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

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Abstract: Inkjet (using either dye-based inks, pigmented inks, or hybrid combinations of both), thermal dye transfer (dye-sub), digitally-printed traditional silver-halide (chromogenic) papers, and other technologies are all used to print photographs from digital camera files. In addition to desktop and wide-format applications, inkjet printing technology is now also being adopted for "dry" minilabs and by professional portrait and wedding photography studios. This paper gives an overview of the various factors affecting the permanence of digitally-printed photographs. Accelerated test methods are described, with emphasis on past and current ANSI and ISO Standards, future ISO Standards, and the "de facto" standards now widely used in the imaging industry, such as the "Wilhelm Imaging Research Indoor Light Stability Test Method" and the "Kodak Test Methods Used with Kodak Ultima Picture Paper" (2003 type) inkjet paper. Image permanence data for representative products evaluated with are given. The potentially large impact of reciprocity failures in high-intensity accelerated light stability tests is described, with data presented from selected products.

Introduction

Image permanence tests serve three main purposes: 1) To provide guidance to consumers in selecting the longest-lasting materials which otherwise meet their needs in terms of cost, image quality, print size, and convenience – refer to Table 3 for an example; 2) Manufacturers of printers, inks, and papers employ image permanence tests in research and development in order to improve the overall permanence of their products and also to identify their position in the marketplace relative to their competitors; and, 3) Marketing departments of the manufacturers use data from image permanence tests to promote their products in a competitive marketplace and to provide the information to consumers as a part of general product specifications.

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.

It has always been the great appeal of photography to preserve a moment in time. While the question, "How many years is long enough?" can never be fully answered, it is very clear that, given a choice, consumers will almost always choose the longest-lasting products, when cost and other factors are equal. Although is it true that most people do not attempt to keep every photograph forever, everyone has some photographs that are extremely important to them and which they would like to pass on to their children and future generations. It is also clear that consumers and museums alike select their most important photographs for display, and display them for the longest periods of time.

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 rather 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 1); 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 the government-mandated tests for automobile fuel consumption used in the United States, Europe, Asia, and most other areas. These government-mandated tests have provided consumers a useful means 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 it has provided automobile manufacturers with a "level playing field" for fair competition and has encouraged the development of cars with improved fuel efficiency such as the Toyota Prius and other hybrid vehicles.

One can only imagine the chaos that would result if each auto manufacturer separately developed its own fuel consumption tests, and the marketing departments of each company from time to time asked Research and Development to "slightly modify" the tests so that the relative rankings of its cars would "improve" in comparison to competitors' cars.

Table 1. "Standard" Indoor Illumination Levels Used by Printer, Ink, and Media Manufacturers

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

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Accelerated Image Permanence 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 heat and humidity to simulate different dark storage conditions. Included were 37.8℃ and 90% RH "to simulate tropical conditions"; 60℃ and 70% RH "to simulate results which occur with long-term storage"; and 76.7℃ and less than 5% RH to simulate "accelerate fading caused primarily by heat." Also included were tests to simulate use in slide projectors, fluorescent viewers, and direct sunlight through window glass. The specifications in this ANSI standard were largely based on work by Hubbell, McKinney, and West of Eastman Kodak.[1] *ANSI PH1.42-1969* never achieved 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. An "illustrative" endpoint criteria was included in *ANSI IT9.9-1990* and although it clearly was not a specification of the standard, it has often been incorrectly cited as such. According to the standard: "...the numerical end-points given here are only illustrative. Each user of the standard shall select end-points for the listed parameters which, in that user's judgement, are appropriate for the specific product and intended application. Selected end-points may be different for light and dark stability tests."

An early use of a 30% dye loss endpoint was by Konica in 1984 with the introduction of Konica Century Paper (also known as "Long Life 100 Paper") in which a dark storage life of greater than 100 years was determined using a 30% dye loss as the endpoint criterion (at the time, neither color balance changes nor d-min behavior were reported). The launch of this product, the first silver-halide (chromogenic) color paper featuring a dye set with high dark stability, was historically important in helping to make color print image permanence an important consumer issue in the worldwide marketplace.

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*.[2] The major change in this revision was the addition of a "sealed bag" condition for the Arrhenius thermal aging test to simulate color films stored in metal cans or other sealed containers. In addition, discussion was added concerning the dark stability testing of color negative films. The revised standard continued to specify a 6.0 klux illumination level for indoor light stability tests, and also specified a single starting density of 1.0. A further revision of this standard is expected to be published by ISO later in 2004 under the designation of *ISO 18909*. Similar to the previous ANSI and ISO standards, both indoor light stability and thermal aging tests are to be conducted at 23℃ and 50% RH (other RH conditions may also be reported).

In several significant respects, the new ISO document is viewed by this author as a further weakening of the previous standards and as such is detrimental to the interests of consumers (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[3] and a standardized indoor illumination condition of 450 lux for 12 hours per day. The tests were conducted using 21.5 klux glass-filtered cool white fluorescent illumination, a temperature of 24℃ and 60% RH. The endpoint criteria set was improved in 2001 to include 0.6 starting densities for pure color cyan, magenta, and yellow in addition to the 1.0 starting densities for the pure color primaries that had been employed previously (the neutral scale endpoint criteria has always included both 0.6 and 1.0 starting densities). In contrast, the ISO "illustrative" endpoint criteria set has almost always been used with only 1.0 starting densities. Because disproportionate density losses occur in the middle and lower densities with many materials as a result of light fading, the use of only a 1.0 starting density serves to significantly extend image-life predictions with many products. The WIR endpoint criteria set allows for greater losses of yellow than for magenta or cyan because studies with a variety of image clearly indicated the greatest visual tolerance for yellow changes, and the least for magenta changes. (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."[4] 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 1 and 2 (and in Table 2), this still appears to produce potentially significant over-estimates 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 perhaps a factor of 3 be considered for future ISO standards.

Predictive light stability data from Wilhelm Imaging Research based on these 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, and other companies. It is the policy of WIR to only allow publication of light stability data when the WIR endpoint criteria set and the 450 lux/12 hour per day illumination level are used. It should

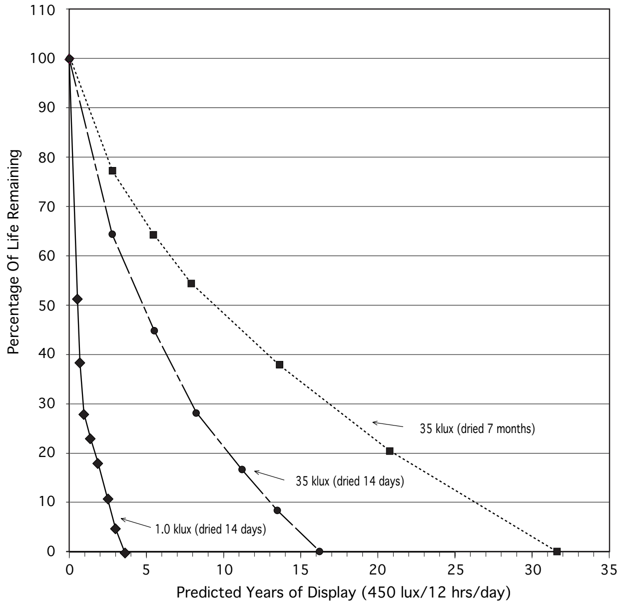

Figure 1. Light-fading reciprocity failure test with Kodak Ultima inkjet paper (original 2001 type) printed with a now-obsolete Kodak Personal PictureMaker PPM200 inkjet printer and the Kodak photo inkset supplied with the printer. With the prints "dried" at 24°C and 60% RH for the WIR standard 14 days 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.

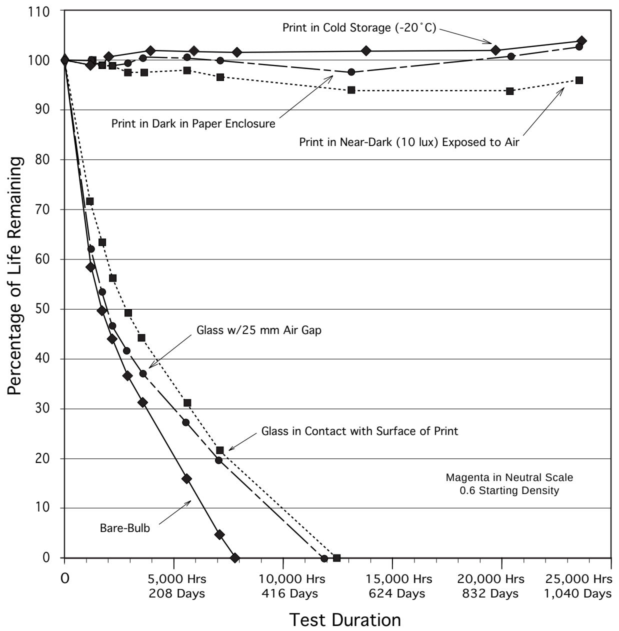

Figure 2. The low-intensity 1.0 klux tests with Kodak Ultima inkjet paper (original 2001 type) were conducted under six conditions: a glass sheet in contact with the surface of the print; a glass sheet with a 25mm air gap between the glass and the print; "bare-bulb" exposure with no glass cover sheet; in two ambient air dark conditions; and in –20°C storage as a long-term instrument calibration check.

Table 2. RFF's of Traditional Photographs (1.35–21.5 klux)

Silver-Halide (Chromogenic) Color Prints		**Reciprocity Failure Factor**
Konica Color PC Paper Type SR Konica Color PC Paper Professional Type EX (EP-2 processs with water wash)		1.8
Konica Color PC Paper Type SR Konica Color PC Paper Professional Type EX (processed with Konica Super Stabilizer in a "washless" Konica minilab)		2.2
Ektacolor Plus Paper Ektacolor Professional Paper (EP-2 process with water wash)		2.4
Ektacolor 74 RC Paper Type 2524 Ektacolor 78 Paper (EP-2 process with water wash)		2.9
Ektacolor 37 RC Paper Type 2261 (EP-2 process with EP-3 stabilizer)		2.2
Kodak Ektachrome 2203 Paper		2.5
Fujicolor Paper Type 8901 (EP-2 process with water wash)		2.4
Fujicolor Paper Type 8901 (EP-2 process with EP-3 stabilizer)		4.6
Agfacolor PE Paper Type 7i		2.7
Agfacolor PE Paper Type 589		2.4
3M High Speed Color Paper Type 19		5.4
Chromogenic Aggregate Totals:	**Average** **2.8**	**Median** **2.4**

Silver Dye-Bleach & Dye-Imbibition Prints		**Reciprocity Failure Factor**
Ilford Ilfochrome Classic Prints (called Cibachrome II Prints, 1980–91) (P-3 process – glossy polyester base)		8.0
Kodak Dye Transfer Prints ("standard" Kodak Film and Paper Dyes)		1.5
Fuji Dyecolor Prints (dye transfer type)		2.2
Dye-Bleach/Imbibition Aggregate Totals:	**Average** **3.9**	**Median** **2.2**

Dye Diffusion-Transfer Prints		**Reciprocity Failure Factor**
Polaroid Polacolor ER Prints (Types 59; 559; 669; and 809)		1.4
Polaroid 600 Plus Prints Polaroid Type 990 Prints Polaroid Autofilm Type 330 Prints Polaroid Spectra Prints Polaroid Image Prints (Spectra in Europe)		1.2
Polaroid Autofilm Type 339 Prints Polaroid High Speed Type 779 Prints Polaroid 600 High Speed Prints		1.4
Kodak Ektaflex Prints (1981–1988)		1.4
Diffusion-Transfer Aggregate Totals:	**Average** **1.4**	**Median** **1.4**

Combined Totals for all Print Types:	**Average** **2.7**	**Median** **2.3**

Table 3. Wilhelm Imaging Research Display Permanence Ratings For Current Products in the 4x6-inch Print Category*

1. Epson PictureMate Personal Photo Lab (pigment-based inkjet prints)	104 years
2. Fujicolor Crystal Archive Type One Paper (silver-halide prints)	40 years
3. Kodak EasyShare Printer Dock 6000 and 4000 (dye-sub prints)	26 years
4. Kodak Ektacolor Edge Generations Paper (silver-halide prints)	19 years
5. HP Photosmart 145, 245, and Similar Printers (dye-based inkjet prints)	18 years
HP Photosmart 245 B&W prints with HP#59 photo gray cartridge printed with HP Premium Plus Photo Paper (dye-based inkjet prints)	115 years
6. Agfa Prestige Digital Paper (silver-halide prints)	14 years
7. Canon CP-200 (dye-sub prints)	7 years
8. Sony DPP EX5 (dye-sub prints)	4 years

*Based on 450 lux/12 hours illumination per day (with glass filter) and WIR v.3.0 Endpoint Criteria Set

In the traditional silver-halide photofinishing field, the approximately 3x5 and 4x6-inch sizes has long been the most popular. With the introduction of digital minilabs, silver-halide papers are now widely used for making digital prints. In the past few years, a variety of small dye-sub and inkjet printers have also been introduced for this market. Most of these are "stand-alone" printers that can function without the need for an attached computer. Larger inkjet printers can of course also be used to make small prints and both small cut-sheet and roll papers are supplied for this purpose.

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 has been based on glass-filtered illumination of either 450 lux, or 500 lux, for 12 hours per day (see Table 1). 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 launched a controversial promotional campaign for the new inkjet paper including package claims that, when used with any brand of inkjet printer (including HP, Epson, Canon, Lexmark, and Dell), the paper was "The longest lasting inkjet photo paper under typical home display conditions. Lasts over 100 years when using latest inks, even when displayed without protection behind glass." These claims were based on 80 klux UV-filtered cool white fluorescent accelerated tests extrapolated to 120 lux for 12 hours per day and used the ISO "illustrative" endpoint criteria set. A modified Arrhenius dark storage test was also employed 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. Ozone resistance tests and humidity-fastness tests were also conducted with the new paper. To date Kodak has supported the 100-year light stability claim with data using the Kodak test methods only for HP printers using the HP #78 ink cartridge, HP #57 cartridge, or HP #57/#58 cartridges, and for Canon printers using current Canon 4-ink dye based inks. At the time of this writing, Kodak had published no light stability data in support of the 100-year claim for Canon 6-ink photo printers, Epson printers using dye-based inks, nor for any Lexmark or Dell printers.

With the use of a 120 lux/12 hours per day indoor illumination standard, a UV-filtered 80 klux 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, HP, Canon, Fuji, and most other companies.

The ISO WG-5/TG-3 group is presently working on a variety of test methods 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
*Fingerprint Tests

The Waterfastness Test Method is presently the closest to publication by ISO, and important meetings will take place during May 18–20, 2004 in Washington, D.C., in an effort to move the other standards forward. Of particular focus is the new ISO Print Life Specifications Standard.

Conclusion

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 locations throughout the world must be taken into account both in the test methods themselves and in reporting test results. Potential reciprocity failures in high-intensity accelerated light stability tests also must be considered.

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Biographical Information

Henry Wilhelm was one of the founding members of American National Standards Institute (ANSI) IT-3, established in 1978 which developed the ANSI IT9.9-1990 image stability test methods standard. For the past 15 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 TC42). Wilhelm serves as Chair of the Indoor Light Stability Technical Subcommittee of WG-5/TG-3. He is cofounder and president Wilhelm Imaging Research, Inc.

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