A Review of Accelerated Test Methods for Predicting the Image Life of Digitally-Printed Photographs – Part II

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Abstract

This paper gives an overview of the various factors affecting the permanence of digitally-printed photographs.[1] Accelerated test methods are discussed, with emphasis on light stability tests specified with past and current ANSI and ISO Standards, future ISO Standards, and the "de facto" test method standards now widely used in the imaging industry, such as the predictive "Display Permanence Rating" test method developed by Wilhelm Imaging Research and the predictive stability test methods employed by Eastman Kodak for evaluation of Kodak Ultima Picture Paper (ColorLast, 2003 type). Light stability data for representative products evaluated with these two "de facto" test methods are given, and the major factors that account for the large differences in outcomes are presented.

The potentially large impact of reciprocity failures in high-intensity accelerated light stability tests is illustrated with long-term test data for an inkjet paper printed with dye-based inks. The importance of the selection of the spectral power distribution of the illumination source employed for accelerated light stability tests is emphasized.

Introduction

Standardized image permanence tests serve a number of important purposes: 1) To provide guidance to consumers wanting to select the longest-lasting materials which otherwise meet their needs in terms of cost, image quality, print size, and convenience (refer to Table 1 for an example); 2) To provide printer, ink, and paper manufacturers' R&D departments image permanence test methods to help evaluate and improve the longevity of future products; 3) To enable manufacturers to understand their position in the marketplace relative to their competitors; 4) To provide manufacturers image permanence data for use in promoting their products in the marketplace while supplying the information to customers as a part of general product specifications; and, 5) To provide museums and archives with data concerning the intrinsic stability properties of the imaging materials in their collections so that suitable display conditions, control of the duration of display, and proper dark storage conditions, including using cold storage if necessary, can be implemented to achieve long-term preservation of the materials in their original, unchanged form.

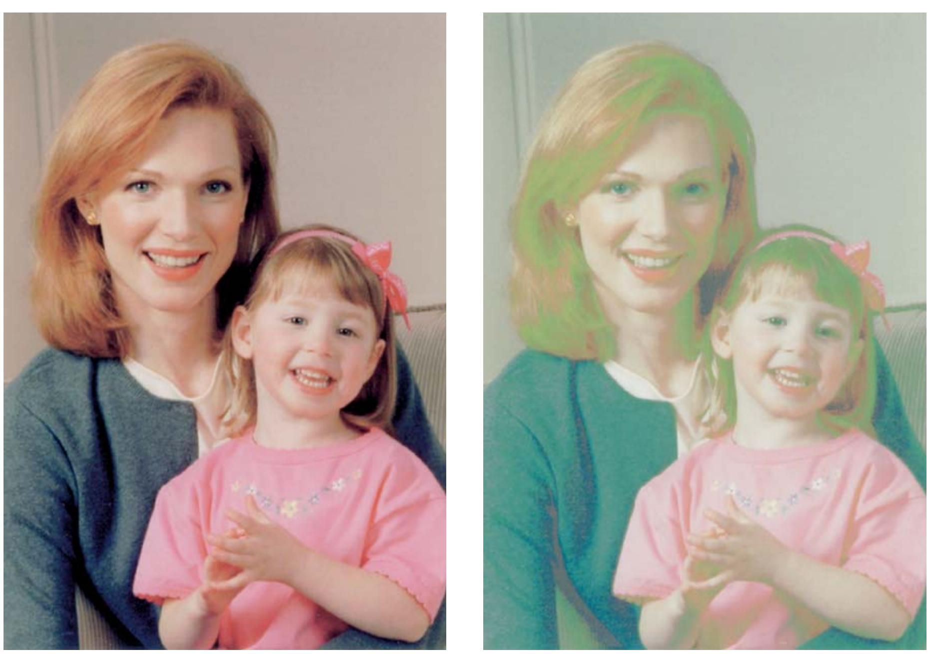

Figure 1. With an unfaded control sample on the left, the inkjet print on the right has been subjected to an accelerated glass-filtered cool white fluorescent light fading test (35 klux/ 24°C/60% RH). The print was made with a widely used 6-ink photo printer utilizing dye-based inks; the print paper was supplied by the manufacturer. When used with this particular paper, the image suffers from pronounced light-induced catalytic fading of the magenta ink in colors where it is intermixed with the yellow and cyan inks; only the higher densities are affected. This has resulted in the woman's reddish hair becoming a rather brilliant green in darker areas. (Note: A color version of this article is available in PDF format from <www.wilhelm-research.com>.) Presently used image permanence test methods utilize measurements made at a single 1.0 density or, in the case of WIR, at the two densities of 0.6 and 1.0. Most inkjet catalytic fading reactions occur at densities higher than 1.0 and, therefore, are not detected by current test methods. The full tonal scale, colorimetric evaluation method developed by Wilhelm Imaging Research corrects this major shortcoming.[2–4]

Table 1. Display Permanence Ratings for Products in the 4x6-inch Print Category Using Two Test Methods

Type of Printer/Paper/Ink	WIR v3.0 Endpoints 1.0 and 0.6 Densities Cool White Fluorescent Glass Filter 450 lux/12 hrs/day	ISO "Illustrative" Endpoints 1.0 Density Only Cool White Fluorescent UV Filter 120 lux/12 hrs/day
1. Epson PictureMate Personal Photo Lab (pigment-based inkjet prints) Printed with Epson PictureMate Photo Paper	104 years	>600 years
2. HP Photosmart 325 and 375 Printers (dye-based inkjet prints) Printed with HP Premium Plus High Gloss Photo Paper	82	>350 (est.)
HP Photosmart 325 and 375 B&W prints with HP No. 100 Gray Photo Cartridge Printed with HP Premium Plus High Gloss Photo Paper (dye-based inkjet prints)	115	>500 (est.)
3. Fujicolor Crystal Archive Type One Paper (silver-halide prints)	40	218
4. Kodak EasyShare Printer Dock 6000 and 4000 (dye-sub prints)	26	152
5. Kodak Ektacolor Edge Generations Paper (silver-halide prints)	19	100
6. HP Photosmart 145 and 245 Printers (dye-based inkjet prints) Printed with HP Premium Plus Photo Paper, Glossy	18	125
HP Photosmart 145 and 245 B&W prints with HP No. 59 Gray Photo Cartridge Printed with HP Premium Plus Photo Paper, Glossy (dye-based inkjet prints)	115	>500 (est.)
7. Agfa Prestige Digital Paper (silver-halide prints)	14	77
8. HP Photosmart 145 and 245 Printers (dye-based inkjet prints) Printed with Kodak Ultima Picture Paper, High Gloss (ColorLast version – 2003)	11	100
9. Olympus P-10 Printer (dye-sub prints)	8	35 (est.)
10. Canon CP-200 Printer (dye-sub prints)	7	29
11. Sony DPP EX5 Printer (dye-sub prints)	4	17

Manufacturers have an understandable desire to emphasize the strengths of their products, and to employ tests and methods of analysis that in general will give the longest possible image-life predictions. But it is of course the consumer who purchases the products and has the greatest interest in their long-term permanence. As a result of the failure over the past 25 years of the largely industry-driven standards organizations such as ANSI and ISO to develop meaningful image permanence standards for either black-and-white or color photographic materials, the field is at present in a very confused state with some manufacturers and independent test labs reporting vastly different image permanence data than others for the same products.

These differing test conclusions are a result of using different test methods; different interior illumination level assumptions for extrapolation of accelerated data (see Table 2); different criteria for "acceptable" fading, changes in color balance, and yellowish stain formation; and different assumptions about ambient temperature and relative humidity in photograph display and storage locations.

The photography and digital imaging field presently has no industry-wide test methods analogous to other industries' product evaluations, such as the government-mandated tests for automobile fuel efficiency used in the United States, Europe, Asia, and most other areas. These tests have provided consumers with

Table 2. "Standard" Indoor Illumination Levels Used by Printer, Ink, and Media Manufacturers

120 lux/12 hrs/day	450 lux or 500 lux/10 hrs/day or 12 hrs/day
Kodak	Fuji Hewlett-Packard Epson Canon Lexmark Ilford Agfa Konica-Minolta DuPont Ferrania InteliCoat Somerset Arches LexJet Lyson Luminos Hahnemuhle American Inkjet MediaStreet

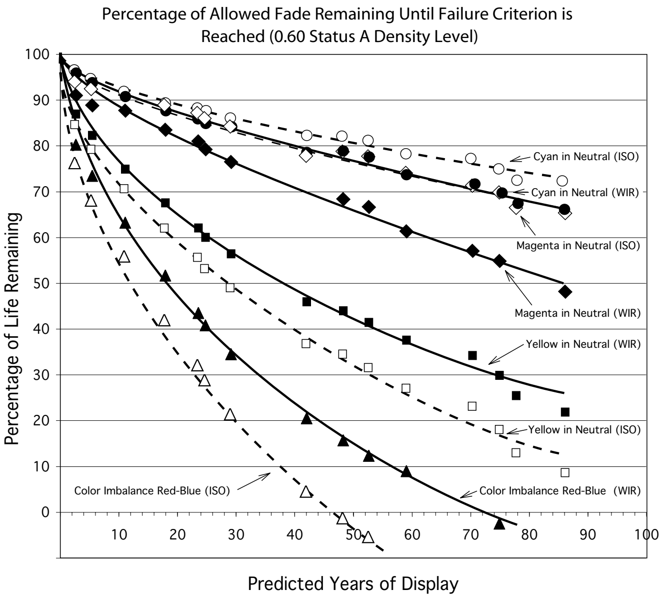

Figure 2. Because changes in yellow have relatively less visual impact with most pictorial scenes than do change in magenta and cyan (yellow also contributes very little to image contrast), the end-point criteria set developed by Wilhelm Imaging Research allows for more fading of pure color yellow and has a greater tolerance for color shifts that result from fading of the yellow ink than it does for magenta and cyan. Illustrated here is a light stability test with the Hewlett-Packard photo inkset consisting of the HP No. 57 and 58 ink cartridges and printed with an HP Photosmart 7550 printer on HP Premium Plus High Gloss Photo Paper. The Display Permanence Rating using the WIR 3.0 Visually-Weighted Endpoint Criteria is 73 years. With the ISO "Illustrative" endpoint set (which for illustrative purposes, gives the same values for all inks), the Display Permanence Rating drops to 47 years. The ISO "Illustrative" endpoint set is not a specification in any past or present ANSI or ISO standard; rather, it was included in the present standards only as an aid to illustrating the image change parameters that should be considered. The choice of actual endpoint values is left to the user – any desired set of values can be selected.

a standardized way to compare the fuel economy of one brand and model of automobile with another, irrespective of the manufacturer of the car. At the same time, they have provided automobile manufacturers with a "level playing field" for fair competition and have encouraged the development of cars with greatly improved fuel efficiency, such as the Toyota Prius and other hybrid vehicles.

Accelerated Light Stability Test Methods

The first ANSI standard for testing the permanence of color photographs was *ANSI PH1.42-1969 – American National Standard Method for Comparing the Color Stabilities of Photographs.* This standard did not contain "predictive" tests that could be reported in terms of years of display or years of storage under specified conditions. Instead it specified a series of comparative tests, including a 5.4 klux glass-filtered xenon arc test to simulate indoor display conditions and three combinations of

Table 3. Percentage Losses of Magenta Dye in Kodak Ektacolor Plus Paper Resulting from Light Fading

60 days under 21.5 klux illumination (data from neutral patches)

Starting Density above d-min	Density Loss at End of Test	Percent Density Loss
0.20	– 0.13	– 65%
0.30	– 0.14	– 47%
0.40	– 0.15	– 38%
0.50	– 0.15	– 30%
0.60	– 0.15	– 25%
1.00	– 0.15	– 15%
1.50	– 0.14	– 9%

heat and humidity to simulate different dark storage conditions. Included were 37.8°C and 90% RH "to simulate tropical conditions"; 60°C and 70% RH "to simulate results which occur with long-term storage"; and 76.7°C and less than 5% RH to simulate "accelerated fading caused primarily by heat." The specifications in this ANSI standard were largely based on work by Hubbell, McKinney, and West of Eastman Kodak.[5] *ANSI PH1.42-1969* did not achieve significant use and during the 1980's was more or less abandoned by Kodak and other manufacturers, as well as independent labs. Relevant to current standards work, however, this early standard specified starting densities of both 1.0 and 0.5 (above d-min). To improve upon *ANSI PH1.42-1969,* ANSI Subcommittee IT-3 was established in 1978 and, for the first time, included international representation from Japan and Europe. After 12 years of work, *ANSI IT9.9-1990 – American National Standard for Imaging Materials – Stability of Photographic Images – Method for Measuring* was published in 1990. This document specified a predictive Arrhenius test for dark storage stability and five "comparative" tests for light fading stability. The light fading tests included both 6.0 klux glass-filtered cool white fluorescent and xenon arc tests to simulate indoor display conditions. Cautions were given with regard to possible reciprocity failures in accelerated light stability tests, and it was recommended that tests also be conducted at 1.0 klux to assess this problem. A single starting density of 1.0 was specified. But like the previous *ANSI PH1.42-1969,* the new standard did not specify limits of acceptability for dye fading, color balance shift, or stain formation; these important factors were left to the user to determine.

With little change, *ANSI IT9.9-1990* was adopted by ISO in 1993 as *ISO 10977:1993 – Photography – Processed photographic colour films and paper prints – Methods for measuring image stability.* In 1996, *ANSI IT9.9-1990* was somewhat revised and redesignated as *ANSI/NAPM IT9.9-1996.*[6] A further revision of this standard is expected to be published by ISO by the end of 2004 under the designation of ISO 18909. In several significant respects, the new ISO 18909 standard is viewed by this author as a further, significant weakening of the previous,

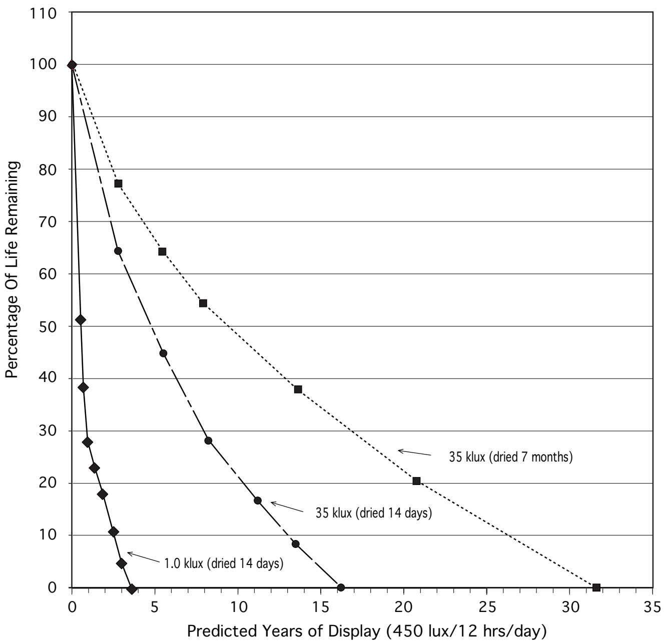

Figure 3. Light-fading reciprocity failure test with Kodak Ultima inkjet paper (original 2001 type) printed with a now-obsolete Kodak Personal PictureMaker PPM200 inkjet printer and the Kodak photo inkset supplied with the printer. With the prints "dried" at 24°C and 60% RH for the WIR standard 14 days prior to the start of the tests, the first endpoint failure was reached at 3.4 years (extrapolated to a display condition of 450 lux for 12 hours per day) with the accelerated test conducted at 1.0 klux. With the accelerated test conducted at 35 klux, the first endpoint failure was reached at the equivalent of 16.4 years. This is a 4.8X reciprocity failure in the 35 klux test compared with the 1.0 klux test.

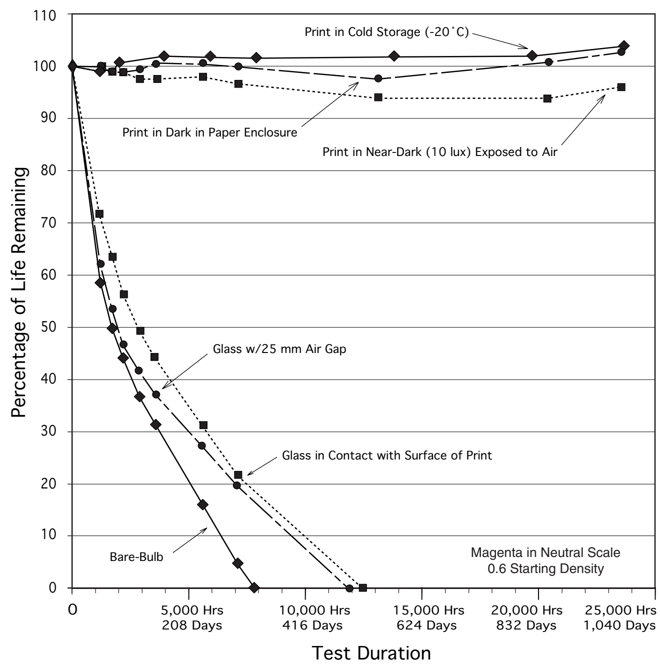

Figure 4. The low-intensity 1.0 klux tests with Kodak Ultima inkjet paper (original 2001 type) were conducted under six conditions: a glass sheet in contact with the surface of the print; a glass sheet with a 25mm air gap between the glass and the print; "bare-bulb" exposure with no glass cover sheet; in two ambient air dark conditions; and in –20°C storage as a long-term check of instrument calibration.

already weak standards (public discussion of the details of pending ISO standards is not permitted by ISO until the documents are actually published).

Wilhelm Imaging Research introduced a "predictive" indoor light stability test in 1990 based on a defined, visually-weighted endpoint criteria set and a standardized indoor illumination condition of 450 lux for 12 hours per day.[7–8] Because disproportionate density losses occur in the middle and lower densities with many materials as a result of light fading (see Table 3), use of a starting density of only 1.0 significantly overstates image-life predictions with many products. The WIR visually-weighted endpoint criteria set allows for greater losses of yellow than for magenta or cyan because studies with a variety of images clearly indicate the greatest visual tolerance is for yellow changes, and the least is for magenta; this is in part because yellow contributes very little to image contrast, while magenta contributes the most. These observations have been corroborated by Robert J. Tuite of Eastman Kodak who stated "...if only one of the dyes fades, we are least sensitive to loss of yellow dye and most sensitive to loss of magenta dye for equivalent density loss."[9]

Because of concern about potential reciprocity failures from high-intensity tests, WIR has since 1996 used an accelerated test condition of 35 klux. However, as shown in Figures 3 and 4, this still appears to produce potentially significant overestimates of light stability, especially with some inkjet materials. Higher test illumination intensities of 80 klux, for example, can be expected to produce even greater reciprocity failures. Because of the very long time periods required for low illumination level tests, it is suggested by the author that a "generic" reciprocity failure correction of a factor of approximately 3 be considered for future ISO standards.

Predictive light stability data from Wilhelm Imaging Research based on the WIR test methods are available at <www.wilhelm-research.com>. Permanence data from Wilhelm Imaging Research has also been widely published by Seiko Epson, Hewlett-Packard, Lexmark, and other companies.

It is the policy of WIR to only allow publication of light stability data when the WIR endpoint criteria set and glass-filtered cool white fluorescent, 450 lux/12 hour per day reporting conditions are used.

It should be noted that, with the exception of Eastman Kodak, indoor light stability data published by virtually all of the world's manufacturers in recent years have been based on glass-filtered illumination of either 450 lux, or 500 lux, for 10 or 12 hours per day (see Table 2). Fuji Photo Film Co., Ltd., for example, has for many years based its published data for indoor display in homes on a condition of 500 lux for 12 hours per day.

With the introduction of an improved version of Kodak Ultima Picture Paper in late 2003, Eastman Kodak began using a predictive display-life test based on 80 klux UV-filtered cool

Figure 5. An example of a digitally-printed silver-halide color print which, in the course of an accelerated light/dark cycle glass-filtered xenon arc test (the light/dark cycle is an attempt to compensate for the high black panel temperature and resulting desiccation of the prints under test), the emulsion went above the glass transition temperature and suffered both physical damage (a loss of surface gloss) and an anomalous fading pattern of the magenta dye. The upper print is an unfaded control. Based on both field experience and long-term fluorescent light fading tests, however, it is not anticipated that this type of deterioration would ever occur in real world display conditions. Although glass-filtered xenon arc illumination provides a much better spectral match to indoor daylight filtered through windows than does cool white fluorescent lamps,[13–16] currently available high-intensity xenon test units do not adequately control temperature and relative humidity that photographs encounter in normal home environments. Another drawback of currently available xenon arc units is that because the units normally operate at 80 klux or higher, there are no means available to conduct reciprocity behavior tests at low lux levels (e.g., 1.0 klux). With properly configured light/dark cycles, xenon arc units can provide a good simulation of commercial window display conditions in which prints are exposed to bright sunlight in store windows. But, for realistic simulations of typically encountered indoor display conditions, a properly filtered, "stand-alone" xenon lamp fixture must be used in a temperature and humidity-controlled room with a moderate lux level (e.g., 35 klux), and an air flow adequate to control sample temperature and moisture content (e.g., 24°C and 60% RH).

white fluorescent accelerated tests, the ISO "illustrative" endpoint criteria set, and the data were extrapolated to 120 lux for 12 hours per day.[10-12] A modified Arrhenius dark storage test was also employed by Kodak using a "constant dewpoint" method that results in a very low relative humidity in the elevated oven temperatures employed in the test. This is in contrast to the 50% relative humidity specified in applicable ANSI and ISO standards.

With a 120 lux/12 hours per day indoor illumination standard, a UV-filtered 80 klux highly accelerated illumination condition, and a single starting density of 1.0, the Kodak test method provides "years of display" predictions that typically range from four to eight times longer than the test methods used by WIR, Hewlett-Packard, Epson, Canon, Lexmark, Fuji, Konica-Minolta, and most other companies (see Tables 1 and 2).

The ISO WG-5/TG-3 group is presently working on a variety of test methods standards for digital photographic prints:

- Specifications (endpoint criteria, light levels, etc.)
- Indoor Light Stability Test Methods
- Arrhenius Thermal Aging (dark stability) Test Methods
- Waterfastness Test Methods
- Humidity-Fastness Test Methods
- Gas Fading (ozone fading) Test Methods
- Outdoor Durability Test Methods and Specifications

The ISO Waterfastness Test Method is presently the closest to publication by ISO, and the next WG-5/TG-3 meeting will take place during October 28–30, 2004 in Salt Lake City, Utah, in an effort to move the other standards forward. Of particular ugency is work on the new ISO Print Life Specifications Standard and the ISO Indoor Light Stability Test Methods Standard.

Conclusions

The worldwide photographic imaging industry urgently needs meaningful accelerated test method standards and reporting methods that focus on consumer interests. Commonly encountered "worst case" – not "average" – display and storage conditions found in homes and offices in a broad range of environments throughout the world must be taken into account, both in the test methods themselves and in reporting test results. Full tonal scale, colorimetric analysis should be implemented to correctly evaluate images produced by the many current inkjet, silver-halide, thermal dye-transfer, and other digital printing technologies, as well as future systems.[2–4] Potential reciprocity failures in high-intensity accelerated light stability tests also must be taken into account when making display-life predictions. For indoor light stability tests, a better spectral match to daylight through window glass than that provided by glass-filtered cool white fluorescent lamps should be adopted in the future.[13–16]

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1. This paper, which is also available as a PDF file with color illustrations at <www.wilhelm-research.com>, is an expanded version of an article published earlier in 2004: Henry Wilhelm, "A Review of Accelerated Test Methods for Predicting the Image Life of Digitally-Printed Photographs," *Proceedings of "Japan Hardcopy 2004" – The Annual Conference of the Imaging Society of Japan,* pp. 81–84, Tokyo, Japan, June 2–4, 2004.
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Biography

Henry Wilhelm was one of the founding members of American National Standards Institute (ANSI) Committee IT-3, which was established in 1978 and developed the *ANSI IT9.9-1990* image stability test methods standard published in 1990 (revised in 1996). For the past 16 years he has served as Secretary of the group, which is now known as ISO Working Group 5/Task Group 3 (a part of ISO Technical Committee 42). Wilhelm serves as Chair of the Indoor Light Stability Technical Subcommittee of WG-5/TG-3. He is co-founder and president of Wilhelm Imaging Research, Inc.