Improved Test Methods for Evaluating the Permanence of Digitally-Printed Photographs

Henry Wilhelm,* Kabenla Armah, Dmitriy Shklyarov, and Barbara Stahl
Wilhelm Imaging Research, Inc., Grinnell, Iowa, U.S.A.

Abstract: Improved test methods are described for accelerated tests used to evaluate various aspects of photographic print permanence. An enhanced test target and calibration procedure is described which includes red, green, blue, and human skintone colors together with cyan, magenta, yellow, and neutral. A new set of endpoint criteria for evaluating changes in prints which makes use of all of these colors is described. To better simulate the spectra of indoor, indirect daylight through window glass that is the primary cause of the fading of displayed prints in homes and apartments, xenon arc illumination filtered by L-37 glass filters, as specified in *JEITA Standard CP-3901*, is used in the evaluation of indoor light stability.

Introduction

Although an ISO task group has for some years been working on standards for evaluating the permanence of digitally-printed photographs, at present no ISO standards have been published for predicting the life of photographs exposed to light on display, stored in albums or other dark places, or exposed to ambient ozone in homes or offices. Nor has an ISO standard been published to measure the resistance of photographs to storage or display in high-humidity conditions. In 2007, *JEITA Standard CP-3901, Digital Color Photo Print Stability Evaluation*[1] was published and some Japanese companies have recently begun to use the JEITA standard for products sold in that market.

In the absence of applicable ISO standards, the predictive, accelerated test methods developed by Wilhelm Imaging Research (*www.wilhelm-research.com*) over the past 25 years have become a *de facto* industry standard.[2-4] Results of WIR tests for light stability, dark storage stability, and exposure to ambient ozone are given as "Print Permanence Ratings" expressed in "years." The resistance of print materials to high humidity conditions is rated as "Very High," "Moderate," or "Low." Resistance to water is rated as "High," "Moderate," or "Low." This paper describes a number of proposed enhancements to the established WIR accelerated print permanence test methods.

Enhanced Test Targets

Traditional silver-halide color prints form images with cyan, magenta, and yellow dyes, with neutral made up of equal concentrations of the three dyes. Digital "dye-sub" or D2T2 printers also use only cyan, magenta, and yellow dyes. For these systems, test targets with cyan, magenta, yellow and neutral generally provide a reasonable indication of density losses and shifts in color balance caused by fading. A white d-min area is also provided to measure yellowish stain formation. The digital test target developed by WIR in 1995 was designed in this manner.

However, inkjet and color electrophotographic printers use cyan, magenta, yellow, and black inks – and advanced inkjet photo printers may also make use of dilute cyan, dilute magenta, red, green, blue, orange, and multilevel black and gray inks. Colors found in photographs, including neutrals and human skintone colors, may be formed by complex combinations of the available ink colors, which are determined by a printer's software and firmware. Adding red, green, blue, and human skintone colors to the test target will provide a more robust analysis of the fading behavior of these modern inkjet systems. Dye-based inkjet inks may be subject to "catalytic fading" in which the presence of one ink may tend to destabilize another ink. When this

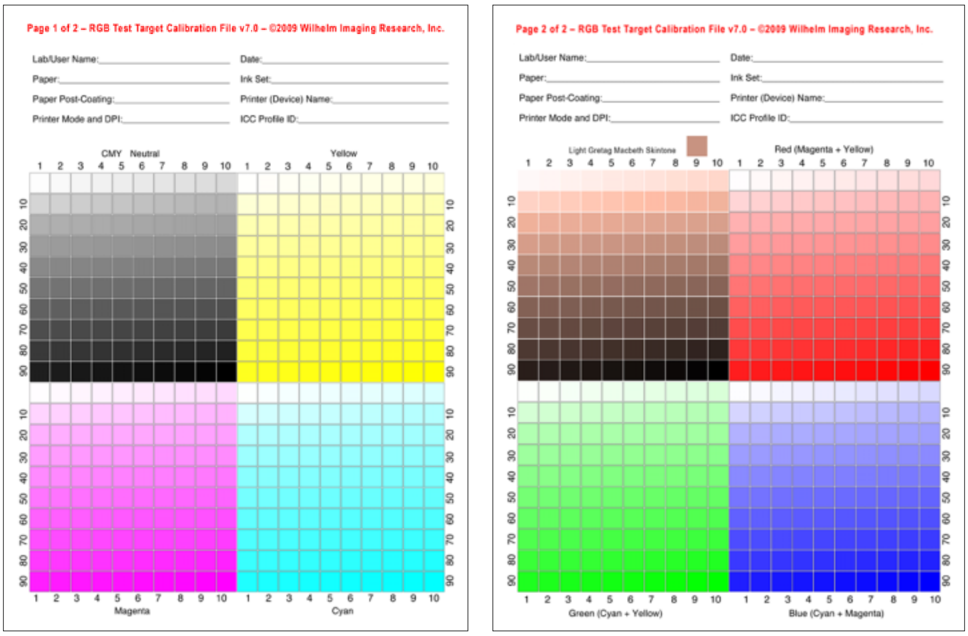

Fig. 1 U.S. Letter or A4 size "Target Calibration Pages" contain 100-step scales for cyan, magenta, yellow, red, green, blue, neutral, and human skintone colors. After printing using a printer's normal settings, the pages are measured with an automated system which selects the patches that will produce the 0.4, 0.5, 0.6, 0.7, 0.9, 1.0, 1.1, 1.4, 1.5, and 1.6 densities in the target shown at the right.

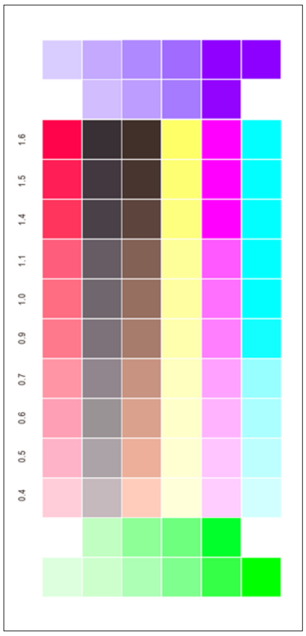

Fig. 2 The small 4x8 cm calibrated test target is designed to fit in a sample holder used in a Suga SX75F xenon arc test unit.

* 713 State Street, Grinnell, Iowa 50112 U.S.A.

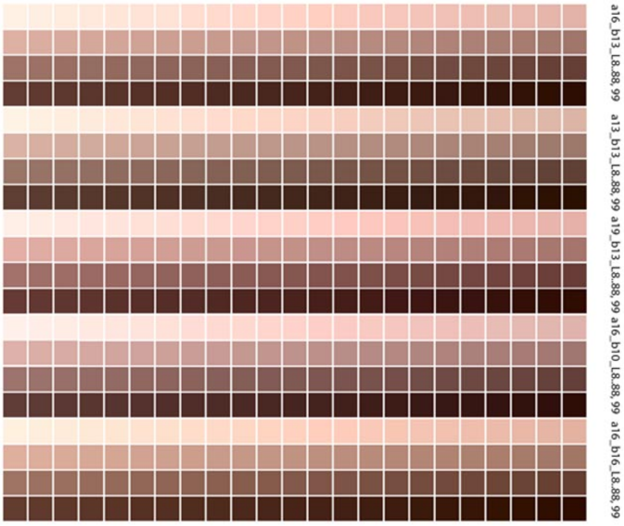

Fig. 3 Experience has shown that many sRGB consumer printers, especially retail kiosk printers, are often not well calibrated. To obtain more accurate skintone patches in the test target, a separate skintone calibration page has been developed that contains five sets of skintone scales in which the hue has been shifted an appropriate amount to accommodate the color reproduction errors of a particular printer, ink, and paper combination.

occurs, it is often especially noticeable in skintone colors. It should also be noted that advanced photo inkjet printers which use multilevel carbon pigment based black and gray inks may print neutrals largely with these highly-stable inks and, because of this, measurement of the neutral patches will not provide a meaningful indication of overall shifts in the color balance of a photograph.

It has been estimated that approximately 80-percent of consumer photographs include people in the scene and people are the central subjects in nearly 100-percent of professional portrait and wedding photographs. The addition of skintone patches is therefore very important. Changes in skintone colors are particularly objectionable in cases where the skin color shifts to green or blue. As shown in Table 1, a new, more robust *WIR Visually-Weighted Endpoint Criteria Set v4.0 for Image Stability Tests* has been developed that adds red, green, blue, and skintone colors to the previous WIR v3.0 endpoint criteria set.[2-3,5] The new WIR v4.0 criteria set also changes the previous 0.6 density patches to 0.5 density, and adds 1.5 density patches for all colors (in the WIR test target, additional patches of 0.1 density both higher and lower than the aim densities are provided to allow for interpolation to the precise aim densities).

Analysis of changes in skintone colors is done with WIR i-Star Retained Image Appearance software.[6-7] Additional psychophysical evaluation of a variety of portraits of people is under way to determine appropriate endpoints for fading and color shifts with skintone colors for different applications.

WIR i-Star is a CIELAB colorimetry-based, full tonal scale “retained image appearance” metric. When used with an appropriate test target (see Figure 4 below), it provides a comprehensive method to evaluate the permanence of not only human skintone colors, but also of neutrals and near-neutrals as well as the full range of the printable colors in sRGB or other color spaces over the full tonal scale found in photographs. The WIR i-Star metric also evaluates changes in both localized and overall image contrast. For the proposed WIR v4.0 endpoint criteria set, the i-Star metric is being used only with skintone colors. However, further research is being done in the application of the WIR i-Star metric with improved WIR i-Star test targets for image permanence applications and it is expected that this methodology will be implemented by WIR more broadly in the future.

Filtered Xenon Arc Simulation of Indoor Indirect Daylight

WIR and most other testing laboratories have long used cool white fluorescent illumination in temperature and humidity controlled test units for accelerated light fading studies. Fluorescent lamps have the advantage of providing evenly distributed, high-intensity illumination and, because these energy-efficient lamps have relative low IR output, it is relatively simple to provide adequate sample temperature and humidity control.

However, fluorescent lamps do not provide a spectral match to indoor indirect daylight through window glass that is as good

Table 1. WIR Visually-Weighted Endpoint Criteria Set v4.0 for Image Stability Tests

Ref. No.	Change Limits in Initial Status A Densities of 0.5, 1.0, and 1.5	Image Change Parameter
1	I* (percent retained) TBD	Changes in representative human skintone colors
2	12%	Cyan minus magenta (R – G) color imbalance in neutral patches
3	15%	Magenta minus cyan (G – R) color imbalance in neutral patches
4	18%	Cyan minus yellow (R – B) color imbalance in neutral patches
5	18%	Yellow minus cyan (B – R) color imbalance in neutral patches
6	18%	Magenta minus yellow (G – B) color imbalance in neutral patches
7	18%	Yellow minus magenta (B – G) color imbalance in neutral patches
8	25%	Loss of cyan (R) in neutral patches
9	20%	Loss of magenta (G) in neutral patches
10	35%	Loss of yellow (B) in neutral patches
11	30%	Loss of cyan (R) in pure color cyan patches
12	25%	Loss of magenta (G) in pure color magenta patches
13	35%	Loss of yellow (B) in pure color yellow patches
14	25%	Loss of magenta or yellow (G or B) in red patches
15	25%	Loss of cyan or yellow (R or B) in green patches
16	25%	Loss of cyan or magenta (R or G) in blue patches
17	18%	Color imbalance between magenta (G) and yellow (B) in red patches
18	18%	Color imbalance between cyan (R) and yellow (B) in green patches
19	18%	Color imbalance between cyan (R) and magenta (G) in blue patches
Change Limits in Minimum-Density Areas (Paper White) Expressed in Density Units		
20	.06	Change [increase] in red or green density
21	.15	Change [increase] in blue density
22	.05	Color imbalance between red and green densities
23	.10	Color imbalance between red and blue densities
24	.10	Color imbalance between green and blue densities

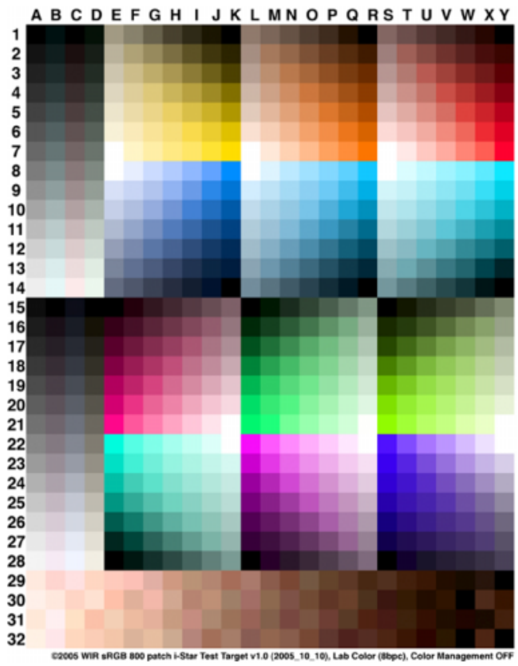

Fig. 4 The WIR i-Star sRGBcolorspace Target (v1.0) is a generic 800 patch test target for I* analysis. The target maps 12 hues with varying lightness and chroma, plus neutrals, near-neutrals, and skintone colors over the full tonal gradient and color gamut of the sRGB color space.

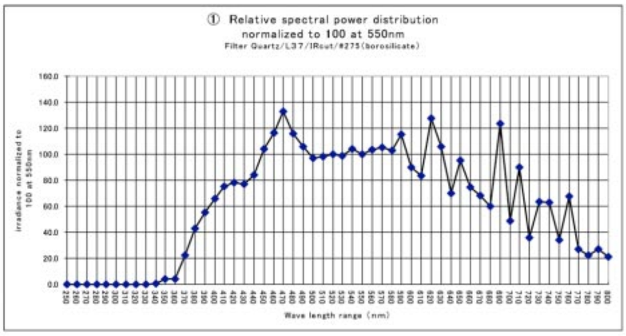

Fig. 5 The relative spectral power distribution of the xenon arc lamp (normalized to 100 at 550 nm) in a refrigerated Suga SX75F accelerated test unit equipped with a soda lime glass inner filter, an L-37 filter which cuts off at approximately 360 nm, and both inner and outer IR filters designed to minimize the heating of test samples. This spectral power distribution provides a reasonably good match to indoor, indirect daylight through window glass.

as filtered xenon arc illumination.[8-9] It is for this reason that *JEITA CP-3901* specifies L-37 (or equivalent) filtered xenon arc illumination.[1] WIR has adopted this specification for the proposed new test procedures. The ambient home light intensity assumption is 250 lux for twelve hours per day. Data are reported in “predicted years” based on *WIR Visually-Weighted Endpoint Criteria Set v4.0*. Data for both prints framed under glass and prints framed with UV-absorbing glass or plastic materials are also provided.

Arrhenius Tests for Album/Dark Storage Stability

WIR conducts Arrhenius dark storage stability tests according to long established procedures in the photography field but, for highly stable materials, also utilizes the 1/2 or 1/3 of the stipulated endpoint method provided in *JEITA CP-3901* (including the *Addendum* to *CP-3901* issued in August 2008).[1] WIR’s tests are conducted at 78°C, 71°C, 64°C, and 57°C, all at 50% RH. Data are reported in “predicted years,” based on the *WIR Visually-Weighted Endpoint Criteria Set v4.0*.

Tests for Unprotected Resistance to Ozone

WIR has been utilizing a SATRA HTC Model 903 Ozone Test Cabinet equipped with extended-range ozone concentration and a Horiba APOA-360 UV absorption ambient ozone monitor.[11] The test chamber is operated with an ozone level of 5 ppm and is maintained at 23°C and 50% RH.[12] Ambient ozone assumptions are based on a 2003 study by Seiko Epson in Japan.[13] Data are reported in terms of “predicted years” of unprotected ozone exposure based on *WIR Visually-Weighted Endpoint Criteria Set v4.0*.

Tests for Resistance to High Humidity Conditions

Test methods for resistance to high humidity and related test methods for evaluating “short-term color drift” of dye-based inkjet inks and the images of some other print systems have been under development at WIR since 1996, when Mark McCormick-Goodhart and Henry Wilhelm first began to study this factor.

These test methods utilize a special “checkerboard” pattern test target (shown in Figure 8) to measure the degree of image bleed and changes in density and color balance.[14] Tests are conducted at 85% RH and 25°C for a period of four weeks.[15] The resistance of print materials to high humidity conditions is rated as “Very High,” “Moderate,” or “Low.”

Tests for Resistance to Water

Tests for resistance to water are in a general way based on *ISO Standard 18935:2005 – Determination of indoor water resistance of printed colour images*.[16] Both “water drip” tests and “standing water droplets/gentle wipe” tests are employed. WIR reports the results in terms of three subjective classes: “High,” “Moderate,” and “Low.”

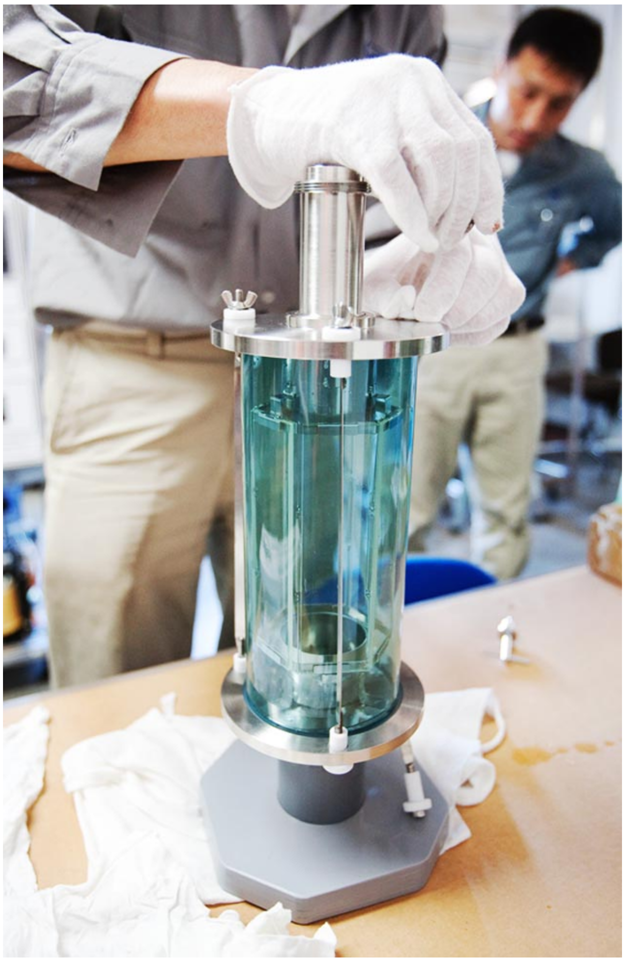

Fig. 6 The water-cooled xenon arc lamp and filter module from the Suga SX75F accelerated test unit.[10] Independent refrigeration systems are provided to cool the lamp as well as to control the air temperature and relative humidity of the test chamber. When operated at 75 klux at the sample plane, the dual IR filters and refrigerated cooling systems are able to maintain a black panel temperature that is only 2°C above the 23°C chamber air temperature (at 50% RH) selected for these tests.

Fig. 7 Photographs displayed in homes under indirect daylight at typical illumination levels (up to 500 lux) are in equilibrium with ambient temperature and relative humidity. At such low light levels, there is essentially no “heating” of a print. It is very important that accelerated light fading tests simulate the temperature and relative humidity conditions of normal display as closely as possible. This can be very difficult to achieve with high-intensity accelerated light fading equipment. Heating a test sample even slightly above the surrounding air temperature will result in a reduction of sample moisture content, which may in turn influence fading behavior. Some ink/paper combinations are more affected than others by temperature and moisture content.

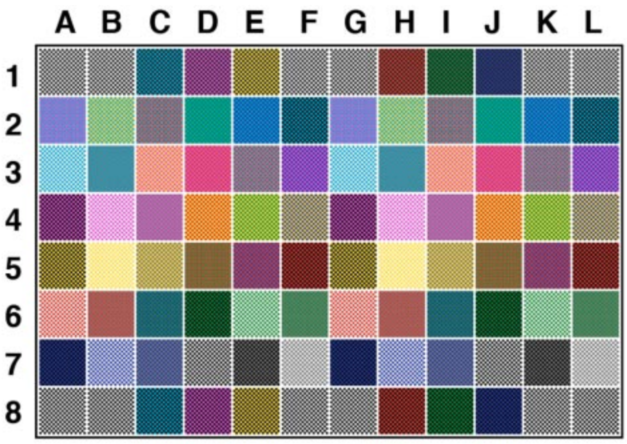

Fig. 8 The "checkerboard" test pattern developed by WIR to evaluate color bleeding, and changes in density and color balance in humidity-fastness studies. The target has 96 patches with 43 unique color pairs. Human skintone patches can be added.

Conclusions

To provide consumers with comprehensive information about print permanence, ***it is WIR policy that data for all five permanence tests must be reported.*** This avoids a situation where a manufacturer might want to emphasize the strong points of a particular product while ignoring one or more weaknesses of the material (for example, a particular ink/media combination may be very stable when stored in the dark in an album or box, but have poor stability when exposed to light during display).

WIR test reports also notes the presence or absence of optical brightening agents (OBAs) in the image side of the print, assigning one of three categories: "Yes," "Some," and "No."

The terms "Will Last X Years," or "Lasts X Years" are not used by WIR to report predictions made with data from accelerated tests. The word "Archival" also is not used to report test results, to rank, describe, or otherwise categorize print materials.

Consumer tolerance for the amount of fading, changes in color balance, contrast variations, and yellowish stain formation that are considered "acceptable" is steadily decreasing as people become ever more accustomed to viewing photographic and video images on brightly lit LCD, Plasma, or OLED displays.

Putting aside the multiple challenges associated with the long-term preservation of digital data, the images themselves are capable of retaining their original clarity and brilliance forever.

Indeed, as electronic display and viewing technologies continue to improve along with the adoption of sophisticated system-wide color management, the overall appearance of digitally-preserved images will be perceived to ***actually improve!***

For all of the above reasons – and to assure consumers, professional photographers, and museums that print permanence test methods are meaningful and credible – stringent end-point criteria must be employed in the evaluation of the permanence of both analog and digitally-printed photographs.

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Author Biography

Henry Wilhelm was a founding member of the Photographic Materials Group of the American Institute for Conservation of Historic and Artistic Works. In 1978, he was one of the founding members of American National Standards Institute Subcommittee IT9-3 (now incorporated into ISO and known as ISO Working Group 5/Task Group 3 [WG-5/TG-3]), which is responsible for developing standardized accelerated test methods and specifications for the permanence of color photographs and digital print materials.

Wilhelm has served as Secretary of the ISO group since 1984 and he presently serves with Yoshihiko Shibahara of Fujifilm Corporation in Japan as Co-Project Leader of the ISO WG-5/TG-3 Technical Subcommittee on test methods for measuring indoor light stability. Wilhelm is also an active member of the ISO task groups responsible for storage standards for color and black-and-white films and prints.

Wilhelm is the co-founder and president of Wilhelm Imaging Research, Inc. www.wilhelm-research.com. In 2007 he was the recipient of the PhotoImaging Manufacturers and Distributors Association (PMDA) *"2007 Lifetime Achievement Award"* for his work on the evaluation of the permanence of traditional and digital color prints and for his advocacy of very low temperature cold storage (minus 20°C [minus 4°F] at 40% RH) for the permanent preservation of black-and-white and color prints, color negatives, transparencies, and motion picture films.

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