample meet the requirements stipulated in the subclauses. Commercial equipment that complies with the Xenon-arc configuration is available on the market. For LED and incandescent light exposures, proprietary prototypes exist in museums and research institutes.

NOTE 2 As one example see the prototype of the Getty Museum: A final report prepared in support of the U.S. DOE Solid-State Lighting Technology Demonstration GATEWAY Program, describes incandescent light as well as a LED test set; Study Participants: Pacific Northwest National Laboratory U.S. Department of Energy, The J. Paul Getty Museum and the Getty Conservation Institute, Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory in March 2012.

5.3.2 Light intensity tolerances and long-term drift

The light intensity shall be maintained and controlled throughout testing in accordance with ISO 18937.

If tests are run over extended periods, one should assure that the relative spectral irradiance of the light source is kept in tolerance over the test period. For commercial equipment, manufacturers provide a recommended service interval to replace lamps on a regular basis.

NOTE For background in LED long-term drift and colour change see References [12][13].

5.3.3 Specifications for filtered Xenon arc lamp to simulate indoor daylight

To simulate indoor indirect daylight, the in-window display (window glass) condition in accordance with ISO 18937 shall be used. For assessing the sensitivity of colour print material set to a specific light source the light source shall be used without additional filters. The xenon lamp shall be configured with a glass filter to provide the spectral irradiation distribution as given in Table 2. It may be used with or without a standard IR filter. The IR filter can be used if it is necessary to attain the black panel temperature and to comply with the specified RSI for in-window display according to ISO 18937 tolerances given in Table 2.

Table 2 — Relative spectral irradiance for filtered Xenon-arc lamp for in-window display

Spectral passband wavelength, λ nm	Spectral energy as a percentage of energy between 300 nm to 800 nm
$300 < \lambda < 340$	0,5 to 1,2
$340 \leq \lambda < 370$	2,8 to 3,5
$370 \leq \lambda < 400$	3 to 5
$400 \leq \lambda < 430$	4 to 7
$430 \leq \lambda < 800$	83 to 88

The in-window-display RSI from ISO 18937, given in Table 2, represents indoor display conditions of a typical museum with large windows. Additional UV filters are most likely in place due to local museum requirements. Examples of such optical filters are described in 5.4.2 and shall be included in the test only if the light stability of museum grade UV filtered light conditions is to be investigated. The RSI of the additional UV filtering must be included when specifying the RSI of the test light source.

The sample specimens are exposed to the light continuously. The intensity shall be set to ≤80 klx.

NOTE 1 Light/dark exposure cycling is sometimes used to simulate day/night cycles. Continuous exposure is used in this document, because the evaluation results are usually not very different from alternating light/dark exposure and the light/dark cycle may introduce other instabilities and require more time for the test.

The set point for control of the BPT (black panel temperature) shall be 25 °C to 35 °C and chamber temperature shall be controlled between 21 °C to 27 °C (see ISO 18937:2020, Annex A). The air above the sample shall not have pollutant levels higher than those given in Table 1. The relative humidity shall be set to 50 %. The tolerance of the operational fluctuation of the temperature shall be less than ±2 °C, and the tolerance of the operational fluctuation of the relative humidity shall be less than ±10 % RH.

NOTE 2 The temperature of the test is slightly higher than the upper limit of the actual temperature range of museum display as commercial equipment cannot easily reach such low temperatures during exposure. However, as the light exposure test is done for only a shorter time span, the thermal aging of prints can usually be neglected.

The uniformity of the exposure should comply with ISO 18937.

5.3.4 Specifications for incandescent light

Incandescent illumination spectral power distribution should match illuminant A of ISO/CIE 11664-2[14].

The unfiltered RSI of CIE illuminant A does not include additional UV filtering as recommended for museum display. Examples of such optical filters are described in 5.4.2 and shall be included in the test only if the light stability of museum grade UV filtered light conditions are to be investigated. The additional UV filtering must be included when specifying the RSI of the test light source.

A sample-plane illumination intensity of between 10 klx to 20 klx shall be used. The sample shall be homogeneously exposed with enough space between light source and the sample specimen to allow free air flow. The surface temperature of the specimen shall be 25 °C ± 5 °C, the set point for the ambient relative humidity shall be 50 % RH. The air above the sample shall not have pollutant levels higher than given in Table 1. The tolerance of the operational fluctuation of the temperature shall be less than ±2 °C, and the tolerance of the operational fluctuation of the relative humidity shall be less than ±10 % RH.

The uniformity of the exposure should comply with ISO 18937.

5.3.5 Specifications for LED light

White LEDs achieve their colour in several ways. There are tuneable LEDs comprising a mixture of several coloured LEDs. Others are based on only one violet or blue pump LED, the light of which is converted to other wavelengths by one or more phosphors. There are also mixtures of both technologies. There is a great variety of LEDs available with many different RSIs and their availability is changing rapidly.

For a test that determines a safe display duration, a LED that has exactly the same RSI as the museum display light should be used. At least, a LED lamp with the same excitation wavelength and same intensity of the blue peak shall be used[15].

NOTE 1 Correlated colour temperature (CCT) and colour rendering index (CRI) of an LED are not suitable metrics to determine a spectral match of two LED, as LED with same CCT and CRI can have very different relative spectral irradiances.

If the actual LED light for museum display is not known or may vary over time[16], the sensitivity to a typical LED light can be determined. Many museums may choose warm white LED light sources for display as they resemble incandescent light, while others may prefer cool white LED to more closely match daylight. Examples of a typical RSI of a cool white LED light source with a CCT of 5 000 K and a warm white LED with CCT 2 700 K are given in Annex B.

Additional UV filters may be in place due to local museum requirements. Examples of such optical filters are described in 5.4.2 and shall be included in the test only if the light stability to museum grade UV filtered LED light conditions are to be investigated. The use of additional UV filters shall be included when specifying the RSI of the test light source.

A sample-plane illumination intensity of less than or equal to 80 klx shall be used. The sample shall be homogeneously exposed with enough space between light source and sample specimen to allow free air flow.

The black panel temperature shall be 30 °C ± 5 °C, the set point for the relative humidity of the air flown over the sample shall be 50 % RH ± 10 % RH.

NOTE 2 The ± tolerances given for testing set points are the allowable fluctuations from the given set point under equilibrium conditions. This does not mean that the value can vary by plus/minus the amount indicated for the given set point. These ± tolerances are also not intended as requirements for chamber uniformity.

The air above the sample shall not have pollutant levels higher than given in Table 1. The uniformity of the exposure should comply with ISO 18937.

5.4 Specifications for additional filters

5.4.1 General

The intention of the test may be to test additional UV filtering, protective glazing or framing glass. For such cases, the spectral power distribution of the test illumination source shall be modified using suitable optical filters in order to simulate the particular usage condition. The filters shall be mounted with a distance to the object to allow free air flow over the specimen surface.

NOTE Ultraviolet and short wavelength blue radiation is considerably more harmful to some types of pictorial colour hard copy images than it is to others, therefore, variations in the level (and spectral power distribution) of the ultraviolet and short wavelength blue radiation in the illumination will affect some materials more than others. Guidance on UV filtering can be found in the conservation literature for example[17].

5.4.2 UV Filter specifications for museum lighting

In addition to the window glass filter used in commercial equipment, an additional long-pass UV cut-off filter may be used if the intention is to test the material under typical museum display conditions.

The RSI of violet- and blue-pumped LEDs may have a high emission in the violet/blue pump wavelength. Special filters exist to efficiently supress wavelengths below 450 nm.

NOTE Examples are ZBPB 097 or ZBPB 079 from Asahi spectra.

If the exact UV filter of the museum display lighting is known, that filter shall be used for the test. If the exact spectral transmission of the long-pass UV cut-off filter is unknown, the spectral transmission of the filter given in Table 3 shall be used.

Table 3 — Example of a typical long-pass UV cut-off filter

Wavelength nm	Transmission %
380	≤2
390	≤1
400	≤6
NOTE Data taken from Meteolight SFC-10.	

Table 3 *(continued)*

Wavelength nm	Transmission %
410	≤40
420	≤72
430	≤85
440	≤88
450	89 to 90
460	89 to 90
>460	≥90
NOTE Data taken from Meteolight SFC-10.	

6 Measurement

6.1 General

One of the most frequently discussed and reported image parameters in permanence studies is colour retention. However, any damage to an art object during display is to be avoided and sample specimens shall be visually inspected for objectionable changes in gloss, deformation, cracks, delamination, or other physical damage caused by the test. Such changes shall be reported and are part of the end point criteria for the test.

6.2 Measurement conditions

Evaluation of colour retention is based on the comparison of colour measurements of the specimen patch before and after the exposure. A spectrophotometer shall be used when making measurements[17]. All colour measurements shall be made in accordance with ISO 18944. If there is a desire to track the degradation of optical brightening agents on the substrate during the light fading test, then measurement shall be done with M0, M1 or M2 colour measuring mode and track the progressive reduction of their difference.

6.3 Calculation of colour difference

At least two printed patches of similar lightness and made up of the same mix of colorants shall be used for testing. The patch to patch variability must be accounted for in the assessment of the effective colour change in addition to the variability of consecutive colour measurements. As a measure of colour change, the colour difference ΔE_{76} before and after light exposure on the same spot of the test specimen is calculated. Only changes of at least $\Delta E_{76} = 3$ above the level of measurement variability (as determined in 5.2.4) shall be considered and reported as light induced colour change.

6.4 Test procedure

The test should be run in small intervals of exposure so that the colour changes between two exposures are $\Delta E_{76} \leq 3$. For materials with unknown stability, a short first test interval should be chosen followed by increasing intervals until a first change is observed. The patches shall be measured as specified in 6.2. In addition to measuring spectral or densitometric change, the test specimen shall be visually examined and compared to the control sample or unexposed parts of the sample to assess other changes. Any visual observations of change in print quality, for example degradation, such as loss of sharpness, change of gloss, and physical deterioration or deformations, such as curl, cockle, cracking, or delamination, that occurred during the test shall be reported.

Depending on evaluation context and material set under test, results from physical test methods, including brittleness and layer adhesion, can be reported. Also, chemical analytical characterization may be of interest (e.g. FTIR).

Should none of the observed changes be objectionable, the colour retention is calculated according to 6.3 and the exposure test continued until at least one colour change is $\Delta E_{76} \geq 10$ or any objectionable degradation of any of the other properties is observed. For very stable materials, it may take a long time to reach the test end point and determine the safe display duration according to Annex A.

If the goal is to assess that a specific display condition will not cause any harm, a fixed load test can be performed.

For example, if the print material is expected to be displayed for 10 years under 250 lx at 12 h light level, the test duration in lux-hours shall be 10 Mlx-h (250 lx × 12 hours per day × 365 days per year × 10 years). A safety factor can be applied to accommodate any experimental errors that may exist.

7 Evaluation

7.1 General

The results of the accelerated test are a quantitative measure for the stability of a colour print under exposure of lighting with a well-defined light source and exposure level. They are not necessarily equivalent to actual years of display at another light level (so-called reciprocal-law-failure) or even the tested light level. Wherever possible, museum objects on display should be monitored to detect any light induced degradation as early as possible and allow correlation with laboratory data. Reference [18] describes one real-time monitoring approach for museum display.

7.2 Comparing light sources

For comparing light sources, the test needs to be run with each of the light sources for the same or a very similar print material set separately as described in Clause 5. It is important to match as closely as possible the number and type of print patches selected according to 5.2.4.

The colour changes shall be evaluated at a selection of same cumulative exposure dose expressed in lx-h that cover the range of overall exposure dose applied in the test. This may require interpolation of the degradation curves, unless the intermediate measurements were collected at the same levels of cumulative exposure across all light sources in the test.

The result of each test will be a colour retention curve for each patch. For each patch, the exposure at which the end of test point is reached will be noted as the limiting exposure for that patch on that material and that particular light source. The first patch that has faded to the end of test point represents the limiting exposure for the particular print material set tested. The higher the limiting exposure the lower the damage potential of the light source.

In the case of exposing a mix of historical materials, the first patch on the first material that reaches the end of test point will determine the limiting exposure for the set.

NOTE If the print material set is not a close representation of the actual museum collection in mind, it is better to take the average of individual limiting exposures of the materials in the mix. This prevents an outlier from dominating the results.

8 Test report

Only tests that have run to the specified end of test point of 6.4 shall be converted into limiting exposure levels for the light source/print material combination.

The report of test results shall include the following:

a) Light sources, exposure levels of test and RSIs of the light sources, and transmittance of filters if used.

b) Duration of the test for each light source.

c) A reference to this document, i.e. ISO/TS 18950:2021.

d) The limiting exposure for each light source on the print material set in Mlx-h, If the test did not reach the specified end of test point, the limiting exposure level should be reported as “over XX Mlx-h.

e) Failure mode, colour retention or other visual damages (such as loss of glossiness, edge sharpness, or physical distortions).

f) A graph of ΔE_{76} versus exposures for every patch on every material, including any observations of changes in gloss, deformation, cracks, delamination or other physical damage caused by the test.

g) When there is any difference from the standard test method or standard measurement conditions described in this document.

For the print material set the following shall be reported:

— In the case of contemporary materials that are produced for the test, details of sample specimens to the extent known, such as printing technology, origin, age, and materials, in the case of ink jet, ink set and substrate material used (brand and suppliers if known)

— In the case of historic samples, the exact mix of imaging materials used for the test with identification of print technology, manufacturer and historical period as far as known

— Details of the patches that were selected (either the test target and the measured patches, or the patches on the historical materials), including densities and colour composition of the patches

NOTE If d_{min} areas are selected in the print material sample set a graph of Δb^* versus exposures measured may be done to investigate yellowing.

Annex A
(informative)

Translation of the test results into safe display duration

A.1 Outline

This document allows one to estimate the degradation caused by single light source illumination over time. The results of the accelerated test are a quantitative measure for the stability of a colour print under light exposure with a well-defined light source and exposure level. These results are not necessarily equivalent to actual years of display at that light level. In actual display, various other ageing factors may come into play that have been excluded from the test. In addition, there can be multiple types of lighting, for example daylight and artificial light in a particular location. Only actual exposure data allows one to correlate actual display years with laboratory data.

The degradation process under high light intensity may be different from the process under lower light intensity (reciprocal-law-failure).

The main challenge of using test results from an accelerated aging study to reliably predict the long-term image stability in actual display stems from a failure of reciprocity which comprises:

— nonlinearity in response of image fading rate under high level of acceleration from a specific stress factor (light)

— convoluted impacts from multiple stress factors acting together synergistically.

To manage this uncertainty, additional investigations are recommended such as

a) adding a few more tests under different combinations of “intensities x test durations”, to determine the range of linearity (reciprocity) zone.

b) minimizing other environmental factors by strict control of the display environment.

A.2 Museum acceptance endpoint and end of test

An endpoint is a measurable densitometric, colorimetric, or physical change in a print parameter that can be used to define a certain level of change in a print. The meaning and interpretation of an endpoint depends on the expectation in a given use case, and it can e.g. define the level of change, at which a print is no longer usable or acceptable in that particular application. Conservator ethics require that museum materials show minimum change after display. A colour change of ΔE_{76} = 10, which is the end of test point from the test in 6.4, is clearly visible and thus not acceptable as the end point for a safe display duration.

In colorimetry, a just visible change is equivalent to ΔE_{76} = 1 to 2. The museum end point for safe display duration should be chosen just significantly above noise at ΔE_{76} = 2 of the worst colour patch. The accumulated exposure up to this point is the maximum exposure allowed for safe display duration for that print material under the specified light source. A change of ΔE_{76} = 2 is close to the measurement error and the experimental fluctuations of the fading test[19]. In addition, test patches chosen from a real image are prone to small positioning errors of the colour measurement equipment. A too small colour difference is thus not suitable as an experimental test end point. This document recommends running the exposure test in very small increments up to an end-of-test-point of $\Delta E_{76} \geq 10$, which will be well above the noise level. The maximum exposure level can be interpolated from the Graph of ΔE_{76} vs exposure at the point of ΔE_{76} = 2. The actual curve should be used to find ΔE_{76} = 2 as the function is not linear.

A.3 Translation of the test results into museum display years

Tests are typically performed at exposure levels that are different from the light level at which a print will actually be displayed. If one can reasonably rule out the other aging factors listed in the first subclause of Annex A (for example, through additional light exposure tests at different light intensity levels (lux) and test temperatures), then by knowing the maximum display exposure level interpolated from the test graph, the safe display duration for any museum display light level may be estimated as shown in the example below.

EXAMPLE The limiting exposure level for a print material was determined as 10 Mlx-h for given RSI. The safe display duration for exposure of the print under the same RSI at 200 lx for 12 hours per day (which represents a year-based exposure duration of 4 380 hours per year) is calculated as 10 000 000 lx-h/(200 lx × 4 380 h/y) =14 years.

NOTE Depending on the nature of the specific materials to be tested, an assumption of reciprocal behaviour, or adherence to the reciprocity law, may not be valid. This is especially important if the user is going to make predictions of performance at ambient light levels based on accelerated test results obtained at the higher light levels. In which case, the user shall rack the behaviour of light degradation at higher intensities versus lower intensities, in order to validate the predictions of performance at ambient light levels. See ISO 18937:2020, Annex A.