The Wilhelm Analog and Digital Color Print Materials Reference Collection

All Materials Printed With Color and Monochrome Test Targets Using the Printers, Processing Chemicals, and Inks of Their Time

- Traditional Analog and Modern Digital Color Print Materials
- Modern Digital Black and White Print Materials
- Definitive Product and Process Identification and Dating
- Extensive 380–730nm Spectral Data from 800-Patch Color and Neutral Gray Scales
- Comprehensive WIR Eight-Factor Print Permanence Ratings Data
- Sortable/Searchable Databases

48 Years: From 1971 to 2019
The Only Collection of Its Kind in the World
THE WILHELM ANALOG AND DIGITAL COLOR PRINT MATERIALS REFERENCE COLLECTION

All Materials Printed With Color and Monochrome Test Targets Using the Printers, Processing Chemicals, and Inks of Their Time

A publication of

WILHELM IMAGING RESEARCH, INC.
www.wilhelm-research.com

©2019 HENRY WILHELM

Wilhelm Imaging Research, Inc.
713 State Street
P.O. Box 775
Grinnell, Iowa 50112
U.S.A.

Cover Photograph ©2003 Bill Nellans

This document is available under the Creative Commons Attribution-ShareAlike License
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to the Wilhelm Analog and Digital Color Print Materials Reference Collection</td>
<td>5</td>
</tr>
<tr>
<td>Itemized Description of the Wilhelm Analog and Digital Color Print Materials Reference Collection</td>
<td>6</td>
</tr>
<tr>
<td>Use of the Wilhelm Reference Collection for Process Identification, Dating, Characterization, Authentication, Print Deterioration Assessment, Understanding Image Permanence Properties</td>
<td>8</td>
</tr>
<tr>
<td>Description of the Wilhelm Analog and Digital Color Print Materials Reference Collection: An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of IN01545</td>
<td>10</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>16</td>
</tr>
<tr>
<td>About Wilhelm Imaging Research and the Center for the Image</td>
<td>17</td>
</tr>
<tr>
<td>Wilhelm Imaging Research and Center for the Image: What We Do</td>
<td>18</td>
</tr>
<tr>
<td>Background: Henry and Carol Wilhelm</td>
<td>19</td>
</tr>
<tr>
<td>The Core of the Wilhelm Digital Print Materials Collection</td>
<td>27</td>
</tr>
<tr>
<td>800-Patch Calibration Target Pages</td>
<td>28</td>
</tr>
<tr>
<td>“Freezer Control” Test Target Print SamplesPreserved in Freezer Storage at –20°C (–4°F)</td>
<td>31</td>
</tr>
<tr>
<td>Inkjet Paper Boxes and Their Tracking and Integration With the WIR Database</td>
<td>33</td>
</tr>
<tr>
<td>Wilhelm Imaging Research Archive of Inkjet, Dye-Sub, and Other Digital Printers</td>
<td>35</td>
</tr>
<tr>
<td>Permanence Test Data Acquisition, Analysis, Report Generation, and Data Storage Systems</td>
<td>36</td>
</tr>
<tr>
<td>The Evolution of Print Permanence Test Targets at Wilhelm Imaging Research</td>
<td>37</td>
</tr>
<tr>
<td>Test Target Preparation, Calibration, and Measurement</td>
<td>39</td>
</tr>
<tr>
<td>The Wilhelm Imaging Research Eight-Factor Print Permanence Testing and Analysis Methods</td>
<td>41</td>
</tr>
<tr>
<td>1–3) Accelerated Tests for Display Permanence (Light Stability) Using High-Intensity Illumination</td>
<td>41</td>
</tr>
<tr>
<td>4) Arrhenius Accelerated Tests for Dark Storage Stability and Yellowish Stain Formation</td>
<td>48</td>
</tr>
</tbody>
</table>
CONTENTS continued...

5) Accelerated Tests for Unprotected Resistance to Atmospheric Ozone 51
6) Tests for Resistance to High Humidity Environments 54
7) Tests for Resistance to Water 56
8) Methods for Determining the Presence or Absence of Optical Brightening Agents (OBAs) 57

• The Analog Era of Color Photography: From the book “The Permanence and Care of Color Photographs” 58
• Annex 1: Imaging Conference JAPAN 2011: “Use of a Multispectral Camera System...[in Permanence Tests]” 62
• Annex 4: Published Papers Concerning Accelerated Test Methods for Evaluating Permanence of Color and Monochrome Prints 87
• Annex 5: Published Papers Concerning the Permanence of Analog and Digital Color Prints 122
• Annex 7: WIR Print Permanence Ratings for a Variety of Media, Inks, and Printers, Published on www.wilhelm-research.com 172
• Annex 8: WIR Subzero Newspaper Preservation Collection and Cold Storage Publications 212
• Annex 9: Chemical and Engineering News 2013: “Saving Endangered Photographs” 240
The Wilhelm Analog and Digital Color Print Materials Reference Collection is a continually expanding resource that consists of more than three thousand unique, documented samples of PRINTED analog color, digital color, and digital black and white photographic print materials coupled with extensive 380-730nm spectral data, print permanence test data, and comprehensive product permanence reports. It is the only collection of its kind in the world.

The reference collection was created and organized by Henry and Carol Wilhelm and their colleagues over the course of more than 48 years of laboratory research on the permanence properties and long-term preservation of color photographs.

It is the Wilhelms’ intention that the reference collection of print materials and permanence databases be located within a major research institution where the collection will continue to expand and to be made available worldwide to photography conservators, conservation research scientists, curators, collectors, dealers, archivists, historians educators, students, and others seeking information about the identification, dating, characterization, authentication, and image permanence properties of color photographic materials.
Itemized Description of the Wilhelm Color Print Materials Reference Collection

(Updated August 20, 2019)

The Wilhelm Analog and Digital Color Print Materials Reference Collection consists of printed analog color, digital color, and digital black and white photographic print materials, with associated accelerated test data and print permanence reports organized in sortable/searchable databases

1) Analog color film and print materials from 1971 to 1993 (includes permanence test data): ~475 products

2) Analog and digital color print materials from 1993 to 2000 (includes permanence test data): ~1,220 products

3) Digital color and B&W print materials from 2000 to 2018 (with spectral data from 380 to 730nm in 10nm increments for 800-patch neutral, cyan, magenta, yellow, red, green, and blue color scales): 2,483 products

4) Total identified film, print paper, and printer/ink/paper products from 1971 to 2019 (48 years): 4,180 products

5) Multiple targets for each printer/ink/media combination subjected to eight separate WIR permanence tests: (1) display permanence (light stability) tests with five different light exposure conditions: glass filter with 5mm air-gap and glass in direct contact with sample surface; (2) acrylic UV filter with 5mm air-gap and acrylic UV filter in direct contact with the sample surface; and (3) unfiltered “bare-bulb” light exposure; (4) multi-temperature Arrhenius dark storage tests; (5) unprotected ozone resistance; (6) resistance to high humidity; (7) water resistance; and (8) determination of the presence or absence of optical brightening agents (OBAs)

6) “Natural Aging” test targets are stored in the dark at ambient room temperature (24°C/60% RH) and “Long-Term Subzero Freezer Preservation” test targets for instrument calibration and visual reference are preserved in a freezer at −20°C (−4°F)

7) Individual, documented test targets included in the digital portion of the collection: 23,420 test targets

8) TOTAL number of calibration pages and digital and analog test targets in the collection: 26,720 individual items

9) Individual test target measurements in the digital portion of the collection: ~165,000 target measurements (an average of 35 test targets are measured daily, most with 135 individual color, neutral scale, and d-min paper white patches)

10) Individual spectral measurements made of the color and neutral (including full-image monochrome) patches in the test targets for all materials in the digital portion of the collection: ~830 million spectral measurements

11) Data storage, backed-up off-site daily, for spectral measurements and permanence reports: ~108 gigabytes

12) Boxes and rolls of unprinted inkjet paper and canvas which are in addition to the printed samples database: ~1,720 packages

13) Large-format inkjet printers (17 to 64-inch; up to 12 inks) and desktop inkjet, dye-sub, and other digital printers: ~350 printers

14) Microsoft Access databases with WIR developed and programmed Borland Delphi interfaces, providing search/sort capabilities
A stack of printouts of an item-level listing of the more than 25,000 individual printed calibration pages and test targets in the Wilhelm Analog and Digital Color Print Materials Reference Collection.
Use of “The Wilhelm Analog and Digital Color Print Materials Reference Collection” for process identification, dating, characterization, authentication, print deterioration assessment, and understanding the image permanence properties of color photographic materials

At a minimum, a full suite of characterization and process ID studies would include:

1) Photomicrographs of image structure, inkjet droplets, and screen patterns, etc.
2) Spectral data in 10nm increments in the UV, visible, and IR regions from both the faceside and backside of prints.
3) ISO surface gloss measurements.
4) “Distinctness of Image” or DOI measurements.
5) Raking light photomicrographs of both the faceside and backside of prints (using the methods developed by Paul Messier et.al.).
6) Print thickness measurements.
7) Backside imaging (back-printing, etc.).
8) Measurements of optical brightening agents (OBAs).
9) Data from X-ray Fluorescence (XRF) analysis of support materials, inks, and other image components.
10) A database of measurements with 1-9 above obtained from prints that have been subjected to the full range of WIR’s accelerated aging tests to characterize the fading, changes in color balance, yellowing, and loss of OBA activity that may have already occurred since the prints were made – or may occur over time in the future – with prints displayed and stored in the real world.

The Wilhelm Reference Collection also includes a large library of unprinted inkjet materials in their original packaging. Although these materials may be useful for future studies of paper permanence, loss of OBA activity that will occur during display and dark storage, surface characterization studies, paper fiber analysis, and chemical analysis of the composition of the ink receptive layer of inkjet papers, sheets of blank, unprinted paper with no images printed on them are of limited use in terms of identifying prints in the real world.
Vision for the Future: The Wilhelm Analog and Digital Color Print Materials Reference Collection

It is expected that within the next several years, using data and physical measurements from the Wilhelm Analog and Digital Color Print Materials Reference Collection – combined with data from a comprehensive black-and-white print materials reference collection – the entire procedure of process identification, dating, authentication, and assessment of the deterioration over time that a particular B&W or color print has suffered will be automated. Furthermore, the database and associated analytical data will be accessible from anywhere in the world by remote Internet query by museums, archives, libraries, galleries, genealogy databases, families, and individuals. The Wilhelm Reference Collection and associated data will play a key role in the development of a worldwide “genome” of the physical photographic print, for both black-and-white and color images across a very wide range of printing technologies.
Description of the Wilhelm Print Materials Reference Collection

An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of IN01545

The Wilhelm Print Materials Reference Collection is rich in data and artifacts and it can be difficult to grasp the full breadth of the collection. So, in an effort to clarify precisely what comprises the Wilhelm Color Print Materials Reference Collection, we have chosen a single Inventory as an example, one of approximately 2000 which are in the collection. The following 14 illustrations identify the various components which are all part of Inventory Number IN01545.

Inventory Number 01545 is an organizational unit which links all the products and files associated with the Epson Stylus Pro 7800 printer using Epson UltraChrome K3 inks with Epson Premium Luster Photo Paper (260). It was created on February 20th, 2007. (Detailed explanations of the items and tests mentioned below can be found on subsequent pages of this publication.)

1. Calibration Pages. The IN01545 Calibration pages are printed with the Epson Stylus Pro 7800 printer, with Epson UltraChrome K3 inks, on Epson Luster Photo Paper (260). There are 400 color patches on each Calibration Page. (Note: the cutout sections make it possible to precisely position the sample on a GretagMcBeth Spectrolino) X-Y measuring table.

2. Data for Calibration Pages. The color of each patch is characterized by wavelengths, from 380 to 730 nanometers, in 10nm increments. The list below shows the data collected for just 20 of these 400 patches, from 380 to 420 nm only. From this it is clear than a great deal of information is collected and saved.
Description of the Wilhelm Print Materials Reference Collection
An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of Inventory Number IN01545

3. RGB Values for Test Targets. The RGB values for each patch on a test target are calculated from the spectral data in the calibration pages:

<table>
<thead>
<tr>
<th>Patch Colors (RGB Scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB</td>
</tr>
<tr>
<td>G 125 188 175 163 145 137 127</td>
</tr>
<tr>
<td>B 121 186 173 163 146 135 127</td>
</tr>
<tr>
<td>YELLOW</td>
</tr>
<tr>
<td>B 187 157 141 125 95 87 79</td>
</tr>
<tr>
<td>MAGENTA</td>
</tr>
<tr>
<td>G 217 175 159 143 115 105 97</td>
</tr>
<tr>
<td>CYAN</td>
</tr>
<tr>
<td>R 225 189 175 163 145 137 127</td>
</tr>
<tr>
<td>G 217 175 159 143 115 105 97</td>
</tr>
<tr>
<td>B 177 175 159 143 115 105 97</td>
</tr>
<tr>
<td>RED</td>
</tr>
<tr>
<td>R 217 175 159 143 115 105 97</td>
</tr>
<tr>
<td>G 221 185 173 163 145 135 127</td>
</tr>
<tr>
<td>BLUE</td>
</tr>
<tr>
<td>B 235 211 189 175 163 145 137</td>
</tr>
<tr>
<td>M 225 189 181 169 153 147 141</td>
</tr>
<tr>
<td>CYAN</td>
</tr>
<tr>
<td>R 217 179 169 153 147 141</td>
</tr>
<tr>
<td>G 177 175 159 143 115 105 97</td>
</tr>
<tr>
<td>B 177 175 159 143 115 105 97</td>
</tr>
</tbody>
</table>

4. Test Targets for Accelerated Tests for Display Permanence (Light Stability). These targets have been put into test under fluorescent lamps, with the appropriate glass or acrylic sheet filters, for the five exposure conditions:

5. Data Gathered for an Accelerated Test for Display Permanence (Light Stability). Each target has an excel file associated with it, where fading and the changes in spectral measurements over time are stored and graphed according to specific visually-weighted criteria limits. All the target types illustrated on the following pages have spectral measurements and graphs associated with them, similar to the data presented below for Light-fastness.
Description of the Wilhelm Print Materials Reference Collection
An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of IN0154

6. Test Targets for the Arrhenius Accelerated Tests for Dark Storage Stability and Yellowish Stain Formation. These targets have been put into test in ovens maintaining four separate temperatures at a humidity of 50%:

7. Control Test Targets. Two test targets were prepared, measured once, and then one put in cold storage and one kept in dark storage at room temperature (in an envelope in the inventory folder). These targets are valuable to use for visual comparison reference, instrument calibration, and comparing various test results with an untested control sample:

8. Test Target for Accelerated Tests for Unprotected Resistance to Atmospheric Ozone. This target has been exposed to 5.00 ppm of ozone in a Satra-Hampden Ozone chamber, at 23 degrees C and 50% RH:

9. Test Targets for Suga Super Xenon Fade Meter SX75, shown in the humidity- and temperature-controlled xenon arc test chamber.
10. Optical Brightening Agents (OBA’s). The untested target has been evaluated regarding the presence or absence of Optical Brighteners. This analysis can be found in each specific excel file, as well as the database. The information has been obtained through illuminating the paper with a UV lamp and comparing it to three internal WIR standards. (These standards have been identified as No, Some, or Yes.)

11. Further Information on Optical Brightening Agents. The backside of the paper is illuminated with a UV lamp below showing Optical Brightener on the back of the paper. Targets which have been in test can also be viewed with a UV radiation source, and information gathered on optical brighteners.
Description of the Wilhelm Print Materials Reference Collection

An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of IN01545

12. Scan of Paper Package. The Premium Luster paper used in this test was from a roll that we identified with a paper package number P0000000204. From the database, we can open two scans of the actual paper package that held the paper used for this test:

![Scan of Paper Package](image1)

![Scan of Paper Package](image2)

13. The Database. At a glance, a great deal of information about this particular sample of Epson Premium Luster Photo Paper (260) can be seen. The columns are specifically labeled, and all the rows together show the number of samples and specific test types. The database is sortable and searchable, generates PDF files, opens each file or folder, updates with the most current information from each sample number's excel file, and opens scans of the paper packages:

![Database Interface](image3)
Description of the Wilhelm Print Materials Reference Collection

An Illustrative Example: The Interconnected Data and Printer/Ink/Paper Artifacts of IN01545

14. The Wilhelm Imaging Research, Inc. Website. The results for the tests with the Epson Premium Luster Photo Paper (260) used with the Epson Stylus Pro 11880 printer (and certain other Epson printers that also use the Epson UltraChrome K3 pigmented inkset) are posted on www.wilhelm-research.com.

15

www.wilhelm-research.com

Epson Stylus Pro 11880 – Print Permanence Ratings

Ink System: Nine pigmented inks are provided in the printer with eight inks used at any given time, as determined by the paper type and print mode selected. Nine individual pressurized 700 ml ink cartridges. The piezo inkjet heads are a permanent part of the printer. Epson UltraChrome K3 with Vivid Magenta inks include pigmented Cyan, Light Cyan, Vivid Magenta, Light Vivid Magenta, Yellow, Photo Black (for glossy photo papers) or Matte Black (for matte photo papers), Light Black, and Light, Light Black. New “Auto Black,” real-time black ink mode switching technology with no ink waste when switching between Photo Black and Matte Black inks. Maximum resolution: up to 2880 x 1440 dpi; ink drop size as small as 3.5 picoliters.

Maximum Paper Width: 64 inches (163 cm). Handles roll or cut-sheet paper and canvas from U.S. Letter size (8.5” x 11”) up to 64 inches. Cut sheet paper thickness up to 500 gsm and 1.5 mm poster board can be accommodated. All media types and sizes are front loaded.

Operating Systems: Windows XP and 7 (both 32 and 64-bit supported); Mac OSX Tiger 10.4 or higher, Snow Leopard 10.6 or higher, USB 2.0 and 10/100 BaseT Ethernet connectivity.

Special Features: Epson “Advanced Black and White Print Mode” for printing high-quality and long-lasting black-and-white images; accessed through the Epson driver, it also provides a simple way to make excellent B&W or toned (warm, cool, sepia) prints from RGB color image files without having to convert the files in Photoshop. The Epson 11880 printer features new automatic head alignment and nozzle cleaning systems.


This document originated at <www.wilhelm-research.com>  File name: <WIR_Ep11880_2010_04_23.pdf>
From the Epson News Release for the Epson SureColor P7000 and P9000 Inkjet Printers and UltraChrome HDX Pigment Inks

NEW YORK – Oct. 22, 2015 – Epson America, Inc. today announced another milestone in photographic ink technology and print longevity with preliminary print permanence ratings for its new Epson UltraChrome® HDX pigment ink technology. Featured in the new SureColor® P7000 and SureColor P9000 printers, data accumulated to date indicates that – depending upon the type of paper – the new inks can provide print permanence ratings of up to 200 years for color prints, and likely in excess of 400 years for black and white prints when printed with Epson’s “Advanced Black and White Print Mode.” According to comprehensive tests conducted by Wilhelm Imaging Research, Inc. (WIR), the world’s leading independent permanence testing laboratory, Epson UltraChrome HDX pigment inks can provide up to twice the Display Permanence Ratings of earlier generations of Epson UltraChrome inks with most Epson photo and fine art papers, including the new line of Epson Legacy Fine Art Papers. fine art and inkjet photo paper suppliers.

Acknowledgements

Henry and Carol Wilhelm gratefully acknowledge the many years of extraordinary contributions by our core staff members, Barbara C. Stahl and Kabenla E. Armah, to WIR’s research, testing programs, print permanence reports, technical publications, and software development.

Working closely with Henry, WIR’s director of research, Barbara serves as the coordinator of permanence testing laboratory operations at Wilhelm Imaging Research. She also manages design and digital composition for WIR’s major publications. Barbara is a sensitive, highly skilled photographer and is an accomplished user of Adobe Lightroom, Photoshop, InDesign, and Microsoft Excel. She produced the majority of the photographs in this document.

Kabenla, who was born in Ghana and is a graduate Grinnell College with a degree in computer science, is WIR’s lead mathematician and programmer. He manages software development, database systems, computer networks, backup offsite data storage, and the WIR website. He is in charge of WIR’s complex, multiple-unit spectrometer measurement, data acquisition, analysis, report generation, and data management systems.

Kabenla coordinates print permanence test target calibration and printing. Over the years, Kabenla has become an expert on the operation and maintenance of the many different brands, models, and vintages of inkjet and other types of digital printers in the WIR printer archive for permanence test target generation and for other research applications.

Working together, Barbara and Kabenla are the managers of the Wilhelm Imaging Research Print Materials Reference Collection and its associated databases. They developed the barcoded inventory and tracking systems used with the many thousands of sets of printer/ink/paper specific calibration pages, test target samples, inkjet paper packages, and other digital print materials that make up the collection, including the instrument calibration and visual reference samples preserved in the walk-in subzero WIR-Smithsonian preservation freezer.

Kabenla, a licensed pilot, is the mathematician and programmer of the educational Apple iPad app, GravitySim, which is a highly visual, interactive simulation of Newtonian gravity and orbiting planets, moons, and satellites.
The Wilhelm Analog and Digital Color Print Materials Reference Collection grew out of the research on the permanence and long-term preservation of black-and-white and color photographs that Henry Wilhelm began in the mid-1960s.

Wilhelm Imaging Research, Inc., widely referred to as the world’s leading independent print permanence testing laboratory, was founded by Henry Wilhelm and Carol Brower Wilhelm in Grinnell, Iowa USA in 1995.

The eight-factor color print permanence test methods developed by Henry and his colleagues over the past thirty-five years have become the de facto standard worldwide for evaluating the permanence of analog and digital photographs. WIR reports provide “apples-to-apples” permanence comparisons of branded products to assist photographers and consumers in making informed purchase decisions.

Despite many years of effort within ISO, there currently are no ISO print permanence test methods standards available that can be used to answer the question: “How long will a print last?”

The test methods, light intensity and other environmental assumptions, and the set of visually-weighted endpoint criteria for fading and yellowish stain formation employed by Wilhelm Imaging Research have filled that void for more than 35 years.

WIR clients have included Hewlett-Packard, Canon, Epson, ChromaLuxe, Kodak, HP Indigo, Xerox, Fuji, Lexmark, and Brother, as well as independent inkjet media suppliers in the United States and Europe.

The WIR website, www.wilhelm-research.com, is believed to be the most visited website in the world for individuals and institutions seeking information about print permanence and subzero freezer storage for preservation of photography and motion picture collections. The website consistently achieves the highest Google rankings for search queries related to print permanence, inkjet permanence, color print permanence, and sub-zero preservation.

Beginning in 1994, all WIR publications have been produced electronically, and all are available worldwide on the WIR website at no cost. In 2003, Henry and Carol Wilhelm’s 761-page book, The Permanence and Care of Color Photographs, was posted as a high-resolution PDF. To date, more than one half million copies of the book have been downloaded by individuals and institutions throughout the world. There is no advertising on the WIR website.

At the end of 2011, after more than ten years of research and software development, Henry Wilhelm and his colleagues completed development of the world’s first practical multispectral camera based system for the full tonal scale, colorimetric evaluation of fading, staining, and deterioration of OBA’s in color and black and white photographs. This was the largest – and most costly – development project ever undertaken by Wilhelm Imaging Research.

In 2016 WIR acquired the MegaVision multispectral imaging and analysis system and, with the assistance of Ken Boydston, chief color scientist at MegaVision and Professor Richard Adams, a color scientist and color imaging expert at Ryerson University in Toronto, Ontario, Canada, began to employ this advanced system in its research laboratory.

WIR is the first image permanence testing laboratory in the world to acquire the MegaVision multispectral imaging and analysis system. In the future the new multispectral system will also be used to image and characterize large number of 800-patch Calibration Pages, Test Targets, and other materials in the Wilhelm Analog and Digital Color Materials Reference Collection.
Wilhelm Imaging Research: What We Do

• “In Their Original Form” Advocacy for the Long-Term Preservation of Photographs, Motion Pictures, Newspapers, Magazines, Books, Documents, and Other Historical Materials

• Print Permanence Evaluation Using WIR’s Comprehensive 8-Factor Test Methods

• Research on Improved Accelerated Test Methods for Analog and Digital Photographs

• Development of Software for Permanence Testing and Colorimetric Image-Change Analysis

• Participation in International ISO Permanence Test Methods and Storage Standards Development

• Research on Humidity-Controlled Subzero Freezer Storage for the Very-Long-Term (“Permanent”) Preservation of Photographs and Motion Pictures

• Research on Humidity-Controlled Subzero Freezer Storage for the Very-Long-Term (“Permanent”) Preservation of Newspapers, Magazines, Books, and Documents

• Photography Collections and Condition Surveys for Museums and Archives

• Consulting Services for the Design of Humidity-Controlled Subzero Preservation Facilities

• Development of Print Materials Reference Collections

• Low-Cost, High-Quality Methods for Rapid Digitization of Photographs and Documents

• Photographic Documentation of Photographers at Work, Printmakers, Museums, and Archives

• Educational Outreach Activities and International Conference Participation

• Writing Technical Articles, Permanence Reports, Guidebooks, and Other Publications

• ePublishing on www.wilhelm-research.com – Free Worldwide Distribution
Background: Henry and Carol Wilhelm

The Wilhelm Analog and Digital Color Print Materials Reference Collection grew out of the research on the permanence and long-term preservation of black-and-white and color photographs that Henry began in the mid-1960s.

In 2010, the black and white fiber-base and RC papers that were accumulated over the years by Henry were donated to Paul Messier and have been integrated into the Messier Reference Collection of Photographic Paper, which was acquired by the Lens Media Lab that was established by Yale University in New Haven, Connecticut in 2015; Messier was appointed director of the new lab, which is part of the Yale Institute for the Preservation of Cultural Heritage.

Wilhelm Imaging Research, a company Henry co-founded with Carol Brower Wilhelm in 1995 in Grinnell, Iowa, has published extensive brand-name-specific permanence ratings for desktop and large-format inkjet printers, other types of digital printers, and for digitally-printed silver halide color papers.

Henry has authored or co-authored more than twenty-five technical papers in the United States, Japan, and Europe on print permanence test methods and the long-term preservation of black-and-white and color prints, negatives, transparencies, and motion pictures.

negatives, transparencies, and motion pictures.

Henry grew out of the research on the permanence and long-term preservation of black-and-white and color photographs that Henry began in the mid-1960s.

In 2010, the black and white fiber-base and RC papers that were accumulated over the years by Henry were donated to Paul Messier and have been integrated into the Messier Reference Collection of Photographic Paper, which was acquired by the Lens Media Lab that was established by Yale University in New Haven, Connecticut in 2015; Messier was appointed director of the new lab, which is part of the Yale Institute for the Preservation of Cultural Heritage.

Wilhelm Imaging Research, a company Henry co-founded with Carol Brower Wilhelm in 1995 in Grinnell, Iowa, has published extensive brand-name-specific permanence ratings for desktop and large-format inkjet printers, other types of digital printers, and for digitally-printed silver halide color papers.

Henry has authored or co-authored more than twenty-five technical papers in the United States, Japan, and Europe on print permanence test methods and the long-term preservation of black-and-white and color prints, negatives, transparencies, and motion pictures.

A wide range of WIR Print Permanence Ratings Reports are available at no cost from Wilhelm Imaging Research.
Henry Wilhelm with Ann Hartman of Corbis and officials of the high-security underground Iron Mountain Vital Records Center, which is located in an isolated area of Pennsylvania, northeast of Pittsburgh. The Corbis cold storage facility was designed to preserve the more than 20 million prints, negatives, color transparencies, and glass plate negatives in the collection for thousands of years.

Henry has been a consultant to a number of collecting institutions, including the Museum of Modern Art in New York, on various issues related to the display and preservation of both analog and digital photographic prints and films.

Since 1995, he has been an advisor to Corbis on the long-term preservation of the Corbis Bettmann photography collections in a high-security underground storage facility designed to be maintained at -20°C (-4F) and 45% RH. With more than 20 million images, Corbis is one of the world’s largest privately held photography collections.

More recently, Wilhelm served as a consultant to Corbis on the design and access workflow of a cold storage facility for the Corbis/Sygma collection in France. Located in Garnay, France, outside of Paris, the facility opened in May 2009. (As a result of legal disputes in France, Corbis/Sygma was disbanded in 2010; however, Corbis continues to operate the Garnay cold storage facility to preserve the huge remaining collection of prints, negatives, and transparencies.)

Corbis, which is headquartered in Seattle Washington, is a private corporation owned by Bill Gates.

**High-Security, Sub-Zero Cold Storage For the PERMANENT Preservation of the Corbis-Bettmann Archive Photography Collection**

Henry Wilhelm* with Ann C. Hartman! Kenneth Johnston! and Els Rigerj (Corbis), and Thomas Benjamint (Iron Mountain Underground Vital Records) *Wilhelm Imaging Research, Inc. 1

Grinnell, Iowa U.S.A.

**Abstract**

Corbis/Sygma in France is one of the most important document photography collections in the world. The Bettmann Archive (Corbis) and Sygma Archive (Corbis) are the two vital functions of Corbis Film Preservation Facility, dedicated to the memory of Dr. Otto Bettmann, performed two vital functions. First, it was the Bettmann Archive, and the most important visual records of the 20th century, will be preserved for generations into the future – it was moved from New York City to an underground home where it would be protected for centuries and 45% RH. With more than 20 million images, Corbis is one of the world’s largest privately held photographic collections. The Corbis holding this collection includes vast amount of material along with the agency’s premises and its photographic archive. During this period from 2002 to 2008, Corbis technology continued to advance in many aspects, and color transparencies, prints, negatives, and contact sheets, and color transparencies are involved in the digital era. Thus, the Corbis-Film-Preservation-Initiative is a preservation effort for the many. The Corbis-Film-Preservation facility - a vital function of Corbis, which is one of the world’s largest privately held photographic collections.

©2008 Society for Imaging Science and Technology

**Long-Term Preservation of Photographic Originals and Digital Image Files in the Corbis/Sygma Collection in France**

Henry Wilhelm; Wilhelm Imaging Research (US); Carlos Gressner; Corbis/Sygma (France); and Drew MacLean; Corbis (US)

**Abstract**

Corbis/Sygma in France is one of the most important document photography collections in the world. The Bettmann Archive (Corbis) and Sygma Archive (Corbis) are the two vital functions of Corbis Film Preservation Facility, dedicated to the memory of Dr. Otto Bettmann, performed two vital functions. First, it was the Bettmann Archive, and the most important visual records of the 20th century, will be preserved for generations into the future – it was moved from New York City to an underground home where it would be protected for centuries and 45% RH. With more than 20 million images, Corbis is one of the world’s largest privately held photographic collections. The Corbis holding this collection includes vast amount of material along with the agency’s premises and its photographic archive. During this period from 2002 to 2008, Corbis technology continued to advance in many aspects, and color transparencies, prints, negatives, and contact sheets, and color transparencies are involved in the digital era. Thus, the Corbis-Film-Preservation-Initiative is a preservation effort for the many. The Corbis-Film-Preservation facility - a vital function of Corbis, which is one of the world’s largest privately held photographic collections.

©2008 Society for Imaging Science and Technology

**The History of the Sygma/Photography Collection**

Corbis/Sygma in France is one of the most important document photography collections in the world. The Bettmann Archive (Corbis) and Sygma Archive (Corbis) are the two vital functions of Corbis Film Preservation Facility, dedicated to the memory of Dr. Otto Bettmann, performed two vital functions. First, it was the Bettmann Archive, and the most important visual records of the 20th century, will be preserved for generations into the future – it was moved from New York City to an underground home where it would be protected for centuries and 45% RH. With more than 20 million images, Corbis is one of the world’s largest privately held photographic collections. The Corbis holding this collection includes vast amount of material along with the agency’s premises and its photographic archive. During this period from 2002 to 2008, Corbis technology continued to advance in many aspects, and color transparencies, prints, negatives, and contact sheets, and color transparencies are involved in the digital era. Thus, the Corbis-Film-Preservation-Initiative is a preservation effort for the many. The Corbis-Film-Preservation facility - a vital function of Corbis, which is one of the world’s largest privately held photographic collections.

©2008 Society for Imaging Science and Technology

**The History of the Sygma/Photography Collection**

Corbis/Sygma in France is one of the most important document photography collections in the world. The Bettmann Archive (Corbis) and Sygma Archive (Corbis) are the two vital functions of Corbis Film Preservation Facility, dedicated to the memory of Dr. Otto Bettmann, performed two vital functions. First, it was the Bettmann Archive, and the most important visual records of the 20th century, will be preserved for generations into the future – it was moved from New York City to an underground home where it would be protected for centuries and 45% RH. With more than 20 million images, Corbis is one of the world’s largest privately held photographic collections. The Corbis holding this collection includes vast amount of material along with the agency’s premises and its photographic archive. During this period from 2002 to 2008, Corbis technology continued to advance in many aspects, and color transparencies, prints, negatives, and contact sheets, and color transparencies are involved in the digital era. Thus, the Corbis-Film-Preservation-Initiative is a preservation effort for the many. The Corbis-Film-Preservation facility - a vital function of Corbis, which is one of the world’s largest privately held photographic collections.

©2008 Society for Imaging Science and Technology
The Early History

Henry has been involved with photography since childhood. He built his first darkroom in a closet in the family home at age twelve. In 1961-62, while attending Yorktown High School in Arlington, Virginia, he was a part-time photographer for the Washington Daily News and also had a summer job assembling and calibrating colorimeters and other electronic instruments for measuring color and “whiteness” at Hunter Associates Laboratory, Inc.

In 1966, while a student at Grinnell College in Grinnell, Iowa, Henry worked as an assistant to Ansel Adams during one of Ansel's photography workshops in Yosemite National Park in California. Discussions with Ansel, who stressed the importance of “archival processing and mounting” of black-and-white prints, furthered Henry's interest in the preservation of photographs. The two became friends and this photograph of Ansel in his darkroom was taken by Henry in 1981 during a visit to Ansel's home in ocean-side village of Carmel, California.

Henry first became interested in the preservation of photographs in 1963 while working in the rainforests of Bolivia as a Peace Corps Volunteer. He troubled by the rapid deterioration of photographs in the hot and humid tropical climate – he lived in a small, open-air thatched roof house with no windows, electricity or air-conditioning – and his alarm about the loss of family photographs and records of cultural history in such an environment would soon lead to his life’s work.

In 1966, Henry was an assistant to Ansel Adams during one of Ansel's photography workshops in Yosemite National Park in California. Discussions with Ansel, who stressed the importance of “archival processing and mounting” of black-and-white prints, furthered Henry's interest in the preservation of photographs. The two became friends and this photograph of Ansel in his darkroom was taken by Henry in 1981 during a visit to Ansel's home in ocean-side village of Carmel, California.

In 1969 Henry published a 26-page booklet entitled Procedures for Processing and Storing Black and White Photographs for Maximum Possible Permanence. More than 40,000 copies of the publication were sold at 50¢ to $1 per copy.

In 1972 Henry received the first of two U.S. Patents for the design of archival washers for black-and-white fiber base prints; he produced the print washers in Grinnell for a number of years under the East Street Gallery name. In the early 1980s, Henry served as a volunteer technical advisor to film director Martin Scorsese in his successful efforts to persuade manufacturers of color motion picture film to improve the permanence of their products and to promote the use of humidity-controlled cold-storage for the long-term preservation of both color and black-and-white motion picture films.

In 1981 Henry was the recipient of a Guggenheim...
During his student years at Grinnell College, Henry was a photographer and writer for the student newspaper and yearbook. He also covered the civil rights movement and protests against the war in Vietnam in Iowa, Chicago, New York, Washington, and elsewhere. In 1966, Henry and three fellow students drove to Selma, Alabama to cover Martin Luther King’s voting rights protests for the college paper. During this period Henry’s documentary work was represented by the Black Star Agency in New York. In 2005 the Black Star Press Print Collection was given to Ryerson University in Toronto by an anonymous donor. Shown above, in 2011, Henry is holding one of the 130 of his prints that are among the almost 300,000 photographs in the collection. The Black Star Collection will be preserved in a humidity-controlled cold storage vault in the new Ryerson Image Centre on the downtown Toronto campus, opened in 2012.

Fellowship for what evolved into a ten-year study of color print fading under low-level tungsten illumination that simulated museum display conditions.

With contributing author Carol Brower Wilhelm, Henry wrote The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures, published in 1993. The book was awarded a special commendation by the Society of American Archivists for “writing of superior excellence and usefulness, which advances the theory and practice of preservation in archival institutions.”

The complete 761-page book the only book on this subject ever published – is available as an high-resolution 35 megabyte PDF/A at no cost from www.wilhelm-research.com.

Since the digital version of the book was posted on the WIR website in 2003, more than one half million copies have been downloaded worldwide.

An exhibition of photographs from the Grinnell College 1966 Yearbook, photographed by Henry and classmate John Phillips, was held at the college’s Faulconer Gallery April 13 through June 3, 2012. The book will be digitally-remastered from the original negatives, which were archivally processed and, in recent years, have been kept in the WIR-Smithsonian Preservation Freezer at minus 20°C (minus 4°F), remain in pristine condition.
The recipient of a Guggenheim Fellowship in 1981, Henry began a ten-year study of the fading and staining effects of incandescent tungsten illumination that simulated museum display conditions. The tests, which included a wide range of color print materials, were conducted in a specially equipped temperature- and humidity-controlled room with a light intensity of 1.35 klux. Glass-covered, UV filtered, and bare-bulb exposure conditions were included. This was the first study of its kind to investigate color print permanence under museum display conditions.

Published in the Fall 1981 issue of the *Journal of the American Institute for Conservation*, Henry Wilhelm’s article, “Monitoring the Fading and Staining of Color Photographic Prints” provided detailed monitoring procedures and, for the first time, recommended a set of visually-weighted end-point criteria for museums and archives.
In May 2011, Henry received an honorary Doctor of Science degree from Grinnell College: “As a citizen of the town of Grinnell, and of the world, and for helping preserve society’s most important photographs as well as our own, Grinnell College is proud to recognize you today.”

In March 2007, at a ceremony held in conjunction with the annual Photo Marketing Association International (PMA) trade show in Las Vegas, Henry was the recipient of the PMDA 2007 “Lifetime Achievement Award,” given by the Photoimaging Manufacturers and Distributors Association. The inscription on Henry’s award reads: “In recognition of your many contributions to the art and science of imaging and printing technologies that will help millions of people worldwide preserve the images of their lives for years to come.” Pictured (left to right) are Steve Sasson of Eastman Kodak Company, who received the PMDA “Visionary Award” for the invention of the first digital camera in 1975; Henry; Bradbury Anderson, CEO of Best Buy, Inc.; Minoru Usui, a Director of Seiko Epson Corporation in Japan, who received the “Technical Achievement Award” for leading the team that in 1993 invented the piezo-electric inkjet head used in Epson printers; and Mark Seliger, the former chief photographer for Rolling Stone Magazine.

**Henry Wilhelm ’68**

**Doctor of Sciences**

Permanence. Preservation. Care. We use these words often when we talk about Henry Wilhelm’s life’s work. A photographer, inventor, and Guggenheim fellow, he’s been called “a legendary figure in the history of photography” and “the world’s leading authority on the permanence and preservation of traditional and digital color photographs.”

Wilhelm first became interested in the preservation of photographs as a Peace Corps Volunteer in Bolivia in 1962. In 1965, he photographed Martin Luther King’s voting rights march in Selma for a series of articles in the College newspaper. He furthered his interest in image preservation during work with master photographer Ansel Adams. He was a photographer for the 1966 Grinnell yearbook, which was banned by the college and not published until 1996.

Since then, through Wilhelm Imaging Research, the company he founded with his wife Carol Brower Wilhelm, he has consulted for the Museum of Modern Art, filmmaker Martin Scorsese, and Bill Gates’ 65-million-image Corbis photography collections. His image permanence test methods are the worldwide standard, and his clients include Hewlett-Packard, Epson, Canon, Kodak, Fuji, and many others. His 744-page book, written with Carol, *The Permanence and Care of Color Photographs*, is a landmark in its field.

Finally, Wilhelm has done all of this pioneering work — and conducted business around the globe — from right here in Grinnell, where he came first as a student and where he chose to live and work. As a citizen of the town of Grinnell and of the world, and for helping preserve society’s most important photographs as well as our own, Grinnell College is proud to recognize you today.
Carol Brower Wilhelm

As a young child, Carol Brower demonstrated a passion for object preservation combined with a powerful drive to produce extensive “metadata” about the objects and related events, which she documented and recorded with every available device and media, including notebooks, letters, audiotapes, camcorders, PDAs, computers, digital recorders and most recently on iPhones, over a period spanning more than 50 years.

At age eleven, Carol saved allowance money to purchase resins and polishes from a local hardware store to mix and apply experimental coatings to flowers, autumn leaves, and bark in an effort to permanently protect their original colors, forms, micro-details, and essential beauty. She tried repeatedly to envelope leaves and objects in this “liquid glass,” losing many specimens and paintbrushes along the way. Writing, drawing, and photographing became a more practical way to preserve life’s moments (if not its objects) unfolding, maturing, and evolving as they were relentlessly vanishing.

It was in 1969, as a first year student in Pratt Institute’s School of Art and Design (Brooklyn, New York), that Carol Brower first began to investigate the longevity of the photographic papers, drawing papers, pencils, inks, and paints used to create her own work.

During the summer of 1970, between freshman and sophomore years, Brower was an administrative assistant to the secretary of Dr. Nasser Sharify, Dean of the Pratt School of Library and Information Science. The following summer, upon being hired by the H. Shickman Gallery to mat and frame its comprehensive collection of James Ensor etchings, Brower was introduced to a small community of professional conservators. Shortly after, she became associated with the newly established LIGHT Gallery when cofounders Tennyson Schad and Harold Jones set out to display contemporary photographs as other fine art prints were traditionally presented – in museum mats and frames. LIGHT associate, Diana Edkins, looked for someone with experience handling fine art prints and Charles Moffett, the young European painting curator with whom Carol had worked while employed by Herman Shickman, recommended that Edkins contact Brower. (After LIGHT, Edkins went on to work with John Szarkowski at The Museum of Modern Art, Department of Photography.)

Carol prepared the museum-quality mats for LIGHT’s November 4, 1971 opening and first exhibit of thirteen living photographers: Thomas Barrow, Michael Bishop, Wynn Bullock, Harry Callahan, Robert Fichter, Emmet Gowin, Roger Mertin, Bea Nettles, Doug Prince, Aaron Siskind, Keith Smith, Frederick Sommer, and Todd Walker – and thereafter nearly every print that LIGHT purchased, sold, and exhibited throughout the next ten years, including those by Alfred Stieglitz, Edward Steichen, Paul Strand, Ansel Adams, Andre Kertesz, Arnold Newman, Eikoh Hosoe, Duane Michaels, and many other legendary photographers.

Shickman and LIGHT set the stage for Carol’s intimate engagement with artwork made by others, cultivating in her a profound respect for all fine prints, photographs, and drawings. Having seen progressive damage to the edges of a miniature Rembrandt etching that had survived more than 300 years in otherwise

Photographer Mitch Epstein and Carol Brower working together in Carol’s matting studio in New York City’s Greenwich Village; the two were discussing details of mounting Epstein’s Kodak Dye Transfer color prints (1981).
excellent condition, Carol was motivated to join an emerging crusade to preserve photographic materials and to uphold the conservators’ Hippocratic Oath: “To prevent [deterioration] whenever one can, for prevention is preferable to cure.” While still attending Pratt, Carol began drawing attention to the proper handling and conservation matting of photographs.

Following graduation from Pratt, Carol established fine art conservation matting studios in Park Slope, Brooklyn, and Greenwich Village, New York City. From 1971 to 1996, Carol mounted and matted thousands of the highest quality prints and drawings for many premier galleries in New York City, including Castelli Graphics (Toney and Leo Castelli with director Marvin Heiferman), Laurence Miller (Laurence Miller, Matthew Postal), LIFE (Doris O’Neil, Marthe Smith, and Debra Cohen), Pace/MacGill (Peter MacGill, Rick Wester), and others. Among her clients were photographers and private collectors, whose prints were routinely exhibited in and/or acquired by major museums, including the Museum of Modern Art, the Metropolitan Museum of Art, and the International Center for Photography in New York City. Carol also matted the 1975 inaugural exhibit of the Center for Creative Photography in Tucson, Arizona, of which Harold H. Jones was its founding director, after being the founding director of LIGHT Gallery (1971–1975).

From the outset, it was clear that the physical survival of individual works of art depended not only on the appropriate use of long-lasting materials: presentation aesthetics could also determine an artwork’s ultimate fate. Visual harmony, balance, and resonance in the mounting became another essential goal.

Carol spent thousands of hours interacting with these highly valued, sometimes unique, prints and photographs and was usually completely alone with them for extended periods. Handling, studying, and absorbing relevant details as a vigilant guardian, she was intensely focused on paper and board quality, color, tone, brightness, whiteness, graphite, fingertips, fingerprints, measurements, proportions, placement, and protecting the physical condition of every little or large masterpiece. Not everything was a masterpiece, but Carol was consistently attentive and inherently suited to the job.

During that 25-year period, Carol worked one-to-one with artists, curators, private collectors, and art dealers, and matted photographs made by a broad spectrum of photographers, ranging from the little known to the historically significant, covering nearly all materials and periods from the late 1800s to 1996. She also worked directly with paper chemists, manufacturers, and distributors, providing information, product specifications and recommendations aimed at addressing the concerns of the emerging photographic conservation field.

From 1976 to 1991, Carol lived in the Greenwich Village home of noted art historian and Columbia University Professor Emeritus, Meyer Schapiro, and his physician wife, Dr. Lillian Milgram. There she met and befriended many distinguished and budding painters, poets, journalists, musicians, publishers, and others. Her closest longtime friends were Helen Gee and Helen Levitt whose decades of friendship nurtured Carol both as an artist and as a professional art service provider living and working in New York City.

In 1970 and 1972, Charles Moffett and Andre Kertesz were the first prominent individuals to ask to see Carol’s artwork, which were then primarily drawings. Moffett purchased one and lobbied for more. Kertesz remarked that the drawings resembled those made by his wife, Elizabeth, so he introduced them to one another. After the tragic loss of his beloved Elizabeth, who passed away in 1977, Andre and Carol shared many hours talking, walking, observing, and expressing both reverence for the endurance of love and concern for the fragility of life, light, and leaves – yes, leaves – until Andre’s death on September 28, 1985.

In June 1974, Carol was invited by Bella Fishko and the Forum Gallery to exhibit six of her drawings in the New Talent Festival; this resulted in offers to represent her work, additional invitations to exhibit, and praise from The New York Times art critic, John Russell (June 6, 1974). Carol was “discovered,” but she remained committed to LIGHT Gallery and the photography community, and chose to take care of other artists’ pictures rather than release her own into a precarious world.

Nevertheless, Carol occasionally sold drawings to collectors in the U.S. and Europe. When Barbaralee Diamonstein Spielvogel eloquently expressed her appreciation of the work, Carol happily sold Mr. and Mrs. Spielvogel two drawings and presented one as a gift. Other drawings are in the collections of Jules and Friedell Wein, Meyer and Lillian Schapiro, Miriam Grosos, Gilbert and Joyce Beldengreen, and Charles Moffett.

Carol and Henry began their collaboration on research projects in April 1978. They were married in 1991 following her move to Grinnell from New York City. As contributing author to The Permanence and Care of Color Photographs, Carol wrote the 58-page chapter titled: “The Handling, Presentation, and Conservation Matting of Photographs.” With Henry as contributing author, she also wrote the chapter titled, “Composition, pH, Testing, and Light Fading Stability of Mount Boards and Other Paper Products Used with Photographs.” They have been partners ever since, editing nearly all of each other’s work, discussing, debating, and brainstorming throughout the past 40 years.

In addition, Carol is significantly involved in the administration of Wilhelm Imaging Research. Carol’s community activities include serving eight years as an elected public school board member for the Grinnell-Newton Community School District (preschool through grade 12). Henry and Carol are the parents of Charlie G. Wilhelm, who graduated from Grinnell College, in 2015, with a major in Chinese language and culture; he also speaks Japanese. Charlie is currently manager of print permanence testing operations at Wilhelm Imaging Research.

Carol, Henry, and Charlie live with their two dogs and six cats in the small college town of Grinnell, Iowa U.S.A.
The Core of the Wilhelm Digital Print Materials Collection
The core of the digitally-printed portion of the Wilhelm Collection is the more than two thousand two-page sets of calibration pages. The specific printer, ink, paper, and printer settings used to create each set of calibration pages is written on each page. The pages and their associated spectral measurements – which date from the beginning of the fine art inkjet era to the present – is the largest collection of documented and spectrally-characterized digital print materials in the world.

Two calibration pages are held in folders labeled “Inventory.” The numbers on these folders provide the basis for the physical and database organization of the entire color and black-and-white digital print materials collection.

Each page of the two-page sets of 800-patch calibration pages are measured with barcode-identified GretagMacbeth SpectroScan/Spectrolino spectrophotometers. The spectral measurements cover the range of 380–730 nm, in 10 nm increments.

A portion of the spectral data from page 1 in the IN01978 Excel file.
The Core of the Wilhelm Digital Print Materials Collection:  
WIR 800-Patch Printer/Ink/Paper Calibration Pages and Associated Spectral Measurements

This stack of paper is a print-out of the total spectral data gathered from the spectral measurements from a single calibration page, which yielded 117 printed pages of numerical data!

Above are the contents of Inventory Folder IN01869. This is a typical folder, although not every inventory folder holds the same items. This folder has two calibration pages, a print-out of RGB values (generated after measuring the calibration pages), five pristine never-in-test ozone targets, and five pristine never-in-test light-fading targets (same target style as for dark-storage Arrhenius Tests).

Also in this folder is a measured “Dark-In-Envelope” reference sample for the Arrhenius Test, which was conducted with this particular printer, ink, and paper combination. Inventory folders typically contain from two to twenty or more virgin targets that have never been measured nor subjected to an accelerated aging test.

This stack of paper is a print-out of the total spectral data gathered from the spectral measurements from a single calibration page, which yielded 117 printed pages of numerical data!
The Core of the Wilhelm Digital Print Materials Collection:

WIR 800-Patch Printer/Ink/Paper Calibration Pages and Associated Spectral Measurements

Target calibration files are opened in Photoshop, and are annotated with the printer, ink, and paper names, as well as the driver settings and print system that will be used to print them.

Calibration Page One is printed using the specified driver settings and print system. The patches on this page were printed with cyan, magenta, yellow, and composite grey/black inks.

Calibration Page Two is printed using the specified driver settings and print system. The patches on this page were printed with red, green, blue, and pure K black ink.

The computer monitor displays the patch colors as the spectral measurements are being made.

The first calibration page is measured with a Gretag-Macbeth spectrophotometer.

The second calibration page is measured with a Gretag-Macbeth spectrophotometer.

The printer, ink, paper, and printer settings for these specific calibration pages are entered into the “Inventory” Log. This combination is then assigned a unique identification number.

This workflow illustrates how calibration pages are generated and prepared for testing at Wilhelm Imaging Research.
One of the unique features of the Wilhelm Reference Collection is the quantity of test prints with associated spectral data and those that have not been measured have been safeguarded in freezer storage since they were first made. Pristine (unused and unmeasured) prints include both analog and digital color print samples. The upright freezer (photo, upper left) houses the control samples for all Arrhenius and Reciprocity Tests. Targets printed and measured for specific tests but, for a variety of reasons, were never put into test are also stored here.

The other three photos show the walk-in Wilhelm-Smithsonian Freezer Preservation Vault, which is maintained at -20°C (-4°F). Targets that have been tested and reached one or more criteria failure endpoints, as well as those that have not been subjected to test conditions, are preserved here.
“Freezer Control” Test Samples and Other Printed Materials Preserved in Moisture-Protected Freezer Storage at -20°C (-4°F)

The photos on this page show a variety of items that are preserved in the Wilhelm-Smithsonian walk-in freezer, inkjet-printed product literature, test targets printed with Iris Graphics prints from the beginning of the fine art inkjet era in the early 1990’s, photographs identified as to the paper, printer, and inks, etc. (Note: the large white storages boxes contain many hundreds of historically important newspapers, including complete issues of The New York Times for both September 11 and 12, 2001, which document the terrorist attacks on the World Trade Center in New York City. These are believed to be the only pristine copies of these two newspapers in existence.)
Inkjet Paper and Canvas Boxes: Their Tracking and Integration with the Wilhelm Print Materials Database

The Wilhelm Print Materials Reference Collection contains original paper boxes of materials tested. Most boxes contain varying amounts of unused paper, and many boxes are unopened.

Since early 2003, WIR has used a barcode system to match paper printed for a test with the actual box that paper came from. The paper package for any test printed at Wilhelm Imaging Research has a barcode affixed to it, and that number is subsequently recorded on the calibration pages and targets printed with paper from that box. Paper package numbers from 0000000282 through 0000000503 can be found in the appropriate Excel file and also the Master Database. From the master database, the two images of the paper packages can be accessed.
Inkjet Paper and Canvas Boxes: Their Tracking and Integration with the Wilhelm Print Materials Database

Above: The paper package number is scanned from the WIR barcode on the box of paper that the paper was taken from to print the target. This number appears in the Excel file for the sample (see below).

<table>
<thead>
<tr>
<th>Printer</th>
<th>Epson Stylus Photo R300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ink</td>
<td>Epson Standard</td>
</tr>
<tr>
<td>Paper</td>
<td>Epson Premium Glossy Photo V. 2001</td>
</tr>
<tr>
<td>Paper ID</td>
<td>IN00864 Brightener P00000002</td>
</tr>
<tr>
<td>Conditions</td>
<td>Free-Hanging (Oven 78C)</td>
</tr>
</tbody>
</table>

Above: The Master Database, filtered on the paper package number, shows all tests with samples printed on paper from package P000000002. The orange font indicates that these are Arrhenius Tests. The “View Paper Pkg” button (circled in red) opens scanned images of the back and front of the paper package with the P0000000002 barcode.

Above: The front and back images of a paper package with the identifier P0000000002 (page 1 and page 2) are opened against a backdrop of the Master Database.
The Wilhelm Imaging Research Archive of Desktop and Large-Format Inkjet Printers, Dye-Sub Printers, and Other Digital Printers

The Wilhelm Digital Printer Archive houses hundreds of large-format, medium-format, and desktop printers made by Epson, Hewlett-Packard, Canon, Kodak, Lexmark, Brother, Olympus, Sony, Alps, and others for producing calibration pages, test targets, and pictorial samples in the Wilhelm Print Materials Reference Collection.
The "File Description" page above shows a report following a series of measurements over a period of approximately 1000 hours of testing. Each measurement is recorded and the increment of time from one measurement to the next is automatically calculated.

Measurement data for 1.0, 0.6, and 0.35 densities are graphed on the "Results" pages. The three graphs (above left) track 17-ink-specific criteria measurement by measurement, over time. The Y axis tracks "Percentage of Life Remaining" and the x axis denotes "Predicted Years on Display." A sample fails on a criterion when the trendline for that criterion reaches zero. The Predictions Page, shown above right for 1.0 and .6 densities, graphs the test progress based on the actual time in test.

The details of this above criteria set are discussed in "Notes on this Report" and defined in the chart.

The Master Database holds all pertinent information about all tests, and is updated daily as targets are measured. The Database allows access to primary information at a glance, allows filtering on multiple parameters, acts as an opener for each file, and also provides functionality for printing PDF reports for each sample. Pictured above is a small portion of the information regarding Job 2005 (Light-Fading).
The Evolution of Print Permanence Test Targets at Wilhelm Imaging Research

Through the years, a succession of target designs have been developed at Wilhelm Imaging Research. They were created alongside software programs for data-acquisition. Some of the targets are test-specific. Below is a progression of test targets and the period that they were in use.

- **Macbeth ColorChecker Target**: Analog era of color photography, printed in the darkroom; 24 patches 1978 through 1997
- **Wilhelm Digital Test Target**: First digital test target designed by Henry Wilhelm; 37 patches 1994 through 1996
- **Wilhelm Imaging Research Digital Target v3.0**: 90 patches; 1997 through 2000
- **WIR Digital Test Target v3.0**: 135 patches; March 2001 to present
- **WIR B&W Digital Test Target v3.2.1**: 135 patches; 2005 through 2006
- **WIR Imaging Research Target with Pictorial Image v2.5**: 90 patches; 2000 through 2001
- **WIR B&W Ozone Test Target v1-135**: 135 patches; Feb. 2007 to present
- **WIR Ozone Test Target v1-135**: 135 patches; Dec. 2006 to present
- **WIR B&W Test Target v1.1.1**: 27 patches; Feb. 2007 to present
The Evolution of Print Permanence Test Targets at Wilhelm Imaging Research

- **WIR Generic i-Star Target**: June 2004 to present
- **WIR i-Star Large Pixel Block Target for Pictorial Analysis**: June 2004 to present
- **WIR Pictorial Image Target For Psychophysical Studies**: 2005 to present
- **WIR 800 Patch i-Star Full Tonal Scale Colorimetric Target**: 2005 to present
- **WIR LQR/Humidity Target**: 2005
- **WIR i-Star Humidity Target**: 2007 to present
One of the three vapor-sealed, humidity- and temperature-controlled test target preparation and measurement rooms at Wilhelm Imaging Research.
The Calibration target measurements are loaded into a macro-enabled Excel file. Here, the spectral data are used to calculate RGB values that will yield targets with specific CMY densities at each patch when the target is printed.

A Light-fading target template (above) and Ozone target template (below) are opened in Illustrator and appropriate RGB values are loaded from the inventory file into each patch by means of a script. The Light-fading template is used to print Light-fading and Arrhenius targets. The Ozone template is used to print Ozone targets.

The resulting Illustrator files are saved and re-opened in Photoshop, and additional information such as Arrhenius Temperature, Print Date, and Paper Package Number are added to the target. (Light-fading and Arrhenius above, Ozone below).

The target is printed using the same Printer, Ink, Paper, and Driver Settings that were used to print the Calibration Page. Above are Light-fading and Arrhenius targets, below are Ozone targets.

The Calibration target measurements are loaded into a macro-enabled Excel file. Here, the spectral data are used to calculate RGB values that will yield targets with specific CMY densities at each patch when the target is printed.

The RGB values generated by the Inventory .xls file macros are shown on this page. This document is printed out and becomes part of the information collected and archived for each Inventory number.
Every target that is in test at Wilhelm Imaging Research is frequently measured and the spectral data is recorded. The sample shown on the left is marked with a black diamond, which signifies that it has been in test under fluorescent bulbs, without filters between the sample surface and the lamps. “Bare-Bulb” is written on the target.  From 1999-2006, inkjet-printed targets were tested in two to three different light-fading conditions. Starting in early in 2006 (Job Number 948), nearly all high intensity light-fading tests have been tested under five exposure conditions:

1. Light filtered with a sheet of glass placed 5mm from the target surface to allow air-flow between the glass sheet and target;

2. Light filtered with a sheet of Acrylite OP-3 UV-filtering acrylic plastic placed 5mm from the target surface to allow air-flow between the glass sheet and the target;

3. No filter (“Bare-Bulb” condition);

4. Light filtered with a sheet of glass in contact with the target surface;

5. Light filtered with a sheet of Acrylite OP-3 UV-filtering acrylic plastic in contact with the target surface.
The targets above have been covered with the appropriate glass or acrylic sheets for the five exposure conditions and are placed under fluorescent lamps that are cooled by high-velocity air flow directed between the lamps and targets. Air at the sample surface is maintained at 24°C (75°F) and 60% RH.

One of the light-fading test rooms at Wilhelm Imaging Research. Under every light fixture are targets undergoing high-intensity, accelerated light-fading tests.

An Excel file template (top) is customized to hold information about each target and the data from each target measurement. Graphs in the Excel file (above) show the result of each measurement according to a set visually-weighted criteria limits for fading, changes in color balance, and yellowish stain formation established by Wilhelm Imaging Research (WIR Endpoint Criteria Set v3.0).
High-quality, enamel-coated steel filing cabinets contain targets that have been in accelerated light-fading tests. The room environment maintained at 72°F (23°C) and 60% RH. Multiple spectral measurements have been saved for each test target. The stack of papers pictured below illustrates the quantity of information associated with six measurements of one test target (WIR Sample Number 20840/Job Number 2005).

The spectral data from each measurement of a test target are imported into a measurement page in an Excel file, which can be accessed through the WIR Master Database System. A small portion of the spectral measurement data for Sample Number 20840 is shown above.
The Master Database lists in sequence the five samples associated with Job Number 10545. A substantial amount of information is available at a glance. This includes the printer, ink, and paper, number of measurements made to date, current test status (Active, Failed, or Retired), and number of equivalent, real world years the sample has been in test. Organizational information, such as the Project Summary (which groups together tests ordered by a particular client at a particular time), Inventory Number, Job Number, Sample Number, location of the test, etc., are also displayed in the Master Database.
After being printed, the light-fading target is trimmed and barcoded. A black diamond tape symbol is added for identification as a Bare-Bulb sample. (Other colored tape symbols indicate other test conditions.) The Job Number and test condition are written on the target.

The Excel template for Light-Fading Tests is prepared for a specific sample, with information pertaining to Job Number, Sample Number, Spectrolino Number (the barcode ID number, location (specific light-fading unit on which the sample will be tested), client, printer, ink, paper, inventory number, paper package number, optical brightener, test conditions, print date, test type, and comments. The Project Summary Number is also entered in the template. This number serves to group together and identify and connect all related tests, including those associated with particular projects, individual clients, companies, and organizations.

Before the target is tested, the first measurement, called the “Zero Measurement” is made to collect data. Changes in density, color balance, and stain formation are calculated using data collected from subsequent measurements.

Next, the measured target is affixed to a stainless steel plate-covered wooden block. Magnets hold the target in place. The reading from a light fading unit's mechanical timer is written on the target along with the starting date. This same timer value and date are also entered in the Excel template, as well as the exact time of the measurement. These values provide backup information in the case a timer malfunctions.

Five targets are prepared for five conditions: Glass-Covered with a 5mm gap, Glass-in-Contact, Bare-Bulb, UV Filter-Covered with a 5mm gap, and UV-Filter-in-Contact. The sample holders are placed under a light fixture. Dummy test targets are placed in all unoccupied target locations.

This workflow illustrates current WIR protocol for preparing targets for accelerated display permanence tests.
For research purposes, low-intensity light fading tests are conducted to evaluate selected printer, ink, and paper combinations in a 1.0 klux accelerated lighting condition. The collected data are compared with high-intensity data from test targets print with the same printer, ink, and paper combination with the same klux/hour accumulated light exposure to quantify high-intensity/low-intensity reciprocity behavior.
The WIR Reciprocity Test consists of targets in six conditions, three light and three dark. The light conditions include a glass filter in contact with the target surface, glass filter separated from the target surface by a 25mm gap (allowing air flow over the target surface), and bare-bulb (no filter). The dark conditions include targets inside an Inventory envelope, dark with air-flow (targets on open shelves), and cold storage (targets inside freezer.) The dark conditions serve as controls for the targets exposed to light.

A test target exposed to low-intensity 1.0 klux illumination is measured with a Gretag Macbeth Spectrolino (above left) with customized Microsoft Excel files to store data (above right). Reciprocity behavior tests for research purposes have been conducted at WIR since August of 2000. Although target designs have been revised three times, the test results are displayed the same manner in the Excel files.

Database showing reciprocity information in context with other tests started before and after. To aid in quick identification, Reciprocity Tests are color-coded a light magenta in the database.

After reciprocity targets have reached their endpoints and are retired, they are inserted into Ziploc bags, which are then stored in the dark. Manila folders labelled with job numbers group the targets in temperature and humidity- controlled enamel-coated steel filing cabinets. (High-Intensity Light-Fading targets are also stored here.)

WIR Eight-Factor Print Permanence Test Methodology – Print Deterioration Factors No. 1–3
Tests to Evaluate High-Intensity/Low-Intensity Light-Fading Reciprocity Behavior
The dark storage Arrhenius test chambers at WIR (four conditions) were built by Lunaire in Williamsport, PA. The ovens are temperature and humidity controlled, according to the selected parameters of each test.
The Arrhenius Test consists of six conditions: four pairs of targets in ovens at four different temperatures (78°C, 71°C, 64°C, and 57°C), and two reference targets, of which one is stored in a Tyvek envelope inside the inventory folder, and one preserved in cold storage in the freezer at -20°C (-4°F).

Beginning in 2002, Arrhenius Test samples have been measured with a GretagMacbeth Spectrolino (above), with the spectral data collection and tracked using customized Excel files (above right). From April to November 2002, WIR held test targets in place in an arrangement that restricted airflow; the tests are identified in the “location” column of the Master Database by the phrase “target held in jewel case.” This was replaced by the current system where test targets are held in place by stainless steel paper clips on a steel plate held upright in a metal CD holder.

When Arrhenius targets have reached their fading or yellowish stain formation endpoints and are retired, they are stored in the dark inside Ziploc bags, then in job number identified manila folders, which are stored in enamel-coated steel file cabinets in the humidity- and temperature-controlled test preparation room.

Database showing Arrhenius information in context with other tests. To aid in quick identification, Arrhenius Tests are color-coded light orange color.
WIR Eight-Factor Print Permanence Test Methodology – Print Deterioration Factor No. 4

Arrhenius Accelerated Tests for Dark Storage Stability and Yellowish Stain Formation

This workflow illustrates current WIR protocol for preparing targets for Arrhenius Dark Storage Tests.

Two printed Arrhenius test targets for each of four ovens must be trimmed and barcoded before having a 0 reference measurement taken with a Spectrolino. Unlike Light-Fading test targets, no information is written directly on the target.

The Excel template for Arrhenius Tests is prepared for specific samples, with information pertaining to Job Number, Sample Number, and the barcode ID number for the specific Spectrolino used to measure and follow this sample for the duration of its test period, including oven location, client, printer, ink, paper, inventory number, paper package number, optical brightener, test conditions, print date, test type, and any notes. The project summary number is also entered in the template to identify and connect all related tests, including those associated with particular projects, individual clients, companies, and organizations.

The Job Number, Sample Number, and oven temperature are written on a blank label which is affixed to the metal plate holder for the target. Stainless steel paper clips hold the target in place.

The target pair is placed in the appropriate oven. A full Arrhenius Test has two targets each for the 78°C oven, 71°C oven, 64°C oven, and 57°C oven. One reference target is stored in an envelope in the dark at room temperature, and another reference target is stored in the WIR Subzero Preservation Vault.
The Satra-Hampden Ozone Test Chamber at WIR; targets hang unimpeded and turn on a carousel to ensure uniform airflow and ozone exposures. Pictorial targets, as well as 135 patch targets, are visible. The interior light was turned on for this picture; during testing, however, the chamber is not illuminated.
The WIR ozone test consists of targets in one condition only: targets are directly exposed to 5.00 PPM of ozone in a Satra-Hampden Ozone Chamber, at 23°C and 50% RH.

Ozone targets are measured with a Gretag Macbeth Spectrolino. The results are collected and tracked in customized Excel files (above right). Ozone Tests using the Satra-Hampden test chamber have been conducted since October 2006.

The database is filtered to show ozone samples. The ozone tests are color-coded blue, which aids in quick identification.

The WIR ozone test consists of targets in one condition only: targets are directly exposed to 5.00 PPM of ozone in a Satra-Hampden Ozone Chamber, at 23°C and 50% RH.

After ozone targets have reached their endpoints and are retired, they are inserted into Ziploc bags, which are then stored in the dark. Manila file folders containing the test targets are labelled with the Job Number are stored in enamel-coated steel filing cabinets kept in a temperature and humidity-controlled room.
After being printed, the Ozone target is trimmed and barcoded. The Job Number and Start Date are written on the target with permanent pigment ink or carbon pencil. The target is now ready for a time-zero measurement.

A time-zero measurement is made before the target is placed in the ozone test unit to allow subsequent measurements to be evaluated against the starting point.

The target is placed in a holder to be suspended in the ozone unit. The door is closed, the machine is turned on, and the test is started.

The Excel template for Ozone Tests is prepared for a specific sample, with information pertaining to Job Number, Sample Number, Spectrolino number (the barcode ID number for the specific Spectrolino used in measuring this sample), location in the Ozone Test unit, client, printer, ink, paper, inventory number, original paper package number, optical brightener, test conditions, print date, test type, and any additional comments. The project summary number is also entered in the template. This number serves to identify and connect all related tests, including those associated with particular projects, individual clients, companies, and organizations.
Tests for resistance to high humidity environments being conducted in a Caron Precision Temperature and Humidity-Controlled Test Chamber. Shown here is an 800-patch WIR i-Star target being temporarily withdrawn from the chamber for measurements during the course of a test.
Humidity samples are color-coded green in the Master Database. Humidity Tests not found in the Master Database are available as Excel files and measurement files. These files can be accessed through the Master disk in folders corresponding to the Spectrolino on which the sample was measured, and the project number.

These two graphs represent the color shift in Status A density over time when exposed to 65% humidity. This graphing system was developed for the LQR target. Other Humidity Tests have been conducted with the i-Star target, with results reported as low, medium, or high resistance to humidity.
WIR Eight-Factor Print Permanence Test Methodology – Print Deterioration Factor No. 7

Tests for Resistance to Water

WIR currently employs some of the test methods described in ISO18935, together with procedures developed at WIR.
The Wilhelm Print Materials Reference Collection provides access to significant information about numerous papers and their individual characteristics. For example, the absence or presence of optical brighteners in specific papers has been documented. Optical brightener information has been noted on calibration pages and printed targets since November, 2007. The information has also been entered into the Excel file corresponding to each test target, and appears in the WIR Master Database.

Papers to be printed as test targets or calibration pages are illuminated with a UV lamp and juxtaposed to papers representing three categories of optical brighteners: No, Some, or Yes.
The Analog Era of Color Photography: From the Book “The Permanence and Care of Color Photographs”

These photographs, taken in 1983 during the analog era of photography, show several testing environments in the Grinnell, Iowa facilities.

Henry Wilhelm prepares color test targets in his darkroom in September 1983.

Accelerated light-fading test unit with 21.5 klux fluorescent illumination (the fixture is raised to view test targets). These analog color test targets are glass-covered, covered with a Plexiglas UF-3 acrylic UV filter, or not covered (bare-bulb condition).

This north-daylight test had an illumination intensity averaging 78 klux during daylight hours. The test room was maintained at 24°C (75°F) and 60% RH. These tests were conducted from 1983 to 1995.

Low-intensity 1.35 klux fluorescent light-stability reciprocity tests were conducted from 1977 to 1992 (24°C [75°F] and 60% RH).

Henry examines color print samples in a low-intensity 1.35 klux incandescent tungsten light-stability test.

These dark-fading tests were conducted at 62°C (144°F) and 45% RH from 1983 until mid-1995.
The Analog Era of Color Photography: From the Book “The Permanence and Care of Color Photographs”

Left: Henry Wilhelm (1980), making densitometric readings using a hand-operated densitometer and recording RGB values in spiral notebooks, also shown at the right. (This method of recording information was practiced from 1977 to 1983.)

Below: Hardcopy printouts and floppy discs with data generated from a proprietary software program on an HP 125 desktop computer acquired in 1981.

In 2011, WIR staff programmer Kabenla Armah successfully accessed and transferred the data from the 30-year old floppy discs into Excel files on an external hard drive (above), making it possible to store and access the data on modern computer systems. (See next page....)
Kabenla Armah holds a 248K floppy disc containing data from the early 1980's. Shown in the background is the copy and transfer set-up with the HP-125 computer, monitor, keyboard and disc drive on the right; farther to the right is the modern Dell Windows computer to which he transferred the data, making it possible to store and access the density data from the analog era of photography using contemporary computers. These data were used to generate the graphs and reports published in the 758-page 1993 book by Henry Wilhelm, with contributing author Carol Brower Wilhelm, *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures.*
The information gathered from the analog era of enlarger-printed targets made on photo papers in the darkroom with wet chemistry, as well as test results from instantly developing photographs (e.g., Polaroid photos), and slide and movie film tests, produced the reports, tables, and graphs published in the 1993 book: *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, by Henry Wilhelm with contributing author, Carol Brower. The complete 758-page book is available as a high-resolution PDF at no charge from www.wilhelm-research.com.

The original color test targets that were used to generate these data are preserved in the walk-in WIR-Smithsonian Preservation Freezer at –20°C (–4°F).
The future direction of image permanence testing utilizes a multispectral camera system:

Use of a Multispectral Camera System and Very Small, Comprehensive “Micropatch” Test Targets for Full Tonal Scale Colorimetric Evaluation of the Permanence of Digitally-Printed Color and B&W Photographs

Henry Wilhelm,* Ken Boydston,** Kabenla Armah,* and Barbara C. Stahl*
* Wilhelm Imaging Research, Inc., Grinnell, Iowa U.S.A.
** MegaVision, Inc., Santa Barbara, California U.S.A.

Abstract: The paper describes the use of the MegaVision EV Multispectral Camera and image processing software together with very small, full tonal scale test targets with 800 or more “micropatches.” The test target includes human skin colors and large sets of neutral and near-neutral patches for the full tonal scale colorimetric evaluation of the permanence of digitally-printed color and monochrome photographs, and other images. Compared with the large test targets now routinely employed by printer, ink, toner, and paper manufacturers, as well as by independent test laboratories, the very small size of the “micropatch” test targets means that approximately ten to fifteen times more test targets can be accommodated in a xenon arc test unit, humidity- and temperature-controlled Arrhenius oven, or in a precision-controlled ozone test chamber. Degradation of optical brighteners can also be measured and quantified. In medium- and large-scale permanence testing laboratories, substantial cost reductions can be achieved in equipment costs – and in operational and maintenance expenses. Sample measurement time can be reduced significantly because multiple targets – including those with very large numbers of patches – can be measured at the same time. Because the camera makes no physical contact with the sample surface, unlimited numbers of measurements can be made with no risk of damage to test targets. Taken together, the procedures described here will provide more meaningful image permanence test data, both faster and at far lower cost than current methods allow. In addition, test equipment energy requirements and environmental impacts are reduced.

Introduction

Nearly all digital cameras – and most other color imaging systems available today – rely on three color filters to define the colors recorded by the system. Such systems typically record the nominal red, green, and blue values reflected from, emitted by, or transmitted through an array of points on a scene illuminated with broadband (white) light by passing the light through filters placed between the scene and the recording sensor. Color accuracy limitations of such tri-color imaging systems are well known.

When an imaging scene or object remains stationary for the duration of the imaging process, it is possible to significantly improve spectral resolution by sequentially capturing images where each captured image records a single narrow wavelength. When an imaging scene or object remains stationary for the duration of the imaging process, it is possible to significantly improve spectral resolution by sequentially capturing images where each captured image records a single narrow wavelength.
band of light from the scene. Capturing a series of images sequentially enables recording the image in as many spectral bands as desired, with no loss of spatial resolution.

MegaVision has developed a spectral imaging system that employs a monochrome area sensor array (Kodak KAF-3900 39 megapixel CCD array with a file size of 78 Mbytes/color at 16 bits per wavelength recorded), files are saved in uncompressed RAW format. Image capture time is about 4 seconds per frame, with a 13-band image capture requiring from 1 to 3 minutes.

The MegaVision system uses narrow-band LED's, ranging from near UV to IR, in place of white light as the illuminant (nominally covering the 350–1000nm range of silicon detectors). This arrangement improves by one or more orders of magnitude the efficacy of the light energy illuminating the scene (important, for example, where damage to delicate museum objects from light exposure is a concern) and eliminates the many problems associated with changeable filters in the optical path. Seven of the nominally thirteen (or more) spectral bands cover the visible range; additional spectral bands, including in the UV and IR regions, can be employed if desired.

The LED illumination system was developed and integrated by Equipose Imaging, and MegaVision typically includes 50,000-hour life LED's with up to 13 specific wavelengths, including:
- UV: 365nm
- Visible: 445, 470, 505, 530, 570, 617, 625nm
- Infrared: 700, 735, 780, 870, 940, 1050nm

To date, the MegaVision EV multispectral camera has primarily been used in the cultural heritage field, including making extremely accurate reproductions of manuscripts and works of art. The camera is being used for imaging historical documents at the Library of Congress in Washington, D.C., including drafts of the United States Declaration of Independence. The camera is also being employed by the Israel Antiquities Authority in Jerusalem (www.antiquities.org.il) for high-resolution, multispectral imaging of the 2,000 year-old Dead Sea Scrolls.

The MegaVision EV multispectral camera is fitted with a specially designed 120mm f4.0 UV-VIS-IR hyperspectral lens that is achromatic over the range of wavelengths from 350 to 1000nm. For the initial experimental work with the WIR iStar and WIR v3.0 test targets reported in this paper, the working distance was set at about 1 meter to image a scene area of approximately 35 x 26 cm. MegaVision’s EV multispectral system relies on external measurements of color targets for its calibration. Typically, a color target that includes a number of colors over a reasonable color range – such as an X-Rite ColorChecker Classic reference target – is measured on a spectrophotometer and these measurements, together with knowledge of the spectral illumination bands, provide the basis of calibration. MegaVision PhotoShoot software uses the calibration data as input to directly derive CIE L*a*b* (1976 D50) color images from the spectral stack of monochrome images captured under the chosen visible illuminant bands.

Like a spectrophotometer, the EV system also employs a neutral (usually white) target as a means of regularly testing and adjusting its values to compensate for small changes in the illuminants and response. Using neutral reference targets such as Labsphere Spectralon Reflectance Standards, whose reflectance properties are defined by the polymer itself, can provide repeatability over a much longer time period than the life of the imaging and measurement system itself.

The surface size of a scene imaged by a high-resolution digital camera at a reasonable resolution (e.g., 300–800 ppi) can be a large fraction of a square meter. Uniformly lighting such a large surface can be difficult, yet very high uniformity is required to meet the requirements of spectral reflectance measurements in many applications. To enable highly accurate measurements over a reasonably-sized surface, MegaVision's PhotoShoot software employs flat field correction. This correction uses images of a...
surface of known uniform reflectance captured under the same illumination conditions in which images of the target scene are captured. This correction also compensates for non-uniform optical response (lens fall off) and non-uniform sensor response. The correction does not require a known reflectance of the flat field surface; however, it must be uniform, reasonably bright, and have similar surface specular properties to the target scene surface.

It is, of course, challenging to obtain measurements with good traceability to NIST standards. However, for evaluating the permanence of inkjet, color silver halide, thermal dye transfer, and prints made with other photographic color imaging systems, measurement repeatability is usually more important than measurement accuracy.

The stability of well-designed LED lighting systems and CCD image arrays, together with regular use of scene-based reflectance target standards, can enable a multispectral imaging system to supplant and, in many ways, improve upon results from point sample instruments as a means of measuring the performance of color reproduction media.

An X-Rite ColorChecker Classic color target is an example of a suitable color reference source. The target is measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer using X-Rite’s Measure Tool, which is one of the applications in X-Rite’s ProfileMaker 5 software. Measure Tool can output measured data as CIEL*a*b* (CIELAB) values. The MegaVision EV system’s PhotoShoot software derives CIEL*a*b* values directly from the six (or more) color bands in the visible region.

MegaVision’s ImageSampler application enables sampling a rectangular array of color samples in an image and outputting the sample values in a standard spectrophotometer output format. This software enables MegaVision’s EV camera to output spectral data in a manner similar to that of traditional spectrophotometers, with the added advantage that large arrays of multiple test samples can be rapidly measured.

Applications in Image Permanence Testing

For image permanence evaluation applications, test target images are sampled and the resulting text files are input to the X-Rite ProfileMaker Measure Tool “compare” application, which calculates, tabulates, and graphically displays ΔE values and statistics between two sets of test targets. Samples for each of the target images are compared and referenced against target values of the larger samples, which have individual patches of sufficient size to be measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer. Target sample measurements can also be imported into Microsoft Excel in spreadsheet format for further manipulation and analysis.

The high-resolution multispectral camera system can image very small test targets consisting of large numbers (800 or more) of very small patches of specific colors. The minimum size of each color patch is limited only by the size and distribution of the ink drops or toner dots from a specific inkjet, liquid or dye toner electrophotographic system, dye-sub, silver-halide, or traditional offset printing system. A conventional spectrophotometer, such as the Gretag Spectrolino, may require a minimum patch size of 8 x 8 mm for repeated, reliable measurements.

With the MegaVision EV camera, depending on the image structure of the particular print system, patch sizes can be as small as 0.6 mm. For example, the 800-patch WIR iStar test target developed by Wilhelm Imaging Research measures 18 x 24 cm, and is printed on an A4 or 8.5 x11-inch US letter-size sheet. The WIR iStar 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.

Theoretical and practical limits for how small an individual test patch can be are currently being improved upon results from point sample instruments as a means of measuring the performance of color reproduction media.

An X-Rite ColorChecker Classic color target is an example of a suitable color reference source. The target is measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer using X-Rite’s Measure Tool, which is one of the applications in X-Rite’s ProfileMaker 5 software. Measure Tool can output measured data as CIEL*a*b* (CIELAB) values. The MegaVision EV system’s PhotoShoot software derives CIEL*a*b* values directly from the six (or more) color bands in the visible region.

MegaVision’s ImageSampler application enables sampling a rectangular array of color samples in an image and outputting the sample values in a standard spectrophotometer output format. This software enables MegaVision’s EV camera to output spectral data in a manner similar to that of traditional spectrophotometers, with the added advantage that large arrays of multiple test samples can be rapidly measured.

Applications in Image Permanence Testing

For image permanence evaluation applications, test target images are sampled and the resulting text files are input to the X-Rite ProfileMaker Measure Tool “compare” application, which calculates, tabulates, and graphically displays ΔE values and statistics between two sets of test targets. Samples for each of the target images are compared and referenced against target values of the larger samples, which have individual patches of sufficient size to be measured on a GretagMacbeth Spectrolino/Spectroscan spectrophotometer. Target sample measurements can also be imported into Microsoft Excel in spreadsheet format for further manipulation and analysis.

The high-resolution multispectral camera system can image very small test targets consisting of large numbers (800 or more) of very small patches of specific colors. The minimum size of each color patch is limited only by the size and distribution of the ink drops or toner dots from a specific inkjet, liquid or dye toner electrophotographic system, dye-sub, silver-halide, or traditional offset printing system. A conventional spectrophotometer, such as the Gretag Spectrolino, may require a minimum patch size of 8 x 8 mm for repeated, reliable measurements.

With the MegaVision EV camera, depending on the image structure of the particular print system, patch sizes can be as small as 0.6 mm. For example, the 800-patch WIR iStar test target developed by Wilhelm Imaging Research measures 18 x 24 cm, and is printed on an A4 or 8.5 x11-inch US letter-size sheet. The WIR iStar 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.

With the multispectral camera, the size of the 800-patch WIR iStar target can be reduced to perhaps only 1.5 x 1.9 cm, thus potentially enabling more than 100 separate 800-patch test targets to fit in the same space required by just one conventional 800-patch WIR iStar target. The theoretical and practical limits for how small an individual test patch can be are currently being

**Table 1 – Target Size and Individual Patch Dimensions for WIR Image Permanence Test Targets**

<table>
<thead>
<tr>
<th>Target Size</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>No. of Columns</th>
<th>No. of Rows</th>
<th>Patch Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Size</td>
<td>188</td>
<td>240</td>
<td>25</td>
<td>32</td>
<td>7.5</td>
</tr>
<tr>
<td>Reduced Size No. 1</td>
<td>51.5</td>
<td>66</td>
<td>25</td>
<td>32</td>
<td>2.6</td>
</tr>
<tr>
<td>Reduced Size No. 2</td>
<td>44</td>
<td>56</td>
<td>25</td>
<td>32</td>
<td>1.8</td>
</tr>
<tr>
<td>Reduced Size No. 3</td>
<td>37</td>
<td>47</td>
<td>25</td>
<td>32</td>
<td>1.5</td>
</tr>
<tr>
<td>Reduced Size No. 4</td>
<td>29.5</td>
<td>37.5</td>
<td>25</td>
<td>32</td>
<td>1.2</td>
</tr>
<tr>
<td>Reduced Size No. 5</td>
<td>22</td>
<td>28</td>
<td>25</td>
<td>32</td>
<td>0.9</td>
</tr>
<tr>
<td>Reduced Size No. 6</td>
<td>15</td>
<td>19</td>
<td>25</td>
<td>32</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Size</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>No. of Columns</th>
<th>No. of Rows</th>
<th>Patch Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Size</td>
<td>72</td>
<td>120</td>
<td>9</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Reduced Size No. 1</td>
<td>33</td>
<td>54</td>
<td>9</td>
<td>15</td>
<td>3.6</td>
</tr>
<tr>
<td>Reduced Size No. 2</td>
<td>27</td>
<td>45</td>
<td>9</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Reduced Size No. 3</td>
<td>37</td>
<td>36</td>
<td>9</td>
<td>15</td>
<td>2.4</td>
</tr>
<tr>
<td>Reduced Size No. 4</td>
<td>16.5</td>
<td>27</td>
<td>9</td>
<td>15</td>
<td>1.8</td>
</tr>
<tr>
<td>Reduced Size No. 5</td>
<td>11</td>
<td>18</td>
<td>9</td>
<td>15</td>
<td>1.2</td>
</tr>
<tr>
<td>Reduced Size No. 6</td>
<td>5.5</td>
<td>9</td>
<td>9</td>
<td>15</td>
<td>0.6</td>
</tr>
</tbody>
</table>
studied. The size limit is in part determined by the dot size, pixel dimensions, driver and firmware settings, and other characteristics of each type of printing system.

Summary

There are significant theoretical and practical advantages in the use of the MegaVision EV Multispectral Camera System for image permanence testing:

• Very small-size test targets, which allows large numbers of test targets to be accommodated in a single xenon arc test chamber, resulting in substantial cost savings, in the expense of the costly test equipment itself, in energy costs, xenon lamp replacement costs, and other operational expenses. There will be correspondingly large cost savings with ozone test chambers, humidity- and temperature-controlled Arrhenius ovens, etc.

• The multispectral camera system can be used to record changes in portraits, landscape photography, and other pictorial images in the course of accelerated fading tests. The images captured by the camera are digitally segmented into large numbers of defined pixel blocks for measurement and evaluation.

• The multispectral camera system can also image large-size test samples that may be required in stability testing of materials intended for large outdoor display applications, for example.

• The camera system can easily handle thick, rigid substrates in both small and large sizes, and with any surface properties.

• In accelerated image stability tests, each test sample will likely be measured ten or more times in the course of a test. With traditional spectrophotometers and traditional test targets, a significant amount of time is required each time a target is measured. The image resolution of the MegaVision EV multispectral camera is sufficient to capture ten or more test targets at the same time, with each target having 800 or more individual patches. The total time required to make separate exposures of a target with 13 different wavelengths is approximately 1 minute.

• Presence of fluorescing optical brighteners (OBA's) and their degradation (loss of activity) over time can be measured and quantified with the MegaVision EV multispectral camera system. Data from both the UV and IR bands provided by the MegaVision camera and analysis system can be used to help identify, characterize, and date both color and B&W print materials.

• The cost savings provided by small test targets in the operation of accelerated image stability test equipment and the speed of measurements makes it practical and economical to use the 800-patch WIR iStar test target with large-size test samples. The multispectral camera system can image large-size test samples that may be required in stability testing of materials intended for large outdoor display applications, for example.

• In addition to the described limitations, current methods cannot accurately simulate the production of yellowish stain. The results much better correlate with human visual perception than is possible with the current industry practice of performing image permanence evaluations based on simplistic test targets that consist of only a limited number of color patches – without skintone colors included – and which are measured with RGB densitometry at only two or three density levels plus d-min.

References


11) Super Xenon Fade Meter Model SX75F, which provides sample plane light intensity of up to 100 klux, is equipped with independent lamp and test chamber refrigeration systems and dual IR filters to control sample temperature. Sega Test Instruments Co., Ltd., 5-4-14, Shinjuku, Shinjuku-ku, Tokyo 160-0022, Japan: tel: 81-3-3354-5241; fax: 81-3-3354-5275; <www.sugatest.co.jp>.

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/TG-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 Yoshikiko 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 film-based motion picture films.

In 1995, with Carol Brower Wilhelm, Colin co-founded Wilhelm Imaging Research, Inc., to conduct image permanence studies with inkjet, silver-halide, electrophotographic, and other imaging materials <www.wilhelm-research.com>. In 2007, he was the recipient of the Photomaging 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.

In 2010, Carol and Henry Wilhelm and colleagues established a new nonprofit organization, The Center for the Image, to expand their research on the permanence and long-term preservation of images.
Use of a Multispectral Camera System and Very Small, Comprehensive “Micropatch” Test Targets for Full Tonal Scale Colorimetric Evaluation of the Permanence of Digitally-Printed Color and B&W Photographs

Paper presented by Henry Wilhelm in Tokyo on June 7, 2011

Monochrome version of this paper was published on pages 131–134 in:

Proceedings “Imaging Conference JAPAN 2011”
The 107th Annual Conference of the Imaging Society of Japan

ISSN: 1881-9958

©2011 The Imaging Society of Japan
June 6–8, 2011

Curian, Shinagawa-ku
Tokyo, Japan

Published by:
The Imaging Society of Japan
The Secretariat
Tokyo Institute of Polytechnics
2-9-5, Honcho, Nakano-ku, Tokyo 164-8678
Japan
Fax: +81-3-3372-4414
http://psi.mls.eng.osaka-u.ac.jp/~isj/isj(e).html
Addenda

Shown on the following pages:

Full Size 800-Patch WIR iStar Test Target and Smaller Versions of the Target for Use With the MegaVision Multispectral Camera System and WIR iStar Image Change Analysis Software

and

Full Size 135-Patch “Standard” WIR v3.0 Test Target and Smaller Versions of the Target for Use With the MegaVision Multispectral Camera System and WIR Image Change and Endpoint Analysis Software

Note: These test target examples are shown here for illustrative purposes. They were not included with the paper submitted to the ISJ Imaging Conference JAPAN 2011. However, all of these images were included in the presentation given by Henry Wilhelm at “Imaging Conference JAPAN 2011” in Tokyo on June 7, 2011.

©2011 by Wilhelm Imaging Research, Inc.
A magnified view of the gray patch to the right of the number 28 in the 800-patch WIR iStar test target. In the full-size iStar target, each square patch measures 7.5 mm on each side. The target was printed with a Canon imagePROGRAF iPF 8300 large-format printer using Canon LUCIA EX pigment inks. As can be seen, the ink drops are uniformly distributed and a target of greatly reduced size, with individual patch dimensions as small as 0.6 mm, can be used.
Annex 2

Published Papers Concerning Evaluating the Permanence of Skintone Colors in Color Prints:

Evaluating the Image Permanence of Full Tonal Scale Human Skintone Colors in Photographs Using the CIELAB Colorimetry Based WIR i-Star “Retained Image Appearance” Metric

Henry Wilhelm and Dmitriy Shklyarov, Wilhelm Imaging Research, Inc., Grinnell, Iowa U.S.A.

Abstract

People are the principal subjects in the great majority of consumer photographs and the rich and vibrant reproduction of skintones in prints is an essential requirement for professional portrait and wedding photographers. Current ISO and WIR methods for the evaluation of image permanence in color prints only take into account fading in cyan, magenta, and yellow patches, as well as fading and color imbalance changes in neutral scale patches (at a single density of 1.0 with ISO 18909 and at two density points, 0.6 and 1.0 with WIR). The ISO and WIR methods do not directly address fading and color balance changes in human skintones. This shortcoming is particularly significant for prints made with complex inkjet inksets that, in addition to cyan, magenta, and yellow inks, may contain dilute cyan and magenta inks, as well as red, green, blue, orange, or other ink colors and multi-level black/gray inks. WIR i-Star, a CIELAB colorimetry-based, full tonal scale "retained image appearance" metric, provides a method to evaluate the permanence of human skintone colors, neutrals and near-neutrals, as well as a 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 can be used to evaluate changes in colors as well as changes in both localized and overall image contrast.

Introduction

It has been estimated that approximately 80-percent of amateur photographs include people in the scene and people are the central subjects in nearly 100-percent of professional portrait and wedding photographs. Despite the obvious importance of human skintone colors in photography, current image permanence test methods such as ISO 18909:2006 [1] with only a single starting density level of 1.0 and the WIR Visually-Weighted Endpoint Criteria Set v3.0 [2] with two starting density levels of 0.6 and 1.0 developed by Wilhelm Imaging Research, do not yet include full tonal scale human skintone colors in the analysis of fading, changes in color balance, or stain formation.

Figure 1. The WIR i-Star sRGB color space 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. Test targets can be made for other color spaces such as Adobe RGB and ProPhoto RGB (a large gamut colorspace also known as ROMM RGB).

Figure 2. The human skintone colors section of the generic WIR i-Star target consists of 100 patches generated by adjusting the L* values of the measured LAB values for the "Light Skin" and "Dark Skin" color patches in the Macbeth ColorChecker chart. Photographs of people may range from very high L* values in specular highlight areas to very low L* values in deep shadow areas of the face. The number of skintone color patches and neutral/near-neutral patches relative to the total number of patches in the test chart provides a means of weighting these colors in the i-Star analysis. The skintone colors section of the target can also be analyzed separately as an i-Star "Region of Interest."

©2007 Society for Imaging Science and Technology NIP23 and Digital Fabrication 2007 Final Program and Proceedings 743
Historically, there have been a number of reasons for this shortcoming. In years past, test targets had to be printed with enlargers or other analog systems that did not lend themselves to precise control of color and density in individual test target color patches. In addition, densitometry – which has long been used in image permanence testing – has not been well suited for the analysis of changes in colors other than the simple “pure color” cyan, magenta, yellow, and neutrals consisting of equal densities of these three colors that make up the images of chromogenic (silver-halide) color prints. Unlike most inkjet prints, chromogenic color prints have no “black” or “gray” colorants.

**The Need for Human Skintone Colors in Permanence Tests**

In the course of conducting psychophysical tests with sets of progressively faded chromogenic professional color portraits in the mid-1980’s, Wilhelm recognized the importance of skintone colors and this was discussed in the book, *The Permanence and Care of Color Photographs* [3] which was published in 1993. Figures 3 and 4 are taken from the book. In particular, it was clear that people have very little tolerance for skin colors.
Figure 8. In these prints, made with a now-discontinued Canon i9900 Photo Printer and subjected to an accelerated glass-filtered cool white fluorescent light fading test, skintones and reddish hair exhibited a significant loss of chroma over time while maintaining fairly good overall color balance and contrast. The now-obsolete Canon ChromaPLUS BCI-6 dye-based inkset includes red and green inks together with cyan, light cyan, magenta, light magenta, yellow and black. The red ink (which is actually closer to an orange in color) proved significantly less stable in light fading than the other inks and this was not detected in tests with either the WIR or "ISO Illustrative" endpoint criteria sets, both of which measure changes only in pure color cyan, magenta, yellow and neutral patches. As shown in the figures below, WIR i-Star tracked the loss of chroma and the resultant loss in "retained image appearance" in the skintones. The printer firmware appears to include a significant amount of the "red" ink in skintone colors. The "years of display" figures were calculated with a light exposure assumption of 450 lux for 12 hours per day. The paper used for these tests was Canon Photo Paper Pro PR-101. The standard "WIR Display Permanence Rating" for this ink and paper combination with the Canon i9900 obtained using the WIR Visually-Weighted Endpoint Criteria Set v3.0 with prints framed under glass is 22 years. The Canon i9900, a 13x19-inch printer, was introduced in 2004 and replaced in 2006 by the Canon PIXMA Pro9000 with improved Canon ChromaLife 100 CLI-8 dye-based inks. As shown in the i-Star figures below, the skintones were much more affected than were the neutrals/all colors in the image while the overall color balance and changes in contrast were similar for both "neutrals/all colors" and "skintones."
that shift toward green as a result of loss of magenta. However, the great difficulty of preparing properly calibrated test targets and the time-consuming limitation of having to make each measurement with a manually-operated densitometer during the course of image stability tests prevented general adoption of skintone analysis in the author’s light stability and Arrhenius dark storage tests. The inability to include skintone colors and full tonal scale analysis in the author’s endpoint criteria sets was a source of great frustration over a period of many years and was the primary motivation for the development of i-Star by WIR (with Mark McCormick-Goodhart, consultant). [7]

The need for full tonal scale skintone and near-neutral analysis in image permanence testing is even more important today with modern, complex inkjet ink systems that may contain up to twelve individual ink colors (e.g., multi-level black/gray inks, red, green, and blue inks, orange inks, violet inks, and other specialized colors). It is necessary to use a spectrophotometer and a large number of color patches to properly measure and comprehensively evaluate changes in images as they deteriorate. It is only fairly recently that automated spectrophotometers and the associated computerized systems for handling large amounts of data have become available at reasonable cost, making this possible.

The necessity for analysis of both neutrals and “near-neutrals” has become clearly evident with the advent of the multi-level black/gray pigmented inksets introduced by Epson in 2005 (Epson UltraChrome K3 pigment inks), and in 2006 by Canon (Canon Lucia pigment inks) and Hewlett-Packard (HP Vivera pigment inks). In print permanence testing, measuring changes in color balance has always been an essential part of the methodology (see ISO 18909:2006 for example). With chromogenic prints, for example, changes in color balance of a neutral patch – composed of equal densities of cyan, magenta, and yellow – could be assumed to indicate associated changes that would take place in other colors, including critical human skin colors.

But with the new multi-level black/grey inkjet inksets, this assumption is no longer valid. The neutral scale is largely composed of these extremely stable carbon-based inks and the fading and changes in color balance of these inks may have very little relationship to the fading and changes in color balance of skintones and other “near-neutral” colors. Exactly how much will depend upon the particular inkset and printer driver configuration used by the printer manufacturer. In effect, with traditional methods, we have lost the ability to analyze changes in color balance of these new inksets.

Today’s inkjet and other color-managed digital printing systems make it a relatively simple matter to print test targets with full tonal scale skintone colors, neutrals, near-neutrals, and the full range of colors and tones that comprise color photographs (see Figures 1 and 2 for a representative sRGB test target
design). Adequate test targets necessarily require a large number of color patches in order to comprehensively evaluate - and fairly rank - the permanence of color images made across the full range of current and future printing technologies. These printing methods include a wide variety of aqueous, solvent-based, and UV-curable inkjet inksets, as well as with digitally-printed chromogenic (silver-halide) color prints, dye-sub prints, and prints made with various types of dry toner and liquid toner electrophotographic systems.

**Application of the WIR i-Star Full Tonal Scale “Retained Image Appearance” Metric in the Permanence Evaluation of Skintone Colors**

As can be seen in Figure 7, human skintone colors have low chroma and in this respect can be thought of as a class of “near-neutral” colors. Varying in lightness, skintone colors have similar spectral reflectance curves across worldwide ethnic groups (Figure 5) and the paints used with the “Light Skin” and “Dark Skin” patches of the Macbeth ColorChecker are a reasonably good match to these curves (Figure 6).

The WIR i-Star metric and associated software applications were developed by Wilhelm Imaging Research for both image permanence evaluations and for image quality assessments. [7] Both applications address the same need: that is, from a starting reference point, to accurately assess changes that may occur in color and tone (including both global and localized contrast) throughout the full tonal scale of color and B&W photographs. The “I” in I* represents “information content” and the asterisk makes reference to the CIELAB color model and the L*, a*, and b* values that are used to make I* calculations. Unlike current color difference models, WIR i-Star metric evaluates both color and tone over the full tonal scale of photographic images.
The application of WIR i-Star in the evaluation of light fading is shown in Figure 8 with a now-obsolete Canon dye-based inkset which includes a relatively unstable orange (“red”) ink that is utilized by the printer driver and firmware when printing skintone colors. The fading that occurs over time with this ink/paper combination is characterized by a progressive loss of chroma of the skin colors with relatively little change in color balance or loss of overall density. Examples of “unprotected ozone resistance” tests with two different ink/porous paper combinations are shown in Figures 10 and 11 (please see Reference 7 for additional information about WIR i-Star data reports).

Conclusions

Human skintone colors over the full density range of photographs are a critically important component of the majority of photographs and, along with neutral and near-neutral colors, need to be included in print permanence assessments. With suitable test targets, WIR i-Star provides a comprehensive method for evaluating fading, changes in color balance, and yellowish stain formation with skintone colors. It also provides a method for evaluating the permanence behavior of both specific photographic images and classes of photographic images.

Ongoing work includes a range of psychophysical tests to better establish “WIR i-Star Based Endpoints” for “noticeable” and “acceptable” deterioration of photographic images that will permit predictions of “years of display,” “years of dark/album storage,” and “years of unprotected ozone resistance.” [8] WIR i-Star metrics and software are applicable for both image permanence and image quality evaluations [9].

Acknowledgments

The authors wish to thank Kabena Armah, Eiko Miyazaki, Yaw Nti-Addae, Barbara Stahl, and Dimitar Tasev for their contributions to this ongoing research and to the development and user-testing of WIR i-Star software applications.

Notes and References


[9] WIR i-Star Image Permanence Pro software is available from Wilhelm Imaging Research, Inc., Grinnell, Iowa, U.S.A. A version of WIR i-Star is also available for image quality evaluations. For additional information visit www.wilhelm-research.com.

Author 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 20 years he has served as Secretary of the group, now known as ISO Working Group 5/Task Group 3 (a part of ISO Technical Committee 42).

Wilhelm currently serves as a member of the Indoor Light Stability Test Methods Technical Subcommittee of WG-5/ITG-3.

Wilhelm received a one-year Guggenheim Fellowship in 1981 for what became a ten-year study of color print fading and staining under low-level tungsten illumination that simulates museum display conditions.


Wilhelm has been a consultant to many collecting institutions, including the Museum of Modern Art in New York, on various issues related to the display and preservation of both traditional photographic prints and digital print media.

Since 1995, he has been an advisor to Corbis on the long-term preservation of the Corbis Bettmann photography collections in a high-security underground storage facility to be maintained at minus 20 degrees C (minus 4 degrees F) and 35% RH. With more than 65 million images, it is one of the world’s largest privately held photography collections.

Wilhelm currently serves as a preservation consultant to Corbis France in the design and access work flow of the new Corbis-Sygma Cold Storage Preservation and Access Facility scheduled to open in Garnay, France in 2008. Corbis is a private corporation that is owned by Bill Gates.

Wilhelm is the recipient of the Photosimaging Manufacturers and Distributions Association (PMDA) “2007 Lifetime Achievement Award” for his work on evaluation of the permanence of traditional and digital color prints and for his advocacy of very low temperature cold storage: “unprotected ozone resistance” of less than 20 degrees C (minus 4 degrees F) at 40% RH for the permanent preservation of black-and-white and color prints, color negatives, transparencies, and motion picture films.

©2007 Society for Imaging Science and Technology
Annex 3

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 Evaluation¹ 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...
In Imaging Conference Japan 2009 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.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

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Change Limits in Initial Status A Densities of 0.5, 1.0, and 1.5</th>
<th>Image Change Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1* (percent retained) TBD</td>
<td>Changes in representative human skin tone colors</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12% Cyan minus magenta (R – G) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>15% Magenta minus cyan (G – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>18% Cyan minus yellow (R – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>18% Yellow minus cyan (B – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>18% Magenta minus yellow (B – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>18% Yellow minus magenta (G – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>25% Loss of cyan (R) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>20% Loss of magenta (G) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>35% Loss of yellow (B) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>50% Loss of cyan (R) in pure color cyan patches</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>25% Loss of magenta (G) in pure color magenta patches</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>35% Loss of yellow (B) in pure color yellow patches</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>25% Loss of magenta or yellow (G or B) in red patches</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>25% Loss of cyan or magenta (R or B) in red patches</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>25% Loss of cyan or magenta (R or B) in green patches</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>18% Color imbalance between magenta (G) and yellow (B) in red patches</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>18% Color imbalance between cyan (R) and yellow (B) in green patches</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>18% Color imbalance between cyan (R) and magenta (G) in blue patches</td>
<td></td>
</tr>
<tr>
<td>Change Limits in Minimum-Density Areas (Paper White) Expessed in Density Units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>.06 Change (increase) in red or green density</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>.15 Change (increase) in blue density</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>.05 Color imbalance between red and green densities</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>.05 Color imbalance between red and blue densities</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>.10 Color imbalance between green and blue densities</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 The WIR i-Star sRGB Colorspace 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.
as filtered xenon arc illumination. It is for this reason that JEITA CP-3901 specifies L-37 (or equivalent) filtered xenon arc illumination. 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). 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. The test chamber is operated with an ozone level of 5 ppm and is maintained at 23°C and 50% RH. Ambient ozone assumptions are based on a 2003 study by Seiko Epson in Japan. 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 inks are presented in Figure 8 to measure the degree of image bleed and changes in density and color balance. Tests are conducted at 85% RH and 25°C for a period of four weeks. The resistance of print materials to high humidity conditions is rated as “Very High,” “Moderate,” or “Low.”

**Tests forResistance 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. 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. 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 note 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 becoming more demanding as people become 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.

References


10) Super Xenon Fade Meter Model SXT5F equipped with independent lamp and test chamber refrigeration systems. Suga Test Instruments Co., Ltd., 5-4-14, Shinjuku, Shinjuku-ku, Tokyo 160-0022, Japan; tel: 81-3-3354-5241; fax: 81-3-3354-5275; www.sugatest.co.jp.

11) SATRA HTM Model 903 Ozone Test Cabinet equipped with extended-range ozone concentration and a Horiba APOA-360 UV absorption ambient ozone monitor, equipped with a HUber distilled water chiller/ recirculator and filters. SATRA Technology Center, SATRA House, Rockingham Road, Northamptonshire, NN16 9JH, UK; tel: 44 1536 64 1000; www.satra.co.uk/portal/test_equipment.


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-S/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 Yoshikiko Shibahara of Fujifilm Corporation in Japan as Co-Project Leader of the ISO WG-S/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 Photofinishing 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.
The abstract for this paper by Henry Wilhelm, Kabenla Armah, Dmitriy Shklyarov, and Barbara Stahl (Wilhelm Imaging Research, Inc.) entitled:

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

was published on page 213 in:

**Proceedings “Imaging Conference JAPAN 2009”**

The 103rd Annual Conference of the Imaging Society of Japan

**ISSN: 1881-9958**

The full paper was distributed at the conference at the time of the presentation by Henry Wilhelm on June 12, 2009

©2009 The Imaging Society of Japan  
June 10–12, 2009  
Kokuyo Hall  
8-35, 1-chome Konan, Shinagawa-ku  
Tokyo, 108-8710, Japan

Published by:

The Imaging Society of Japan  
The Secretariat  
Tokyo Institute of Polytechnics  
2-9-5, Honcho, Nakano-ku, Tokyo 164-8678  
Japan  
Fax: +81-3-3372-4414  
http://psi.mls.eng.osaka-u.ac.jp/~isj/isj(e).html
Published Papers Concerning Accelerated Test Methods for Evaluating Permanence of Color and Monochrome Prints:

Imaging Conference JAPAN 2007: “Humidity Fastness Test Methods” p. 93
A Study of “Unprotected Ozone Resistance” of Photographs Made With Inkjet and Other Digital Printing Technologies

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

Abstract: Ozone fading (or “gas fading” as it is sometimes called) is a potential cause of image deterioration with unframed digitally-printed photographs when the prints are attached to kitchen refrigerator doors with magnets, pinned to office walls, or displayed inside of fluorescent illuminated glass display cases in schools, stores, and offices. This paper discusses the effects of various relative humidity levels on the rate of ozone-induced image deterioration. Included are image stability data for a selection of “off-brand” or “third-party” dye-based inks and photo papers along with OEM products. Also discussed are differences between current densitometric analysis of fading, changes in color balance, and staining with the evaluation of print deterioration using the WIR i-Star full tonal scale colorimetric “retained image appearance” method. The WIR i-Star metric evenly weights color and tonal changes that occur anywhere along the full color and tonal scale of the image, whether the changes are manifested as fading, staining, darkening, hue shift, and/or increase or decrease in chroma (including human skin colors, which are an important part of most consumer photographs).

Introduction

Experience with prints displayed in consumer’s homes and apartments has shown that, as a general class of prints, microporous “instant dry” inkjet papers printed with dye-based inks can be very vulnerable to gas fading when unframed prints are displayed and/or stored exposed to the open atmosphere where even very low levels of ozone and certain other air pollutants are present. Resistance to ozone exposure varies considerably, depending on the specific type and brand of dye-based inks and photo paper. In some locations, displayed unframed prints made with certain types of microporous papers and dye-based inks have suffered from extremely rapid image deterioration.

This type of premature ink fading is not caused by exposure to light (framing a print under glass or plastic sheet usually protects it from ozone exposure). However, as shown in the illustrations to the right, light can also cause fading and color balance changes that are similar in appearance to that resulting from exposure to ozone. When prints are displayed unframed, the fading effects of light and ozone can be cumulative. Polluted outdoor air is the source of most of the ozone found indoors in

---

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

©2007 Wilhelm Imaging Research, Inc.

Figure 1

OEM Mfg. A (dye ink/porous paper)  
OEM Mfg. B (dye ink/porous paper)  
OEM Mfg. C (dye ink/porous paper)

- 40% Relative Humidity @23°C
- 50% Relative Humidity @23°C
- 60% Relative Humidity @23°C
- 70% Relative Humidity @23°C
- 80% Relative Humidity @23°C

©2007 日本画像学会
homes, offices and public buildings. Ozone can also be generated indoors by electrical equipment such as electrostatic air filters. The tests described in this paper for “Unprotected Resistance to Ozone” are conducted with an accelerated ozone exposure test using a SATRA/Hampden Test Equipment Ltd. Model 903 Automatic Ozone Test Cabinet (with the test chamber maintained at 23°C and 50% RH; and the ozone level measured by a Horiba Ambient Ozone Monitor APOA-360).

Predicted “years of exposure” are based on the first endpoint to be reached in the WIR Visually-Weighted Endpoint Criteria Set v3.0.1 An ambient ozone exposure assumption of 40 ppm/hours equals one year is based on the study reported in a 2003 paper by Kazuhiko Kitamura, Yasuhiro Oki, Hidemasa Kanada, and Hiroko

©2007 日本画像学会

Table 1 – WIR Print Permanence Ratings for the 4x6-Inch Digital Printer Category

<table>
<thead>
<tr>
<th>Printer/Ink/Photo Paper Printed With Inkjet, Dye-Sub, Silver-Halide Printers</th>
<th>Displayed Prints Under Glass</th>
<th>Unprotected Resistance to Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Photosmart Express (retail inkjet kiosk printer)</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>HP Vivera 95 dye-based ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lexmark P350 Portable (4x6-inch inkjet printer)</td>
<td>&gt;100 years now in test</td>
<td></td>
</tr>
<tr>
<td>Licensed ColorJet 3 pigment ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epson PictureMate (original) dye-based ink/PictureMate Paper</td>
<td>104 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Epson PictureMate PM-200 (4x6-inch inkjet printer)</td>
<td>96 years</td>
<td>17 years</td>
</tr>
<tr>
<td>Epson PictureMate dye-based ink/PictureMate Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Photosmart 325 and 475 (4x6-inch inkjet printer)</td>
<td>82 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>HP Vivera 95 dye-based ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>68 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>HP Vivera 95 dye-based ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Photosmart 416/417 (4x6-inch inkjet printer)</td>
<td>51 years</td>
<td>16 years</td>
</tr>
<tr>
<td>HP Vivera 115 dye-based ink/Advanced Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canon PIXMA 260 (4x6-inch inkjet printer)</td>
<td>now in test</td>
<td>now in test</td>
</tr>
<tr>
<td>Canon ChromoLife 100 dye-based ink/Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canon Selphy Q7050 (4x6-inch inkjet printer)</td>
<td>41 years</td>
<td>2 years</td>
</tr>
<tr>
<td>Canon BCI-120 dye-based ink/Photo Paper Pro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fujicolor Crystal Archive (silver-halide color print)</td>
<td>40 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Fuji Frontier 370 dye-based ink/4x6-inch photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kodak PictureMaker (original dye-sub printer)</td>
<td>26 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Kodak Strada 4x6-inch photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kodak EasyShare Printers (4x6-inch dye-sub printer)</td>
<td>26 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Kodak Strada 4x6-inch photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dell Photo Printer 540 (4x6-inch dye-sub printer)</td>
<td>26 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Dell 4x6-inch dye-sub printer ribbon and paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuji Xerox 711 (4x6-inch laser jet printing)</td>
<td>23 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Fuji Xerox color toner/Fuji Xerox glossy photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agfa color Sensitix (silver-halide color print)</td>
<td>22 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Agfa ink, Agfa film, high washfastness chemicals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kodak Edge Generations (silver-halide color print)</td>
<td>19 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Kodak Strada 4x6-inch photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nikon PictureStation (4x6-inch dye-sub printer)</td>
<td>18 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Sony dye-based ink/ribbon and paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>18 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>HP Vivera 95 dye-based ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Konica Minolta impressa (silver-halide color print)</td>
<td>17 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Konica 4x6-inch dye-sub printer and paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leamark SnapShot P315 (4x6-inch inkjet printer)</td>
<td>16 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Leamark 31 dye-based ink/Leamark Professional Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>11 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>HP Vivera 95 dye-based ink/Premium Plus Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>10 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>8 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>7 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>6 years</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>3 years</td>
<td>3 months</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>2 years</td>
<td>2 months</td>
</tr>
<tr>
<td>*HP Photosmart 145 and 245 (4x6-inch inkjet printer)</td>
<td>4 months</td>
<td>2 months</td>
</tr>
</tbody>
</table>

*Note: Products listed with an * have been tested with non-recommended, third-party inks and/or papers and do not represent the performance of OEM inks and papers supplied by that printer's manufacturer.

Fig. 6 The relative humidity of the environment can have a major impact on the rate of ozone fading and both the magnitude and changes in color balance vary depending on the product. The individual CMY fading curves for these three OEM dye ink and paper combinations are shown in Fig. 1. Elevated temperature can also increase the rate of ozone fading. Based on these studies, the author recommends 60% RH and 28°C for ozone resistance tests.

Hayashi of Seiko Epson.12 See Table 1 for display permanence (light stability) and ozone resistance ratings for prints made with dye-based inks and microporous papers; dye-based inks and swellable papers; pigmented ink and microporous papers; silver-halide color prints; dye-sub prints; and xerographic color prints.

Current densitometric endpoint criteria sets such as WIR v3.0 and the non-visual weighted “Illustrative” endpoint criteria set included in ISO 18909 do not allow evaluation of the full range of colors and tones found in photographs. Nor do these endpoint criteria sets include human skin tones or “near neutral” colors. These deficiencies can result in poor psychophysical correlation and product ranking between various products and printing technologies. The WIR i-Star retained image appearance evaluation method was developed to provide improved correlation to observed fading, color shifts, tonescale changes, and stain formation in photographic images.3

References

A Study of “Unprotected Ozone Resistance” of Photographs Made With Inkjet and Other Digital Printing Technologies

Paper presented by Henry Wilhelm on June 7, 2007
Monochrome version of paper published on pages 137–140 in:

Proceedings
“Imaging Conference JAPAN 2007”
The 99th Annual Conference of the Imaging Society of Japan

ISSN: 1881-9958

©2007 The Imaging Society of Japan
June 6–8, 2007
Curian, Shinagawa-ku
Tokyo, Japan

Published by:
The Imaging Society of Japan
The Secretariat
Tokyo Institute of Polytechnics
2-9-5, Honcho, Nakano-ku, Tokyo 164-8678
Japan
Fax: +81-3-3372-4414
http://psi.mls.eng.osaka-u.ac.jp/~isj/isj(e).html
New Test Methods for Evaluating the Humidity-Fastness of Inkjet Prints

Mark McCormick-Goodhart* and Henry Wilhelm
Wilhelm Imaging Research, Inc., Grinnell, Iowa, U.S.A.

Abstract: Humidity-induced changes in inkjet prints can affect line and edge quality as well as overall color and tone reproduction. A practical “line quality retention” metric that utilizes a simple 72 dpi checkerboard pattern of colors and standard colorimetric analysis of ΔE to correlate change in line and edge quality was used to evaluate seven inkjet printer/ink/paper systems. Changes in color and tone reproduction were also analyzed with a novel “Retained Image Appearance” metric, I* (“i-Star”), recently developed by Wilhelm Imaging Research, Inc. The I* metric evaluates loss of tone and color information content in terms of I* (lightness and contrast retention). The metric can be applied to light fading, gas fading, and humidity-induced changes as well as proofing and quality control applications. It is well suited to humidity-fastness tests where humidity-induced changes can cause image darkening, hue shifts, and increased chroma rather than image fading.

Introduction

The humidity-induced loss of line and edge quality in inkjet prints is due to lateral migration of the colorants within the image layer, whereas color and tone scale changes can be caused by both lateral and vertical diffusion of the colorants. The migration effects vary with colorant mixtures and ink loading. In an earlier study, we showed that ΔE measurements for solid-fill areas of color did not correlate with line quality degradation. However, ΔE measurements made with a 4mm aperture instrument of color patches printed in a simple 72 dpi “checkerboard” pattern (see Figure 1) correlated well with line quality degradation as judged by a psychophysical scaling experiment.1 In this paper, a “line quality retention” (LQR) rating has been derived from the results of the original study.

The I* method was recently developed to colorimetrically evaluate changes in image appearance over the full tonal and color gamut range of modern digital printing systems using a comprehensive approach not previously undertaken with more conventional densitometric test methods.2 The I* method has also been programmed in a software application with enhanced features that allow one to evaluate not only the overall I* results but also filter the data for image specific color and tonal ranges (e.g., near grays, skin tones, highlights, shadows, etc). The application can also show data distributions within a large sample population of color patches.

Line Quality Retention

Figure 2 shows a logarithmic fit of the psychophysical data collected in the original study. A log function fits the data well. The bleed rating values, 0-4, can be re-scaled to give a line quality retention score:

$$LQR = \begin{cases} 100 \left(10^{-y}\right) & \text{for } y > 0 \\ 100 & \text{for } y \leq 0 \end{cases}$$

where $y = 1.6898 \ln(\Delta E) - 1.3592$

The LQR equation re-scales the psychophysical data so that a conventional numerical test score is obtained. 100% is a perfect score with no noticeable change in line quality even under 16X magnification. The LQR equation allows a ΔE change of approximately 2.6 before the result drops from 100%. An LQR rating equal to 90 is a just noticeable loss of line quality under 16X magnification, 80 is noticeable under magnification and just noticeable to the unaided eye, 70 is noticeable to the unaided eye, and 60 is very noticeable at 16X magnification. This graduated numerical scaling method avoids the “letter grade” ranking problem where two closely performing systems are sorted into two rank levels that suggest the performance differences are larger than they really are. Similarly, it avoids making two systems that are nearly three levels apart appear no worse than two close performers that just barely sorted into two grade levels. Table 1 shows the results for seven inkjet systems when exposed to 30°C at 80% RH for up to 28 days. Dry time at 23°C/60%
Figure 2. Average ΔE values corresponding to bleed rating score given in psychophysical study of inkjet samples exposed to high humidity. A total of 720 line pair samples were evaluated.

RH after printing was approximately 2 days. However, line quality for system F was unstable even in this environment, so the reference measurement was made within two hours after printing. It is not surprising that System F had the lowest LQR performance.

The I* Test

I* calculations can be made for a specific photo graphic image by using a downsampling technique to prepare a target that still retains the global color and contrast relationships associated with that image. However, for standardized test results a general purpose target is needed. Figure 3 illustrates the test target that was used in this study. Note that the target contains a full range of color and tones where nearest-neighbor patches have contrast gradients that the I* sampling method utilizes to determine changes in image contrast. I* results for the seven tested systems are summarized in Table 2.

Figures 4, 5, and 6 show an I* plot, the tone reproduction drift, and an I* color histogram of the 800 patch data set for System E. System E exhibited the most significant global color and tonal changes of the seven tested systems. Figure 7 shows before and after results in an actual photograph printed on System E when exposed to just 1 day at 27°C/80% RH. Although System E showed significant darkening and chroma increase within just one day exposure to high humidity, 28 days of aging at 30°C/80% RH further caused enough vertical diffusion of the colorants into the paper that lightening and contrast losses in the deep shadows (lowest L* values) also occurred (see Figure 5).

Results and Conclusions

This study included numerous photographic images printed and aged in parallel with the test targets in an effort to understand how well the LQR and I* test results predict what might be observed by customers in actual photographic images. In general, we found that both LQR and I* analyses were required to determine the possible...
magnitude of visual appearance changes in inkjet photographs subjected to high humidity, but the actual observed outcome is highly image dependent. Figures 8 and 9 illustrate the fact that the outcome in a real inkjet photograph is one of statistical probability rather than absolute certainty. Even though these two images were printed identically on System F, the human observer notices the significant loss of sharpness in the cat’s eyes, fur, and whiskers, whereas in the photo of the zebra viewers responded mainly to the localized color problem. The zebra grew pink stripes! This color fringe problem was detected in the checkerboard pattern of the LQR test target (see Figure 10) but not in the large solid-fill color patches measured by the spectrophotometer in the I* target. Yet the I* analysis indicated that System E, for example, has significantly more overall color and tonal changes than System F although both systems are comparable in the LQR tests. Inkjet photos printed on System E were predicted to darken significantly in mid tones with accompanying increase in highlight contrast and decrease in shadow contrast. A significant increase in chroma was also predicted as the main loss of color accuracy. The results were confirmed by looking at actual inkjet photos.
Because the average response of a system can be significantly different than worst-case response, the calculation of both the average and worst 10% population statistics was very useful in explaining why actual images can reveal humidity-fastness problems to a greater or lesser degree depending on their image content. When exposed to high relative humidity, inkjet systems can demonstrate a large distribution of changes depending on colorant mixture, ink loading, driver settings, GCR and other ink replacement methods (e.g., use of red, orange, green, or blue inks to supplement cyan, magenta, and/or yellow), etc. Large sampling statistics are necessary in order to fully characterize system performance. Traditional permanence testing methods often rely on small sample sets of primary and/or secondary color patches which are not likely to accurately predict overall inkjet system behavior.

Systems A, B, C, and D are newer systems on the market. Systems E, F, and G are older and now mostly obsolete systems. One trend in this seven-system study was that the manufacturers of matched ink/media systems have significantly improved the humidity-fastness performance of dye-based inkjet technologies. System A, the only pigmented ink system tested, passed the LQR test with a perfect 100% LQR score and nearly perfect I* results. Photos printed on System A showed essentially no visual changes in appearance. The small change in I* was caused by a slight loss of gloss in the Dmax (lowest L* value) areas of the print. Finally, the increasing ∆E response necessary to generate LQR values below 60 starts to become non-sustainable in the checkerboard test pattern so scores much lower than 50-60% are unlikely. Nevertheless, by the time a score lower than 60% is reached a system has indeed been properly diagnosed as having serious humidity-fastness problems.

Acknowledgements

The authors thank Barbara Stahl for her assistance in completion of all of the laboratory tests, organization and data analysis, and valuable insights throughout the course of this research project. The authors also thank Dmitriy Shklyarov, Yaw Nti-Addae, and Kabenla Armah of the Wilhelm Imaging Research programming staff for their continuing work with the development of the I* software application.

References


Paper by Mark McCormick-Goodhart and Henry Wilhelm (Wilhelm Imaging Research, Inc.) entitled:

New Test Methods for Evaluating the Humidity-Fastness of Inkjet Prints

Paper presented on June 9, 2005

Paper (monochrome, with no color) published on pages 95–98 in:

Proceedings

“Japan Hardcopy 2005”
The Annual Conference of the Imaging Society of Japan

ISSNN: 0916-8087

©2005 The Imaging Society of Japan

June 8–10, 2005
Kokuyo Hall
Tokyo, Japan

Published by:
The Imaging Society of Japan
The Secretariat
Tokyo Institute of Polytechnics
2-9-5, Honcho, Nakano-ku, Tokyo 164-8678
Japan
Fax: +81-3-3372-4414
http://psi.mls.eng.osaka-u.ac.jp/~isj/isj(e).html
A “Retained Image Appearance” Metric For Full Tonal Scale, Colorimetric Evaluation Of Photographic Image Stability

Mark McCormick-Goodhart, Henry Wilhelm, and Dmitriy Shklyarov
Wilhelm Imaging Research, Inc.
Grinnell, Iowa USA

Abstract

This paper describes a computational model based on CIELAB colorimetry and full tonal scale evaluation to define objective boundary conditions for “Retained Image Appearance” in a photograph where 100% retention equates to no visual change and 0% retention means total functional loss of image information content. The “Retained Image Appearance” model, I*, examines the color information (hue and chroma) and the black-and-white spatial information (lightness and contrast) in order to characterize the complete lifecycle of a photograph as it ages with respect to color, contrast, and lightness. The I* model can also be used to compare tone reproduction accuracy between different renderings of a photographic image and may therefore have applicability in initial print or proof print quality studies as well.

Introduction

Image permanence test methods for photographs routinely extrapolate results from accelerated testing environments to real-world conditions. Endpoint criteria have traditionally been based on densitometric changes which are intended to correlate with noticeable and perhaps objectionable changes in perceived image appearance. Unfortunately, densitometry does not adequately characterize modern digital printing systems. Moreover, the consumer generally believes the reported test results are the “end of life” of the photograph. Yet the chosen endpoint denotes only one point in the aging cycle of the photographic record when, in reality, the photo may continue to have informational value and therefore some “remaining life” well beyond this endpoint. Thus, image permanence predictions are subject to criticism not only for the uncertainties caused by the extrapolation of the accelerated test conditions, but also for the chosen endpoint criteria which may be too harsh or too forgiving, depending upon the end-user’s requirements.

The I* model can be used to evaluate the complete aging cycle of a photograph as it changes over time, and each calculated value is a measure of image reproduction accuracy at a specific point in time. In other words, how accurate is the image reproduction in its latest state compared to its original state? In order to develop the I* metric we had to understand how colorimetry could be used to quantify tone reproduction accuracy. We considered widely used color difference models such as ∆E and more recent variants such as ∆E2000. Color difference models essentially compare the relationship between two colors in a side-by-side reference situation and weight lightness, chroma, and hue differences in a combined-term metric for overall color difference. Color scientists widely acknowledge that current color difference models are valid in a psychophysical sense for small observed changes in appearance only. ∆E values no greater than 8–10 are often considered to be the useful limit. Although larger ∆E values can be reported, they do not continue to correlate in a meaningful visual way to the perceived magnitude of change. Because the loss of photographic tone reproduction accuracy necessarily involves large displacements in hue, chroma, and lightness, we rejected this approach and went back to basic photographic fundamentals by asking the question: what is tone reproduction accuracy? A comprehensive assessment of retained image appearance seemed possible only if full tonal scale evaluation was undertaken and if the attribute of image contrast was added to the colorimetric attributes of lightness, hue, and chroma. Also, the contribution of specific color and contrast errors to the total overall observed change depends on the area occupied by those values in a particular photograph. For example, catalytic fading between magenta and yellow dyes will have greater impact on red hues and skin tones than on other colors not comprised of magenta and yellow dyes. When a system with this failure mode is used to reproduce a scene containing large areas of skin tones (e.g., a close-up portrait) then the retained image appearance over time is likely to be poorer in comparison to a landscape scene containing mostly blues and greens. We wanted the I* metric to be able to calculate image specific results when required rather than being tied solely to an image test target with a predefined array of color patches. In order to accomplish this objective, the extraction of contrast data from the image requires a “nearest neighbor” picture element sampling method.

The I* Metric

Black-and-white photography beautifully conveys spatial information in the form of scene brightness and contrast reproduction while devoid of any chroma and hue informa-
tion (other than subtle hues which may be a coveted feature of the process itself, e.g., sepia toned prints). Color photography adds the hue and chroma attributes to the black-and-white information. It is logical and indeed important to devise a retained image appearance model that analyzes hue and chroma information separately from lightness and contrast information.\(^{6}\) The color information (hue and chroma) is supplemental to the black-and-white information (lightness and contrast) in the sense that it can only be conveyed if the lightness and contrast information is reasonably intact. Nevertheless, for certain applications the color information accuracy may be essential whereas in other cases it may be of minor importance. A total \(I^*\) figure of merit needs the flexibility of a weighting factor as shown in the following equation:

\[
I^*_m = \frac{I^*_\text{color} + (I^*_\text{b&w} \times \omega)}{1 + \omega}
\]  

(1)

The term, \(\omega\), is the weighting factor. \(I^*_\text{b&w}\) is the retained image appearance function for the lightness and contrast information, and \(I^*_\text{color}\) is the retained image appearance function for the color information.

The \(I^*\) Color Component

\[
I^*_{\text{color}} = \sum_{n=1}^{x} \left( I^*_{\text{color}} \right)_n , \text{ where } \quad (2)
\]

\[
\left( I^*_{\text{color}} \right)_n = 1 - \frac{(\Delta a^* b^*)_n - \varepsilon}{(C^*_n)_n}, \quad \text{for } (C^*_n)_n > 9.5
\]

or

\[
\left( I^*_{\text{color}} \right)_n = 1 - \frac{(\Delta a^* b^*)_n - \varepsilon}{9.5}, \quad \text{for } (C^*_n)_n \leq 9.5
\]

or

\[
\left( I^*_{\text{color}} \right)_n = 1, \quad \text{for } (\Delta a^* b^*)_n < \varepsilon
\]

\[
\Delta a^* b^* = \sqrt{(\Delta a)^2 + (\Delta b)^2}, \quad C^* = \sqrt{a^2 + b^2},
\]

and \(\varepsilon\) is a positive offset correction factor.

The term, \(\varepsilon\), ensures that \(I^*\) equals 1.00 (i.e., 100% color appearance retention) when no change has occurred by compensating for the small error caused by the squaring of residual \(\Delta a\) and \(\Delta b\) measurements that are otherwise within instrumental error limits. A default value for \(\varepsilon\) would typically be approximately 0.5. \((C^*_n)_n\) is the initial chroma of the \(n^\text{th}\) sampled picture element of \(x\) total elements which is calculated by the formula above using only the initial \(a^*\) and \(b^*\) values, denoted \(a_n\) and \(b_n\), respectively. \(\Delta a\) is the difference between the initial (i.e., reference print) and final (i.e., compared print) \(a^*\) values, and \(\Delta b\) is the difference between the initial and final \(b^*\) values.

A logical and unambiguous boundary condition where \(I^*_{\text{color}}\) equals zero was derived by considering some essential aspects of the color information in a photograph:

First, as chroma goes to zero all color information is lost. When the color in a photograph fully desaturates, the photo becomes a black-and-white photo, and the \(I^*_{\text{color}}\) value of each picture element must mathematically approach zero as this boundary condition is approached. Thus, the \(I^*_{\text{color}}\) = 0 boundary must expand or contract as a function of the initial chroma of each picture element (hence, the inclusion of the \((C^*_n)_n\) term in the denominator of the equation).

Second, some color scientists classify only four unique or primary hues; blue, green, red, and yellow, preferring to think of cyan as a mixture of blue and green and magenta as a mixture of blue-red. However, color photography is so fundamentally built on the principles of additive and subtractive color, that we choose to elevate cyan and magenta to equal status as unique hues. With six fundamental hues, the LCH color space of CIELAB can be divided mathematically into 60 degree sectors. As \(a^*\) and \(b^*\) collapse to zero, chroma decreases, but another consequence is that the determination of hue angle becomes increasingly less accurate. Hue angle is determined by calculating the arctan\((a^*/b^*)\) value. As perfect gray is reached where chroma equals zero, the hue angle becomes undefined (i.e., division by zero). A practical solution to make the determination of hue well-resolved and without discontinuity is to add a seventh sector of color for gray and near grays. Thus, we define seven sectors of color as shown in Figure 1. These sectors categorize hue into seven zones; cyan, magenta, yellow, blue, green, red, and “gray”. The gray sector denotes picture elements with initial chroma less than or equal to 9.5. This choice was determined by considering the CIELAB concept of just noticeable differences for the standard human observer, then setting chroma large enough so that a standard observer can accurately identify the hue of a given color with enough precision for colors differing by approximately 3 degrees in hue angle. In other words, when initial chroma exceeds 9.5, a picture element has lost all essence of grayness and acquires the color of one of the six other hue sectors to the standard observer. Retained “grayness” appearance goes to zero.

Third, when a picture element in a photograph retains chroma level but fails to reproduce hue correctly, then color information is not merely lost. It may become a completely false color which is an even more extreme loss of color accuracy than full loss of chroma. Negative values are possible, and their mathematical significance is that they represent falsely encoded color data. Consider the consequence of a hue shift for a picture element from location 1 to location 1 prime, and finally to 1 double prime as shown in Figure 1. After
appears to be a yellow or magenta color element, depending on the direction of the shift. Thus, color accuracy is totally lost as the shift reaches 60 degrees. \( (I^*_{\text{color}})_n \) must again approach zero as hue shifts approach 60 degrees, and hue shifts greater than 60 degrees should cause \( (I^*_{\text{color}})_n \) to become negative, thus indicating false color encoding. To summarize, when \( (I^*_{\text{color}})_n < 0 \) for the \( n \)th picture element of \( x \) in a photograph, the color accuracy in that location of the image is not merely lost. It is now falsely colored.

Finally, the preceding facts can be combined as illustrated in Figure 2 to derive an \( I^*_{\text{color}} \) equation that accommodates chroma changes, hue changes, and \( \Delta a^*b^* \) changes in gray sector picture elements. Equation 2 achieves a seamless mathematical transition in the way a picture element is treated right at the boundary of the gray sector and as the color moves into one of the other six hues. There is no discontinuity in the math calculation at this transition point, and this feature is a notable result of having also defined a 60 degree hue angle shift as one pathway to reach an \( (I^*_{\text{color}})_n = 0 \) condition.

The \( I^*_{\text{B&W}} \) Component

\[
I^*_{\text{b&w}} = \frac{\sum_{n=1}^{x} \gamma_n}{x}, \quad \text{where} \tag{3}
\]

\[
\gamma_n = \begin{cases} 
\frac{(\Delta L_i)_n}{(\Delta L_f)_n}, & \text{for } \frac{(\Delta L_i)_n}{(\Delta L_f)_n} > 1 \\
\frac{(\Delta L_i)_n}{(\Delta L_f)_n}, & \text{for } \frac{(\Delta L_i)_n}{(\Delta L_f)_n} \leq 1 
\end{cases}
\]

\( \gamma_n \) is the contrast retention factor of the group neighboring the \( n \)th of \( x \) picture elements. In the simplest calculation, a pair of picture elements is used, and \( (\Delta L_i)_n \) is the initial lightness difference (i.e., the reference measurement at time \( t = 0 \)) between the \( n \)th pair and \( (\Delta L_f)_n \) is the final lightness difference (i.e., the comparison measurement made at time \( t > 0 \)). Contrast sampling at this location in the image can be improved using a nearest neighbor sampling technique that compares a picture element to its surrounding neighbors. Figure 3 illustrates the nearest neighbor sampling approach. Equation 4 shows that \( \gamma_n \) at the \( n \)th picture element location is the arithmetic mean of the \( \Delta L \) initial differences compared to the final differences. The sampling order between the \( m \)th and \( n \)th picture elements must be consistent because \( \Delta L \) must be assigned positive or negative status. Keeping track of positive and negative \( \Delta L \) values allows positive or negative contrast relationships...
The condition is analogous to a bit-mapped image with two bit depth of information encoding. In figure 4e, this residual information content is still enough to identify some aspects of the original scene. The tonal breakpoint in figure 4e occurred at a fortuitous value. However, with the high probability that the tonal break will not occur at an optimum value and with the full loss of continuous tone details in the image, gamma approaching infinity also defines for all practical purposes another \( I^*_{raw} = 0 \) boundary condition. Thus, the basic linear symmetry to the gamma function is the essential feature of Equation 3. Consider a totally inverted tonal scale with gamma = \(-1\) compared to the original image shown in Figure 4a. The print would look like a photographic film negative. Equation 3 computes a \(-100\%\) value in this case which signifies the falsely encoded image data. This perfectly inverted condition is, of course, extremely unlikely to occur in an actual photograph, but small “flat spots” and slightly negative slopes within the full tonal scale of a print are possible as colorant mixtures fade or change unevenly in a modern digital print. The metric therefore assigns negative values to image areas of inverted contrast.

Threshold Values for \( \Delta L \)

Although equations 3 and 4 are conceptually correct, a practical implementation of \( I^*_{raw} \) requires a threshold treatment for nearest neighbor picture elements that have very small initial or final \( \Delta L \) values. The plain solid background of a passport photo, for example, would present a large image area where lightness is uniform and little or no visual contrast is observed. Without a threshold evaluation method, the measurement of very small \( \Delta L \) changes in these areas would give rise to large deviations when dividing \( \Delta L \) and \( \delta L \) terms, and consequently, an \( I^*_{raw} \) valuation which is too low. Hence, the \( I^*_{raw} \) component requires a threshold value for \( \Delta L \) to compare with actual \( \Delta L \) measurements. A set of conditional instructions for the \( \gamma_{mn} \) calculations is also needed in order to properly evaluate areas of uniform lightness in an image. The instruction set determines the correct formula to use for the \( \gamma_{mn} \) calculation based on the initial and final \( \Delta L \) values compared to the chosen threshold value which we denote as \( \delta L \). Because \( \Delta L \) can be positive or negative, the threshold value, \( \delta L \), can also be considered to have positive or negative direction, so the comparison is made using absolute values. Figure 5 is a schematic diagram that maps the full instruction set. There are four main paths, A, B, C, and D. Path A has two branches, A1 and A2. The arrows in the diagram trace initial and final states for \( \Delta L \) in relation to \( +\delta L \) and \( -\delta L \). These states determine the path and possible branch to use when selecting the appropriate \( \gamma_{mn} \) calculation. For example, Path A is the nominal case where good contrast exists and the measured initial and continuous tone.

Figure 3. Nearest neighbor sampling method. \( \Delta L \) initial and \( \Delta L \) final values between picture elements, \( n \) and \( m_1 \), \( n \) and \( m_2 \), etc., are divided and averaged to calculate \( \gamma_{n} \) according to Equation 4.

\[
\gamma_{n} = \frac{\sum_{i=1}^{8} \gamma_{mn}}{8}, \text{ where}
\]

\[
\gamma_{mn} = \frac{(\Delta L)_{mn}}{\left(\Delta L\right)_{mn}}, \text{ for } \frac{(\Delta L)_{mn}}{\left(\Delta L\right)_{mn}} > 1
\]

or

\[
\gamma_{mn} = \frac{(\Delta L)_{mn}}{\left(\Delta L\right)_{mn}}, \text{ for } \frac{(\Delta L)_{mn}}{\left(\Delta L\right)_{mn}} \leq 1
\]
been sacrificed to varying amounts, \( Y_n \) values of the affected picture elements would differ from those elements still on the linear tonal curve, and the \( I^*_{B&W} \) calculation for 6b, c, and d would not have stayed at 50%. Photos 6b, c, and d all retain the same information content which can be extracted, though overall lightness appearance of the three photos is different. Equation 5 includes a lightness error factor, \( \beta_n \), in order to account for changes in lightness of the picture elements in the photograph.

### A Lightness Error Factor

Equation 3 evaluates contrast without an additional compensation factor for changes in overall lightness level. For this reason, Equation 3 is more accurately described as a “retained information content” metric than a “retained image appearance” metric. Figure 6 illustrates this point. Photos b, c, and d in Figure 6 are tone reproductions of the same scene at the same contrast retention but at different overall lightness levels. Their tone curves were linearly scaled to lower the contrast from the photo shown in Figure 6a to those in 6b, c, and d. The reduced contrast compressed the dynamic range of the scene which in turn allowed variations in overall lightness level to be introduced without clipping any highlight or shadow detail. Had highlight or shadow detail

\[
I^*_{B&W} = \frac{\sum_{n=1}^{8} [Y_n - (\gamma_n \times \beta_n)]}{8}, \quad \text{where} \quad \gamma_n = \frac{\sum_{n=1}^{8} Y_n}{8} \quad \text{(defined in equation 4)}
\]

and

\[
\beta_n = \frac{\left( L_i \right)_n \left( L_i \right)_n + \sum_{m=1}^{8} (L_i)_m (L_i)_m}{(8 + 1) \times 100}
\]
The lightness error factor could be characterized as a “retained lightness” factor if the term were \[1-\beta\]. Equation 5 produces less change in \(I_{B&W}^*\) when picture elements retain their original lightness level with greater accuracy, and changes to both contrast and lightness produce lower \(I_{B&W}^*\) values than comparable amounts of contrast or lightness invoked separately. Some viewers may prefer the appearance of photo 6d over 6b. However, the metric gives a higher rating to 6b because all picture elements taken collectively have less lightness error when compared to the original photo in 6a. The discrepancy may in part be due to the specific image which has important highlights in the face and the shirt that we expect to be of high lightness levels. The metric would require scene identification intelligence to determine that those highlights have special significance greater than the shadow values. A viewer preference of 6d over 6b may also be an indication that people generally accept muddy shadow detail better than muddy highlights. If the latter hypothesis is true, then Equation 5 could be modified further to weight highlight lightness accuracy higher than shadow lightness accuracy. Psychological testing of this hypothesis may lead to an improved metric in the future.

**Limit Values for False Encoding**

False encoding values significantly less than –100% for both \(I_{B&W}^*\) and \(Y_m*\) picture elements are possible. Negative picture elements cancel positive elements in a mathematical sense and possibly in terms of human visual assessment of the print. However, the extent to which false encoding affects the viewer’s judgement of print quality does not nec-
Experimental Results

Figures 8–11 show \( I^* \) data for two inkjet print systems. A portrait of a mother and child was printed, and a generic test target having L channel ramps of red, green, blue, cyan, magenta, and yellow, plus grays and skin tones was also printed (see Figure 7). Figures 8 and 9 are light-fastness results for System A, and Figures 10 and 11 are the System B results. System A exhibited a severe loss of yellow dye. The color fidelity was rapidly lost and the prints appeared to turn excessively blue. However, yellow dye does not contribute significantly to the overall contrast of an image, so the prints retain a large amount of original contrast and lightness levels. System B is a more fade resistant system and is losing color information more proportionally to lightness and contrast. The System B prints still look in reasonably good condition at the 10 year extrapolated fading time, and this visual assessment is consistent with the \( I^* \) metric result so far. The tests are continuing.

The \( I^* \) values have been calculated with and without a limit value for false encoding. Compare graph lines b and c (\( I^*_{\text{RAW}} \)) and lines d and e (\( I^*_{\text{color}} \)). The chosen limit value was 0% for both \( I^*_{\text{color}} \) and the \( \gamma_n \) calculations. Few if any picture elements have reached the \( \gamma_n \) false encoding limit in either print system, so the \( I^*_{\text{RAW}} \) plot was essentially unchanged by the inclusion of the limit value, and the lines overlap. The use of an encoding limit shows the greatest effect in the \( I^*_{\text{color}} \) plots for System A (Figures 8 and 9).

Each graph in Figures 8–11 also has a second y-axis which plots the percentage of picture elements that have reached or exceeded a minimum quality value. The minimum quality value can be but doesn’t have to be the same as the false encoding limit value. Figures 8–11 use \( (I^*_{\text{color}})_n = 0 \) and \( \gamma = 0.2 \) (20%) as the respective minimum quality values. Plotting the percentage of elements that are lower than a minimum quality level is one way to evaluate the distribution of picture element quality.

Percent minimum quality used in conjunction with the \( I^* \) calculations may prove useful when defining image quality limits that viewers may tolerate in specific applications.

Finally, a comparison of the pictorial image results to the generic test target results reveals generally similar
Figure 8. System A, Generic Target. Line a: \( I^*_{\text{RAW}} \) Equation 3 (contrast only), Line b: \( I^*_{\text{RAW}} \) Equation 5 (lightness and contrast) with false encoding limit = 0%, Line c: \( I^*_{\text{RAW}} \) Equation 5, false encoding not limited, Line d: \( I^*_{\text{color}} \) with false encoding limit = 0%, Line e: \( I^*_{\text{color}} \) with no false encoding limit, Line f: \( I^* \) as per Equation 1 with \( \omega = 1 \), Line g: \( \gamma_n \) percentage at minimum quality value (20%), Line h: \( (I^*_{\text{color}})_n \) percentage at minimum quality value (0%).

Figure 9. System A, Pictorial Target: Lines a–g as per Figure 8.

Figure 10. System B, Generic Target: Lines a–g as per Figure 8. Lines b and c as well as d and e are essentially identical because no picture elements have reached the false encoding limits.

Figure 11. System B, Pictorial Target: Lines a–g as per Figure 8.
behavior but also some significant differences. The differences are especially true for System A because the portrait of mother and child has more areas of reds, flesh tones, near grays, and pale beige background that are adversely affected by the loss of yellow dye.

**Conclusion**

The mathematics of the I* metric have been presented in this paper. Theory of the boundary conditions, threshold values for contrast, a lightness error factor, false encoding theory and limits, and percent minimum quality values pertaining to color and contrast information, all derived from full tonal scale analysis, have been discussed. The authors programmed the I* metric with these features in a spreadsheet program, and the experimental results to date indicate that the I* metric is generating data consistent with visual observations of print aging in terms of color and contrast losses. Further psychophysical studies are needed in order to better understand the impact of false encoding values on perceived image quality and how typical observers weight color information, especially memory colors such as skin tones, versus black-and-white information when judging overall retention of image appearance.

Wilhelm Imaging Research, Inc. intends to make the I* test target files and analysis software described in this paper available to other researchers.

**References**


2. Henry Wilhelm and Carol Brower (contributing author), *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, Preservation Publishing Company, Grinnell, Iowa, 1993. Although it was recognized that assessment of the full tonal scale was desirable to fully characterize both light stability and dark storage stability behavior of color photographs, the difficulty of preparing properly calibrated full tonal scale test targets with the analog optical enlarger technology available at the time precluded putting this into general practice (see discussion on pages 77–80).


Paper by Mark McCormick-Goodhart, Henry Wilhelm, and Dmitriy Shklyarov (Wilhelm Imaging Research, Inc.) entitled:

A “Retained Image Appearance” Metric For Full Tonal Scale, Colorimetric Evaluation Of Photographic Image Stability

Paper presented by Mark McCormick-Goodhart on November 1, 2004

Paper (monochrome, with no color) published on pages 680–688 in:

Final Program and Proceedings:

IS&T’s NIP20: 2004 International Conference on Digital Printing Technologies

ISBN: 0-89208-253-4

Sponsored by:

IS&T: The Society for Imaging Science and Technology
ISJ: The Imaging Society of Japan

©2004 The Society for Imaging Science and Technology

October 31–November 5, 2004
Little America Hotel and Towers
Salt Lake City, Utah  U.S.A.

Published by:

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org (e-mail: info@imaging.org)
Yellowish Stain Formation in Inkjet Prints and Traditional Silver-Halide Color Photographs

Henry Wilhelm
Wilhelm Imaging Research, Inc.
Grinnell, Iowa U.S.A.

Abstract

Inkjet printing of photographs using both dye-based and pigmented inks has become the most popular form of output 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. Various factors affecting both light-induced and thermally-induced yellowish stain formation in inkjet prints are described. Stain behavior for representative inkjet papers as well as for selected traditional chromogenic (“silver-halide”) color photographs are discussed. Using data obtained from high-intensity 35 mm light tests, potential stain formation and fluorescent brightener activity loss reciprocity failures are described. Problems with the integration of light-induced and thermally-induced yellowing data in accelerated image stability tests are also discussed.

Introduction

Color photography has had a very long history of problems with gradual yellowish stain formation that has occurred both with prints stored in the dark and when exposed to light on long-term display. Kodacolor, introduced by Eastman Kodak in 1942, was the first mass market chromogenic color negative film and color print process and was the historical predecessor of today’s chromogenic color film and print materials. With prints made for more than a decade after its introduction, Kodacolor prints suffered from severe thermally-induced yellowish stain that developed gradually during storage (Figure 1). Many examples from this period studied by this author now have d-min blue densities actually above 1.0! These Kodacolor prints also had very poor light stability and, with no known examples of prints still surviving in reasonable condition, that period of color photography has been referred to as “The Totally Lost Kodacolor Era of 1942–1953.”

The primary cause of the yellowish stain that occurred in dark storage has been attributed to the presence of non-reacted (non-developed) magenta coupler remaining in the prints during storage (Figure 1). Many examples from this period studied by this author now have d-min blue densities actually above 1.0! These Kodacolor prints also had very poor light stability and, with no known examples of prints still surviving in reasonable condition, that period of color photography has been referred to as “The Totally Lost Kodacolor Era of 1942–1953.”

The primary cause of the yellowish stain that occurred in dark storage has been attributed to the presence of non-reacted (non-developed) magenta coupler remaining in the prints after the completion of processing and washing procedure. Over time, these residual couplers can develop significant stain levels. Improvements were made by Kodak in 1954–55, but magenta-coupler-produced-stain has continued to be a problem for chromogenic prints. As shown in Figures 2–4, further complicating the matter is the fact that rates of yellowish stain formation may significantly increase when prints are stored in the dark after exposure to light during display.

Figure 1. Typical of Kodacolor prints produced by Kodak during the period following their introduction in 1942 until around 1953, this print, which was made in 1950 and stored in the dark for 53 years, now exhibits an extremely high level of yellow/orange stain. This type of dark storage (thermal) stain is primarily caused by gradual discoloration of the residual magenta-dye-forming coupler that remains in the prints after the completion of the standard processing and washing procedure. Because the print had to be reproduced as a monochrome image for this IS&T publication, the original very stained color image was digitally converted to channel-separated monochrome images with Adobe Photoshop 7.0. The white reference strip placed on the left of each image is a d-min sample of modern Kodak Ektacolor Elite 7 Paper processed in 1999 and, when measured in 2003, had d-min densities of 0.09 [R]; 0.09 [G]; 0.07 [B] (Status A densitometry).
Imaging Science & Technology 2003: “Yellowish Stain Formation in Inkjet Prints and Traditional...”

The first “low-thermal-stain” color negative paper was introduced by Fuji in 1985 under the Fujicolor Paper Type 12 name. Further improvements were made by both Fuji and Konica and both companies introduced enhanced-stability, low-stain color papers in the early 1990’s. Kodak’s first “low-thermal-stain” color negative papers, Ektacolor Edge 7 and Portra III, were introduced in the mid-1990’s.

With the advent of digital minilabs introduced in recent years by Fuji, Noritsu, Agfa, Konica, and other companies, chromogenic color papers such as Fujicolor Crystal Archive and Kodak Generations Paper are now extensively used for printing digital camera files, either directly from camera memory cards brought to retail stores by consumers, or from CD’s, ZIP disks, or files sent to the retailer via the Internet.

Figure 2. Light-induced “dark staining” with Fujicolor Crystal Archive Paper, Kodak Edge 7 Paper, and Kodak Edge 5 Paper. The three papers were exposed to the equivalent of 450 lux for 12 hours per day for the stated time periods before being placed in the dark for 5 years (100 year light exposure data for Edge 5 were not available). Nearly all of the yellowish stain occurred during the dark storage period.

Figure 3. Light-induced “dark staining” of Ektacolor 74 RC Paper (initial type: 1977–82). Yellowish staining occurred at a much more rapid rate after a print was exposed to light for 960 days and then placed in the dark than it did in an identical print that was never exposed to light. Both prints were stored in the same environment.

Figure 4. Ilford Cibachrome II RC paper suffered a very large increase in yellowish stain during dark storage after a period of light exposure. Only negligible staining occurred with the glossy, polyester-base version of Ilford Cibachrome II (Ilford Cibachrome was renamed Ilford Ilfochrome in 1991). It is not yet known if TiO$_2$ pigmented polyethylene-coated RC paper supports may similarly contribute to long-term light-induced yellowish stain formation with RC inkjet photographic papers.

**Inkjet Photographic Prints**

Photographic-quality inkjet prints came into the market in the mid-1990’s and now, with printers, inks, and media supplied by Epson, Hewlett-Packard, Canon, Lexmark, and others, the great majority of prints made by consumers from digital camera files are printed at home with inkjet printers. Desktop and large-format inkjet printers are now used extensively by professional photographers and photo labs.

With inkjet printing, problems with yellowish stain have once again become a major area of concern. One of the key advantages of inkjet printing is the ability to print on a very wide variety of papers, films, canvas, and other substrates. Unfortunately, this wide choice of print media has resulted in products with a very wide range of quality. Some have poor yellowing behavior, either in dark storage, or when exposed to light on long-term display, or under both conditions. The introduction of high-stability pigmented and dye-based inkssets by Epson, Hewlett-Packard, and others has further increased the stability demands on media.

Especially when inkjet prints are stored in albums or other dark locations, yellowish stain formation in the media – and not fading of the inks – may often be the limiting factor that determines the life of the prints.

**Types of Yellowish Stain and Applicable Accelerated Test Methods**

There are a number of potential types and causes of yellowish stain formation in inkjet prints and in traditional color photographs; some, such as light-induced and thermally-induced staining, may affect both types of prints while others are specific to inkjet prints.
IS&T’s NIP19: 2003 International Conference on Digital Printing Technologies

**Figure 5.** An Arrhenius test with a matte surface inkjet paper in which the data have been extrapolated to storage at 23°C and 50% RH for 110 years before the first d-min stain parameter listed in Table 1 is predicted to be reached. The test was conducted at five temperatures between 50°C and 78°C at 50% RH. At the time of this writing, the highest four of these temperatures had reached the first criteria failure point.

**Thermally-Induced Yellowish Stain Occurring in Dark Storage**

Thermal stability is evaluated with the accelerated multi-temperature Arrhenius test which allows extrapolation of estimates to normal room temperature storage. The test procedure for traditional color photographic materials is described in ISO and ANSI standards. It should be noted that the ANSI and ISO standards to date do not have an acceptability limit for d-min stain formation; only an illustrative endpoint of 0.06 d-min density color imbalance is given (or a d-min density increase of 0.10 if the 0.06 color imbalance is not exceeded). It is emphasized, however, that this endpoint is NOT a part of these standards. As listed in Table 1, Wilhelm Imaging Research has long used a d-min density color imbalance of 0.10 (or a 0.15 d-min density increase if the 0.10 d-min color imbalance is not exceeded, which is rarely the case). Stain estimates for chromogenic papers have been published since the early 1990’s by Fuji (most recently in an article Shibahara and colleagues) and by Konica. Limited data have also been provided by Kodak. Onishi of Epson has applied the Arrhenius test method to a microporous inkjet paper printed with dye-based inks. Wilhelm Imaging Research currently has Arrhenius tests in progress with a wide range of inkjet and other digital printing materials (see Figure 5). Additional data will be published in the future. However, the yellowing of inkjet papers occurs as well as with traditional color photographs, may occur in the imaging layer, in the paper or other support material, or in both. Research to date shows that the level of relative humidity can have a major impact on the yellowing of inkjet papers. These investigations also suggest that the “sealed vapor-proof bag” test method may not be applicable to testing inkjet prints and instead the “free-hanging” test method should be used. Thermally-induced stain itself may be relatively unstable on exposure to light (see Figure 6).

**Light-Induced Yellowish Stain Occurring as a Result of Exposure to Light During Display**

With high-intensity accelerated light exposure tests, there is frequently a reciprocity failure with both chromogenic and inkjet prints that results in significantly higher levels of stain occurring at the lower illumination level (for example, 35 klux vs. 1.0 klux for equivalent klux/hours of exposure). As discussed previously, exposure to light during display may result in much higher rates of stain formation when prints are subsequently stored in the dark. It is clear from tests with many different types of media that exposure to UV radiation (for example, the 313 nm and 365 nm emissions of bare-bulb cool white fluorescent lamps) can greatly increase the rate of light-induced staining that occurs in dark storage. Tests are now in progress with UV-absorbing filters to determine what improvement might be gained. Further complicating the situation, as shown in Figure 7, is that in many cases light-induced stain is relatively unstable and may be “bleached” by further exposure to light. In addition, as shown in Figure 9,
Table 1. WIR Visually-Weighted Endpoint Criteria Set v3.0 for Color Image Print Stability Tests

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Allowed Percentage of Change in Initial Status A Densities of 0.6 and 1.0&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Image Change Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25% Loss of cyan (red density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20% Loss of magenta (green density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35% Loss of yellow (blue density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30% Loss of cyan (red density) in pure color cyan patches</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25% Loss of magenta (green density) in pure color magenta patches</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>35% Loss of yellow (blue density) in pure color yellow patches</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>12% Cyan minus magenta (R – G) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>15% Magenta minus cyan (G – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>18% Cyan minus yellow (R – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>18% Yellow minus cyan (B – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>18% Magenta minus yellow (G – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18% Yellow minus magenta (B – G) color imbalance in neutral patches</td>
<td></td>
</tr>
</tbody>
</table>

| Change Limits in Minimum-Density Areas (Paper White) Expressed in Density Units |
|-----------------------------------------------|-----------------------------------------------|
| 13    | .06 Change [increase] in red or green density                                      |
| 14    | .15 Change [increase] in blue density                                               |
| 15    | .05 Color imbalance between red and green densities                                |
| 16    | .10 Color imbalance between red and blue densities                                 |
| 17    | .10 Color imbalance between green and blue densities                                |

<sup>1</sup> Initial (starting) densities are absolute measurements (not measured “above d-min”). A weighted criteria set for fading, color balance shifts, and d-min stain was first developed by H. Wilhelm in 1978–83 and was slightly modified in 1990, 1992, and 1996. Version 3.0 above was implemented on August 25, 2001 and for the first time included 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 in earlier versions of the weighted criteria set. From the outset, the neutral scale parameters have always included both 0.6 and 1.0 starting densities.

after light-induced yellowish stain that occurred in the dark has been bleached by further exposure to light, additional stain can be generated after the print is once again placed in the dark. This cycle apparently can be repeated many times.

“Apparent Stain” Caused by Losses in Activity of Fluorescent Brighteners
Fluorescent brighteners (also called “UV brighteners,” “optical brighteners,” or “optical brightening agents” [OBA’s]) are white or colorless compounds added to most inkjet and other papers in order to make them appear whiter and “brighter” than they really are. Fluorescent brighteners absorb ultraviolet (UV) radiation, causing the brighteners to fluoresce (emit light) in the visible region, especially in the blue and green portions of the spectrum. As shown in Figure 8, fluorescent brighteners can lose activity – partially or completely – as a result of exposure to light. Brighteners may also lose activity when subjected to high temperatures in accelerated thermal aging tests and, it may be assumed, in long-term storage in albums or other dark places under normal room tempera-
Figure 7. Light-induced “dark staining” of a glossy microporous inkjet paper printed with pigmented inks. After exposure to glass-filtered 35 klux fluorescent light for 675 days, the paper rapidly yellowed in the dark. Upon further exposure to 35 klux light, the stain was quickly bleached and it no longer exceeded the d-min stain color balance criteria limit.

Figure 8. Exposure to light during display gradually degrades fluorescent brighteners resulting in a loss of activity and an apparent yellowing of the paper. In the examples shown here, test target prints made with a matte-coated inkjet paper printed with pigmented inks were photographed illuminated by 365nm UV radiation to visually indicate the level of brightener activity. The print on the left was stored in the dark after printing. The print on the right was exposed to glass-filtered 35 klux fluorescent illumination for 210 days at 24°C and 60% RH, and suffered almost total loss of brightener activity. Under typical indoor illumination, which contains adequate UV radiation to activate fluorescent brighteners, the print appears somewhat yellowed and not as “white” compared with the print that was kept in the dark. Prints made with high-stability inks can be exposed to light on display for much longer periods before reaching the first criteria failure endpoint than that required for significant – or even total – degradation of many types of fluorescent brighteners. When image permanence may be an important factor, fluorescent brighteners should be avoided in the manufacture of photographic materials.

Stain Caused by Exposure to Air Pollutants And Other Environmental Contaminants

The dry gelatin of traditional color photographic prints offers significant protection from the effects of airborne pollutants. In contrast, inkjet papers must be highly absorbent in order to absorb the ink immediately when it contacts the print surface in order to prevent spreading or “pooling” of the droplets. Unfortunately, inkjet papers – especially microporous papers – remain highly absorbent after the prints are dry. Unless protected from the atmosphere by glass or plastic sheet when displayed or kept in suitable albums or other storage materials, prints may develop stains over time. This author and others have reported that certain matte-coated fine art inkjet papers may develop either subtle or very bright yellow stains as a result of contact with corrugated cardboard, brown kraft wrapping paper, and packaging tapes with pressure-sensitive adhesives (substances from which appear to pass through packaging paper). This type of stain has also been observed when prints made with these papers have been mounted with many current brands of dry mount tissues. The staining became apparent in the days or weeks after mounting. The mechanism causing this type of stain formation is not understood; however, this type of stain is extremely unstable to light and may be bleached to the point where it is no longer visible after exposure to bright light for only minutes or up to a few hours. Because the stain is so unstable to light, it has been seen only on prints stored in the dark and not with those on normal display. Bienfang Adhesives ClearMount, a thermal dry mount tissue that was recently introduced by the Hunt Corp., is claimed by the manufacturer to be free of this problem. Bugner has reported that nitrogen oxides (but probably not ozone) may cause inkjet papers to form yellowish stain. Mizen and Mayhew have reported that corrugated cardboard and manila paper file folders could produce
yellowing when in contact with some inkjet papers. It was also reported that inkjet papers may absorb antioxidants such as BHT (frequently present in polyethylene and polypropylene) which, over time, may produce yellowing in some inkjet papers.

Coatings and laminates for inkjet prints and traditional color photographs may offer significant protection from many common sources of stain. However, these products must be individually evaluated with each ink/media combination because there is the possibility that the laminates and their adhesives, as well as solvent or water-based coatings applied to inkjet prints or to traditional color photographs after printing, could themselves cause stain formation over time.

Conclusions

Together with light fading, thermally-induced fading, and gas (ozone) fading of dye or pigment inkjet printed images and traditional chromogenic color photographs, it is very important to also evaluate paper stain behavior. Because yellowish stain with many products is unstable to light (subject to light fading) it is not possible to integrate light-stability and dark-stability test data in a simple manner as is now described in ISO 18909 for traditional color photographic materials. Additional research is being conducted at Wilhelm Imaging Research concerning how to best evaluate potential light-induced and thermally-induced yellowish stain formation with short-term, accelerated tests in the context of long-term display and dark storage of both traditional chromogenic photographs, inkjet photographs, and other types of digitally-printed images.

References


Paper by Henry Wilhelm (Wilhelm Imaging Research, Inc.) entitled: “Yellowish Stain Formation in Inkjet Prints and Traditional Silver-Halide Photographs” appeared on pages 444–449 in:

Final Program and Proceedings:

IS&T’s NIP19: International Conference on Digital Printing Technologies


©2003 The Society for Imaging Science and Technology

September 28–October 3, 2003
The Hyatt Regency New Orleans Hotel
New Orleans, Louisiana  U.S.A.

Published by:

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org
How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints And Traditional Color Photographs

Henry Wilhelm
Wilhelm Imaging Research, Inc.
Grinnell, Iowa, U.S.A.

Abstract
Inkjet printing of photographs has become the most common form of output from digital camera files and in 2002 inkjet printing will start to expand from the desktop to higher volume minilab and stand-alone kiosk applications. At the same time, the proliferation of digital silver-halide printers in minilabs, and increasingly in centralized wholesale labs, has brought traditional process RA-4 silver-halide photographic papers firmly into the digital output world. This paper gives an overview of the various factors affecting the light fading stability of both types of color prints. The similarities and differences between inkjet prints, made with both dye-based and pigmented inks, and traditional chromogenic color prints are discussed in the context of image stability, and certain improvements in test methods are proposed.

Introduction
With the rapid proliferation of affordable, high-quality digital cameras, scanners, and digitized image files made from color negative and transparency originals, there has been tremendous growth in the use of inkjet printers, digital minilabs, and other digital output devices for printing color photographs. As these new technologies continue to rapidly advance into mainstream markets, many questions have been asked about how the permanence of inkjet and other types of digital prints compares with that of traditional silver halide color prints.

For the majority of consumer digital camera users, inkjet printing has become the primary – and often the only – method of making prints from their digital image files. For these people, inkjet-printed photographs are either displayed framed under glass (or not framed and displayed freely exposed to the ambient air) in their homes and offices, placed in albums, posted on refrigerator doors, or otherwise used in the same ways that photographs have always been used. For most people, inkjet prints are photographs and they think about them in much the same way they have always thought about color photographs – and they also have the very same expectations about image permanence.

Because high-quality photographs printed with desktop inkjet printers have come into significant use only since 1998, people have no long-term experience with these new products of a very different and rapidly evolving technology. Consumers are confronted with a bewildering choice of inkjet printers (virtually all of which are now advertised as being “photo quality”) and countless types of inkjet photo papers. “How long will these inkjet prints last and how do they compare with traditional color prints?” is a frequently heard question.

The same question is also increasingly being asked by professional photographers, photo labs, service bureaus, commercial galleries, fine art publishers, interior decorators, and countless other producers and users of photographs. In addition, it is critically important for museum curators and archivists to know the answers to this question.

In professional portrait and wedding photography markets, a major growth area for high-quality inkjet printing, good print permanence is essential. Good humidity-fastness behavior and dark storage stability under the wide range of temperature and humidity conditions found in homes throughout the seasons in diverse geographic locations is also required.

A high level of resistance to the effects of air pollutants, or “gas-fading” as it has recently come to be known, is another essential attribute. Taking into account the all-important “intrinsic light stability” of a particular ink/media combination, the many display, storage, and use factors both separately and together influence the useful life of displayed inkjet prints and traditional color photographs.

The Permanence of Displayed Prints
Illumination intensity and spectral distribution, method of framing (or display without framing under glass), temperature, and relative humidity can all influence rates of fading, degree and direction of color balance changes, and yellowish stain formation that occur over time from exposure to light when prints are displayed. Table 1 gives the “predicted years of display before noticeable fading occurs” for a variety of inkjet prints made with dye-based and pigmented inks as well

©2002 The Society for Imaging Science and Technology
### Table 1. Predicted “Years of Display” Before Noticeable Fading Occurs with Color Prints

<table>
<thead>
<tr>
<th>Desktop Inkjet Printer and Inks</th>
<th>Print Paper and Type of Coating</th>
<th>Years of display before noticeable fading occurs(^1) (prints framed under glass)</th>
</tr>
</thead>
</table>
| **Printer:** Canon S800 Photo Printer  
**Ink:** Canon BCI-6 (6-ink, dye-based) | Canon Photo Paper Pro PR-101  
(microporous coating)  
Canon Glossy Photo Paper GP-301  
(microporous coating) | 27 years\(^2\)  
6 years\(^2\) |
| **Printer:** Epson Stylus Photo 890, 1280, 870, and 1270  
**Ink:** Epson inks (6-ink, dye-based) | Epson ColorLife Photo Paper  
(swellable polymer coating)  
Epson Matte Paper – Heavyweight  
(matte coated paper)  
Epson Premium Glossy Photo Paper (v2001)  
(microporous coating)  
Epson Photo Paper  
(microporous coating) | 26 years  
25 years  
9 years\(^2\)  
6 years\(^2\) |
| **Printer:** Epson Stylus Photo 2000P  
**Ink:** Epson “Archival” (6-ink, pigmented) | Epson Premium Luster Photo Paper  
(microporous coating)  
Epson Premium Semi-Gloss Photo Paper  
(microporous coating)  
Epson Enhanced [Archival] Matte Paper  
(matte coated paper) | More than 100 years  
More than 100 years  
More than 100 years |
| **Printer:** Hewlett-Packard PhotoSmart P-1000, 1215, DeskJet 970 series  
**Ink:** HP #78 (4-ink, dye-based) | HP Colorfast Photo Paper  
(swellable polymer coating)  
HP Premium Plus Photo Paper  
(swellable polymer coating)  
HP Premium Photo Paper  
(swellable polymer coating) | 19 years  
5 years\(^3\)  
3 years\(^3\) |
| **Printer:** Kodak Personal Picture Maker PPM200 (mfg. by Lexmark)  
**Ink:** Kodak “Photo” (6-ink, dye-based) | Kodak Ultima Picture Paper, High Gloss  
(swellable polymer coating)  
Kodak Premium Inkjet Paper, Matte  
(matte coated paper)  
Kodak Picture Paper, Soft Gloss  
(microporous coating) | 24 years\(^3\)  
6 years\(^3\)  
3 years\(^2, 3\) |
| **Printer:** Lexmark Z52 Color Jetprinter  
**Ink:** Lexmark “Photo” (6-ink, dye-based) | Kodak Premium Picture Paper, High Gloss  
(swellable polymer coating) | Less than 1 year |
| **Traditional Chromogenic Color Prints** | Fujicolor Crystal Archive Paper  
(multilayer gelatin-coated RC photo paper)  
Kodak Ektacolor Edge 8 Paper  
(multilayer gelatin-coated RC photo paper) | 60 years\(^4\)  
22 years\(^4\) |

---

1) Predictions based on accelerated light stability tests conducted at 35 klux with glass-filtered cool white fluorescent illumination at 24°C and 60% RH. Data were extrapolated to display conditions of 450 lux for 12 hours per day using WIR Visually-Weighted Endpoint Criteria Set v2.0 (reciprocity failures are assumed to be zero). 2) Field experience has shown that, as a class of media, microporous papers used with dye-based inks can be very vulnerable to “gas fading” when displayed unframed and/or stored exposed to the open atmosphere where even very low levels of certain air pollutants are present; to a greater or lesser degree, these papers have a pronounced sensitivity to pollutants such as ozone and, in some locations, displayed unframed prints have suffered from extremely rapid image deterioration. 3) These ink/media combinations have poor humidity-fastness and, when stored or displayed in commonly encountered conditions of high relative humidity, over time the prints may suffer from one or more of the following: color balance changes, density changes, lateral ink bleeding, “bronzing” in high density areas, and sticking and ink transfer. 4) Display-life predictions integrated with the manufacturer’s Arrhenius dark stability data. Note: An earlier version of this table was included in an article by Anush Yegyazarian entitled, “Fight Photo Fade-Out,” *PC World*, July 2001, pp. 48–51.
Table 2. WIR Visually-Weighted Endpoint Criteria Set v3.0 for Color Image Print Stability Tests

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Allowed Percentage of Change in Initial Status A Densities of 0.6 and 1.0&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Image Change Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25% Loss of cyan (red density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20% Loss of magenta (green density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35% Loss of yellow (blue density) in neutral patches</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30% Loss of cyan (red density) in pure color cyan patches</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25% Loss of magenta (green density) in pure color magenta patches</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>35% Loss of yellow (blue density) in pure color yellow patches</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>12% Cyan minus magenta (R – G) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>15% Magenta minus cyan (G – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>18% Cyan minus yellow (R – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>18% Yellow minus cyan (B – R) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>18% Magenta minus yellow (G – B) color imbalance in neutral patches</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18% Yellow minus magenta (B – G) color imbalance in neutral patches</td>
<td></td>
</tr>
</tbody>
</table>

Change Limits in Minimum-Density Areas (Paper White) Expressed in Density Units

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>.06 Change [increase] in red or green density</td>
</tr>
<tr>
<td>14</td>
<td>.15 Change [increase] in blue density</td>
</tr>
<tr>
<td>15</td>
<td>.05 Color imbalance between red and green densities</td>
</tr>
<tr>
<td>16</td>
<td>.10 Color imbalance between red and blue densities</td>
</tr>
<tr>
<td>17</td>
<td>.10 Color imbalance between green and blue densities</td>
</tr>
</tbody>
</table>

<sup>1</sup>Initial (starting) densities are absolute measurements (not measured “above d-min”). A weighted criteria set for fading, color balance shifts, and d-min stain was first developed by H. Wilhelm in 1978–83 and was slightly modified in 1990, 1992, and 1996. Version 3.0 above was implemented on August 25, 2001 and for the first time included 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 in earlier versions of the weighted criteria set. From the outset, the neutral scale parameters have always included both 0.6 and 1.0 starting densities.

as two current types of chromogenic color papers. These predictions are based on prints framed under glass and illuminated at 450 lux for 12 hours per day. Dye fading and color balance changes that constitute “noticeable fading” are specified in the visually-weighted criteria set in Table 2. Visually-weighted endpoint criteria sets were developed by H. Wilhelm beginning in 1978 and are based on psychometric evaluations of groups of incrementally-faded Kodak Ektacolor prints of representative portraits and wedding pictures photographed by professional photographers. Version 3.0 listed here is being employed by Wilhelm Imaging Research, Inc. for current image permanence evaluations. For the products listed in Table 1, an earlier version of the weighted endpoint criteria set was used which employed endpoints for pure color cyan, magenta, and yellow only at 1.0 starting density. The addition of endpoints for pure color primaries at 0.6 starting densities would reduce the predicted years of display rating for some, but not all, of these products. Future publi-

Imaging Science & Technology 2002: “How Long Will They Last?...”

IS&T’s 12th International Symposium on Photofinishing Technology

Figure 1. Influence of drying method on the light stability of inkjet prints made with Epson Premium Glossy Photo Paper (a microporous-type media) and an Epson Stylus Photo 890 printer using standard 6-ink Epson dye-based inks.

Figure 2. Effects of print drying method on “predicted years of display” for Epson PGPP/890 at 0.6 starting density (magenta).

Figure 3. Effects of print drying method on “predicted years of display” for Epson PGPP/890 at 1.0 starting density (magenta).

Figure 4. Percentage of allowed fading remaining until first failure criterion is reached (0.6 starting density).

Figure 5. Percentage of allowed fading remaining until first failure criterion is reached (1.0 starting density).

The collection of data for these materials will reflect these changes where they occur. Investigations conducted at Wilhelm Imaging Research, Inc. have shown that with dye-based inkjet prints, the drying method and the period between the time of printing and the start of an accelerated light fading test frequently will have a major impact on measured light stability. Figures 1–3 show the influence of two “drying” methods on the stability of prints made with microporous Epson Premium Glossy Photo Paper (v.2001) and an Epson 890 printer.

Figure 4 is for a swellable-polymer glossy photo paper printed with a dye-based 4-ink printer. In terms of evaporation of water from freshly made prints, it is believed that prints become “dry,” or in moisture-equilibrium with the surrounding atmosphere, within a maximum of approximately eight hours after printing. (Because microporous papers instantly absorb water-containing inks upon contact with the print surface, they appear to be fully dry immediately upon emerging from the printer. However, the absorbed water will slowly diffuse from the microporous structure and evaporate during the hours following printing until equilibrium with the surrounding air is reached.)

In normal display and use, prints are naturally “aged” for periods of months and years and accelerated test procedures should take this into account if test results are to be meaningful. These investigations of “drying” conditions suggest that the usual industry practice of air-drying prints for a few days prior to the start of light stability tests will seriously underestimate the light stability of many ink/media combinations. For the past several years, this author has provided...
Figure 4. Influence of drying method and duration on the light stability of inkjet prints made with a swellable-polymer glossy photo paper and a 4-ink dye-based inkset. For clarity, the plot for the cyan ink has been omitted from this graph (the rate of cyan fading was reduced with the print stored in the paper folder for 30 days; however, the rate of cyan fading was not affected by the drying method nearly so much as was the rate of fading with the magenta ink).

Figure 5. Light-induced dark storage yellowish stain formation in an inkjet paper. Aqueous inkjet inks contain a significant percentage by weight of glycols and other high-boiling point solvents and humectants; after evaporation of the water component of the inks, the solvents and humectants remain; their presence in the ink receptive layers at the site of image dye molecules may negatively influence their light stability behavior. It is hypothesized that over time these non-volatile ink components slowly diffuse into the media structure (or, in the case of “drying” in contact with paper, they may diffuse into adjacent absorbent materials), thus lowering their concentration in the print image receptive layers. With susceptible ink dyes, this may in turn reduce the rate of light fading. Other changes in the chemistry or morphology of the inks and ink receptive layer that occur over time may also be involved.

When inkjet prints are subjected to the high-intensity illumination employed in accelerated light stability tests, the print may suffer from light-induced yellowing that only manifests itself during a period of storage in the dark after the prints are removed from exposure to light. Bare-bulb fluorescent illumination, which contains significant UV radiation at 313nm, generally exacerbates this type of staining behavior. An example of this, with a microporous inkjet photo paper exposed to bare-bulb illumination, is shown in Figure 5. Traditional chromogenic color prints may be similarly affected. Because short-term high-intensity light exposure tests may not yield meaningful data on long-term stain growth, further investigations into how to better model this behavior in a reasonably short time period are being undertaken. Potential reciprocity failures in accelerated light fading tests are also a major concern. Studies at Wilhelm Imaging Research are currently in progress with a variety of dye-based and pigmented ink ink/media combinations exposed to 1.0 klux illumination; glass-covered, glass with a 2 cm air...
Imaging Science & Technology 2002: “How Long Will They Last?…”

References

1. An earlier version of Table 1 was included in a article by Anush Yegyazarian, “Flight Photo Fade-Out,” PC World, July 2001, pp. 48–51. Regularly updated image stability data from Wilhelm Imaging Research, Inc. is available from www.wilhelm-research.com


Final Program and Advance Printing of Paper Summaries:

IS&T’s 12th International Symposium on Photofinishing Technology


©2002 The Society for Imaging Science and Technology

February 20–21, 2002
Radisson Barceló Hotel
Orlando, Florida  U.S.A.

Published by:

IS&T– The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org
Annex 5

Published Papers Concerning the Permanence of Analog and Digital Color Prints:


Henry Wilhelm
Wilhelm Imaging Research, Inc.
Grinnell, Iowa U.S.A.

Abstract
Since digital fine art photography printing began in 1991 with the difficult to operate and costly to maintain $126,000 Iris Graphics Model 3047 inkjet printer using water-soluble cyan, magenta, yellow and black dye-based inks with poor light stability – but which could nevertheless print beautiful large-format photographs from digital files on a wide variety of artists papers, both thick and thin – the industry has seen rapid progress in the development of far lower cost, faster and easier to operate printers. Central to this evolution have been the dual concerns of image permanence and image quality. An increasingly competitive inkjet industry has driven the development of, at first, more stable dye-based inks and ink-specific optimized inkjet media. More recently, piezo and thermal head printers using high-stability, multi-colorant pigmented ink systems from Epson, Hewlett-Packard, and Canon have come to dominate the field. At the same time, in a massive reshaping of the industry, the reduced costs of both printers and computer systems coupled with Adobe Photoshop and other advanced image editing software has made it possible for digital fine art printmaking to move from a small group of specialized providers into the hands of individual photographers and artists – worldwide.1

Introduction
Digital printing of fine art photographs – and a broad-based concern about the permanence of digital prints – can be traced to the founding of Nash Editions in Manhattan Beach, California, in 1991. At that time, the only printer capable of producing high-quality, large photographic prints (up to 34x46 inches) on a wide range of papers and canvas was the Iris Graphics Model 3047 inkjet printer made by Iris Graphics, Inc. in Bedford, Massachusetts. The Iris 3047, which had been designed for direct digital graphic arts proofing, was an expensive machine, costing $126,000. As recounted by Steve Boulter, then national sales manager for Iris Graphics:

“The 3047 was developed for the Marubeni Corporation of Japan as an eight-up proofer. Hence, the A0 sheet size. The printer was introduced in 1989. I started working for Iris in 1988 and the development activity for the 3047 began shortly after that. Marubeni is kind of like the GE [General Electric Company] of Japan. They are a very large conglomerate and they functioned as a reseller for Iris. They funded the development of the 3047 with about $500,000.”

The Iris 3047 was not conceived of nor intended for printing valuable photographs and art reproductions that would be framed and displayed for long periods of time. Because long-term light stability was not of concern in the proofing business, the dye-based ink sets initially available for the printer had poor light stability. Instead, the design goal was to print direct-digital proofs that could match the color gamut and tone scale of the inks used in offset printing: the proofs had only short-term use.

It was rock musician Graham Nash and his concert tour road manager Mac Holbert, both accomplished photographers, who first recognized the potential of the Iris as a fine art printer when, on March 14, 1989, they watched a 3047 printing a color photograph. As Holbert wrote in a one of a series of diary entries: “The digital images are stored on a ½-inch recording tape that is inserted into an automatic tape reader. The color and image placement is controlled through a series of menus you access through a digital readout panel on the printer. They printed an image of a bride holding a bouquet of pink roses. Not exactly our type of image.... The print was about 16” x 20” and took about 20 minutes to complete. When the printer stopped spinning and they opened it, both Graham and I got chills. It was astounding! I couldn’t believe what I was looking at! The paper they used was a little glossy for my taste, but the technology is there!” Steve Boulter mentioned he’s been printing painting reproductions on very heavy watercolor paper back in the lab and that had gotten encouraging results. Graham was excited about the prospect of printing a photograph on thick art paper. Graham asked the Iris operator about
Graham Nash (left) and Jack Duganne detach a completed monochrome print from one of the two Iris Model 3047 ink jet printers at Nash Editions. This photograph is a black-and-white self-portrait of Nash, which he made during the early days of Crosby, Stills, Nash & Young.

Iris ink jet printers lay down the cyan, magenta, yellow, and black images in a single pass with the print material attached to a rapidly rotating drum. With the cover removed, the leading band of the image printed by the cyan ink jet, which slowly moves across the image from left to right, is clearly visible.

Duganne and Holbert work on an image using Photoshop running on an Apple Macintosh computer with visiting New York City fashion photographer George Holz (center). Prints could be made from scanned transparencies and negatives or directly from a variety of Macintosh and IBM image file formats.

Bottles of the water-base inks employed in the Iris ink jet printers. Initially designed for graphic arts proofing, the standard Iris inks have very poor light fading stability. Inks made with dyes having improved light stability for fine art and photography applications started to become available in 1994.

Duganne and Holbert work on an image using Photoshop running on an Apple Macintosh computer with visiting New York City fashion photographer George Holz (center). Prints could be made from scanned transparencies and negatives or directly from a variety of Macintosh and IBM image file formats.

A high-resolution flatbed CCD scanner custom-built by Photometrics, Ltd. was used by Nash Editions to input images from color prints, paintings, and other art work. The scanner could accommodate originals of up to 4x4 feet.

Nash Editions was originally located in this picturesque building, not far from the Los Angeles International Airport.
### Table 1 – WIR Display Permanence Ratings for Selected Digital Print Materials 1991–2006\(^{(a)}\)

<table>
<thead>
<tr>
<th>Type of Inkjet Printer/Ink/Paper Combination and Digital Silver-Halide or Digital Silver Dye-Bleach Color Papers Printed with RGB Laser/LED Digital Photo Printers</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Year listed is the date stability tests were conducted by Wilhelm Imaging Research, Inc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1991 – Iris Graphics 3047 printer</strong> (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>Printed with Iris ID Inks (4-ink dye-based inkjet prints)</td>
<td>4 years</td>
</tr>
<tr>
<td></td>
<td>Iris Semi-Matte coated inkjet proofing photo paper</td>
<td>1.4 years</td>
</tr>
<tr>
<td></td>
<td>Arches BFK Heavy Watercolor Paper (uncoated 100% cotton fine art paper)</td>
<td>4 years</td>
</tr>
<tr>
<td><strong>1994 – Iris Graphics 3047 printer</strong> (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>Printed with Lyson FA Inks (4-ink dye-based inkjet prints)</td>
<td>14 years</td>
</tr>
<tr>
<td></td>
<td>Arches BFK Heavy Watercolor Paper (uncoated 100% cotton fine art paper)</td>
<td>17 years</td>
</tr>
<tr>
<td></td>
<td>Iris Semi-Matte coated inkjet proofing photo paper</td>
<td>5 years</td>
</tr>
<tr>
<td><strong>1994 – Durst Lambda 130 digital printer</strong> (first large-format RGB laser silver-halide printer)</td>
<td>Printed with Fujicolor SFA3 Color Negative Paper (silver-halide color prints)</td>
<td>36 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Cibachrome print material (silver dye-bleach color prints)</td>
<td>40 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Kodak Ektacolor Portra II Color Negative Paper (silver-halide color prints)</td>
<td>29 years</td>
</tr>
<tr>
<td><strong>1994 – Epson Stylus Color printer</strong> (first “photo-quality” 720 dpi desktop inkjet printer)</td>
<td>Printed with Epson Inks and Epson Inkjet Paper (4-ink dye-based inkjet prints)</td>
<td>&lt;0.5 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Iris Longevity inks (4-ink dye-based inkjet prints)</td>
<td>2 years</td>
</tr>
<tr>
<td><strong>1996 – Iris Graphics 3047 printer</strong> (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>Printed with American Inkjet Corporation “NE” [Nash Editions] inks consisting of</td>
<td>22 years</td>
</tr>
<tr>
<td></td>
<td>All cyan and magenta inks and Lyson FA-I yellow and black inks printed on</td>
<td>25 years</td>
</tr>
<tr>
<td></td>
<td>Arches for Iris 100% cotton fine art paper</td>
<td></td>
</tr>
<tr>
<td><strong>1997 – Iris Graphics 3047 printer</strong> (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>Printed with Iris Equipoise inks (4-ink dye-based inkjet prints)</td>
<td>34 years</td>
</tr>
<tr>
<td></td>
<td>Arches Cold Press uncoated 100% cotton fine art paper</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Arches for Iris 100% cotton fine art paper</td>
<td>32 years</td>
</tr>
<tr>
<td></td>
<td>Iris Canvas</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Lysonic Standard Fine Art Paper matte-coated fine art paper</td>
<td>8 years</td>
</tr>
<tr>
<td></td>
<td>Somerset Enhanced Velvet matte-coated fine art paper</td>
<td>3 years</td>
</tr>
<tr>
<td><strong>2000 – Iris Graphics 3047 printer</strong> (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>Printed with American Ink Jet Pinnacle Gold Iris inks (4-ink dye-based inkjet prints)</td>
<td>70 years</td>
</tr>
<tr>
<td></td>
<td>Somerset Velvet uncoated 100% cotton fine art paper</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Arches for Iris 100% cotton fine art paper</td>
<td>32 years</td>
</tr>
<tr>
<td></td>
<td>Pinnacle Gold Enhanced Watercolor fine art paper</td>
<td>24 years</td>
</tr>
<tr>
<td></td>
<td>UltraStable Canvas</td>
<td>19 years</td>
</tr>
<tr>
<td><strong>2000 – Epson Stylus Photo 870 and 1270 desktop printers</strong> (“improved stability” dye-based photo inks)</td>
<td>Printed with Epson Photo inks (6-ink dye-based inkjet prints)</td>
<td>25 years</td>
</tr>
<tr>
<td></td>
<td>Epson Matte Paper – Heavyweight (matte-coated paper)</td>
<td>10 years</td>
</tr>
<tr>
<td></td>
<td>Epson Premium Glossy Photo Paper</td>
<td>7 years</td>
</tr>
<tr>
<td></td>
<td>Epson Photo Paper</td>
<td></td>
</tr>
</tbody>
</table>

\(^{(a)}\) For a complete list of ratings, please refer to the full reference.
## Table 1 – WIR Display Permanence Ratings Continued

<table>
<thead>
<tr>
<th>Type of Inkjet Printer/Ink/Paper Combination and Digital Silver-Halide or Digital Silver Dye-Bleach Color Papers Printed with RGB Laser/LED Digital Photo Printers</th>
<th>Displayed Prints Framed</th>
<th>Displayed Prints Framed</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Year listed is the date stability tests were conducted by Wilhelm Imaging Research, Inc.)</td>
<td>Under Glass</td>
<td>With UV Filter</td>
</tr>
</tbody>
</table>

### 2000 – Epson Stylus Pro 7500, 9500, Stylus Photo P2000 printers
- Epson’s first pigmented inkjet printers  
  - Printed with Epson Archival pigmented inks (6-ink pigmented inkjet prints)  
  - Epson Premium Luster Photo Paper  
  - Epson Watercolor Paper – Smooth (matte-coated 100% cotton fine art paper)  
  - >225 years >250 years

### 2002 – Hewlett-Packard DesignJet 5000 printer
- HP’s first 6-ink pigmented inkjet printer  
  - Printed with HP “UV” inks and select fine art papers (6-ink pigmented inkjet prints)  
  - >200 years >250 years

### 2002 – Epson Stylus Pro 4000, 7600, 9600, Stylus Photo 2200 printers
- 2-level pigmented black inks  
  - Printed with Epson UltraChrome pigmented inks (7-ink pigmented inkjet prints)  
  - Epson UltraSmooth Fine Art Paper (matte-coated 100% cotton fine art paper)  
  - Epson Premium Luster Photo Paper (250)  
  - 108 years 175 years  
  - Somerset Velvet for Epson (matte-coated 100% cotton fine art paper)  
  - 61 years 125 years

### 2004 – Durst Lambda, Océ LightJet, and other RGB laser/LED digital printers
- Printed with FujiColor Crystal Archive color negative paper (silver-halide color prints)  
  - >225 years  
  - Printed with Kodak Edge Generations color negative paper (silver-halide color prints)  
  - >225 years  
  - Printed with Kodak Edge Generations color negative paper (silver-halide color prints)  
  - >225 years

### 2004 – Hewlett-Packard DesignJet 130 printer
- HP’s first 18x24-inch desktop inkjet photo printer  
  - Printed with HP 8/BS inks (6-ink dye-based inkjet prints)  
  - HP Premium Plus Photo Paper and other HP swellable RC-base photo papers  
  - 82 years 100 years

### 2004 – Canon i9900 and (in 2005) PIXMA iP8500 printers
- Canon’s first 8-ink desktop inkjet printers  
  - Printed with Canon ChromaPLUS inks (6-ink pigmented inkjet prints)  
  - Canon Matte Photo Paper MP-101 (see Note B below)  
  - Canon Photo Paper Pro PR-101 (glossy) (see Note B below)  
  - 10 years 12 years  
  - 6 years 8 years

### 2004 – Epson Stylus Photo R800 and (in 2005) R800 printers
- First use of clear “gloss-optimizer” ink  
  - Printed with Epson UltraChrome Hi-Gloss pigmented inks (7-ink pigment inkjet prints)  
  - Epson Watercolor Paper – Radiant White (matte-coated fine art paper)  
  - 200 years >250 years  
  - Epson Premium Glossy Photo Paper Paper  
  - 104 years >175 years  
  - Epson Premium Luster Photo Paper  
  - 64 years >150 years

### 2005 – Hewlett-Packard Photosmart 8750 desktop printer
- HP’s first 9-ink pigmented inkjet printer  
  - Printed with HP Viverra inks (9-ink dye-based inkjet prints)  
  - HP Premium Plus Photo Paper and other HP swellable RC-base photo papers  
  - 108 years 140 years

### 2005 – Epson Stylus Pro 4800, 7800, 9800, Stylus Photo R2400 printers
- 3-level pigmented black inks  
  - Printed with Epson UltraChrome K3 pigmented inks (8-ink pigmented inkjet prints)  
  - Epson UltraSmooth Fine Art Paper (matte-coated 100% cotton fine art paper)  
  - Epson Premium Luster Photo Paper (250)  
  - 108 years 175 years  
  - Somerset Velvet for Epson (matte-coated 100% cotton fine art paper)  
  - 61 years 125 years

### 2006 – Canon PIXMA Pro9500 printer
- Canon’s first 10-ink desktop pigment inkjet printer  
  - Printed with Canon Lucia pigmented inks (9-ink pigment inkjet prints)  
  - Canon Fine Art Photo Rag Paper and select other Canon matte-coated fine art papers  
  - Canon Luster Photo Paper, Canon Photo Paper Pro, and select other Canon photo papers  
  - >100 years >150 years  
  - >100 years >150 years

### 2006 – HP Photosmart Pro B9180 printer
- HP’s first 12-ink desktop pigment inkjet printer  
  - Printed with HP Viverra Pigment inks (8-ink [7-inks w/ glossy papers] pigment inkjet prints)  
  - HP Advanced Photo Paper Glossy (improved version with 10.5 mil paper thickness)  
  - HP Photo Matte Paper (matte-coated fine art paper)  
  - HP Hahnemühle Smooth Fine Art Paper (matte-coated fine art paper)  
  - >230 years >230 years  
  - >230 years >230 years

### 2006 – Canon imagePROGRAF iPF5000 and iPF9000 printers
- Canon’s first 12-ink pigment inkjet printers  
  - Printed with Canon Lucia pigmented inks (11-ink pigment inkjet prints)  
  - Canon Fine Art Photo Rag Paper and select other Canon matte-coated fine art papers  
  - Canon Luster Photo Paper, Canon Photo Paper Pro, and select other Canon photo papers  
  - >100 years >150 years  
  - >100 years >150 years

---

(a) The WIR Display Permanence Ratings given here were derived from accelerated glass-filtered cool white fluorescent light fading tests conducted at 24°C (75°F) and 60% relative humidity and are based on the “standard” indoor display condition of 450 lux for 12 hours per day employed by Wilhelm Imaging Research, Inc. Illumination conditions in homes, offices, and galleries do vary, however, and color images will last longer when displayed under lower light levels; likewise, the life of prints will be shortened when displayed under illumination that is more intense than 450 lux. The predictions given here are the years of display required for the changes in color balance, and/or aging specified in the visually-weighted WIR Var. 3.0 Endpoint Criteria Set to occur; with most types of images, these changes are easily noticeable in side-by-side comparisons with an unfaded original.  
(b) Because of the disportionately rapid light fading of the red (orange) ink in the 8-ink Canon ChromaPLUS dye-based inkset used in the Canon i9900 printer, which is not properly assessed by the Status A densitometrically-based WIR 3.0 Endpoint Criteria Set, the Display Permanence Ratings should in reality be lower than the figures given here. The disproportionately rapid fading of the red (orange) ink is particularly noticeable in skin tones.
When made with long-lasting 100% cotton fiber artists papers (non-coated), the Iris inkjet prints also had very low levels of d-minyellowish stain formation – even after more than two years of aging at 62°F and 45% RH. Tests conducted with prints made with more recent inks and papers (protected from ozone) show that the dark storage stability of most inkjet prints is limited by the thermal stability (yellowing) of the print paper itself – and not by the stability of the inks.

Figure 2.
Prints as an analogous term to “Serigraph.” In reference to inkjet technology in which inkjet nozzle “spray” inks onto paper, Giclée was derived from the French word “giclée,” which means to spray or squirt a liquid. The term is only applied to prints made with matte surface fine art papers or canvas, and not to RC base semigloss or glossy photo papers. It has been pointedly avoided by Nash Editions and other digital print providers catering to high-end artists and photographers—and is also shunned by most photographers themselves.

In 1999 Nash Editions became one of Epson’s beta test sites for the ground-breaking Epson Stylus Pro 9500 large-format printers using Epson “Archival” pigmented inks and, as a result, Mac Holbert was asked by Epson America to work with New York photographer Stephen Wilkes to print a major exhibition of his work, “Epson’s America in Detail.” The show opened on January 11, 2001 in San Francisco and, with extensive press coverage, went on to New York, Santa Monica, and Chicago. Nash Editions was not only the first digital fine art printing studio, but it also printed the first major photography exhibition to be printed with high-stability pigmented inks.

Said Wilkes: “The year 2000 ushers in the explosion of the digital revolution, which will undoubtedly change all of our lives, much in the same way the industrial revolution did at the turn of the 20th century. It is now possible to create beautiful images without ever stepping into a darkroom. Epson has provided me with the opportunity and the archival printing technology to produce the images captured during [his photographic tour across the United States in 2000] through a unique new method—one that is the wave of the future.”

The introduction of the Epson Stylus Pro 7500 (24-inch) and 9500 (44-inch) pigmented ink printers in 2000 started a period of rapid change in the fine art printing business. The new Epson printers were able to handle a wide variety of fine art and photo media, including very thick papers which could be sent through the printer’s straight-through paper path without bending, and they were easy to operate and practically maintenance free. Nash Editions started to convert its printing operations to the new Epson printers, and by the end of 2004 it had retired its last Iris 3047. The original 3047 purchased by Nash was accepted by the Smithsonian Institution in a ceremony on August 12, 2005 in Washington, D.C., that was attended by Graham Nash, Mac Holbert, and Steve Boulter.

The large-format Epson printers cost only a small fraction of the price of an Iris printer, making the printers accessible to photographers themselves and this brought about far-reaching changes in the printmaking field. Photography has had a very long tradition of serious photographers making black-and-white prints in their own darkrooms. Ansel Adams, Edward Weston, Paul Strand and W. Eugene Smith are but well-known examples. With the advent of color photography, however, the high cost and complexity of color printing and processing equipment caused most photographers to abandon their darkrooms and send their color films to commercial laboratories. As a result, photographers lost touch with using or even understanding the limited controls that were available in color printing with an enlarger. When printing color negatives with an enlarger, it is not possible to adjust image contrast, the tone reproduction curve shape, or color saturation—only overall density and color balance can be controlled. Adobe Photoshop and other image editing software offers far greater control with just a few clicks of a mouse.

In the modern inkjet era, far more people are printing their own photographs than was ever true in the history of photography. With a little practice, even school children are printing beautiful color photographs taken with their family’s digital cameras! Now, as the 70-year period of “traditional” silver-halide color (chromogenic) photography is coming to an end, printmaking has finally returned to the photographer. The result, of course, has been a complete transformation of the photography industry.

The Shift to Pigmented Inks

To understand the evolution of print permanence in the inkjet field, it is important to appreciate the fact that among the four major manufacturers of inkjet printers, inks, and papers—Canon, Epson, Hewlett-Packard,
Los Angeles photographer Greg Gorman making a print of the actress Sharon Stone with his Epson Stylus Pro 9800 printer and UltraChrome K3 pigmented inks. Gorman’s printers and computers are located in the living room of his home in the Hollywood Hills. Gorman long printed his own black-and-white silver gelatin prints in a darkroom, but when he started shooting in color, he, like most other photographers, had to send his negatives to a commercial lab to have prints made. But with the advent of digital cameras, Photoshop, and inkjet printers, he now makes all of his black-and-white and color prints himself. Gorman is internationally known for his photographs of movie stars and other celebrities. <www.douglaskirkland.com>

James Nachtwey, a New York based documentary photographer, with a black-and-white photograph printed with an Epson Stylus Photo R2400 printer. For much of his photography, James Nachtwey has long preferred black-and-white and, when assignments and deadlines permit, he still shoots B&W film. The “Advanced Black and White Print Mode” provided with the Epson R2400 and other Epson UltraChrome K3 printers gives subtle control of the hue and tonescale of black-and-white images and also provides a simple way to make high-quality B&W Prints from RGB image files. Nachtwey, a founder of Agency VII, a group of nine of the world’s most renowned photojournalists, has been a contract photographer with Time Magazine since 1984. <www.jamesnachtwey.com>

Douglas Kirkland with a photograph of actress Marilyn Monroe made with his Hewlett-Packard Photosmart Pro B9180 using HP Vivera Pigment inks and HP Hahnemühle Smooth Fine Art Paper. The photograph was one of a series made in 1961 on assignment for Look magazine. In a far ranging career as a photojournalist and portrait photographer that spans five decades, Kirkland has published 10 books and his work has appeared in countless publications. Kirkland has always driven to make his own prints. In 1946, when Kirkland was 12 years old and living in Port Erie, Canada, near Niagara Falls, he built his first darkroom in a closet on the second floor of the family home and taught himself to develop B&W films and prints. Kirkland and his wife and business partner, Francoise, live in Los Angeles, California. <www.douglasskirkland.com>

and Lexmark – none were in the traditional photograph field. Canon of course has long made cameras and lenses, but neither Canon nor any of these other companies have ever made photographic films or papers. All four of these companies developed inkjet technology to print plain paper text and pie charts in color. Over time, initially in an effort to print sharper text, image quality got better and better. One can cite the 1994 introduction of the Epson Stylus Color 720dpi printer – which came to market only five years after the Iris 3047 became available – as the start of low cost inkjet photo printing. Quite suddenly, Epson found itself in the photography business. Hewlett-Packard, Canon, and Lexmark soon followed. Like Iris Graphics, none of these four companies had even considered the permanence requirements of photographs coming out of their printers that would be hung on the wall in the very same way that photographs have always been displayed. The inks supplied with all of these early inkjet printers had very poor light fading stability. But as shown in Figures 1 and 2, it was clear to this author that inkjet inks and papers from the beginning had the potential to be far more stable in dark storage than the then available silver halide color photographic papers. At the time, the principal permanence shortcoming of inkjet prints was light stability.

Once this was understood, the industry set about to improve light fading stability, initially with the goal of reaching a level of light stability equal to that of traditional Kodak Ektacolor silver halide color prints. (Fujicolor prints had significantly better light stability than the Kodak prints, so the printer manufacturers initially only attempted to equal the stability of the Kodak prints.) Hewlett-Packard came close to reaching this in 1997 with the introduction of the original PhotoSmart printer, and Epson achieved it with dye-based photo inks introduced in early 2000. At the time, dye-based inks had the advantage of a wider color gamut, high d-max, little or no differential gloss, and minimal metamerism. But, compared with pigmented inks, dye-based inks suffered from inferior light stability, high sensitivity to ozone on instant dry porous papers, poor water fastness on swellable papers, potential catalytic fading problems (see Figure 3), humidity-fastness problems, often high sensitivity to different types of media, generally poor light stability with most matte-coated fine art papers (see Table 1 and Figure 4), and short-term color drift behavior that can be very problematic for color-managed workflows and proofing applications.⁴

From a permanence point of view, pigmented inks were better than dye-based inks in virtually every respect. The shortcomings of pigmented inks involved image quality and appearance issues, including reduced color gamut and lower d-min which results in a lack of color brilliance, differential gloss problems on glossy photo papers, metamerism problems, and a tendency toward “bronzing” on glossy or semigloss photo papers. But beginning with the Epson UltraChrome pigmented inkset introduced in 2002 with the Epson 9600 printer, these problems started to be resolved – or at least minimized – one by one. By the end of 2006, Epson, Hewlett-Packard, and Canon had all moved to pigmented inksets for their advanced amateur and professional level printers. In the end, with the image quality of new pigmented ink/media systems approaching or in some cases even exceeding that of dye-based inks, the considerable overall permanence advantages of pigmented inks triumphed. It was very clear that a new era of enduring color photography had arrived!

Conclusion

Digital fine art photography has in many ways defined the market for advanced amateur and professional inkjet printers, inks, and media. Photographers in this segment want to be able to make large prints on a wide range of inkjet papers and canvas, including very thick, almost rigid papers that require straight-through printer paper paths. They also want the best, most brilliant color reproduction that can be achieved while at the same time desiring a very high level of image permanence for displayed prints. And many photographers desire to make black-and-white prints that are equal to the best of black-and-white silver gelatin prints in terms of brilliance and smooth, long lasting tonal behavior.

Escalating prices are being paid for photographs in the art market – in 2006 many color photographs by major artists sold for more than...
$100,000 in galleries and in art auctions – and this has also helped push demands for a high level of print permanence. Photographers have come to understand that their place in history requires that their vision – including the subtleties of color and tone in the prints that they work so hard to create – must endure essentially without change.

The professional portrait and wedding photography market has many of these same requirements, including very high print permanence expectations. Photographs become all the more appealing to customers when they can be sold as family heirlooms that have the intrinsic stability to remain in excellent condition when displayed for many generations.

Inkjet technology has proven to be extremely well suited for these markets: inkjet printers are readily scalable and can provide large print sizes by merely extending the length of travel of the inkjet heads. Inkjet technology allows use of a greater range of dye and pigment colors than any other printing process. Inkjet technology also allows use of a wider range of glossy and matte-surface paper photos as well as canvases and other materials than any other imaging process – all in compact and relatively low cost printers that require no darkroom, no processing chemicals, and no wash water. The ease, accessibility, and excellence of inkjet printmaking has allowed – and encouraged – more people to become involved in printing their own photographs than has ever been possible in the more than 160-year history of photography.

Throughout the 15-year formative period of digital fine art printing, Wilhelm Imaging Research has provided a uniformly applied image permanence testing methodology that has both made print permanence a more visible issue in the marketplace, and encouraged manufacturers to develop better, longer-lasting inks and papers. With no applicable permanence test methods standards available from ANSI (American National Standards Institute) or from ISO (International Organization for Standardization, based in Geneva, Switzerland), WIR has provided fair comparisons of print permanence across brands and between available printing technologies.3 WIR testing methodology has also given manufacturers permanence design goals for research and development of new inks, papers, and print systems. This in turn has fostered major R&D efforts in improved systems with manufacturers having confidence that the performance of their products would be fairly evaluated and that permanence data would be made broadly available to photographers and the marketplace through WIR’s website www.wilhelm-research.com. This has helped provide an environment where honest competition has flourished to the benefit of photographers and manufacturers alike.

Permanence properties as aspects of a print that cannot be seen when a print emerges from the printer. If one ignores permanence, it is relatively simple to manufacture inkjet inks that have a wide color gamut and produce beautiful images. If one ignores image quality, it is not difficult to select colorants that provide a very high level of permanence. What has proven to be very difficult is to accomplish both. That is, to develop inks, media, and printer systems that provide wide gamut, brilliant color prints and black-and-white prints with high d-max and a luminous, smooth, linear tonality – and with excellent permanence characteristics.

Future projects at WIR include work with the ISO WG 5/TG 3 standards group in the development of improved test methods which better simulate the spectral power distribution of indoor daylight through window glass for accelerated light stability tests, and the implementation and marketing of the WIR i-Star full tonal scale colorimetric image deterioration analysis software developed over the past four years by Mark McCormick-Goodhart, Dmitriy Shklyarov, Yaw Nu-Addae, Kabena Armah, and the author. Current densitometric image analysis methods have proven inadequate for the complex, multi-colorant inks used with modern inkjet printers.

WIR’s central mission has always been to serve as a fair and visible advocate for the importance of permanence and the long-term preservation of photographs.3 We have tried to be an advocate for photographers of every level, for museums, archives, and film libraries – for everyone who has come to understand and appreciate the unique power, beauty, and historical value of photography.

References
2. Steve Boutilier, e-mail correspondence with the author, August 1, 2006.

Biography

Wilhelm is co-founder and president of Wilhelm Imaging Research, Inc. and has served as a consultant on the long-term preservation of the photography collections at the Museum of Modern Art in New York, the Corbis photography collections in the United States and France (Corbis is private corporation personally owned by Bill Gates of Microsoft). Wilhelm has also served as an advisor on the preservation of traditional and digital photographs to other museum, archive, commercial, educational, and personal collections worldwide.

Wilhelm has been an active photographer since childhood; at age 12 he built his first black-and-white darkroom in a closet of his mother’s home in Arlington, Virginia. He holds two patents for the design of archival print washers which isolated individual black-and-white silver-gelatin prints in vertical compartments to thoroughly remove fixer and other processing chemicals without physically damaging the delicate surfaces of the prints during prolonged washing.

In recent years, as a personal project, Wilhelm has been spending time with photographers, commercial silver-halide processing laboratories, and print service providers to document their shift from analog to digital photography and printing.

Wilhelm took his last photograph using a traditional camera and silver-halide color negative film during the summer of 1999; since that time he has been shooting and printing digitally.

Paper presented by Henry Wilhelm on September 19, 2006

Paper (monochrome, with no color) published on pages 308–315 in:

Final Program and Proceedings:

NIP 22: The 22nd International Conference on Digital Printing Technologies

ISBN: 0-89208-263-1

Sponsored by:

IS&T: The Society for Imaging Science and Technology
ISJ: The Imaging Society of Japan

©2006 The Society for Imaging Science and Technology

September 17–22, 2006
Hyatt Regency Denver Hotel at the Colorado Convention Center
Denver, Colorado U.S.A.

Published by:

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151 U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org (e-mail: info@imaging.org)
A Survey of Print Permanence in the 4x6-Inch Consumer Digital Print Market in 2004–2007

Henry Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa U.S.A.

Abstract

This paper gives an overview of the various factors affecting the display permanence and dark-storage stability of many types of color prints commonly found in the consumer 4x6-inch print market. The similarities and differences between inkjet prints, made with dye-based inks, pigmented inks, dye-sub prints, and traditional silver-halide (chromogenic) color prints are discussed. Print permanence test methods are described for light stability, dark storage stability, ozone resistance, waterfastness, and humidity-fastness. The effects of ozone in polluted air, or “gas-fading” as it has come to be known, is an especially important factor to consider in evaluating the permanence of dye-based inkjet prints made with “instant dry” porous photo papers. In this study, both the Wilhelm Imaging Research “Display Permanence Ratings” and the WIR “Unprotected Ozone Resistance Ratings” were found to cover an extremely wide range – the most stable prints were rated to last more than 200 times longer than the least stable prints.

Introduction

An increasing variety of printing technologies are being used in the rapidly-growing market for prints made from digital camera files. Many consumers are making prints at home with inkjet and dye-sub printers; in retail outlets using digital silver-halide minilabs, dye-sub kiosks, and inkjet kiosks. In Japan, self-service dry-toner electrophotographic printers found in Seven-Eleven convenience stores are another means for making prints from digital cameras. Consumers can also obtain prints by uploading image files to online services that employ high-volume digital silver-halide minilabs, which produce prints that are then mailed to their homes.

Consumers display digitally-printed photographs framed under glass (or display prints unframed and freely exposed to the ambient air) in their homes and offices, post prints on refrigerator doors, and/or place them in albums in the same ways that photographs have always been used. Most consumers consider digital color prints to be “real photographs.” They think about them in much the same way they have always thought about photographs, and they have the same high expectations about image permanence.

In terms of the total volume of prints being made in the consumer market, 4x6-inch format prints comprise the largest segment. A variety of compact 4x6-inch dye-sub and inkjet printers have been introduced in recent years for home use. Although 4x6-inch inkjet prints can be made with larger, U.S. letter-size (A4 size) printers, this study focuses on compact 4x6-inch home printers and on the 4x6-inch retail segment. As has been the case in the traditional analog silver-halide photofinishing market of past years, most consumers continue to prefer a glossy surface for their digital prints in the relatively small, 4x6-inch size range.

For the first time in the history of photography, digital era consumers are selecting and purchasing inks and papers for making...
Table 1

| Printer/Ink/Photo Paper Printed With Inkjet, Dye-Sub, Silver-Halide Printers | Displayed Prints Framed Under Glass | Displayed Prints Framed With UV Filter | Displayed Prints Not Framed (Bare Bulb) | Album/Dark Storage Rating at 72°F & 50% RH | Unprotected Resistance to Ozone | Resistance to High Humidity | Resistance to Water | Are UV Brightening Present | Cumulative Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| HP Photosmart Express (Retail Inkjet Kiosk Printer) | >200 years | >250 years | 102 years | >200 years | >100 years | very high | high | no | 5 |
| Lexmark P350 Portable (4x6-inch inkjet printer) | >100 years | >100 years | now in test | now in test | Now in test | very high | high | no | 4 |
| Epson PictureMate PM-200 (4x6-inch inkjet printer) | 96 years | 147 years | 17 years | >200 years | 17 years | now in test | high | no | 3 |
| HP Photosmart 325 and 475 (4x6-inch inkjet printer) | 82 years | 105 years | 42 years | >200 years | now in test | low | no | 2 |
| HP Photosmart 145 and 245 (4x6-inch inkjet printer) | 68 years | 77 years | 32 years | >200 years | now in test | low | no | 1 |
| HP Photosmart A616/A717 (5x7-inch inkjet printer) | 51 years | 53 years | 16 years | >200 years | 16 years | now in test | high | no | 0 |

*Note: Products listed with an "*" have been tested with non-recommended, third-party inks and/or papers and do not represent the performance of OEM inks and papers supplied by that printer’s manufacturer.*
color prints themselves at home. For many of these products, no print permanence data of any kind are available and the consumer does not know how long a print made with a specific ink/paper combination or a dye-sub print might last – or how the permanence of one product compares with that of another. The print permanence data presented here are based in part on predictive test methods developed over the past 30 years by Wilhelm Imaging Research. Table 1 gives test results for 28 different products in the 4x6-inch consumer print category. Included in the table are inkjet prints made with dye-based and pigmented inks, silver-halide color prints, dye-sub prints, and a xerographic color photographic process. These products were available in the marketplace from 2004 through January 2007. Countless millions of prints made with these materials are displayed and stored by consumers throughout the world.

As can be seen in Table 1, the WIR Display Permanence Ratings of these products vary over an extremely wide range. For example, pigmented inkjet prints made with a Hewlett-Packard Photosmart Express retail kiosk were rated more than 200 times longer lasting than prints made with Office Depot store-brand ink in refillled HP 57 ink cartridges printed with Office Depot Professional Photo Paper. The Display Permanence Rating of Staples store-brand refillled HP 57 cartridges and Staples Photo Supreme paper was also very poor. As shown in Table 1 and in the accompanying illustrations, the ozone resistance of the Office Depot ink and paper combination was also found to be extremely poor. Both the Staples and Office Depot refillled HP 57 ink cartridges and photo papers were purchased in January 2007 and were the highest-quality and most expensive store-branded products available at the two stores. The HP Vivera 57+ inks and HP Premium Plus Photo Paper were the highest quality, most expensive HP inks and photo paper available for the Photosmart 245 printer at the time this article was written in January 2007.

Epson, Hewlett-Packard, and Lexmark now manufacture inkjet printers, inks and photo papers for home printing that have higher WIR Display Permanence Ratings than traditional silver-halide color prints. Kodak was found to have the longest-lasting dye-sub prints of those tested in that category. Fujicolor Crystal Archive prints had the highest Display Permanence Rating among silver-halide color prints made with digital minilabs and available from retail outlets and online print providers; all of the silver-halide prints tested had excellent ozone resistance.

As with the products tested for Display Permanence Ratings, the WIR Unprotected Ozone Resistance Ratings were found to vary over an extremely wide range: pigmented inkjet, silver-halide, and most dye-sub prints rated more than 200 times longer-lasting than the Staples and Office Depot refillled inks printed with their respective store-brand photo papers.

How the Prints Were Tested

To obtain a comprehensive evaluation of the permanence of any type of photograph – both traditional and digital prints – they must be tested for their resistance to all factors that can cause deterioration. These factors include exposure to light on display, and storage in albums or other locations away from light.[1] Included are accelerated light fading tests (“WIR Display Permanence Rating Tests”) for prints framed under glass,[2] framed with UV absorbing glass or plastic,[3] or displayed without framing under glass or plastic.[4] Prints are also tested for permanence in dark storage, or “thermal stability” at a specified relative humidity (“Album/Dark Storage Rating Tests”).[5] These tests utilize the Arrhenius test method long employed by Kodak, Fuji, and others in the photographic industry. The WIR Visually-Weighted Endpoint Criteria Set v3.0 was used as the basis for predictions made for prints stored at 23°C (73°F) and 50% RH.

Many display and storage environments have levels of ambient ozone in the air that are sufficient to harm prints exposed to the open air over time. This is especially the case for certain types of dye-based inks printed on “instant-dry” porous papers. A test for “Unprotected Resistance to Ozone”[6] is provided; years of exposure ratings are based on an Epson study, which indicated that exposure to 40 ppm of ozone for one hour is equal to 1 year of unprotected display or storage in areas with relatively high levels of ozone pollution. (Refer to images on the first page of this article for a photographic portrayal of the comparative ozone resistance of three ink/paper combinations printed with an HP Photosmart 245 printer.) Also of concern is the resistance of prints to changes in color and/or density as a result of exposure to high humidity.[7] In addition, some types of prints are very susceptible to damage from even momentary contact with water.[8]

Although work has been underway for a number of years to develop a comprehensive group of ISO print permanence tests, including predictive light stability tests, dark storage tests, ozone resistance tests, and humidity-fastness ranking tests, methods and specifications standards for these tests had not yet been published at the time this article was written in January 2007.

Acknowledgments

The author wishes to thank Kabenla Armah, Eiko Miyazaki, Dmitriy Shklyarov, Barbara Stahl, and Dimitar Tasev for their assistance in preparing the many print test samples, conducting the tests, and handling the data analysis involved in this ongoing study.

Notes and References

Potentially harmful pollutants may be found in combustion products from gas stoves; in addition, microscopic droplets of cooking oil and grease in cooking fumes can damage unframed prints. Because of the wide range of environmental conditions in which prints may be displayed or stored, the data given here will be limited by the “Unprotected Resistance to Ozone” ratings. That is, when ozone resistance tests are complete, in cases where the “Unprotected Resistance to Ozone” predictions are less than the “Display Permanence Ratings” for displayed prints that are NOT framed under glass (or plastic), and are therefore exposed to circulating ambient air, the “Display Permanence Ratings” will be reduced to the same number of years given for “Unprotected Resistance to Ozone” even though the “Display Permanence Rating” for unframed prints displayed in ozone-free air is higher. For all of the reasons cited above, all prints made with microporous papers and dye-based inks should always be displayed framed under glass or plastic. For that matter, ALL displayed prints, regardless of the technology with which they are made, should be framed under glass or plastic sheets. This includes silver-halide black-and-white and color prints, dye-sub prints, and inkjet prints made with dye-based or pigmented inks on swellable or microporous papers, canvases, or other materials.

Prints stored in the dark may suffer slow deterioration that is manifested in yellowing of the print paper, image fading, changes in color balance, and physical embrittlement, cracking, and/or delamination of the image layer. These types of deterioration may affect the paper support, the image layer, or both. Each type of print material (ink/paper combination) has its own intrinsic dark storage stability characteristics; some are far more stable than others. Rates of deterioration are influenced by temperature and relative humidity, high temperatures and/or high relative humidity exacerbate the problems. Long-term dark storage stability is determined using Arrhenius accelerated dark storage stability tests that employ a series of elevated temperatures (e.g., 57°C, 71°C, and 78°C) at a constant relative humidity of 50% (see discussion in No. 5 below).

Field experience has shown that, as a class of media, microporous “instant dry” papers used with dye-based inkjet inks and photo paper. In some locations, displayed unframed prints made with certain types of microporous papers and dye-based inks have suffered from extremely rapid image deterioration. This type of premature ink fading is not caused by exposure to light. Polluted outdoor air is the source of most ozone found indoors in homes, offices, and public buildings. Ozone can also be generated indoors by electrical equipment such as electrostatic air filters ("electronic dust precipitators") that may be part of heating and air conditioning systems in homes, office buildings, restaurants, and other public buildings to remove dust, tobacco smoke, etc. Electrostatic air filtration units are also supplied as small "tabletop" devices.

Changes in image color and density, and/or image diffusion (“image bledding”) classes may take place over time when prints are stored and/or displayed in conditions of high relative humidity are evaluated using a humidity-fastness test maintained at 30°C (86°F) and 55% RH. Depending on the particular ink/media combination, slow humidity-induced changes may occur at much lower humidities – even at 50–60% RH. Test methods for resistance to high humidity and related test methods for evaluating “short-term color drift” in inkjet prints have been under development since 1996 by Mark McCormick-Goodhart and Henry Wilhelm at Wilhelm Imaging Research, Inc. See: Mark McCormick-Goodhart and Henry Wilhelm, “New Test Methods for Evaluating the Humidity-Fastness of Inkjet Prints,” Proceedings of “Japan Hardcopy 2005” – The Annual Conference of the Imaging Society of Japan, Tokyo, Japan, June 9, 2005, pp. 95–98. Available in PDF format from <www.wilhelm-research.com> <WIR_Japan HarDCopy2005MMG_HW.pdf>.


Data from waterfastness tests are reported in terms of three subjective classes: “high,” “moderate,” and “low.” Both “water drip” tests and “standing water droplets/gentle wipe” tests are employed.

Fluorescent brighteners (also called “UV brighteners,” “optical brighteners,” or “optical brightening agents” [OBA’s]) are white or colorless compounds added to the image-side coatings of many inkjet papers – and nearly all “plain papers” – to make them appear whiter and “brighter” than they really are. Fluorescent brighteners absorb ultraviolet (UV) radiation, causing the brighteners to fluoresce (emit light) in the visible region, especially in the blue portion of the spectrum. Fluorescent brighteners can lose activity – partially or completely – as a result of exposure to light. Brighteners may also lose activity when subjected to high temperatures in accelerated thermal aging tests and, if may be assumed, in long-term storage in albums or other dark places under normal room temperature conditions. With loss of brightener activity, papers will appear to have yellowed and to be “less bright” and “less white.” In recent years, traditional chromogenic (“silver-halide”) color photographic papers have been made with UV-absorbing interlayers and overcoats and this prevents brighteners that might be present in the base paper from being activated by UV radiation. It is the relative UV component in the viewing illumination that determines the perceived “brightening effect” produced by fluorescent brighteners. If the illumination contains no UV radiation (for example, if a UV filter is used in framing a print), fluorescent brighteners are not activated and, comparatively speaking, the paper appears to be somewhat yellowed – and not as “white.” This spectral dependency of fluorescent brighteners makes papers containing such brighteners look different depending on the illumination conditions. For example, prints displayed near windows are illuminated with direct or indirect daylight, which contains a relatively high UV component, and if an inkjet paper contains brighteners, this causes the brighteners to strongly fluoresce. When the same print is displayed under indirect tungsten illumination, which has a low UV component, the brighteners have little effect. Another potential drawback of brighteners is that brightener degradation products may themselves be a source of yellowish stain. These problems can be avoided by not adding fluorescent brighteners to inkjet photographic papers during manufacture. When long-term image permanence is of critical importance – with museum fine art collections, for example – papers with fluorescent brighteners should be avoided where possible.

Author 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 20 years he has served as Secretary of the group, now known as ISO Working Group 5/Task Group 3 (part of ISO Technical Committee 42). Wilhelm serves as Chair of the Indoor Light Stability Test Methods Technical Subcommittee of WG-5/TG-3.


International Symposium on Technologies for Digital Fulfillment

Wilhelm Imaging Research Display Permanence Rating Tests (Glass-Filtered) with Hewlett-Packard Vivera 57+ Inks and HP Premium Plus Photo Paper, Staples and Office Depot Refilled HP #57 Ink Cartridges and Photo Papers

Predicted years of display in a WIR indoor light stability test with Hewlett-Packard Vivera 57+ inks and HP Premium Plus Photo Paper printed with a compact 4x6-inch Hewlett-Packard Photosmart 245 home inkjet printer.

Predicted years of display in a WIR indoor light stability test with an Office Depot refilled HP #57 ink cartridge and Office Depot Professional Photo Paper printed with a Hewlett-Packard Photosmart 245 printer. The Office Depot ink and paper were purchased in January 2007.

Predicted years of display in a WIR indoor light stability test with a Staples refilled HP 57 ink cartridge and Staples Professional Photo Paper printed with a Hewlett-Packard Photosmart 245 printer. The Staples ink and paper were purchased in January 2007.

Original Print 2 Years 5 Years 7.5 Years 10 Years 15 Years

Note: The progressive pictorial light fading comparison reproduced above was not available in time to be included in the IS&T paper, however it was shown as part of the presentation given at the IS&T TDF Symposium in Las Vegas, Nevada on March 5, 2007.

Paper by Henry Wilhelm (Wilhelm Imaging Research, Inc.) entitled:

“A Survey of Print Permanence in the 4x6-Inch Consumer Digital Print Market in 2004–2007”

Paper presented by Henry Wilhelm on March 5, 2007

Paper published on pages 43–47 in:

Technical Program, Abstracts, and Proceedings

IS&T’s International Symposium on Technologies for Digital Fulfillment

ISBN: 0-89208-269-0

Sponsored by:

IS&T: The Society for Imaging Science and Technology

©2007 The Society for Imaging Science and Technology

March 3–5, 2007

The Westin Casurina Las Vegas Hotel
Las Vegas, Nevada  U.S.A.

Note: Accelerated print permanence tests for some of the products reported in Table 1 were still in progress at the time the initial version of this paper was submitted to IS&T prior to the Symposium. Additional data had become available by the time the paper was presented on March 5, 2007 and Table 1 was updated to include these new data points. This version of the paper, including the illustrations on page 43 and Table 1 on page 44, are reproduced here exactly as presented at the Symposium.

Published by:

IS&T: The Society for Imaging Science and Technology

7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.

Phone: 703-642-9090; Fax: 703-642-9094

www.imaging.org  (e-mail: info@imaging.org)
Abstract
The market for digitally-printed photobooks has rapidly expanded in recent years, and they have become an increasingly important method of viewing and preserving photographic images together with captions and other textual material. A photobook may be printed as a single copy, or in multiple copies for distribution to relatives and friends. Many advanced amateur and professional photographers make use of photobook printing and binding technology for producing illustrated books for sale, and this has spawned an entirely new industry of high-quality, print-on-demand books. In the short-runs typical of photobooks, the per-unit costs of this type of book would be prohibitive using traditional offset printing.

The great majority of the photographs that appear in photobooks do not exist in any other hardcopy form and, for this reason, the images in a photobook can be thought of as having the same validity and importance as traditional silver-halide, inkjet, or other black-and-white and color photographic prints. As is the case with traditional photographs, the long-term permanence of photobook pages is very important to both the photographers – the authors – of photobooks, and to the people who purchase the books or receive them as gifts.

This paper discusses testing methods for evaluating the permanence of photobook pages printed by a variety of commonly used technologies, including liquid toner electrophotography, dry toner electrophotography, digitally-printed silver-halide papers, inkjet, and thermal dye transfer (dye-sub) printing.

The primary permanence concerns for photobook pages are dark storage stability – including resistance to yellowish stain formation over time – and light stability. Arrhenius tests conducted at a series of elevated temperatures in precision temperature and humidity-controlled ovens are used to evaluate dark storage (thermal) stability. High intensity, temperature- and humidity-controlled accelerated light fading equipment is employed to evaluate the high stability of photobook pages and printed covers.

In common with other books, photobooks are normally stored closed on a bookshelf and the brief exposure to light that an interior page might receive when opened for viewing is negligible — unless of course a book is left opened for display on a table or shelf for extended periods of time. Of much greater concern is the light stability of pictorial photobook covers, which are usually printed with the same toners or inks used to print interior pages. Whether a book is placed on a table or stored on a shelf, the cover and spine will in time likely receive considerable accumulated light exposure, which may result in objectionable fading.

Resistance to page damage resulting from storage in high humidity conditions, as well as short-term water resistance, is also important.

For all of these photobook page permanence tests, preparation of calibrated test targets, image change measurement systems, endpoint criteria, environmental assumptions, predictive calculations, and other aspects of the testing methodology are similar to the test methods developed by Wilhelm Imaging Research for evaluating the permanence of silver-halide, inkjet, and other types of photographic materials.

Because of the very wide range of binding methods, materials, and adhesives that are used in photobook production, the authors believe that meaningful, comparative test methods for the long-term permanence and physical durability of complete, bound photobooks may be difficult or impossible to develop – there are simply too many variables involved in this rapidly evolving industry.

Biography
Henry Wilhelm is co-founder and director of research at Wilhelm Imaging Research, Inc. He has authored or co-authored more than 25 technical papers in the United States, Japan, and Europe on permanence testing, the stability of traditional and digital color photographs, and the long-term preservation of photographic collections. The company publishes brand name-specific permanence data for desktop and large-format inkjet printers and other digital printing devices on its website <www.wilhelm-research.com>. Wilhelm serves as co-project leader for the development of Indoor Light Stability Test Methods Standards within ISO WG-5/TG-3. In 2010, Henry Wilhelm, Carol Brower Wilhelm, and Harold Fuson established The Center for the Image, a nonprofit organization with the mission of conducting research and developing web-based publications and other educational materials related to both traditional analog photographs and digitally captured still and video images.
Annex 6


White Photography and the Art of Digital Printing

Nash Editions: Photography and the Art of Digital Printing

Introduction by Graham Nash

With essays by Richard Benson, R. Mac Holbert, Henry Wilhelm

Edited by Garrett White

NASH EDITIONS
PHOTOGRAPHY AND THE ART OF DIGITAL PRINTING

INTRODUCTION BY GRAHAM NASH
WITH ESSAYS BY RICHARD BENSON, R. MAC HOLBERT, HENRY WILHELM
EDITED BY GARRETT WHITE

Co-founded in 1990 by rock musician and photographer Graham Nash and R. Mac Holbert, Nash Editions was the world’s first professional fine-art digital printmaking studio. In the more than fifteen years since opening its doors in Manhattan Beach, California, Nash Editions has attracted leading artists—including Manuel Alvarez Bravo, Horace Bristol, Eileen Cowin, Eric Fischl, Lynn Goldsmith, Robert Heinecken, David Hockney, Pedro Meyer, Jenny Okun, Stephen Shore, and Maggie Taylor—and established an unparalleled international reputation for fine-art photographic digital printing.

_Nash Editions: Photography and the Art of Digital Printing_ charts the history of digital photographic printing from early experiments in the mid-1980s to the present explosion in digital imaging and printing technology that has overtaken traditional darkroom printing and brought the medium to a wide public. The work of Nash Editions represents the entire spectrum of artistic involvement in digital imaging since its inception as a viable alternative form of expression, from images composed in the computer or on a scanner to traditional photographs printed digitally from scans of a print or negative.

The essays collected in this volume include an overview of the founding and development of Nash Editions by R. Mac Holbert; a history of photographic printing processes from the inception of the medium to the digital revolution by photographer and educator Richard Benson; and a detailed capsule history of advancements in digital printing technology, ink sets, and print permanence by Henry Wilhelm.

In 1998, a traveling exhibition, _Digital Frontiers: Photography’s Future at Nash Editions_, was organized by the George Eastman House International Museum of Photography in Rochester, New York. On August 12, 2005, the first Nash Editions Iris 3047 inkjet printer was incorporated into the photographic history collection of the Smithsonian’s National Museum of American History, along with selected prints from the Nash Editions archive.

With more than 180 full-color and black-and-white illustrations.
FROM THE ESSAY BY **HENRY WILHELM**:

There are people who dream of better ways of doing things. These are the people who focus their usually considerable energies on the potential of new ideas and inventions, and are not held back by the problems that almost always hinder early adoption. With the creation of Nash Editions, Graham Nash, R. Mac Holbert, and Jack Duganne joined that very special group of people in photography’s history who got there first. They played a pivotal role in moving photographic printmaking into a completely new and clearly superior technology.

FROM THE ESSAY BY **RICHARD BENSON**:

If we date the practical implementation of the dry plate at 1900, then we can say that silver reigned unchallenged for a century, up to about the year 2000. Electronic image making began well before that date, but only by 2000 did most of us realize that silver photography was effectively dead — still being practiced, but fatally wounded by the wonders of electronic light-sensitive materials and computer-driven printing machines.
RICHARD BENSON has worked as a photographer, printer, and teacher since the 1960s. He has taught at Yale University since 1979, and became Dean of the Yale School of Art in 1986. His photographic work is in the collections of the Metropolitan Museum of Art and the Museum of Modern Art, New York, Yale University Art Gallery, and many other institutions and private collections. Benson has received two National Endowment for the Arts publication grants, two Guggenheim Fellowships, and a MacArthur Foundation Fellowship. He presently photographs with a digital camera and prints his images with inkjet printers.

R. MAC HOLBERT is a photographer and co-founder of Nash Editions. Prior to his work with Nash Editions, he was tour manager for Crosby, Stills & Nash; Peter, Paul & Mary; and Carole King. Holbert has lectured extensively and conducted workshops on digital output, digital imaging, and fine-art printing on Iris and Epson large-format printers. Under his supervision, Nash Editions is a beta tester for Epson America, Inc., and other software and hardware manufacturers.

GRAHAM NASH is a lifelong photographer and co-founder of the rock group Crosby, Stills & Nash. While best known as a musician — Nash first became famous as a member of The Hollies during the British Invasion of the mid-1960s — he has also pursued a parallel career as a photographer, collector, and digital imaging pioneer. His photographs have been exhibited in solo and group exhibitions in numerous museums and galleries. A retrospective book of his photographic work, Eye to Eye: Photographs by Graham Nash, was published in 2004.

HENRY WILHELM is co-founder and president of Wilhelm Imaging Research, Inc., which conducts research on the stability and preservation of traditional and digital color photographs and motion pictures. He has been a consultant to the Museum of Modern Art, New York, and many other collecting institutions, and is the co-author, with Carol Brower Wilhelm, of the landmark reference work The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures.


Cover and book design by AC Berkheiser
Printed in the United States
NASH EDITIONS
PHOTOGRAPHY AND THE ART OF DIGITAL PRINTING
# TABLE OF CONTENTS

001. **INTRODUCTION**  
   Graham Nash  

011. **THE HISTORY OF NASH EDITIONS**  
   R. Mac Holbert  

071. **THE FOUR STAGES OF PHOTOGRAPHY**  
   Richard Benson  

097. **A HISTORY OF PERMANENCE IN TRADITIONAL AND DIGITAL COLOR PHOTOGRAPHY: THE ROLE OF NASH EDITIONS**  
   Henry Wilhelm  

222. **SELECTED BIBLIOGRAPHY**  

224. **ACKNOWLEDGMENTS**  

225. **INDEX**
From the very beginning of photography—Joseph Nicéphore Niépce’s photograph of the view from a window in his home near Chalon, France, made in 1826—followed by Louis Daguerre’s announcement of the daguerreotype in Paris in 1839, Fox Talbot’s negative-positive colotype process in England in 1841, and Sir John Herschel’s critically important discovery of a hyposulfite of soda (later known as sodium thiosulfate) fixing bath following development of silver-halide-based black-and-white films and prints to render them “permanent” upon exposure to light during use, storage, and display—photography has seen a long struggle between the often conflicting requirements of making a beautiful image, and then keeping it beautiful as the years, decades, and centuries pass.1

People of course see the world as a very colorful place, and the early inventors of photography worked hard to endow their monochrome creations with color. Long before Daguerre publicly revealed his daguerreotype process in France in 1839, he and Niépce had been experimenting with various materials that they hoped could be used to produce color images. In 1816, Niépce wrote to his brother Claude:

The experiments I have thus far made lead me to believe that my process will succeed as far as the principal effect is concerned, but I must succeed in fixing the colors; this is what occupies me at the moment, and it is the most difficult.

While neither Daguerre nor Niépce were successful in producing a workable color process, the desire to make photographs in color persisted, and it was not long before many photographers began to hand-color their daguerreotypes. Often this consisted of nothing more than adding a little rosy color to the cheeks of people in their portraits; sometimes rather elaborate work was done in an attempt to simulate the full range of colors in the original scene.

It is interesting to speculate about what place black-and-white pictures would have had in the history of photography if practical color processes had been invented before black-and-white systems had become widespread. Assuming equal costs and ease of use of both black-and-white and color, it is not unlikely that black-and-white photography would have been considered something of a curiosity, perhaps desirable only for certain scientific or artistic applications. The principal achievement of photography has always been to record events, people, and scenes; color is almost always a very important part of this reality.

It was in the early 1870s in Agen, a small town in the south of France, that the photographer and inventor Louis Ducos du Hauron first succeeded in making a color photographic print.
Building on the work of Isaac Newton, James Clerk Maxwell, and other pioneers in understanding color and how the human eye and brain perceive it, Ducos du Hauron developed a color photography process in which he exposed a succession of three black-and-white negatives through red, green, and blue filters to produce an RGB record of the scene, adapting the well-established “carbon process” used to make black-and-white photographs with highly stable carbon pigments.

Ducos du Hauron used his RGB separation negatives to make three positive gelatin images, one with a cyan pigment printed from the red record negative, one with a magenta pigment from the green record negative, and one with a yellow pigment from the blue record negative. These thin gelatin-pigment films were transferred in register to a final paper support, producing a full-color print! This was a difficult and tedious process and, unlike the immediate and widespread adoption of the much easier to manage black-and-white daguerreotype, met with little commercial success during Ducos du Hauron’s lifetime. He died in modest circumstances, supported by a pension from the French government given in honor of his pioneering work in photography.

Ducos du Hauron fully understood the theory of subtractive color photography, and he also invented many other processes to make color images. He wrote two small books describing his color processes in detail—including selection and preparation of appropriate cyan, magenta, and yellow pigments—and they remain classics in the field today. As recently noted by Kim Timby, the director of collections at the Musée Nicéphore Niépce in Chalon, France, Ducos du Hauron also had an appreciation of the role of human judgment and preference in color photography: And for color, how many images suffice to satisfactorily deconstruct the phenomenon? And of what exact hues should the filters and final images be? These decisions emphasize that color photography, as well, is not a natural occurrence but man-made. This, also, was both praised and criticized at the beginning. Ducos du Hauron argued that “the arbitrary and the human judgment” that necessarily influence the results in indirect color photography (and are already present in ‘ordinary photography’) take the image into the realm of artistic expression: he claims his method simply ‘offers the sun a selection of colors and makes it use them as a painter might.’

One could say that Ducos du Hauron’s work in color photography and the use of pigments to make color prints laid the groundwork that 127 years later, in 1997, brought us to the use of high-stability cyan, magenta, and yellow pigments in modern inkjet photo printers. And, as we do today with digital cameras and Adobe Photoshop and other image editing software, he made use of full RGB channel separation and control of the curve shape to adjust the tone scale of his color images. Like many innovators throughout history who have spent their lives...
working hard and following their dreams, Ducos du Hauron was simply ahead of his time. The most extensive collection of Ducos du Hauron’s work, including a number of his earliest color prints, made from 1870 to 1875, is in the Musée Nicéphore Niépce. Perhaps his best-known color photograph, a beautiful picture of the city of Agen made in 1877, is now in the George Eastman House collection in Rochester, New York.

**The Organic Dye Images of Silver-Halide–Era Color Films and Prints Versus the Metallic Silver Images of Black-and-White Photographs**

Black-and-white silver-halide photographs have images made of metallic silver. The images appear black because the filamentary structure of the tiny grains of silver absorbs, rather than reflects, light. These silver images are unaffected by prolonged exposure to light, and are also essentially permanent when stored in the dark. (At least this is true with correctly processed fiber-base prints; the black-and-white RC papers introduced in the early 1970s, with their often self-destructing images when exposed to light during display, are another matter altogether and these papers should be avoided.) Many people have fiber-base black-and-white photographs of their ancestors that have remained in good condition for 50 to 100 years—or even longer. Museum collections have significant numbers of fiber-base black-and-white photographs from the late 1800s and early 1900s that are still in excellent condition.

Unlike the usually very long-lasting silver images of black-and-white photographs, most color photographs made in the silver-halide era now drawing to a close have images formed of cyan, magenta, and yellow organic dyes that fade when exposed to light on display. The brighter the light, the faster they fade. While current Fuji and Kodak silver-halide color papers have relatively good dark storage stability, earlier silver-halide color prints and most other types of color photographs found in collections also gradually fade and form a yellowish stain when stored in the dark; the slow but inexorable image deterioration begins the moment processing is completed. High temperatures and/or high humidity in storage accelerate the deterioration process.

With the market for silver-halide black-and-white papers rapidly shrinking, Kodak discontinued manufacture of all black-and-white papers—both fiber-base and RC-base—at the end of 2005; Ilford, Fuji, and a few other companies still continue to manufacture wet-processed silver-halide black-and-white papers.

**Now Drawing to a Close, the Era of Silver-Halide Color Photography Began in 1935–36 with the Introduction of Kodachrome and Agfacolor Neu Color Transparency Films**

Although a number of color processes were available in the early 1900s, such as the additive screen Autochrome plates introduced by the Lumière brothers in France in 1907 and dye-transfer and tricolor carbro prints made from glass-plate separation negatives photographed sequentially through red, green, and blue filters—or in complex “one-shot” cameras that exposed all three separation negatives with a single exposure—all of these early color processes saw only limited use. They were either so cumbersome and time-consuming that only the most dedicated photographers would consider using them, or, in the case of Autochrome plates and the other additive screen processes of the time, they lacked the resolution necessary to produce satisfactory results in any but large-format cameras, and making good-quality prints from the additive screen images was difficult and time-consuming.

With the introduction of Kodak Kodachrome transparency film in 1935 and Agfa Agfacolor Neu transparency film in 1936, high-quality color photography suddenly became accessible to everyone.

---

2 Kim Timby, “Colour Photography and Stereoscopy: Parallel Histories,” History of Photography, Vol. 29, No. 2, Summer 2005, pp. 183–196, ISSN 03087298, the Taylor and Francis Group Ltd. Kim Timby, director of collections at the Musée Nicéphore Niépce in Chalon, France, has been researching the life and work of Ducos du Hauron.
Among the available color processes, chromogenic films and prints as a group have the distinct limitation of being relatively unstable in dark storage.

to everyone. These films, which formed images by a process known as chromogenic development, were the first successful integral tripack color films. Kodachrome film was first marketed in 1935 as a 16mm amateur movie film. Kodachrome for 35mm color slides was introduced in 1936; the film had an ASA speed of 10. Kodachrome sheet films in sizes up to 8” x 10” were supplied for the professional market from 1938 until 1951.

Beginning in 1941, Kodak supplied the amateur market with prints made with the Kodachrome process under the Minicolor name; the prints, which had rounded corners, were made with a white pigmented acetate base. From 1946 until 1955, the acetate-base prints were sold under the Kodachrome Print name. The Kodachrome Print name continued to be used for many years after 1955 to signify any print made from a Kodachrome or Ektachrome transparency by Kodak Processing Laboratories. Most of these prints were made on Kodak fiber-base or RC-base color negative papers with an internegative made from the transparency. In later years, many “Kodachrome Prints” were made with Ektachrome RC reversal papers.

Kodachrome process acetate-base prints supplied to the professional market were called Kodalochrome Prints from 1941 until 1946; from 1946 until 1956, the prints were sold under the Kodachrome Professional Print name. All Kodachrome process prints have relatively good dark storage stability. Kodachrome grew out of the research of Leopold D. Mannes and Leo Godowsky, Jr., who were professional musicians and avid amateur photographers. Interested in the work of the two inventors, Kodak coated a number of experimental plates for Mannes and Godowsky beginning in about 1922, and in 1930 Mannes and Godowsky accepted an invitation to join the staff of the Kodak Research Laboratories and work with other Kodak personnel in perfecting their new process. From 1935 to 1938 Kodachrome was designed to be processed using what was known as the controlled-diffusion bleach method; this was a very complex twenty-eight-step, more than three-hour process requiring three separate processing machines. The dark-storage stability of this first version of Kodachrome was relatively poor, and most examples have by now suffered nearly total loss of yellow dye.

In 1938 the processing of Kodachrome—as well as some aspects of the film itself—was changed to the selective re-exposure method, and the use of controlled-diffusion bleach baths was abandoned. Beginning with the improved film and processing procedure introduced in 1938, Kodachrome has had very good dark fading stability. Kodachrome film is still the only transparency film that remains totally free of yellowish stain formation during long-term storage. Kodachrome processing has continued to be a very complex procedure and can be done only with large, continuous processors. The three separate color developers and the two precisely controlled colored light re-exposure steps make it impractical for the user to process the film. Kodak itself no longer processes Kodachrome film, and only a small market remains for the product.

Agfacolor Neu transparency film was the first incorporated-coupler color film. Introduced by Agfa in Germany in 1936, one year after Kodachrome became available, Agfacolor Neu film was probably more significant than Kodachrome in that the basic incorporated-coupler design of Agfacolor Neu is now used in all chromogenic materials except Kodachrome. Because the color couplers were incorporated into the emulsion layers during manufacture, only one color developer was required, and processing was greatly simplified compared with that required with Kodachrome film.

Although the technique Agfa devised to prevent color couplers in Agfacolor Neu film from migrating from one emulsion layer to another when the emulsion was wet and swollen during manufacturing and processing has been replaced by other methods (e.g., the “protected” or oil-encapsulated couplers invented by
In the years following the introduction of Kodachrome film, there have been tremendous differences in the permanence of the many types of color films and prints that have been marketed. While Kodachrome films and prints were successful products for Kodak, the company, which from its very beginnings has always been oriented toward the mass market, believed that the Kodachrome system had several serious shortcomings. First, in common with all color transparency films designed to be viewed by projection, Kodachrome films had a very narrow exposure latitude, which meant that the film was unusable in the simple, fixed-exposure box cameras of the day. This limitation alone effectively closed Kodak out of the bulk of the potentially huge market for amateur color snapshots. Kodak was well aware of the fact that although advanced amateur photographers were the most part satisfied with putting on family slide shows to view their color photographs, most people preferred to have color prints which could be displayed, sent to friends and relatives, kept in wallets and purses, and arranged in carefully inscribed and dated albums.

With the Kodacolor process, introduced in 1942, Kodak believed that it had solved most of the marketing limitations of Kodachrome. Kodacolor was a wide-latitude chromogenic color negative film designed for use in fixed-exposure box cameras; both the film and prints were relatively simple to process.

The Totally Lost Kodacolor Era of 1942–53

The fact that both Kodacolor films and prints were far less stable than Kodachrome films and prints—and black-and-white films and prints—did not dissuade Kodak from marketing the products to an unsuspecting public. Consumers who made the unfortunate decision to use Kodacolor now have nothing left but unprintable negatives and faded, severely stained prints. In fact, this author does not know of a single Kodacolor print taken from 1942 until 1953 (the year that Kodak managed to significantly reduce the print staining problem) that survives today in reasonable condition; all have faded and developed an ugly, overall orange or yellow stain regardless of whether they were exposed to light on display or kept in the dark in albums. The discoloration was caused by unstable magenta dye-forming color couplers that re-
mained in the print after processing. These hundreds of millions—perhaps billions—of Kodacolor prints and negatives represent the first great era of color photography to be totally lost.

In the early days of color photography Kodak adopted a policy of strict secrecy on matters of color stability; the company concluded that it would not be in its best interests to let the public become aware of the extreme stability advantages of Kodachrome over Kodacolor. (Looking back on the history of color photography, it is difficult to find another pair of products offered by a manufacturer at the same time that had such an extreme difference in image stability.) Kodak apparently feared that if the general public knew just how poor the stability of Kodacolor prints was—even if the prints were kept in an album in the dark—the market for Kodacolor would be seriously restricted. Most amateur photographers would simply continue to use black-and-white films. Color photography was much more profitable to Kodak than was black-and-white photography.

The decision not to disclose color stability information to the public meant that there was little incentive to introduce more stable color print processes. With stability data kept secret, Kodak could not advertise improvements in image stability, and over the years this effectively doomed Kodak’s interest in silver dye-bleach materials and other potentially long-lasting (and probably more expensive) color print processes for the general market.

As a result, during the early 1940s Kodak made a policy decision that was to have far-reaching consequences in terms of color permanence. The company decided that it should try to satisfy the requirements of nearly every branch of photography with one basic chromogenic color print material. This allowed considerable economies of production and a concentration of research and development activities. The design, processing speed, and cost requirements of this color print material were unfortunately dictated by its principal market: drugstore photofinishing. This is a highly competitive market in which every fraction of a cent spent in producing a print is considered important.

Thus we have arrived at the present, with professional portrait and wedding photographers, fine-art photographers, and photographers producing prints for historical documentation, all using a color print material whose every design aspect was dictated by the drugstore photofinishing and minilab business. Very few people know that the most expensive color portrait or wedding photograph made on Kodak Edge Generations paper, is more stable than portrait and wedding photographs costing hundreds of dollars.

The worldwide shift from black-and-white photography to color photography began to proceed in earnest in the 1960s, and by 1975 was essentially complete. Unfortunately, the change to color resulted in the loss of the essentially permanent images provided by black-and-white photography that had long been taken for granted by photographers and the general public alike. These faded and cracked Kodak Ektacolor prints made between 1969 and 1976 were returned to a portrait studio by angry customers asking for free replacements.
When Kodak replaced large-format Kodachrome sheet films with Ektachrome films at the beginning of the 1950s, no one outside of the company was aware that these new films faded in the dark at least twenty times faster than the discontinued Kodachrome films. The large difference in image stability between these films was a closely held secret within Kodak. The unfortunate results of this product downgrading can be seen in the now severely faded Ektachromes from the period in the collections of *Life* magazine (at Time Warner, Inc.), *Vogue* magazine, the National Geographic Society, the Library of Congress, the George Eastman House International Museum of Photography, and other institutions around the world.

For example, the original 8” x 10” Process E-1 Ektachromes of the famous Marilyn Monroe calendar photographs taken by Los Angeles photographer Tom Kelly in 1947 have suffered severe fading. The images survive only because Dye Transfer and tricolor carbro (pigment) prints were made from the Ektachromes, and because many photomechanical reproductions have been published in the years since the photographs were made.

During the period from 1959 to 1976, most professional commercial, advertising, and fashion photographers in the United States used Kodak Process E-3 Ektachrome films in sheet-film and roll-film formats. These films, and the E-3 duplicating films, had very poor dark fading stability and were far inferior to the then-available “amateur” 35mm Process E-4 Ektachrome films (1966–1977). Kodak has never explained why—for a ten-year period—professional photographers using Ektachrome were supplied with a far less stable product than were amateurs, a fact that was kept secret from professionals and amateurs alike. It was not until 1977, when all Ektachrome films were replaced by improved E-6 Ektachrome films, that the stability of the professional films finally equaled that of the amateur films.

**The Eastman Color Motion Picture Process: A Major Problem for Film Studios and Archives**

Color motion pictures, most of which are now made with a negative/positive color process that is in most respects similar to that used with still-camera color negatives and prints, have (with some exceptions) been significantly improved in terms of image stability since the mid-1980s. However, even the improved products require humidity-controlled cold storage for long-term preservation. Most motion picture color negatives and prints made after the introduction of the Eastman Color process in 1950 until about 1985 have by now suffered significant fading. Nearly all Eastman Color prints made between 1950 and around 1970 have now lost most of the cyan dye component of their images (and usually much of the yellow dye as well), and all that remains is a ghastly reddish-magenta reminder of what once were brilliant, full-color images.

![](image-url)

In 1974, as a replacement for its then popular Agfacolor fiber-base paper, Agfa-Gevaert introduced Agfacolor PE Paper Type 4, the firm’s first RC color paper. As the lowest-cost color paper available, Type 4 paper enjoyed wide use, especially in the mass portrait business, from the mid-1970s until the paper was discontinued in 1982. The paper was also used by a significant number of photofinishing labs in Europe and the U.S. The cyan dye in Agfacolor Type 4 paper had unbelievably poor dark fading stability, with the prints in most cases suffering from near-total cyan dye fading in less than six years. Untold millions of portraits of children, adults, and families made with Type 4 paper by PCA International, Inc., of Matthews, North Carolina, and other mass-market portrait labs are now worthless. Business losses resulting from the exceedingly poor stability of the paper led to the filing of a nationwide class-action suit in 1985 against Agfa-Gevaert on behalf of labs and photographers across the United States who had used Type 4 paper. The case was settled out of court for an undisclosed sum in 1987. It is almost certain that, had the extremely poor stability of the paper been known, not a single lab would have used the product.

Agfa did manage to improve its color papers by the early 1990s; however, with rapidly declining sales as photographers switched to digital cameras and inkjet printers, Agfa filed for bankruptcy and went out of business in 2005.

In what can be viewed as a landmark event that helped alert the museum world to the magnitude of the color stability problem and the need to better care for their collections, the George Eastman House International Museum of Photography in Rochester, New York, presented a “Colloquium on the Collection and Preservation of Color Photographs” in 1975. This was the first event of its type in the United States (earlier, in 1973, a conference on color preservation sponsored by the Royal Photographic Society was held at the Victoria and Albert Museum in London). In a letter of invitation to those attending the meeting, which was not open to the public, William Jenkins, a George Eastman House staff member and the organizer of the conference, wrote:

As you may know, the International Museum of Photography has been concerned for some time with the difficulty of collecting color photographs. We have collected dye transfer and carbro prints believing these to be relatively permanent, but our policy has been to refrain from acquiring the less stable materials such as “Type C” prints. [Note: In current usage, “Type C print” is a generic term used to refer to a Kodak Ektacolor print or other silver-halide (chromogenic) prints made from a color negative.]

George Larson, a key figure in stability research at Eastman Kodak, and Charleton Bard, who during the 1980s became Kodak’s regular speaker on the subject of color stability, represented Kodak at the conference. Larson and Bard, for the first time, gave some basic room-temperature dark-keeping stability data for the then-current Kodachrome and Ektachrome films. The meeting was marked by some strong denunciations of Kodak for its secrecy policies and for the very poor image stability of many of its color products. The renowned portrait photographer Arnold Newman said at the conference, “Millions and millions of people have taken color wedding pictures, vacation pictures, and family snapshots. What’s going to happen to these pictures in twenty-five years? They’re going to disappear.”

Newman, who passed away in 2006, showed the group a selection of severely faded Ektachrome transparencies he had taken some years earlier of President John F. Kennedy, and expressed alarm about the fate of color portraits: “These things are carefully hung on walls and
they are expected to last. The great American public doesn’t know it, but it is buying junk. [Kodak and other manufacturers] are going to find that the public is going to start getting angry in about eight to ten years from now when all these personal pictures begin to fade.” Eastman House later changed its policy of not collecting Kodak Ektacolor prints (a potentially embarrassing situation in light of the fact that this is by far the largest-selling print material produced by Kodak, the museum’s most important benefactor); the collection now includes a sizable number of recently acquired Ektacolor prints.

Refrigerated storage was one of the major recommendations to emerge from the 1975 conference. With the acquisition of the 3M-Sipley Collection in 1976, Eastman House possessed the most valuable collection of historical color processes in the United States. Many of these early color photographs have already seriously deteriorated because of improper storage in the past, and the damage is becoming worse with each passing year.

In spite of the immense value of these photographs, many of which were made by color processes of which examples exist in no other collection in the United States, Eastman House did not include a refrigerated vault in its $7.4 million archive building completed in 1988. At the time this was written in 2006, Eastman House continued to store its priceless collection of color photographs under improper conditions, without refrigeration.

Neither Ilford, the manufacturer of Ilfochrome (then called Cibachrome and, at the time of the Eastman House Conference, the world’s most stable color print material), nor Polaroid or Fuji was invited to attend the 1975 Eastman House conference.

Art Museums Begin to Respond to the Problems Posed by Color Photographs

Almost immediately after the fine-art photography world had finally embraced color photography as an art form in its own right in the late 1970s, museum curators, private collectors, and a new generation of photographers working in color began asking questions about how long color prints could safely be displayed. Some wondered if Kodak Ektacolor color prints actually faded in the dark. Others would collect nothing but Kodak Dye Transfer prints, hearing that they would last forever. Some museum curators and collectors, fearing that their investments would depreciate as the prints faded, would not collect color photographs at all.

Among fine-art museums, a three-part strategy to deal with the color print fading problem gradually emerged. The first step was to obtain from the photographer two identical copies of each color photograph chosen for acquisition. This approach provides an “expendable” copy for display purposes, for use as a study print, and for loan to other institutions for exhibition. The second “preservation copy” is kept in the dark under the best storage conditions available. A major benefit of the two-print approach is that the condition of the “expendable” print can easily be assessed at any point in time by a simple side-by-side visual comparison with the “preservation” print.

The Museum of Modern Art in New York and the Art Institute of Chicago are among the museums that have instituted a two-print acquisition program. Both of these museums have found that photographers working in color are almost always supportive of efforts to preserve their work for posterity and are happy to provide the second copy at a sharply reduced “lab price” (the actual cost of making the print). The Museum of Modern Art—which is generally credited with launching the modern era of fine-art color photography with its 1976 exhibition of William Eggleston’s color photographs curated by John Szarkowski, then director of MoMA’s Department of Photography—issued the following statement in 1984:

Millions and millions of people have taken color wedding pictures, vacation pictures, and family snapshots. What’s going to happen to these pictures in twenty-five years? They’re going to disappear.
The Museum of Modern Art New York Statement to Photographers Who Work in Color

It is now well known that with a few exceptions color print materials show a noticeable fading or color shift within as little as ten to twenty years when stored under normal room temperature and humidity conditions, even in the dark. Most such works in the Museum’s Collection, prints up to 20” x 24”, are now stored at about 30°F [-1.1°C] and 35% relative humidity. These conditions will substantially increase the life of the prints.

However, these same photographs also fade or change color when, on exhibition, they are exposed to light. Since it is our purpose not only to preserve but also to show the pictures we collect, we propose the following:

When we decide to purchase a color print in unstable materials, we will ask to buy two prints, one at the artist’s price, the other at the presumably much lower “lab” price, or what it costs to make the print. The Museum will agree to regard the two prints as equivalent versions of a single work of art, and will record them. Neither print ever will be sold. Both prints will be placed in cold low-humidity storage. One will be available for exhibition and loan; the other will be kept in effect as a back-up, until such time as the first is judged to have faded significantly. This solution is not perfect, but it will help to resolve the conflict between our goals of preserving the Collection and making it known through exhibition here and elsewhere.

The second preservation step being taken by concerned fine-art museums is to provide humidity-controlled cold storage for their silver-halide (chromogenic) color prints and other materials with problematic dark storage stability. The Art Institute of Chicago constructed a two-part humidity-controlled cold storage vault in 1982 for housing its entire photography...
collection; color materials are kept in the colder of the two vault sections.

The National Gallery of Canada in Ottawa began operation of a cold storage vault for its extensive fine-art collection in 1988. Corbis, a commercial photography collection, which includes the historic Bettmann Archive, opened a cold storage preservation center in a high-security underground facility near Pittsburgh, Pennsylvania, in 2002; the humidity-controlled vault was designed to temperature at minus 20 degrees Celsius (minus 4 degrees Fahrenheit). In 2004, The Museum of Modern Art in New York opened a large new cold storage facility to preserve its fine-art photography collection.

Among other museums providing cold storage for their photography collections are: the Whitney Museum of American Art in New York; the Amon Carter Museum in Ft. Worth, Texas; the Museum of Photographic Arts in San Diego, California; and the J. Paul Getty Museum in Los Angeles (the new Getty Photography Center has a cold storage vault for large-scale color prints). In the coming years, many additional institutions with important fine-art and historical photography and motion picture collections are expected to provide low-temperature cold storage facilities for the long-term preservation of their collections.


Digital printing of fine-art photographs—and a broad-based concern about the permanence of digital prints—can be traced to the founding of Nash Editions in Manhattan Beach, California, in 1991. At that time, the only printer capable of producing high-quality, large photographic prints (up to 34" x 46") on a wide range of papers and canvas was the Iris Graphics Model...
3047 inkjet printer made by Iris Graphics, Inc. in Bedford, Massachusetts. The Iris 3047, which had been designed for direct digital graphic arts proofing, was an expensive machine, costing $126,000. As recounted by Steve Boulter, then national sales manager for Iris Graphics: “The 3047 was developed for the Marubeni Corporation of Japan as an eight-up proofer. Hence, the A0 sheet size. The printer was introduced in 1989. I started working for Iris in 1988 and the development activity for the 3047 began shortly after that. Marubeni is kind of like the GE [General Electric Company] of Japan. They are a very large conglomerate, and they functioned as a reseller for Iris. They funded the development of the 3047 with about $500,000.”

The Iris 3047 was not originally intended for printing valuable photographs and art reproductions that would be framed and displayed for long periods of time. Because long-term light stability was not of concern in the proofing business, the dye-based ink sets initially available for the printer had poor light stability. Instead, the design goal was to print direct-digital proofs that could match the color gamut and tone scale of the inks used in offset printing; the proofs had only short-term use.

It was rock musician Graham Nash and his concert tour road manager R. Mac Holbert, both accomplished photographers, who first recognized the potential of the Iris as a fine-art printer when, on March 14, 1989, they watched a 3047 printing a color photograph. This excited them greatly, and in December 1989 Graham signed the papers to purchase an Iris 3047. The colorful history of Nash Editions is chronicled elsewhere in this book by Mac Holbert.

They first used their new 3047 to print their own photographs, but Graham and Mac soon realized that other photographers and artists...
wanted to have their work printed on the Iris, and in July 1991 Nash Editions opened its doors as the world’s first digital fine-art photography printing company. Other pioneers who set up Iris 3047 printing businesses included John and Maryann Doe of Harvest Productions in Anaheim Hills, California; Jon Cone of Cone Editions Press, Ltd., in East Topsham, Vermont; Peter Hogg of the Digital Pond in San Francisco, California; and David Adamson of Adamson Editions in Washington, D.C.

Graham, Mac, Adamson, and other print-makers were quite concerned about “the permanence problem,” and it was not long before Jeff Ball, head of lyson in the United Kingdom, and Michael Andreottola of American Inkjet in the United States, began development of improved-stability dye-based ink sets. The unique continuous flow inkjet head and nozzle design employed with the Iris printers precluded the use of pigmented inks. In 1994, Adamson became the first Iris studio to print an exhibition, The Washington Portfolio, using the then newly introduced lyson Fine Arts ink set.

Galleries, photographers, and artists were concerned about the lack of permanence, in part because of a negative effect on sales to collectors and museums, and this led to the founding in 1997 of an influential but short-lived organization known as the International Association of Fine Art Digital Printmakers (IAFADP). The author was involved in testing new inkjet materials throughout this period and was asked to provide image permanence test data to the IAFADP for distribution to its members. It was also in 1997 that Wilhelm Imaging Research (WIR) launched free-access website, www.wilhelm-research.com, for the purpose of publishing frequently updated print permanence information.

Much of this data was also published by Digital Fine Art, an influential magazine edited...
by Patrick Sarver, that abruptly ceased publication following the September 11, 2001, terrorist attack on the World Trade Center in New York. The magazine’s publisher, who was located on Long Island near New York City, came to fear that anxiety about future attacks would cause the art market to collapse and decided to close the magazine. IAFADP’s demise was caused in part by tensions that developed between members who owned fine-art printmaking companies that supplied reproductions of watercolors and paintings to the art decor market, and an emerging group of members who wanted to shift the focus of the organization to individual photographers and artists who wanted to learn how to make and market their own prints.

The author also gave presentations on the light fading stability of digital print materials at the Society for Imaging Science and Technology’s annual conferences in 1994 and 1995, and numerous presentations on digital print permanence and preservation at industry conferences, and museum and archive meetings. Wilhelm Imaging Research received its first contract to test digital print materials from Iris Graphics in 1996, and since that time WIR’s business has come to focus almost entirely on permanence testing of inks and media for inkjet printer manufacturers, including Canon, Epson, Hewlett-Packard, and Lexmark, as well as suppliers of inkjet photographic papers, canvas materials, and print coatings. During this period a number of companies specializing in digital art reproduction using Iris 3047 printers were started, and most placed great importance on good image permanence. In 1999, one of these printing studios, Old Town Editions in Alexandria, Virginia, founded by Chris Foley and Mark McCormick-Goodhart, was the first to use the improved-stability Lysonic iW2 hybrid ink set in an Iris 3047 in combination with the then-new flat-matte coated Lysonic Standard Fine Art Paper. Old Town Editions was among the first fine-art digital printmakers to implement a full ICC profile-based color-managed workflow with soft proofing and remote proofing for customers.

The Iris printers allowed on-demand printing of limited edition prints as they were sold—something that had not been possible before with screen printing (generally called serigraphs in the art reproduction business), litho printing, and other reproduction technologies. Inkjet printers provided another advantage that quickly proved very attractive to photographers and art reproduction houses alike: They can print on a very wide variety of types, surfaces, and thickness of papers and canvas. This degree of media independence was new to both photography and to the printing business. For use by the art reproduction market, which for various reasons often felt uncomfortable with telling customers they were buying inkjet prints, Jack Duganne coined the name “giclée” for inkjet prints as an analogous term to “serigraph.” In reference to inkjet technology in which inkjet nozzles “spray” inks onto paper, giclée was derived from the French word “gicler,” which means to spray or squirt a liquid. The term is only applied to prints made with matte-surface fine-art papers or canvas, and not to RC-base semigloss or glossy photo papers. It has been pointedly avoided by Nash Editions and other digital print providers catering to high-end artists.
and photographers—and is also shunned by most photographers.

The introduction of the Epson Stylus Pro 7500 (24-inch) and 9500 (44-inch) pigmented ink printers in 2000 started a period of rapid change in the fine-art printing business. The new Epson printers were able to handle a wide variety of fine art and photo media, including very thick papers which could be sent through the printer’s straight-through paper path without bending, and they were easy to operate and practically maintenance free. Nash Editions began to convert its printing operations to the new Epson printers, and by the end of 2004 it had retired its last Iris 3047. On August 12, 2005, the Smithsonian Institution in Washington, D.C., accessioned the original 3047 purchased by Nash in a ceremony attended by Graham Nash, Max Holbert, and Steve Boulter. The large-format Epson printers cost only a small fraction of the price of an Iris printer, making the printers accessible to photographers themselves, and this brought about far-reaching changes in the printmaking field.

Photography has had a very long tradition of serious photographers making black-and-white prints in their own darkrooms. Ansel Adams, Edward Weston, Paul Strand, and W. Eugene Smith are but well-known examples. With the advent of color photography, however, the high cost and complexity of color printing and processing equipment caused most photographers to abandon their darkrooms and send their color film to commercial laboratories. As a result, photographers lost touch with using or even understanding the limited controls that were available in color printing with an enlarger. When printing color negatives with an enlarger, it is not possible to adjust image contrast, the tone reproduction curve shape, or color saturation—only overall density and color balance can be controlled. Adobe Photoshop and other image editing software offer far greater control with just a few clicks of a mouse. In the modern inkjet era, more people are printing their own photographs than was ever true in the history of photography. With a little practice, even school children are printing beautiful color photographs taken with their family’s digital cameras! Now, as the seventy-year period of traditional silver-halide color (chromogenic) photography comes to a close, printmaking has finally returned to the photographer. The result, of course, has been a complete transformation of the photography industry.

The Shift to Pigmented Inks

To understand the evolution of print permanence in the inkjet field, it is important to appreciate the fact that among the four major manufacturers of inkjet printers, inks, and papers—Canon, Epson, Hewlett-Packard, and Lexmark—none were in the traditional photography field. Canon of course has long made cameras and lenses, but neither Canon nor any of the other companies has ever made photographic films.
In 1999 Nash Editions became one of Epson’s beta test sites for the ground-breaking Epson Stylus Pro 9500 large-format printers using Epson Archival pigmented inks. As a result, Mac Holbert was asked by Epson America to collaborate with New York photographer Stephen Wilkes to print a major exhibition of his work, Epson’s America in Detail. Over 52 days, Wilkes traveled across the United States with the goal of capturing a cross-section of American life, chronicling Americans at work on farms in Iowa and oil rigs in the Gulf of Mexico, street musicians in Venice Beach and Times Square, and spectacular landscapes in several states. The show of forty images, curated by Marvin Heiferman and Carole Kismaric, opened on January 11, 2001, in San Francisco and, with extensive press coverage, went on to New York, Santa Monica, and Chicago. Nash Editions was not only the first digital fine-art printing studio, but it also printed the first major photography exhibition to be printed with high-stability pigmented inks.

“The year 2000,” Wilkes wrote, “ushers in the explosion of the digital revolution, which will undoubtedly change all of our lives, much in the same way the industrial revolution did at the turn of the twentieth century. … Epson’s America in Detail offers me a unique opportunity to capture a moment in American history, and to be on the forefront of digital printing, taking advantage of the ability to control the entire photographic process…. It is now possible to create beautiful images without ever stepping into a darkroom. Epson has provided me with the opportunity and the archival printing technology to produce the images captured during this shoot through a unique new method—one that is the wave of the future.”

In her review of the exhibition for the New York Times, critic Vicki Goldberg wrote, “Color photographs up to now have been compromises, but we
were accustomed to them. No photographer can print quite what he or she saw or what was registered on the negative or transparency because no enlarger can handle it adequately. The computer program Photoshop, however, can—in combination with the right inks, printer, and paper, and in the hands of a master printmaker like R. Mac Holbert, who printed Mr. Wilkes’s images. Mr. Wilkes made his photographs with standard cameras and film, then scanned them into a computer; Mr. Holbert added nothing that was not there but brought out what was.

“Digital color printers have up to now used dye-based inks, just as traditional color printing processes have. The new Epson printers use pigment-based ink sets, similar to those used by the automotive industry. Both Epson and Hewlett-Packard devised such ink sets for outdoor signs; they had been looking for something permanent and resistant to pollutants. Dyes fade: consider your upholstery. Pigments last: consider oil paintings.”

— HENRY WILHELM
or papers. All four of these companies developed inkjet technology to print plain paper text and pie charts in color. Over time, initially in an effort to print sharper text, image quality got better and better.

One can cite the 1994 introduction of the Epson Stylus Color 720 dpi printer—which came to market only five years after the Iris 3047 became available—as the start of low-cost inkjet photo printing. Quite suddenly, Epson found itself in the photography business. Hewlett-Packard, Canon, and Lexmark soon followed. Like Iris Graphics, none of these companies had even considered the permanence requirements of photographs coming out of their printers that would be hung on the wall in the very same way that photographs have always been displayed. The inks supplied with all of these early inkjet prints had very poor light fading stability. But as shown in Figures 1 and 2, it was clear from the beginning to this author that inkjet inks and papers had the potential to be far more stable in dark storage than the then available silver-halide color photographic papers. At the time, the principal permanence shortcoming of inkjet was light stability.

Once this was understood, the industry set about to improve light fading stability, initially with the goal of reaching a level of light stability equal to that of traditional Kodak Ektacolor silver halide color prints. (Fuji color prints had significantly better light stability than the Kodak prints, so the printer manufacturers initially only attempted to equal the stability of the Kodak prints.) Hewlett-Packard came close to reaching this in 1997 with the introduction of the original PhotoSmart printer, and Epson finally achieved it with dye-based photo inks introduced in early 2000. At the time, dye-based inks had the advantage of a wide color gamut, high D-max, little or no differential gloss, and minimal metamerism. But, compared with pigmented inks, dye-based inks suffered from inferior light stability, high sensitivity to ozone on instant dry porous papers, poor water fastness on swellable papers, potential catalytic fading problems (see Figure 3), humidity-fastness problems, often high sensitivity to different types of media, generally poor light stability with most matte-coated fine art papers (see Table 1 and Figure 4), and short-
term color drift behavior that can be very problematic for color-managed workflows and proofing applications.

From a permanence point of view, however, pigmented inks were better than dye-based inks in virtually every respect. The shortcomings of pigmented inks involved image quality and appearance issues, including reduced color gamut and lower Dmin, which results in a lack of color brilliance, differential gloss problems on glossy photo papers, metameter problems, and a tendency toward "bronzing" on glossy or semigloss photo papers. But beginning with the Epson UltraChrome pigmented ink set introduced in 2002 with the Epson 9600 printer, these problems started to be resolved—or at least minimized—one by one. By the end of 2006, Epson, Hewlett-Packard, and Canon had all moved to pigmented ink sets for their advanced amateur and professional level printers. In the end, with the image quality of new pigmented ink/media systems approaching or in some cases even exceeding that of dye-based inks, the considerable overall permanence advantages of pigmented inks triumphed. It was very clear that a new era of enduring color photography had arrived!

**Conclusion**

Digital fine-art photography has in many ways defined the market for advanced amateur and professional inkjet printers, inks, and media. Photographers in this segment want to be able to make large prints on a wide range of inkjet papers and canvas, including very thick, almost rigid papers that require straight-through printer paper paths. They also want the best, most brilliant color reproduction that can be achieved while at the same time desiring a very high level of image permanence for displayed prints. And many photographers desire to make black-and-whites that are equal to the best black-and-white silver-gelatin prints in terms of brilliance and smooth, linear tone scale.

Escalating prices paid for photographs in the art market—in 2006 many color photographs by major artists were selling for more than $100,000 in galleries and in art auctions—have helped push demands for a high level of print permanence. Photographers have come to understand that their place in history requires that their vision—including the subtleties of color and tone in the prints that they work so hard to create—must endure essentially without change.

The professional portrait and wedding photography market has many of these same requirements, including very high print permanence expectations. Photographs become all the more appealing to customers when they can be sold as family heirlooms that have the intrinsic stability to remain in excellent condition when displayed for many generations.

Inkjet technology has proven to be extremely well suited for these markets: inkjet printers are readily scalable and can provide large print sizes by merely extending the length of travel of the inkjet heads. Inkjet technology allows use of a greater range of dye and pigment colors than any other printing process. Inkjet technology also allows use of a wider range of glossy and matte-surface photo papers as well as canvas and other materials than any other imaging process—all in compact and relatively low-cost printers that require no darkroom, no processing chemicals, and no wash water. The ease, accessibility, and excellence of inkjet printmaking has allowed—and encouraged—more people to become involved in printing their own photographs than has ever been possible in the more than 150-year history of photography.

Throughout the fifteen-year formative period of digital fine-art printing, Wilhelm Imaging Research has provided a uniformly applied image permanence testing methodology that has both made print permanence a more visible issue in the marketplace, and encouraged manufacturers to develop better, longer-lasting inks and papers. With no applicable permanence test method standards available from ANSI

---

(American National Standards Institute) or from ISO (International Organization for Standardization, based in Geneva, Switzerland), WIR has provided fair comparisons of print permanence across brands and between available printing technologies.\(^5\) WIR testing methodology has also given manufacturers permanence design goals for research and development of new inks, papers, and print systems.

This in turn has fostered major R&D efforts in improved systems. Manufacturers now have confidence that the performance of their products will be fairly evaluated and that permanence data will be made broadly available to photographers and the marketplace through WIR’s website. This has helped to provide an environment where honest competition has flourished to the benefit of photographers and manufacturers alike.

Permanence properties are aspects of a print that cannot be seen when a print emerges from the printer. If one ignores permanence, it is relatively simple to manufacture inkjet inks that have a wide color gamut and produce beautiful images. If one ignores image quality, it is not difficult to select colorants that provide a very high level of permanence. What has proven to be very difficult is to accomplish both. That is, to develop inks, media, and printer systems that provide wide gamut, brilliant color, and black-and-white prints with high D-max and a luscious, smooth, linear tonality—and with excellent permanence.

Future projects at WIR include work with the ISO WG-5/TG-3 standards group in the development of improved test methods which better simulate the spectral power distribution of indoor daylight through window glass for accelerated light stability tests, and the implementation and marketing of the WIR i-STAR full tonal scale colorimetric image deterioration analysis software developed over the past four years by Mark McCormick-Goodhart, Dmitriy Shklyarov, Yaw Nti-Addae, Kabenla Armah, and the author.\(^6\) Current densitometric image analysis methods have proven inadequate for the complex, multicolorant ink sets used with modern inkjet printers.

WIR’s central mission has always been to serve as a fair and visible advocate for the importance of permanence and the long-term preservation of photographs.\(^7\) We have tried to be an advocate for photographers of every level, for museums, archives, and film libraries—for everyone who has come to understand and appreciate the unique power, beauty, and historical value of photography.

The Special Place of Nash Editions in the Ongoing History of Photography

There are people who dream of better ways of doing things. These are the people who focus their usually considerable energies on the potential of new ideas and inventions, and are not held back by the problems that almost always hinder early adoption. With the creation of Nash Editions, Graham Nash, Mac Holbert, and Jack Duganne joined that very special group of people in photography’s history who got there first. They played a pivotal role in moving photographic printmaking into a completely new and clearly superior technology.

With Nash Editions, there were really three firsts: Creation of the world’s first digital fine-art inkjet photography studio in 1991. (By that time, Nash Editions had already made the first photographic portfolio printed by digital tech-
nology. Printed in an edition of sixteen during the formation of Nash Editions from 1989 to 1991, Nash’s Portraits Portfolio of sixteen images sold at Christie’s on April 8, 1998, for $21,500.) Then, in 1999, Nash Editions printed the first major photography exhibition to be printed with the new Epson large-format inkjet printers and highly stable Epson pigmented inks introduced into the market the following year, in 2000.

Considering that Nash Editions was born when museums and collectors strongly resisted showing and collecting “digital” photography, the third important contribution was their highly visible and vocal advocacy of the control, beauty, and permanence that only digital photography can provide. From the very beginning, Graham and Mac worked hard to engage a field that initially rejected inkjet prints as even being legitimate “photographs.” At that time, many people believed that because images printed with an Iris 3047 had an image structure built up of millions tiny dots (which could be clearly seen under low-power magnification), they were “photomechanical reproductions,” belonging to the same group of processes that includes ordinary offset lithography printing. Others insisted that a true photograph must have an image that is created as a direct result of exposure to light and, therefore, an inkjet print could not be considered to be a photograph.

In July 1991, when Nash Editions opened its doors, digital imaging was in its infancy. Photographers were still using film, and moving the analog image into the digital space required the use of then very specialized and expensive high-resolution scanners. Making a good scan required a level of expertise and experience that photographers did not have. Adobe Photoshop Version 1.0 had been shipped only a little over a year earlier, in February 1990 (at first, Photoshop was an Apple Macintosh—only application; the first Windows PC version was not introduced until 1993). When Nash Editions started, most photographers had never even heard of


<table>
<thead>
<tr>
<th>Year</th>
<th>Printer/Ink/Paper Combination</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>4 years</td>
<td>4 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Iris ID Inks (4-ink dye-based inkjet prints)</td>
<td>1.4 years</td>
<td>1.8 years</td>
</tr>
<tr>
<td></td>
<td>Iris Semi-Matte coated inkjet proofing photo paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>14 years</td>
<td>17 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Lyson FA Inks (4-ink dye-based inkjet prints)</td>
<td>4 years</td>
<td>5 years</td>
</tr>
<tr>
<td></td>
<td>Arches BFK Heavy Watercolor Paper (uncoated 100% cotton fine-art paper)</td>
<td>36 years</td>
<td>40 years</td>
</tr>
<tr>
<td></td>
<td>Iris Semi-Matte coated inkjet proofing photo paper</td>
<td>29 years</td>
<td>33 years</td>
</tr>
<tr>
<td></td>
<td>FujiColor SFA3 Color Negative Paper (silver-halide color prints)</td>
<td>12 years</td>
<td>12 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Cibachrome print material (silver dye-bleach color prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>Durst Lambda 130 digital printer (first large-format RGB laser silver-halide printer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Printed with FujiColor SFA3 Color Negative Paper (silver-halide color prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Printed with Cibachrome print material (silver dye-bleach color prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>Epson Stylus Color printer (first “photo-quality” 720 dpi desktop inkjet printer)</td>
<td>+0.5 years</td>
<td>+0.5 years</td>
</tr>
<tr>
<td></td>
<td>Printed with Epson Inks and Epson Inkjet Paper (4-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>22 years</td>
<td>25 years</td>
</tr>
<tr>
<td></td>
<td>Printed with American Inkjet Corporation “NE” (Nash Editions) inks consisting of All cyan and magenta inks and Lyson FA1 yellow and black inks printed on</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Somerset Velvet uncoated 100% cotton fine-art paper (4-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>2 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with Lysonic FA II inks (4-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Somerset Velvet uncoated 100% cotton fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liege Inkjet Fine Art Paper matte-coated fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Hewlett-Packard PhotoSmart printer (HP’s first “photo-quality” desktop inkjet printer)</td>
<td>6 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with HP PhotoSmart Inks and HP PhotoSmart Paper (6-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Hewlett-Packard DesignJet 2500 and 3500 printers (HP’s first pigment inkjet color printers)</td>
<td>&gt;200 years</td>
<td>&gt;250 years</td>
</tr>
<tr>
<td></td>
<td>Printed with HP “UV” inks and matte-coated fine-art papers (4-ink pigment inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>Roland Hi-Fi Jet printers (Roland’s first large-format pigment inkjet printers)</td>
<td>125 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with Roland inks and Legion Concorde Rag paper (6-ink pigment inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>30 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with Lysonic i W2 inks consisting of Lysonic i Cyan #006, i Magenta,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i Yellow #005, and i Black (neutral) (4-ink dye-based inkjet prints)</td>
<td>4 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Lysonic Standard Fine Art Paper matte-coated fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Somerset Enhanced Velvet matte-coated fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>34 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with Iris Equipoise Inks (4-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arches Cold Press uncoated 100% cotton fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Somerset Velvet uncoated 100% cotton fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arches Canvas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lysonic Standard Fine Art Paper matte-coated fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Somerset Enhanced Velvet matte-coated fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Iris Graphics 3047 printer (introduced in 1989, the first large-format inkjet photo printer)</td>
<td>70 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with American InkJet Pinnacle Gold Iris Inks (4-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arches for Iris 100% cotton fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinnacle Gold Enhanced Watercolor fine-art paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultra Stable Canvas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Epson Stylus Photo 870 and 1270 desktop printers (“improved stability” dye-based photo inks)</td>
<td>25 years</td>
<td>– na –</td>
</tr>
<tr>
<td></td>
<td>Printed with Epson photo inks (6-ink dye-based inkjet prints)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Epson Matte Paper – Heavyweight (matte-coated paper)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Epson Premium Glossy Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Epson Photo Paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>Printer/Ink/Paper Combination</td>
<td>Displayed</td>
<td>Printed</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>2000</td>
<td>Epson Stylus Pro 7500, 9500, Stylus Photo P2000 printers (Epson’s first pigmented inkjet printers)</td>
<td>&gt;225 years</td>
<td>&gt;250 years</td>
</tr>
<tr>
<td>2002</td>
<td>Hewlett-Packard DesignJet 5000 printer (HP’s first 6-ink pigmented inkjet printer)</td>
<td>&gt;200 years</td>
<td>&gt;250 years</td>
</tr>
<tr>
<td>2002</td>
<td>Epson Stylus Pro 4000, 7600, 9600, Stylus Photo 2200 printers (2-level pigmented black inks)</td>
<td>108 years</td>
<td>175 years</td>
</tr>
<tr>
<td>2004</td>
<td>Durst Lambda, Océ LightJet, and other RGB laser/LED digital printers</td>
<td>40 years</td>
<td>49 years</td>
</tr>
<tr>
<td>2004</td>
<td>Hewlett-Packard DesignJet 130 printer (HP’s first 18 x 24-inch desktop inkjet printer)</td>
<td>Printed with HP 84/85 inks (6-ink dye-based inkjet prints)</td>
<td>82 years</td>
</tr>
<tr>
<td>2004</td>
<td>Canon (1990 and (2005) PIXMA IP8500 printers (Canon’s first 8-ink desktop inkjet printers)</td>
<td>10 years</td>
<td>12 years</td>
</tr>
<tr>
<td>2004</td>
<td>Epson Stylus Photo R800 and (2005) R1800 printers (first use of clear “glass-optimizer” ink)</td>
<td>Printed with Epson UltraChrome Hi-Gloss pigmented inks (7-ink pigmented ink prints)</td>
<td>200 years</td>
</tr>
<tr>
<td>2005</td>
<td>Hewlett-Packard Photosmart 8750 desktop printer (HP’s first 9-ink inkjet printer)</td>
<td>HP Premium Plus Photo Paper and other HP swellable RC-base photo papers</td>
<td>108 years</td>
</tr>
<tr>
<td>2005</td>
<td>Epson Stylus Pro 4800, 7800, 9800, Stylus Photo R2400 printers (3-level pigmented black inks)</td>
<td>Printed with Epson UltraChrome K3 pigmented inkjet prints (8-ink pigmented inkjet prints)</td>
<td>108 years</td>
</tr>
<tr>
<td>2006</td>
<td>Canon PIXMA Pro9500 printer (Canon’s first 10-ink desktop pigmented inkjet printer)</td>
<td>Printed with Canon Lucia pigmented inks (9-ink pigmentInf inkjet prints)</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>2006</td>
<td>Canon imagePROGRAF IPF5000 and IPF9000 printers (Canon’s first 12-ink inkjet printers)</td>
<td>Printed with Canon Lucia pigmented inks (11-ink pigmentInf inkjet prints)</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>2006</td>
<td>HP Designjet Z3100 printer (HP’s first 12-ink pigmented inkjet printer)</td>
<td>Printed with HP Vivosa Pigment inks (11-ink pigmentInf inkjet prints)</td>
<td>&gt;150 years</td>
</tr>
</tbody>
</table>

Note A: The WIR Display Permanence Ratings given here were derived from accelerated glass-filtered cool white fluorescent light fading tests conducted at 24°C (75°F) and 60% relative humidity and are based on the “standard” indoor display condition of 450 lux for 12 hours per day employed by Wilhelm Imaging Research, Inc. Illumination conditions in homes, offices, and galleries do vary; however, and color images will last longer when displayed under lower light levels. Likewise, the life of prints will be shortened when displayed under illumination that is more intense than 450 lux. The predictions given here are the years of display required for the changes in color balance, and/or storing specified in the visually-weighted WIR Ver. 3.0 Endpoint Criteria Set to occur; with most types of images, these changes are easily noticeable in side-by-side comparisons with an unaltered original. Note B: Because of the disproportionately rapid light fading of the red (orange) ink in the 8-ink Canon ChromaPLUS dye-based ink set used in the Canon 9900 printer, which is not properly assessed by the Status A density-spectrally-weighted WIR 3.0 Endpoint Criteria Set, the Display Permanence Ratings should in reality be lower than the figures given here. The disproportionately rapid fading of the red (orange) ink is particularly noticeable in skin tones.
Photoshop. And few owned a Macintosh computer with enough power and memory to run Photoshop. Once a transparency or negative had been scanned and digitized, there was little one could do except to gaze at its beauty on a Macintosh screen—or send it into prepress. Affordable photo-quality dye-sub printers and RGB laser silver-halide photo printers had not yet appeared in the marketplace.

And the Iris 3047, the only printer capable of outputting a digital file as a high-quality, large-format print, was far too expensive and complex to operate for an individual to actually own one. The “digital darkroom” was simply beyond the reach of even the most committed photographer. Thus the logic of Nash Editions—a small digital printmaking studio operated by skilled and passionate individuals whom photographers could enlist to have their work printed.

In the early days, Nash’s customers often visited the studio, both to learn what digital printing and Adobe Photoshop were all about, and to work with Mac Holbert, Jack Duganne, and other staff members to achieve exactly what they wanted in their prints. From the beginning, teaching photographers how to use Photoshop and the fine points of printmaking has always been very central to Nash Editions. While most of the other Iris printmaking studios that started after Nash Editions have focused their businesses on the short-run art reproduction market, Nash Editions has remained firmly committed to photography. There has always been a certain purity and energetic charm about Nash Editions. Just to walk in the door is to be immediately immersed in the latest digital technology—and a love of photography and of making beautiful, long-lasting prints.

Indeed, in recent years a whole new community has formed of people who are passionate about digital photography, Photoshop, and digital fine-art printmaking. These people love to share their knowledge and enthusiasm. They write articles and books, conduct workshops, run websites, lecture at conferences, and do beta testing of new software, printers, inks, and papers for manufacturers. Many travel widely and get together with members of this informal and far-flung group at every possible opportunity. They are all bound together by a deep love of and involvement in photography. Mac Holbert and Graham Nash, both accomplished photographers and gifted teachers, are firmly a part of this new and expanding worldwide digital photography community.

A working knowledge of Photoshop has become the language of photography. And now that powerful computers, high-quality and low-cost inkjet printers with long-lasting pigmented inks, and calibrated monitors running under fully color-managed workflows have become readily available, the early dreams of having one’s own digital darkroom have become the reality for most photographers. Printmaking has finally returned to the photographer—at a twenty-year-plus absence that began when silver-halide color printing proved too complex and too costly for most photographers to be able to make their own color prints. Printmaking has returned to the tradition of Edward Weston, Ansel Adams, Alfred Stieglitz, Edward Steichen, Paul Strand, Walker Evans, Paul Caponigro, Lee Friedlander, Joel Meyerowitz, and the many other great photographers in history who have viewed making their own prints to be central to the expression of their work—and to be deeply intertwined with their evolution as artists.

With the continued evolution of photography and, in turn, of the role served by the small digital printmaking studio, Mac Holbert has been utilizing the broad experience gained over the years in working with photographers at Nash Editions and with his own photography to devote more of his energy to teaching—to help photographers gain a deeper understanding of what they can accomplish with Photoshop, and of the nuances of fine-art printmaking using inkjet printers, beautiful papers, and long-lasting pigmented inks.

Annex 7

WIR Print Permanence Ratings published on www.wilhelm-research.com:

- Epson Stylus Pro 11880  p. 180
- Canon imagePROGRAF iPF6100  p. 190
- Epson Stylus Pro 4900  p. 194
- Canson Infinity Papers  p. 200
- Canon PIXMA Pro 9500  p. 207
- Epson 2400  p. 210
- Epson Stylus NX400  p. 215
- Kodak ESP Office 6150  p. 218
Epson Stylus Pro 11880 – Print Permanence Ratings

Ink System: Nine pigmented inks are provided in the printer with eight inks used at any given time, as determined by the paper type and print mode selected. Nine individual pressurized 700 ml ink cartridges. The piezo inkjet heads are a permanent part of the printer. Epson UltraChrome K3 with Vivid Magenta Inks include pigmented Cyan, Light Cyan, Vivid Magenta, Light Vivid Magenta, Yellow, Photo Black (for glossy photo papers) or Matte Black (for matte photo papers), Light Black, and Light, Light Black. New "Auto Black," real-time black ink mode switching technology with no ink waste when switching between Photo Black and Matte Black inks. Maximum resolution: up to 2880 x 1440 dpi; ink drop size as small as 3.5 picoliters.

Maximum Paper Width: 64 inches (163 cm). Handles roll or cut-sheet paper and canvas from U.S. Letter size (8.5" x 11") up to 64 inches. Cut sheet paper thickness up to 500 gsm and 1.5 mm poster board can be accommodated. All media types and sizes are front loaded.

Operating Systems: Windows XP and 7 (both 32 and 64-bit supported); Mac OSX Tiger 10.4 or higher; Snow Leopard 10.6 or higher. USB 2.0 and 10/100 BaseT Ethernet connectivity.

Special Features: Epson "Advanced Black and White Print Mode" for printing high-quality and long-lasting black-and-white images; accessed through the Epson driver, it also provides a simple way to make excellent B&W or toned (warm, cool, sepia) prints from RGB color image files without having to convert the files in Photoshop. The Epson 11880 printer features new automatic head alignment and nozzle cleaning systems.


The 11880 is Epson’s first 64-inch printer and was quickly adopted by photographers and artists for making large-scale prints. A resident of New York City, Greenfield-Sanders is a contributing photographer to Vanity Fair magazine. He has published a series of acclaimed books and his work is in many museum collections. <www.greenfield-sanders.com>
Epson Stylus Pro 11880 – Print Permanence Ratings¹

( . . . . continued from previous page)

Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)²

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Hot Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(9)</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Cold Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(9)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Cold Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(9)</td>
<td>yes</td>
</tr>
<tr>
<td>Somerset Velvet for Epson</td>
<td>62 years</td>
<td>128 years</td>
<td>37 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(9)</td>
<td>some</td>
</tr>
<tr>
<td>Somerset Velvet for Epson w/PremierArt™Spray(12)</td>
<td>166 years</td>
<td>&gt;200 years</td>
<td>75 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(9)</td>
<td>some</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper</td>
<td>61 years</td>
<td>125 years</td>
<td>34 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(9)</td>
<td>some</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper w/PremierArt™Spray(13)</td>
<td>82 years</td>
<td>168 years</td>
<td>55 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(9)</td>
<td>some</td>
</tr>
<tr>
<td>Epson Textured Fine Art Paper</td>
<td>118 years</td>
<td>236 years</td>
<td>68 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(9)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Enhanced Matte Paper(13)</td>
<td>82 years</td>
<td>110 years</td>
<td>48 years</td>
<td>110 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(9)</td>
<td>yes</td>
</tr>
</tbody>
</table>

Nash Editions prints for clients around the world and Mac Holbert often works with photographers remotely using MacChat AV video conferencing (left). The Epson Stylus Pro 11880 was introduced in the U.S. at the PhotoPlus Expo show in New York City in October 2007 and Nash Editions was commissioned to print the large exhibition of prints shown at the Epson booth with the new printer. In the picture of the print of the red Ferrari car, Mac Holbert is shown with Steve Gorman of Gorman Custom Framing of Costa Mesa, California who mounted and framed the entire show. <www.gormanframing.com> For an article about Gorman in Digital PhotoPro magazine, see: <www.digitalphotopro.com/studio/suitable-for-framing.html>
### Epson Stylus Pro 11880 – Print Permanence Ratings

(Continued from previous page)

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed With UltraChrome K3 with Vivid Magenta Inks</th>
<th>Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Premium Canvas – Satin</td>
<td>75 years</td>
</tr>
<tr>
<td>Epson Premium Canvas – Satin w/PremierArt™ Print Shield Spray(12)</td>
<td>85 years</td>
</tr>
<tr>
<td>Epson Premium Canvas – Satin w/PremierArt™ Eco Print Shield Coating(12)</td>
<td>&gt;100 years</td>
</tr>
<tr>
<td>Epson Premium Canvas – Matte</td>
<td>to be tested</td>
</tr>
</tbody>
</table>

1. Display Permanence Ratings and Album/Dark Storage Permanence Ratings
2. Unprotected Resistance to Ozone
3. Resistance to High Humidity
4. Resistance to Water
5. Are UV Brighteners Present?

---

This document originated at <www.wilhelm-research.com>  
File name: <WIR_Ep11880_2010_04_23.pdf>
## Epson Stylus Pro 11880 – Print Permanence Ratings

Black-and-White prints made with Epson UltraChrome K3 with Vivid Magenta Inks and the Epson “Advanced Black and White Print Mode”

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Premium Glossy Photo Paper (250)</td>
<td>&gt;200 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Epson Premium Luster Photo Paper (260)</td>
<td>&gt;315 years</td>
<td>&gt;315 years</td>
<td>&gt;315 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Premium Semimatte Photo Paper (260)</td>
<td>&gt;200 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Exhibition Fiber Paper (&quot;Epson Traditional Photo Paper&quot; in Europe)</td>
<td>&gt;200 years</td>
<td>&gt;250 years</td>
<td>&gt;200 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>yes</td>
</tr>
<tr>
<td>Epson UltraSmooth Fine Art Paper</td>
<td>205 years</td>
<td>395 years</td>
<td>140 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Hot Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Hot Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Cold Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Cold Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (11)</td>
<td>yes</td>
</tr>
</tbody>
</table>

*Note: Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur) 2*
## Epson Stylus Pro 11880 – Print Permanence Ratings

Black-and-White prints made with Epson UltraChrome K3 with Vivid Magenta Inks and the Epson “Advanced Black and White Print Mode”

| Paper, Canvas, or Fine Art Media Printed With UltraChrome K3 with Vivid Magenta Inks | Displayed Prints Framed Under Glass | Displayed Prints Framed With UV Filter | Displayed Prints Not Framed With UV Filter | Album/Dark Storage Rating at 73°F & 50% RH (incl. Paper Yellowing) | Unprotected Resistance to Ozone | Resistance to High Humidity | Resistance to Water | Are UV Brighteners Present |
|---|---|---|---|---|---|---|---|---|---|
| Somerset Velvet for Epson | >200 years | >250 years | >100 years | >200 years | >100 years | very high | moderate | very high | some |
| Somerset Velvet for Epson w/ PremierArt™ Spray | 311 years | >400 years | 142 years | >200 years | >100 years | very high | moderate | very high | some |
| Epson Velvet Fine Art Paper | >406 years | >400 years | 190 years | >200 years | >100 years | very high | moderate | very high | some |
| Epson Velvet Fine Art Paper w/ PremierArt™ Spray | >400 years | >450 years | >150 years | >200 years | >100 years | very high | moderate | very high | no |
| Epson Enhanced Matte Paper | >110 years | >110 years | >110 years | 110 years | >100 years | very high | moderate | very high | yes |
| Epson Premium Canvas – Satin | >105 years | >150 years | >100 years | >200 years | >100 years | very high | moderate | very high | no |
| Epson Premium Canvas – Satin w/ PremierArt™ Print Shield Spray | >150 years | >150 years | >100 years | >200 years | now in test | very high | moderate | very high | no |
| Epson Premium Canvas – Matte | to be tested | to be tested | to be tested | to be tested | to be tested | to be tested | to be tested | to be tested | – |

---

*Note: The ratings are based on the conditions specified and may vary depending on the storage environment.*

1. WIR Print Permanence Ratings Published on www.wilhelm-research.com

---

*Table continues on next page.*
Epson Stylus Pro 11880 – Print Permanence Ratings

Notes on These Tests:
1) The image permanence data presented here are based on tests done with prototype Epson UltraChrome K3 with Vivid Magenta inks on a variety of media and on long-term tests with the previous generation of UltraChrome inks used in several different Epson large-format printers. Tests to date indicate that with color images, UltraChrome, UltraChrome K3, and UltraChrome K3 with Vivid Magenta inks have similar permanence characteristics. However, with black and white prints, the display permanence ratings with UltraChrome K3 inks are significantly improved because the three-level, highly-stable carbon pigment based black inks in the UltraChrome K3 inkset are used over the entire tonal scale and largely replace the less stable cyan, magenta, and yellow color inks in B&W prints when they are made with the "Advanced Black and White Print Mode." Tests are continuing and this webpage will be updated regularly (very high stability inks such as these require extended test times). Extensive "confirmation tests" with an Epson Stylus Pro 11880 and commercially packaged inks and papers are also being conducted by Wilhelm Imaging Research to make certain that the products consumers actually purchase have essentially the same permanence characteristics as those of the prototype products tested earlier in the product cycle, and upon which much of the data reported here are based.

2) There are currently no ISO or ANSI standards which provide a means of evaluating the permanence of inkjet or other digitally-printed photographs. As a member of ISO WG 5/TG 3 permanence standards group, WIR is actively involved in the development of a new series of ISO standards for testing digital prints. However, as of January 2010, no dates have been announced for the completion and publication of these new ISO standards. The WIR Display Permanence Ratings (DPR) given here are based on accelerated light stability tests conducted at 35 klux with glass-filtered cool white fluorescent illumination with the sample plane air temperature maintained at 24°C and 60% relative humidity. Data were extrapolated to a display condition of 450 lux for 12 hours per day using the Wilhelm Imaging Research, Inc. "Visually-Weighted Endpoint Criteria Set v3.0." and represent the years of display for easily noticeable fading, changes in color balance, and/or staining to occur. See: Henry Wilhelm, "How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs," IS&T's 12th International Symposium on Photofinishing Technologies, pp. 664-668, sponsored by the Society for Imaging Science and Technology, Salt Lake City, Utah, November 2004. Also available, with color illustrations: <www.wilhelm-research.com> <WIR_IST_2004_11_HW.pdf>.


Table 1. “Standard” Home Display Illumination Levels Used by Printer, Ink, and Photo Paper Manufacturers

<table>
<thead>
<tr>
<th>120 lux/12 hrs/day</th>
<th>450 lux or 500 lux/10 hrs/day or 12 hrs/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewlett-Packard</td>
<td>Epson</td>
</tr>
<tr>
<td>Canon</td>
<td>Lexmark</td>
</tr>
<tr>
<td>Fuji</td>
<td>Ilford</td>
</tr>
<tr>
<td>Canson</td>
<td>DNP Konica</td>
</tr>
<tr>
<td>Kodak (for Kodak silver-halide papers and Kodak dye-subs)</td>
<td></td>
</tr>
<tr>
<td>Ferrania</td>
<td>InteliCoat</td>
</tr>
<tr>
<td>Somerset</td>
<td>Harman</td>
</tr>
<tr>
<td>LexJet</td>
<td>Lyson</td>
</tr>
<tr>
<td>Lyson</td>
<td>Luminos</td>
</tr>
<tr>
<td>Hahnemuhle</td>
<td>Premier Imaging Products</td>
</tr>
<tr>
<td>American Inkjet</td>
<td>MediaStreet</td>
</tr>
<tr>
<td>Kodak (for Kodak consumer inkjet prints)</td>
<td></td>
</tr>
</tbody>
</table>


High-intensity light fading reciprocity failures in these tests are assumed to be zero. Illumination conditions in homes, offices, museums, and galleries do vary, however, and color images will last longer when displayed under lower light levels; likewise, the life of prints will be shortened when displayed under illumination that is more in-
Epson Stylus Pro 11880 – Print Permanence Ratings

Notes on These Tests (continued from previous page):

Table 2. Filtration Conditions Used by Printer, Ink, and Paper Manufacturers with CW Fluorescent Illumination

<table>
<thead>
<tr>
<th>UV Filter</th>
<th>Glass Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewlett-Packard</td>
<td>Kodak (for Kodak silver-halide papers and Kodak dye-sub prints)</td>
</tr>
<tr>
<td>Epson</td>
<td>Dell</td>
</tr>
<tr>
<td>Canon</td>
<td>Lexmark</td>
</tr>
<tr>
<td>Fuji</td>
<td>DNP Konica</td>
</tr>
<tr>
<td>Ilford</td>
<td>Kodak (for Kodak consumer inkjet prints)</td>
</tr>
<tr>
<td>Canson</td>
<td>Ferrania</td>
</tr>
<tr>
<td>DNP Konica</td>
<td>IntelCoat</td>
</tr>
<tr>
<td>Kodak</td>
<td>Somerset</td>
</tr>
<tr>
<td>Harman</td>
<td>Kodak, Fujifilm, and Fuji</td>
</tr>
<tr>
<td>LexJet</td>
<td>Ilford</td>
</tr>
<tr>
<td>Lyson</td>
<td>InteliCoat</td>
</tr>
<tr>
<td>Luminos</td>
<td>InteliCoat</td>
</tr>
<tr>
<td>Hahnemuhle</td>
<td>Premier Imaging Products</td>
</tr>
<tr>
<td>Premier Imaging Products</td>
<td>American Inkjet</td>
</tr>
<tr>
<td>MediaStreet</td>
<td>American Inkjet</td>
</tr>
</tbody>
</table>

Tense than 450 lux. Ink and paper combinations that have not reached a fading or color balance failure point after the equivalent of 100 years of display are given a rating of “more than 100 years” until such time as meaningful dark stability data are available (see discussion in No. 5 below).

Eastman Kodak has licensed WIR image permanence data for the Kodak line of consumer inkjet printers, and WIR data for these printer tests are posted on the WIR website (see, for example, <http://www.wilhelm-research.com/kodak/esp9.html>). WIR’s tests with the Kodak consumer inkjet printers are performed using the exact same methodologies employed for all other inkjet printers and other print products posted on the WIR website.

Kodak’s internally-developed print permanence test methodologies have been used by the company for many years and the company continues to base its home display-life calculations for Kodak silver-halide (chromogenic) color papers and Kodak dye-sub (thermal dye transfer) prints on 120 lux/12 hours per day, rather than the 450 lux/12 hours per day adopted by WIR. It is important to understand this and other differences between WIR’s test methods and Kodak’s test methods (see, for example, the article by Charlie Brewer titled “At Least For Ink Jet Print Permanence, WIR and Kodak Mend Fences,” *The Hard Copy Supplies Journal*, Lyra Research, Newtonville, MA 02460, March 2008, pp. 1–2. The article is available for download at <http://www.wilhelm-research.com/hc/Kodak-WIR_Permanence2008_03.pdf>). Some of Kodak’s display-life predictions for the now-obsolete Kodak Ultima Picture Paper (a swellable inkjet paper designed for dye-based inks) were almost 15X longer than the predictions obtained in the more conservative tests conducted by WIR for this ink/media combination, and can be accounted for by differences in the two test methodologies. For example, Kodak uses 80 klux UV-filtered cool white fluorescent illumination; WIR uses 35 klux glass-filtered cool white fluorescent illumination. Kodak uses a starting density for fading measurements of only 1.0; WIR uses starting densities of both 0.6 and 1.0. Kodak uses the “ISO Illustrative” endpoint criteria set; WIR uses the visually-weighted WIR Endpoint Criteria Set v3.0. Kodak’s display environment light exposure assumption for calculating display life is 120 lux for 12 hours per day (UV filtered); WIR uses 450 lux for 12 hours per day (glass filtered). Kodak maintains 50% RH in their accelerated tests; WIR uses 60% RH. Key aspects of Kodak’s test methodology and assumptions for calculation of “years of display” are also very different from those used by most other manufacturers of printers, inks, and media. The display lux level assumption of 120 lux (see Table 1) alone makes Kodak’s display-life predictions 3.75X greater than the display-life predictions provided by other manufacturers and by WIR.

With many ink/media combinations, Kodak’s use of a UV filter instead of the glass filter used by other companies in accelerated light fading tests (see Table 2) further increases Kodak’s display-life predictions. For a description of the Kodak tests, see: D. E. Bugner, C. E. Romano, G. A. Campbell, M. M. Oakland, R. J. Kapusniak, L. L. Aquino, and K. E. Maskasky, “The Technology Behind the New KODAK Ultima Picture Paper – Beautiful Inkjet Prints that Last for Over 100 Years,” Final Program and Advanced Printing of Paper Summaries – IS&T’S 13th International Symposium on Photofinishing Technology, pp. 38–43, Las Vegas, Nevada, February 8, 2004. Together with Kodak’s own test data, the articles also include light stability data for Kodak Ultima Picture Paper obtained from ongoing tests conducted by the Image Permanence Institute at the Rochester Institute of Technology (Rochester, New York), and from Torrey Pines Research (Torrey Pines, California). The tests were conducted using the Kodak test procedures and in-
Epson Stylus Pro 11880 – Print Permanence Ratings

Notes on These Tests (continued from previous page):

1) Included the use of a UV filter with cool white fluorescent illumination; the Image Permanence Institute and Torrey Pines Research also based print-life calculations on 120 lux for 12 hours per day.

3) In typical indoor situations, the “Displayed Prints Framed Under Glass” test condition is considered the single most important of the three display conditions listed. All prints intended for long-term display should be framed under glass or plastic to protect them from staining, image discoloration, and other deterioration caused by prolonged exposure to cigarette smoke, cooking fumes, insect residues, and other airborne contaminants; this precaution applies to traditional silver-halide black-and-white and color photographs, as well as inkjet, dye-sub, and other types of digital prints.

4) Displayed prints framed with ultraviolet filtering glass or ultraviolet filtering plastic sheet generally last longer than those framed under ordinary glass. How much longer depends upon the specific print material and the spectral composition of the illuminate, with some ink/paper combinations benefiting a great deal more than others. Some products may even show reduced life when framed under a UV filter because one of the image dyes or pigments is disproportionately protected from fading caused by UV radiation and this can result in more rapid changes in color balance than occur with the glass-filtered and/or the bare-bulb illumination conditions. For example, if a UV filter protects the cyan and magenta inks much more than it protects the yellow ink in a particular ink/media combination, the color balance of the image may shift toward blue more rapidly than it does when a glass filter is used (in which case the fading rates of the cyan, magenta, and yellow dyes or pigments are more balanced in the neutral scale). Keep in mind, however, that the major cause of fading with most digital and traditional color prints in indoor display conditions is visible light and although a UV filter may slow fading, it will not stop it. For the display permanence data reported here, Acrylite OP-3 acrylic sheet, a “museum quality” UV filter supplied by Cyro Industries, was used.

5) Illumination from bare-bulb fluorescent lamps (with no glass or plastic sheet between the lamps and prints) contains significant UV emissions at 313nm and 365nm which, with most print materials, increases the rate of fading compared with fluorescent illumination filtered by ordinary glass (which absorbs UV radiation with wavelengths below about 330nm). Some print materials are affected greatly by UV radiation in the 313–365nm region, and others very little.

6) “Gas fading” is another potential problem when prints are displayed unframed, such as when they are attached to kitchen refrigerator doors with magnets, pinned to office walls, or displayed inside of fluorescent illuminated glass display cases in schools, stores, and offices. Field experience has shown that, as a class of media, microporous “instant dry” papers used with dye-based inkjet inks can be very vulnerable to gas fading when displayed unframed and/or stored exposed to the open atmosphere where even very low levels of ozone and certain other air pollutants are present. Resistance to ozone exposure varies considerably, depending on the specific type and brand of dye-based inks and photo paper. In some locations, displayed unframed prints made with certain types of microporous papers and dye-based inks have suffered from extremely rapid image deterioration. This type of premature ink fading is not caused by exposure to light. Polluted outdoor air is the source of most ozone found indoors in homes, offices and public buildings. Ozone can also be generated indoors by electrical equipment such as electrostatic air filters (“electronic dust precipitators”) that may be part of heating and air conditioning systems in homes, office buildings, restaurants, and other public buildings to remove dust, tobacco smoke, etc. Electrostatic air filtration units are also supplied as small “tabletop” devices. Potentially harmful pollutants may be found in combustion products from gas stoves; in addition, microscopic droplets of cooking oil and grease in cooking fumes can damage unframed prints. Because of the wide range of environmental conditions in which prints may be displayed or stored, the data given here will be limited by the “Unprotected Resistance to Ozone” ratings. That is, when ozone resistance tests are complete, in cases where the “Unprotected Resistance to Ozone” predictions are less than the “Display Permanence Ratings” for displayed prints that are NOT framed under glass (or plastic), and are therefore exposed to circulating ambient air, the “Display Permanence Ratings” will be reduced to the same number of years given for “Unprotected Resistance to Ozone” even though the “Display Permanence Rating” for unframed prints displayed in ozone-free air is higher. For all of the reasons cited above, all prints made with microporous papers and dye-based inks should always be displayed framed under glass or plastic. For that matter, ALL displayed prints, regardless of the technology with which they are made, should be framed under glass or plastic sheets. This includes silver-halide black-and-white and color prints, dye-sub prints, and inkjet prints made with dye-based or pigmented inks on swellable or microporous papers, canvas, or other materials.

6) Prints stored in the dark may suffer slow deterioration that is manifested in yel-
Epson Stylus Pro 11880 – Print Permanence Ratings

Notes on These Tests (continued from previous page):

...owing of the print paper, image fading, changes in color balance, and physical embrittlement, cracking, and/or delamination of the image layer. These types of deterioration may affect the paper support, the image layer, or both. Each type of print material (ink/paper combination) has its own intrinsic dark storage stability characteristics; some are far more stable than others. Rates of deterioration are influenced by temperature and relative humidity, high temperatures and/or high relative humidity exacerbate the problems. Long-term dark storage stability is determined using Arrhenius accelerated dark storage stability tests that employ a series of elevated temperatures (e.g., 57°C, 64°C, 71°C, and 78°C) at a constant relative humidity of 50% RH to permit extrapolation to ambient room temperatures (or other conditions such those found in sub-zero, humidity-controlled cold storage preservation facilities). Because many types of inkjet inks, especially those employing pigments instead of dyes, are exceedingly stable when stored in the dark, the eventual life of prints made with these inks may be limited by the instability of the paper support, and not by the inks themselves. Due to this concern, as a matter of policy.

Wilhelm Imaging Research does not provide a Display Permanence Rating of greater than 100 years for any inkjet or other photographic print material unless it has also been evaluated with Arrhenius dark storage tests and the data indicate that the print can indeed last longer than 100 years without noticeable deterioration when stored at 73°F (23°C) and 50% RH. Arrhenius dark storage data are also necessary to assess the physical and image stability of a print material when it is stored in an album, portfolio box, or other dark place. The Arrhenius data given here are only applicable when prints are protected from the open atmosphere; that is, they are stored in closed boxes, placed in albums within protective plastic sleeves, or framed under glass or high-quality acrylic sheet. If prints are stored, displayed without glass or plastic, or otherwise exposed to the open atmosphere, low-level air pollutants may cause significant paper yellowing within a relatively short period of time. Note that these Arrhenius dark storage data are for storage at 50% RH; depending on the specific type of paper and ink, storage at higher relative humidities (e.g., 70% RH) could produce significantly higher rates of paper yellowing and/or other types of physical deterioration.


8) Changes in image color and density, and/or image diffusion ("image bleeding"), that may take place over time when prints are stored and/or displayed in conditions of high relative humidity are evaluated using a humidity-fastness test maintained at 86°F (30°C) and 80% RH. Depending on the particular ink/media combination, slow humidity-induced changes may occur at much lower humidities – even at 50–60% RH. Test methods for resistance to high humidity and related test methods for evaluating "short-term color drift" in inkjet prints have been under development since 1996 by Mark McCormick-Goodhart and Henry Wilhelm at Wilhelm Imaging Research, Inc. See: Mark McCormick-Goodhart and Henry Wilhelm, “New Test Methods for Evaluating the Humidity-Fastness of Inkjet Prints,” Proceedings of “Japan Hardcopy 2005” – The Annual Conference of the Imaging Society of Japan, Tokyo, Japan, June 9, 2005, pp. 95–98. Available in PDF format from <www.wilhelm-research.com> <WIR_JapanHardcopy2005MMG_HW.pdf>.

9) Data from waterfastness tests are reported in terms of three subjective classes: “high,” “moderate,” and “low.” Both “water drip” tests and “standing water drops/gentle wipe” tests are employed.

10) Fluorescent brighteners (also called “UV brighteners,” “optical brighteners,” or “optical brightening agents” [OBA’s]) are white or colorless compounds added to the image-side coatings of many inkjet papers – and nearly all “plain papers” – to make them appear whiter and “brighter” than they really are. Fluorescent brighteners absorb ultraviolet (UV) radiation, causing the brighteners to fluoresce (emit light) in the visible region, especially in the blue portion of the spectrum. Fluorescent brighteners can lose activity – partially or completely – as a result of exposure to light. Brighteners may also lose activity when subjected to high temperatures in accelerated thermal aging tests and, if it is assumed, in long-term storage in albums or other dark places under normal room temperature conditions. With loss of brightener activity, papers will appear to have yellowed and to be “less bright” and “less white.” In recent years, traditional chromogenic (“silver-halide”) color photographic papers have been made with UV-absorbing interlayers and overcoats and this prevents brighteners that might be present in the base paper from being activated by UV radiation. It is the relative UV component in the viewing illumination that determines the perceived “brightening effect” produced by fluorescent brighteners. If the illumination contains no UV radiation (for example, if a UV filter is used in framing a print), fluorescent brighteners are not activated and, comparatively speaking, the paper appears to be somewhat yellowed – and not as “white.” This spectral dependency of fluorescent brighteners makes papers containing such brighteners look different depending on the illumination conditions. For example, prints displayed near windows are illuminated with direct or indirect daylight, which contains a relatively high UV component, and if an inkjet paper contains brighteners, this causes the brighteners to strongly fluoresce. When the same print is displayed under incandescent tungsten illumination, which has a low UV component, the brighteners have little effect. Another potential drawback of brighteners is that brightener degradation products may themselves be a source of yellowish stain. These problems can be avoided by not adding fluorescent brighteners to inkjet photographic papers during manufacture. When long-term image permanence is of critical importance – with museum fine art collections, for example – papers with fluorescent brighteners should be avoided where possible.

11) Although the waterfastness of the color image itself is very high with this paper, the absorbent paper base itself may become cockled, curled, and physically distorted after contact with water. For this reason, the waterfastness of this paper/ink combination is listed as “moderate.”

12) PremierArt™ ECO Print Shield, a water-based protective overcoat made specifically for inkjet prints made with water-resistant canvas, and PremierArt™ Print Shield, an easy-to-apply “low-solids” spray supplied in aerosol spray cans for protecting inkjet prints are available from Premier Imaging Products, Inc. <www.premierart.info> and <www.premierimagingproducts.com>, 121 Lombard Street, Oxnard, California 93030; tel: 805-983-1472; fax: 805-988-0213.

13) In these tests, the UV-Filter Display Permanence Rating for Epson Enhanced Matte Paper was 155 years; however, because the Album/Dark Storage Rating for this paper is 110 years (40 years less than the 155-year UV-Filter Display Permanence Rating), the Display Permanence Rating is being limited to 110 years for both color and black-and-white prints.
General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Canon imagePROGRAF iPF6100 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/canon/ipf6100.html>
# Canon imagePROGRAF iPF6100 – Print Permanence Ratings

Ink System: Twelve high-stability Canon LUCIA pigment inks are provided in the printer with eleven inks used at any given time, as determined by the paper type and print mode selected. Twelve individual 130ml LUCIA PFI-101 and 103 ink cartridges: Cyan, Photo Cyan, Magenta, Photo Magenta, Yellow, Red, Green, Blue, Photo Black (for glossy photo papers), Matte Black (for matte fine art papers), Gray, and Photo (light) Gray. The inks have the same formulation as the inks used in Canon’s other large-format 12-ink printers, including the iPF5100, iPF8100, and iPF9100. The dual thermal inkjet heads are designed to last the life of the printer, but are user-replaceable; maximum of 2,400 x 1,200 dpi (dots per inch) with ink drop sizes as small as 4 picoliters.

Maximum Paper Width: Cut sheet and roll papers 8 to 24 inches. Media thickness: Top loading feed: 0.07 to 0.8mm (2.8 to 31.4mil); Front loading feed: 0.5 to 1.5mm (19.6 to 59.0mil); Roll media: 0.07 to 0.8mm (2.8 to 31.4mil). Maximum print length: 62 inches (top feed) and 36 inches (front feed). Borderless printing with roll media.

Operating Systems: Windows XP and Vista (32/64 bit); Mac OSX 10.2–10.4 and 10.5x. High-speed USB 2.0 and Ethernet; optional IEEE 1394 (Firewire).

Special Features: Both Photo Black and Matte Black inks are installed, eliminating the need to change black ink cartridges when switching between papers. Built-in calibration system to help achieve consistent results. Print plug-in for Adobe Photoshop.

Price: Canon imagePROGRAF iPF6100: $2,895.00 (USA list price). Canon Item Code: 1016B002AA. Announced in late 2007. Improved pigment ink formulations help reduce bronzing and minimize graininess.

## Display Permanence Ratings and Album/Dark Storage Permanence Ratings

(Years Before Noticeable Fading and/or Changes in Color Balance Occur)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon Glossy Photo Paper (170 gsm)</td>
<td>96 years</td>
<td>170 years</td>
<td>55 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canon Semi-Glossy Photo Paper (167 gsm)</td>
<td>98 years</td>
<td>179 years</td>
<td>54 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canon Heavyweight Coated Paper (140 gsm)</td>
<td>121 years</td>
<td>234 years</td>
<td>67 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(16)</td>
<td>yes</td>
</tr>
<tr>
<td>Canon Premium Matte Paper (210 gsm)</td>
<td>97 years</td>
<td>202 years</td>
<td>49 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(16)</td>
<td>some</td>
</tr>
<tr>
<td>Canon Fine Art Photo Rag Paper (188 gsm) (by Hahnemühle)</td>
<td>95 years</td>
<td>203 years</td>
<td>47 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(16)</td>
<td>some</td>
</tr>
</tbody>
</table>

©2009 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to www.wilhelm-research.com are welcomed. Address e-mail inquiries to: info@wilhelm-research.com Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.

---

This document originated at <www.wilhelm-research.com>  File name: <WIR_Canon6100_2009_06_15.pdf>
Canon imagePROGRAF iPF6100 – Print Permanence Ratings

Black-and-White prints made with Canon LUCIA Pigment Inks

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper, Canvas, or Fine Art Media Printed With Canon LUCIA Pigment Inks</td>
<td>Displayed Prints Framed</td>
<td>Displayed Prints Framed</td>
<td>Displayed Prints Framed</td>
<td>Album/Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing)</td>
<td>Unprotected Resistance to Ozone</td>
<td>Resistance to High Humidity</td>
<td>Resistance to Water</td>
<td>Are UV Brighteners Present?</td>
</tr>
<tr>
<td>Canon Glossy Photo Paper (170 gsm)</td>
<td>&gt;200 years</td>
<td>&gt;300 years</td>
<td>&gt;150 years</td>
<td>&gt;300 years</td>
<td>very high</td>
<td>high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canon Semi Glossy Photo Paper (167 gsm)</td>
<td>&gt;200 years</td>
<td>&gt;300 years</td>
<td>&gt;150 years</td>
<td>&gt;300 years</td>
<td>very high</td>
<td>high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canon Heavyweight Coated Paper (140 gsm)</td>
<td>&gt;200 years</td>
<td>&gt;300 years</td>
<td>&gt;150 years</td>
<td>&gt;300 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Canon Premium Matte Paper (210 gsm)</td>
<td>&gt;200 years</td>
<td>&gt;300 years</td>
<td>&gt;150 years</td>
<td>&gt;300 years</td>
<td>very high</td>
<td>moderate</td>
<td>some</td>
<td></td>
</tr>
<tr>
<td>Canon Fine Art Photo Rag (188 gsm) (by Hahnemühle)</td>
<td>&gt;200 years</td>
<td>&gt;300 years</td>
<td>&gt;150 years</td>
<td>&gt;300 years</td>
<td>very high</td>
<td>moderate</td>
<td>some</td>
<td></td>
</tr>
</tbody>
</table>

The 12-color high-stability Canon LUCIA pigment inks used with the iPF6100 printer include red, blue and green inks together with light cyan and light magenta inks to broaden the color gamut and increase color brilliance. The inks are supplied in twelve individual 130ml cartridges.

The Canon iPF6100 printer is equipped with an internal calibration system that returns the printer to the original factory settings across various types of media. Especially important for photographers using color-managed workflows – and for proofing applications – the calibration system provides consistent and predictable results with changes of inks and media, and when the printer is operated under changing temperature and humidity conditions.

The three-level black and gray pigment inks cover the full tonal scale to provide beautiful, very long lasting black-and-white prints. The Canon iPF6100 and other large-format Canon 12-ink printers, such as the 60-inch imagePROGRAF iPF9100 pictured at the left, feature automatic switching between photo black and matte black inks to avoid ink waste.
“Celebrating the Arts and the Environment,” the Ansel Adams Gallery is located in the heart of Yosemite National Park.

William Neill discussing his photographs with Ansel Adams Gallery curator Glenn Crosby in the gallery’s print room.

Thousands of people visit the gallery each year. In the summer months, the Ansel Adams Gallery offers a series of photography workshops.

Crosby and Neill hanging a group of Neill’s photographs in the main gallery display area. Neill made all of the prints with Canon imagePROGRAF printers and LUCIA pigment inks.
Epson Stylus Pro 4900 – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Epson Stylus Pro 4900 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/epson/ESP4900.html>
Jim Richardson, a longtime contributor to National Geographic magazine, making prints with an Epson Stylus Pro 4900 in the spacious studio and gallery he and his wife Kathy operate in the small, picturesque town of Lindsborg, Kansas. <www.smallworldgallery.net.com> ©2010 Henry Wilhelm

Ink System: Eleven individual pressurized 200 ml ink cartridges are provided in the printer with ten inks used at any given time, as determined by the paper type and print mode selected. Piezo inkjet heads are a permanent part of the printer. Epson UltraChrome HDR Ink pigmented Cyan, Light Cyan, Vivid Magenta, Vivid Light Magenta, Yellow, Orange, Green, Photo Black (for glossy photo papers) or Matte Black (for matte photo papers), Light Black, and Light, Light Black. For the highest d-max with both glossy papers or matte papers, the printer automatically switches between Photo Black and Matte Black inks. Maximum resolution of 2880 x 1440 dpi (dots per inch); variable drop size technology with minimum of 3.5 picoliters.

Maximum Paper Width: 17 inches (43 cm). Top-loading paper feeder handles cut sheet media from 8 x 10 to 17 x 24 inches (43 x 61 cm) and straight-through front manual feeder capable of handling paper up to 1.5mm thick. Auto-loading cassette handles cut sheet paper up to 17 x 24 inches, from 0.08 to 0.27mm thickness. Roll media up to 17 inches wide; built-in automatic and manual rotary media cutter. Borderless (full bleed) cut sheet and roll printing up to 17 x 22 inches.

Special Features: Epson “Advanced Black and White Photo Mode” provides a simplified way to make excellent B&W or toned (neutral, warm, cool, or sepia) prints from RGB color image files without having to convert the files in Photoshop. Optional in-line Epson SpectroProofer spectrophotometer available for proofing applications.

Price: $2,495 (USA) Epson Model No. SP4900HDR (Standard Edition) and $2,995 for SP4900DES (Designer Edition). The two printers were announced September 2010 and started shipping in December 2010.

©2010 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to <www.wilhelm-research.com> are welcome. Address e-mail inquiries to: <info@wilhelm-research.com> Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.

Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Premium Photo Paper Glossy (250) (Epson Premium Glossy Photo Paper outside USA)</td>
<td>85 years</td>
<td>98 years</td>
<td>60 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Epson Ultra Premium Photo Paper Luster (260) (Epson Premium Luster Photo Paper outside USA)</td>
<td>83 years</td>
<td>&gt;200 years</td>
<td>45 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Exhibition Fiber Paper (Epson Traditional Photo Paper outside USA)</td>
<td>90 years</td>
<td>150 years</td>
<td>44 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>yes</td>
</tr>
<tr>
<td>Epson UltraSmooth Fine Art Paper</td>
<td>108 years</td>
<td>175 years</td>
<td>57 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Epson Hot Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
</tbody>
</table>

Epson Stylus Pro 4900 – Print Permanence Ratings
( . . . . continued from previous page)

Epson's "Advanced Black and White Photo Mode" utilizes the three-level UltraChrome HDR ink black and gray inks to provide excellent neutrality throughout the tonal scale and also allows the user to shift the overall hue or "tone" of a monochrome image.

<table>
<thead>
<tr>
<th>Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper, Canvas, or Fine Art Media Printed With Epson UltraChrome HDR Pigment Inks</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper</td>
</tr>
<tr>
<td>Epson Watercolor Paper Radiant White</td>
</tr>
<tr>
<td>Epson Enhanced Matte Paper</td>
</tr>
<tr>
<td>Epson Premium Canvas – Matte</td>
</tr>
</tbody>
</table>

Note: The ratings are based on laboratory testing and may vary under different environmental conditions. Benefits of using archival papers and inks are recommended for long-term preservation of prints.

©2010 Henry Wilhelm

Exhibition Prints
Unframed
Displayed
Display Permanence Ratings
Album/Dark Storage Permanence Ratings
Printed With Epson UltraChrome HDR Pigment Inks
Unprotected
Resistance to Ozone
Resistance to High Humidity
Resistance to Water
Are UV Brighteners Present?

Epson Premium Canvas – Matte
w/PremierArt™ Print Shield Spray

. . . . continues next page
Located in central Kansas, Lindsborg is near the beautiful Flint Hills prairie region of the state.

Lindsborg’s Swedish Country Inn features Swedish-style breakfasts. Settled by Swedish immigrants in 1869, the town is the home of Bethany College.

A billboard near the Lindsborg exit on Interstate Highway 135 for Jim Richardson’s Small World Gallery and Jim Turner’s Brick Street Gallery.

Both Jim and Kathy Richardson grew up in Kansas and they met each other while working for the Capitol-Journal newspaper in Topeka, Kansas – she was a reporter and he was a photographer. After living in Denver, Colorado for a few years, they decided to return to Kansas and chose Lindsborg for their new home because it is a college town with a diverse and artistic population. Kathy is a jewelry artist and shares studio space with her husband. A longtime contributor to National Geographic and other magazines, Jim travels worldwide shooting long-form stories for six months or more a year, and Kathy manages the gallery when Jim is away. They do all of their printing in the studio with Epson Stylus Pro 9900 and 4900 printers. With a large number of images available, visitors to the gallery may order prints in any size they desire – while they wait – and matting and framing are conveniently available next door at Jim Turner’s Brick Street Gallery. Customers may also order prints through the Small World Gallery website. The gallery also has an extensive greeting card business, printing only the twenty or so cards needed to keep each spot on the display racks full, thus avoiding the need to maintain an inventory. When an image sells out, Jim simply prints additional copies.
## Epson Stylus Pro 4900 – Print Permanence Ratings

Black-and-white prints made with the Epson UltraChrome HDR inks and the Epson “Advanced Black and White Print Mode”

Note: The Display Permanence Ratings given here are based on long-term testing with the previous generation of UltraChrome K3 and ongoing tests with UltraChrome HDR inks indicates that significant increases in Display Permanence Ratings for black-and-white prints can be expected because the three-level, highly-stable carbon pigment based black inks in the UltraChrome HDR inkset largely replace the orange, green, cyan, magenta, and yellow color inks in B&W prints when they are made with the “Advanced Black and White Print Mode.” Very high stability inks such as these require extended test times; tests are continuing and this webpage will be updated regularly. “>150 Years” means “greater than 150 years,” and that tests are continuing.

### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed With Epson UltraChrome HDR Pigment Inks</th>
<th>Displayed Prints Framed Under Glass (^{(3)})</th>
<th>Displayed Prints Framed With UV Filter (^{(4)})</th>
<th>Displayed Prints Not Framed (Bare-Bulb) (^{(5)})</th>
<th>Album/Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing) (^{(6)})</th>
<th>Unprotected Resistance to Ozone (^{(7)})</th>
<th>Resistance to High Humidity (^{(8)})</th>
<th>Resistance to Water (^{(9)})</th>
<th>Are UV Brighteners Present? (^{(10)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Premium Photo Paper Glossy (250) (Epson Premium Glossy Photo Paper outside USA)</td>
<td>&gt;135 years</td>
<td>&gt;135 years</td>
<td>&gt;76 years</td>
<td>&gt;300 years</td>
<td>now in test</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Epson Ultra Premium Photo Paper Luster (260) (Epson Premium Luster Photo Paper outside USA)</td>
<td>&gt;90 years</td>
<td>&gt;218 years</td>
<td>&gt;58 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Exhibition Fiber Paper (Epson Traditional Photo Paper outside USA)</td>
<td>&gt;200 years</td>
<td>&gt;200 years</td>
<td>&gt;150 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>yes</td>
</tr>
<tr>
<td>Epson UltraSmooth Fine Art Paper</td>
<td>&gt;205 years</td>
<td>&gt;300 years</td>
<td>&gt;138 years</td>
<td>&gt;300 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>no</td>
</tr>
<tr>
<td>Epson Hot Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>no</td>
</tr>
<tr>
<td>Epson Hot Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Cold Press Natural Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>no</td>
</tr>
<tr>
<td>Epson Cold Press Bright Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper</td>
<td>&gt;115 years</td>
<td>&gt;125 years</td>
<td>&gt;112 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>some</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper w/ PremierArt™ Spray (^{(12)})</td>
<td>&gt;170 years</td>
<td>&gt;145 years</td>
<td>&gt;118 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>no</td>
</tr>
<tr>
<td>Epson Watercolor Paper Radiant White</td>
<td>&gt;200 years</td>
<td>&gt;200 years</td>
<td>&gt;200 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Enhanced Matte Paper (^{(13)})</td>
<td>&gt;110 years</td>
<td>&gt;110 years</td>
<td>&gt;110 years</td>
<td>110 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (^{(11)})</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Premium Canvas – Matte</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
</tr>
<tr>
<td>Epson Premium Canvas – Matte w/PremierArt™ Print Shield Spray (^{(12)})</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
<td>to be tested</td>
</tr>
</tbody>
</table>

---

1. WIR Print Permanence Ratings Published on www.wilhelm-research.com
2. Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)
3. unprotected
4. crops
5. to reduce uv damage to the ink.
6. tested at 73°f and 50%RH.
7. based on an ozone generator and testing for 100 hours.
8. tested with a humidity generator and a relative humidity of 95%.
9. tested with a water sprayer at 90°f and 50%RH.
10. tested for 1000 hours.
11. tested for 1000 hours.
12. tested for 1000 hours.
13. tested for 1000 hours.

---

Note: The Display Permanence Ratings given here are based on long-term testing with the previous generation of UltraChrome K3 and ongoing tests with UltraChrome HDR inks indicates that significant increases in Display Permanence Ratings for black-and-white prints can be expected because the three-level, highly-stable carbon pigment based black inks in the UltraChrome HDR inkset largely replace the orange, green, cyan, magenta, and yellow color inks in B&W prints when they are made with the “Advanced Black and White Print Mode.” Very high stability inks such as these require extended test times; tests are continuing and this webpage will be updated regularly. “>150 Years” means “greater than 150 years,” and that tests are continuing.
Epson Stylus Pro 4900 – Print Permanence Ratings

Notes on These Tests:

1) The image permanence data presented here are based on tests done with Epson UltraChrome K3 with Vivid Magenta inks and Epson UltraChrome HDR inks on a variety of media used in several different Epson large-format printers. Tests to date indicate that with color images, UltraChrome K3, UltraChrome K3 with Vivid Magenta, and UltraChrome HDR inks have similar permanence characteristics. However, with black and white prints, the display permanence ratings with UltraChrome K3 and HDR inks are significantly improved because the three-level, highly-stable carbon pigment based black inks in these inkssets are used over the entire tonal scale and largely replace the less stable cyan, magenta, and yellow color inks in B&W prints when they are made with the “Advanced Black and White Print Mode.” Tests are continuing and this webpage will be updated regularly (very high stability inks such as these require extended test times). Extensive “confirmation tests” with an Epson Stylus Pro 4900 and commercially packaged inks and papers are also being conducted by Wilhelm Imaging Research to make certain that the products consumers actually purchase have essentially the same permanence characteristics as those of the prototype products tested earlier in the product cycle, and upon which much of the data reported here are based.

2) There are currently no ISO or ANSI standards which provide a means of evaluating the permanence of inkjet or other digitally-printed photographs. As a member of ISO WG-5/TG-3 permanence standards group, WIR is actively involved in the development of a new series of ISO standards for testing digital prints. However, as of January 2010, no dates have been announced for the completion and publication of these new ISO standards. The WIR Display Permanence Ratings (DPR) given here are based on accelerated light stability tests conducted at 35 klux with glass-filtered cool white fluorescent illumination with the sample plane air temperature maintained at 24°C and 60% relative humidity. Data were extrapolated to a display condition of 450 lux for 12 hours per day using the Wilhelm Imaging Research, Inc. “Visually-Weighted Endpoint Criteria Set v3.0.” and represent the years of display for easily noticeable fading, changes in color balance, and/or staining to occur. See: Henry Wilhelm, “How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs,” IS&T’s 12th International Symposium on Photolabeling Technologies, sponsored by the Society for Imaging Science and Technology, Orlando, Florida, February 2002. This paper may be downloaded in PDF form at no charge from: <http://www.wilhelm-research.com/pdf/is_t/WIR_ISTpaper_2002_02_HW.pdf>.

For a study of endpoint criteria correlation with human observers, see: Yoshitake Shibahara, Makoto Machida, Hideyasu Ishibashi, and Hiroshi Ishizuka, “Endpoint Criteria for Print Life Estimation,” Final Program and Proceedings: IS&T’s NIP20 International Conference on Digital Printing Technologies, pp. 673–679, sponsored by the Society for Imaging Science and Technology, Salt Lake City, Utah, November 2004. Also available, with color illustrations: <www.wilhelm-research.com> <WIR_NIP20_2004_HW_11.pdf>. High-intensity light fading reciprocity failures in these tests are assumed to be zero. Illumination conditions in homes, offices, museums, and galleries do vary, however, and color images will last longer when displayed under lower light levels; likewise, the life of prints will be shortened when displayed under illumination that is more intense than 450 lux. Ink and paper combinations that have not reached a fading
Canson Infinity Papers – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Canson Infinity papers can be downloaded at no charge from: <http://www.wilhelm-research.com/Canson/canson_infinity.html>
Canson Infinity Papers with Epson Inks – Print Permanence Ratings

The print permanence data given here are based on tests with samples printed with an Epson Stylus Pro 9880 printer and Epson UltraChrome K3 with Vivid Magenta pigment inks. Canson Infinity fine art papers, fine art canvas, and photo papers are supplied by Canson International, BP 139, 07104 Annonay, Cedex, France. Canson Infinity papers are available from suppliers and dealers in countries throughout the world.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity BFK Rives</td>
<td>72 years</td>
<td>140 years</td>
<td>39 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Edition Etching Rag</td>
<td>69 years</td>
<td>132 years</td>
<td>36 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Arches Velin Museum Rag</td>
<td>67 years</td>
<td>129 years</td>
<td>39 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique</td>
<td>69 years</td>
<td>125 years</td>
<td>36 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique DUO</td>
<td>65 years</td>
<td>123 years</td>
<td>37 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Baryta Photographique</td>
<td>45 years</td>
<td>99 years</td>
<td>28 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Platine Fibre Rag</td>
<td>53 years</td>
<td>113 years</td>
<td>32 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity High Gloss Premium RC Photo</td>
<td>60 years</td>
<td>104 years</td>
<td>36 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity PhotoGloss Premium RC Photo</td>
<td>87 years</td>
<td>145 years</td>
<td>49 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity PhotoSatin Premium RC Photo</td>
<td>88 years</td>
<td>147 years</td>
<td>48 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Arches Aquarelle Rag</td>
<td>67 years</td>
<td>129 years</td>
<td>36 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate(11)</td>
<td>no</td>
</tr>
</tbody>
</table>

©2011 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to www.wilhelm-research.com are welcomed. Address e-mail inquiries to: info@wilhelm-research.com Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.
Canson Infinity Papers with Epson Inks – Print Permanence Ratings

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity Montval Aquarelle</td>
<td>75 years</td>
<td>135 years</td>
<td>43 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Montval Torchon</td>
<td>114 years</td>
<td>212 years</td>
<td>63 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Mi-Teintes 50% Rag</td>
<td>71 years</td>
<td>134 years</td>
<td>41 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Museum Canvas Water Res. Matte</td>
<td>73 years</td>
<td>125 years</td>
<td>43 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Water Res. Matte</td>
<td>87 years</td>
<td>148 years</td>
<td>56 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Professional Gloss</td>
<td>66 years</td>
<td>99 years</td>
<td>50 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
</tbody>
</table>

See pages 3 through 6 for Canson permanence data with Canon and HP pigment inks.
Canson Infinity Papers with Canon Inks – Print Permanence Ratings

The print permanence data given here are based on tests with samples printed with a Canon imagePROGRAF iPF 5100 12-ink printer and Canon LUCIA pigment inks. Canson Infinity fine art papers, fine art canvas, and photo papers are supplied by Canson International, BP 139, 07104 Annonay, Cedex, France. Canson Infinity papers are available from suppliers and dealers in countries throughout the world.

---

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed With Canon LUCIA Pigment Inks</th>
<th>Displayed Prints Framed Under Glass(3)</th>
<th>Displayed Prints Framed With UV Filter(4)</th>
<th>Unprotected Resistance to Ozone(7)</th>
<th>Resistance to High Humidity(6)</th>
<th>Resistance to Water(9)</th>
<th>Are UV Brighteners Present?(10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity BFK Rives</td>
<td>116 years</td>
<td>212 years</td>
<td>59 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Edition Etching Rag</td>
<td>96 years</td>
<td>199 years</td>
<td>57 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Arches Velin Museum Rag</td>
<td>119 years</td>
<td>226 years</td>
<td>61 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique</td>
<td>108 years</td>
<td>199 years</td>
<td>56 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique DUO</td>
<td>104 years</td>
<td>198 years</td>
<td>54 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Baryta Photographique</td>
<td>69 years</td>
<td>146 years</td>
<td>39 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Platine Fibre Rag</td>
<td>73 years</td>
<td>130 years</td>
<td>41 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity High Gloss Premium RC Photo</td>
<td>106 years</td>
<td>&gt;175 years</td>
<td>60 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity PhotoGloss Premium RC Photo</td>
<td>122 years</td>
<td>185 years</td>
<td>69 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity PhotoSatin Premium RC Photo</td>
<td>116 years</td>
<td>191 years</td>
<td>64 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
<tr>
<td>Canson Infinity Arches Aquarelle Rag</td>
<td>128 years</td>
<td>238 years</td>
<td>65 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
</tr>
</tbody>
</table>

©2011 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to <www.wilhelm-research.com> are welcomed. Address e-mail inquiries to: <info@wilhelm-research.com> Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.

See pages 5 through 6 for Canson permanence data with HP pigment inks.
## Canson Infinity Papers with Canon Inks – Print Permanence Ratings

### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed With Canon LUCIA Pigment Inks</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
<th>Displayed Prints Not Framed (Bare-Bulb)</th>
<th>Album/Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing)</th>
<th>Unprotected Resistance to Ozone</th>
<th>Resistance to High Humidity</th>
<th>Resistance to Water</th>
<th>Are UV Brighteners Present?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity Montval Aquarelle</td>
<td>126 years</td>
<td>220 years</td>
<td>64 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Montval Torchon</td>
<td>193 years</td>
<td>358 years</td>
<td>105 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Mi-Teintes 50% Rag</td>
<td>129 years</td>
<td>242 years</td>
<td>70 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Museum Canvas Water Res. Matte</td>
<td>136 years</td>
<td>271 years</td>
<td>86 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Water Res. Matte</td>
<td>149 years</td>
<td>246 years</td>
<td>101 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Professional Gloss</td>
<td>171 years</td>
<td>221 years</td>
<td>119 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
</tbody>
</table>

See pages 5 through 6 for Canson permanence data with HP pigment inks.
Canson Infinity Papers with HP Inks – Print Permanence Ratings

The print permanence data given here are based on tests with samples printed with a Hewlett-Packard Designjet Z3100 12-ink printer and HP Vivera pigment inks. Canson Infinity fine art papers, fine art canvas, and photo papers are supplied by Canson International, BP 139, 07104 Annonay, Cedex, France. Canson Infinity papers are available from suppliers and dealers in countries throughout the world.

www.cansoninfinity.com

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed With Hewlett-Packard Vivera Pigment Inks</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
<th>Album/Dark Storage Rating at 73 F &amp; 50% RH (incl. Paper Yellowing)</th>
<th>Unprotected Resistance to High Humidity</th>
<th>Resistance to Water</th>
<th>Are UV Brighteners Present?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity BFK Rives</td>
<td>198 years</td>
<td>360 years</td>
<td>83 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Edition Etching Rag</td>
<td>235 years</td>
<td>&gt;450 years</td>
<td>88 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Arches Velin Museum Rag</td>
<td>218 years</td>
<td>358 years</td>
<td>90 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique</td>
<td>219 years</td>
<td>&gt;450 years</td>
<td>85 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Rag Photographique DUO</td>
<td>246 years</td>
<td>&gt;450 years</td>
<td>87 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Baryta Photographique</td>
<td>160 years</td>
<td>&gt;180 years</td>
<td>56 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity Platine Fibre Rag</td>
<td>117 years</td>
<td>&gt;261 years</td>
<td>39 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
<tr>
<td>Canson Infinity High Gloss Premium RC Photo</td>
<td>150 years</td>
<td>&gt;180 years</td>
<td>57 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, high</td>
</tr>
<tr>
<td>Canson Infinity PhotoGloss Premium RC Photo</td>
<td>220 years</td>
<td>&gt;360 years</td>
<td>70 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, high</td>
</tr>
<tr>
<td>Canson Infinity PhotoSatin Premium RC Photo</td>
<td>221 years</td>
<td>&gt;450 years</td>
<td>68 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, high</td>
</tr>
<tr>
<td>Canson Infinity Arches Aquarelle Rag</td>
<td>228 years</td>
<td>&gt;450 years</td>
<td>90 years</td>
<td>&gt;250 years</td>
<td>&gt;100 years</td>
<td>very high, moderate</td>
</tr>
</tbody>
</table>

©2011 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to <www.wilhelm-research.com> are welcomed. Address e-mail inquiries to: <info@wilhelm-research.com> Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.

HP ink permanence data continues next page . . . .
## Canson Infinity Papers with HP Inks – Print Permanence Ratings

### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canson Infinity Montval Aquarelle</td>
<td>201 years</td>
<td>&gt;365 years</td>
<td>85 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Canson Infinity Montval Torchon</td>
<td>365 years</td>
<td>&gt;365 years</td>
<td>109 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Canson Infinity Mi-Teintes 50% Rag</td>
<td>248 years</td>
<td>&gt;365 years</td>
<td>92 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Canson Infinity Museum Canvas Water Res. Matte</td>
<td>252 years</td>
<td>&gt;365 years</td>
<td>69 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Water Res. Matte</td>
<td>340 years</td>
<td>&gt;365 years</td>
<td>106 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Canson Infinity Artist Canvas Professional Gloss</td>
<td>365 years</td>
<td>&gt;365 years</td>
<td>166 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
<td></td>
</tr>
</tbody>
</table>
Canon PIXMA Pro9500 – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Canon PIXMA Pro9500 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/canon/9500.html>
Canon PIXMA Pro9500 – Print Permanence Ratings (preliminary)

Ink System: Ten high-stability pigmented inks are provided in the printer with nine inks used at any given time, as determined by the paper type and print mode selected. Ten individual Canon PGI-9 ink cartridges. The thermal inkjet heads are a semi-permanent part of the printer; maximum of 4800 x 2400 dpi (dots per inch) with ink drop sizes as small as 3 picoliters. Canon high-stability LUCIA pigmented included are Cyan, Light Cyan, Magenta, Light Magenta, Yellow, Red, Green, Photo Black (for glossy photo papers), Matte Black (for matte fine art papers), and Gray. The two-level black/gray inks are used over the full tonal scale for black-and-white printing. The inks used in the PIXMA Pro9500 are part of the same ink family as the LUCIA inks used in Canon’s large-format 12-ink printers, including the Canon imagePROGRAF iPF 5100, 6100, 8100, and 9100 printers.

Maximum Paper Width: 14 inches. Top-loading paper feeder handles cut sheet papers including 4"x6", 5"x7", 8"x10", 11"x14", 13"x19", and 14"x17". Borderless printing in sizes from 4"x6" to 13"x19". Two separate paper paths with front feeder for heavyweight fine art papers.

Operating Systems: Windows XP/Vista; Mac OS X 10.4 or later. USB 2.0 and Direct Print.

Special Features: Both Photo Black and Matte Black inks are installed, eliminating the need to change ink cartridges when switching between gloss, semi-gloss, and matte fine art papers. Printer software includes EasyPhotoPrint Pro to simplify printing (plug-in for Adobe Photoshop).


Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed with Canon LUCIA Pigment Inks</th>
<th>Displayed Prints Framed Under Glass (2)</th>
<th>Displayed Prints Framed With UV Filter (3)</th>
<th>Displayed Prints Not Framed (Bare-Bulb) (4)</th>
<th>Album/Dark Storage Rating at 73°F &amp; 50% RH (5)</th>
<th>Unprotected Resistance to Ozone (6)</th>
<th>Resistance to High Humidity (7)</th>
<th>Resistance to Water (8)</th>
<th>Are UV Brighteners Present (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon Photo Paper Plus Semi-gloss SG-201</td>
<td>104 years</td>
<td>190 years</td>
<td>52 years</td>
<td>&gt;300 years</td>
<td>now in test</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Canon Fine Art Photo Rag Paper FA-PR1</td>
<td>95 years</td>
<td>190 years</td>
<td>42 years</td>
<td>&gt;300 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate (10)</td>
<td>yes</td>
</tr>
</tbody>
</table>

Note: Additional papers are currently being tested.

©2007 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to <www.wilhelm-research.com> are welcomed. Address e-mail inquiries to: <info@wilhelm-research.com> Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.
Canon PIXMA Pro9500 – Print Permanence Ratings (preliminary ¹)
Black-and-white prints made with Canon LUCIA pigment inks

<table>
<thead>
<tr>
<th>Paper, Canvas, or Fine Art Media Printed with Canon LUCIA Pigment Inks</th>
<th>Display Permanence Ratings</th>
<th>Album/Dark Storage Permanence Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Displayed Prints Framed Under Glass</td>
<td>Displayed Prints Framed with UV Filter</td>
</tr>
<tr>
<td></td>
<td>&gt;300 years</td>
<td>&gt;300 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canon Photo Paper Plus Semi-gloss SG-201</td>
<td>&gt;300 years</td>
<td>233 years</td>
</tr>
<tr>
<td>Canon Fine Art Photo Rag Paper FA-PR1</td>
<td>&gt;300 years</td>
<td>&gt;250 years</td>
</tr>
</tbody>
</table>

Note: Additional papers are currently being tested.

---

A reception and exhibition honoring Michel Tcherevkoff’s book, Shoe Fleur – A Footware Fantasy, was held at the Museum of Arts & Design in New York. The photographs were whimsical constructions of “women’s shoes and handbags” designed by Michel using the flowers, leaves, stems, and seeds of plants.

The gala event featured an illustrated lecture by Michel recounting the inspiration and evolution of Shoe Fleur.

Exhibition prints were made by Michel using both the Canon PIXMA Pro9500 and imagePROGRAF iPF 8100.

Original prints from the exhibition are available from www.shoefleur.com.

A book signing. People from fashion, publishing, and photography attended.

©2007 Henry Wilhelm (8)

The book may be purchased from www.amazon.com.

. . . . continues next page
Epson Stylus Photo 2400 – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Epson Stylus Photo 2400 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/epson/R2400.html>
### Epson Stylus Photo R2400 – Print Permanence Ratings

**Ink System:** Eight inks in the printer; nine individual ink cartridges total. Epson UltraChrome K3 pigmented Cyan, Light Cyan, Magenta, Light Magenta, Yellow, Photo Black (for glossy photo papers) or Matte Black (for matte photo papers), Light black, and Light, Light Black. For optimum results with either glossy papers or matte papers, the user can change between Photo Black and Matte Black ink cartridges respectively. The three-level black inks are used over the complete tonal scale to improve the printer’s gray balance and eliminate color casts in neutrals and near-neutrals. Maximum resolution: up to 5760 x 1440 dpi (dots per inch). The piezo inkjet heads are a permanent part of the printer.

**Maximum Paper Width:** Single sheet: 13 inches; roll paper: 4”, 8.3” and 13”; maximum printable area: 13 x 44 inches. Sheet paper sizes: 4”x6”; 5”x7”; 8”x10”; U.S. letter (8.5”x11”); 11”x14”; 12”x12”; 13”x19”; B (11”x17”); A3, A3+, Super B (13”x19’), user definable; 4”, 8.3”, and 13” roll paper; borderless sizes: 4”x6”; 5”x7”; 8”x10”; 8.5”x11”; 11”x14”; 12”x12”; 13”x19”; panoramic sizes. Four paper paths: sheet, roll, manual, and straight-through (up to 1.3mm thick media).

**Operating Systems:** Windows 2000/XP; Mac OSX 10.2.4 or later. USB 2.0 and FireWire (IEEE 1394).

**Special Features:** New Epson “Advanced Black and White Print Mode” for printing high-quality and long-lasting black-and-white images. The “Advanced Black and White Print Mode” also provides a simple way to make excellent B&W or toned (warm, cool, sepia) prints from RGB color image files without having to convert the files in Photoshop.


---

### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

<table>
<thead>
<tr>
<th>Paper, Canvas, or Plastic Film Media Printed with UltraChrome K3 Pigment Inks</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
<th>Displayed Prints Not Framed</th>
<th>Album/Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing)</th>
<th>Unprotected Resistance to Ozone</th>
<th>Resistance to High Humidity</th>
<th>Resistance to Water</th>
<th>Are UV Brighteners Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Premium Glossy Photo Paper</td>
<td>85 years</td>
<td>98 years</td>
<td>60 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>no</td>
</tr>
<tr>
<td>Epson Premium Luster Photo Paper</td>
<td>83 years</td>
<td>&gt;200 years</td>
<td>45 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Premium Semigloss Photo Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>very high</td>
<td>very high</td>
<td>no</td>
</tr>
<tr>
<td>Epson Exhibition Fiber Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>very high</td>
<td>very high</td>
<td>no</td>
</tr>
<tr>
<td>Epson UltraSmooth Fine Art Paper</td>
<td>108 years</td>
<td>175 years</td>
<td>57 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>PremierArt™ Matte Scrapbook Paper for Epson</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>Epson Watercolor Paper Radiant White</td>
<td>118 years</td>
<td>&gt;200 years</td>
<td>68 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Velvet Fine Art Paper</td>
<td>61 years</td>
<td>125 years</td>
<td>34 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>some</td>
</tr>
</tbody>
</table>

©2007 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to www.wilhelm-research.com are welcomed. Address e-mail inquiries to: info@wilhelm-research.com Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.

. . . . continues next page
## Epson Stylus Photo R2400 – Print Permanence Ratings

(continued from previous page)

### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

(Years Before Noticeable Fading and/or Changes in Color Balance Occur)

<table>
<thead>
<tr>
<th>Paper, Canvas, or Plastic Film Media Printed with UltraChrome K3 Pigment Inks</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
<th>Displayed Prints Not Framed</th>
<th>Album/Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing)</th>
<th>Unprotected Resistance to Ozone</th>
<th>Resistance to High Humidity</th>
<th>Resistance to Water</th>
<th>Are UV Brighteners Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Velvet Fine Art Paper w/PremierArt™ Spray</td>
<td>82 years</td>
<td>168 years</td>
<td>55 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>some</td>
</tr>
<tr>
<td>Epson Enhanced Matte Paper</td>
<td>76 years</td>
<td>110 years</td>
<td>45 years</td>
<td>110 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Matte Paper Heavyweight</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>185 years</td>
<td>now in test</td>
<td>now in test</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>Epson Double-Sided Matte Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>185 years</td>
<td>now in test</td>
<td>now in test</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson</td>
<td>75 years</td>
<td>132 years</td>
<td>46 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson w/PremierArt™ Print Shield Spray</td>
<td>85 years</td>
<td>142 years</td>
<td>60 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson w/PremierArt™ Eco Print Shield Coating</td>
<td>&gt;100 years</td>
<td>&gt;100 years</td>
<td>&gt;100 years</td>
<td>now in test</td>
<td>now in test</td>
<td>very high</td>
<td>moderate</td>
<td>no</td>
</tr>
</tbody>
</table>

---

. . . . continues next page
Epson Stylus Photo R2400 – Print Permanence Ratings
Black-and-white prints made with Epson UltraChrome K3 inkset and the “Advanced Black and White Print Mode”

For much of his photography, James Nachtwey has long preferred black-and-white and, when assignments and deadlines permit, he still shoots B&W film. The “Advanced Black and White Print Mode” provided with the Epson R2400 and other Epson UltraChrome K3 printers gives subtle control of the hue and tonescale of black and white images. In the picture to the right, Nachtwey and staff members Ichiyo Ikezaki, Erin Siegal, and Will Sterns discuss prints being prepared for an upcoming exhibition.

**Epson Premium Glossy Photo Paper**
- >200 years
- >300 years
- >100 years
- very high
- high
- no

**Epson Premium Luster Photo Paper**
- >315 years
- >315 years
- >200 years
- >100 years
- very high
- high
- yes

**Epson Premium Semigloss Photo Paper**
- now in test
- now in test
- now in test
- now in test
- very high
- high
- no

**Epson Exhibition Fiber Paper**
- now in test
- now in test
- now in test
- now in test
- very high
- moderate (11)
- yes

**Epson UltraSmooth Fine Art Paper**
- >205 years
- >300 years
- >138 years
- >300 years
- >100 years
- very high
- moderate(3)
- yes

**PremierArt™ Matte Scrapbook Paper for Epson**
- now in test
- now in test
- now in test
- >200 years
- now in test
- very high
- moderate(3)
- no

**Epson Velvet Fine Art Paper**
- >115 years
- >125 years
- >112 years
- >200 years
- >100 years
- very high
- very high
- some

**Epson Velvet Fine Art Paper w/ PremierArt™Spray(12)**
- >178 years
- >145 years
- >118 years
- >200 years
- >100 years
- very high
- moderate(3)
- no

**Epson Watercolor Paper Radiant White**
- >200 years
- >200 years
- >200 years
- >200 years
- now in test
- very high
- moderate(3)
- yes

**Epson Enhanced Matte Paper(13)**
- 110 years
- 110 years
- 110 years
- 110 years
- now in test
- very high
- moderate(3)
- yes

**Epson Matte Paper Heavyweight**
- now in test
- now in test
- now in test
- 185 years
- now in test
- now in test
- moderate(3)
- yes

---

Note: The Display Permanence Ratings given here are based on long-term testing with the previous generation of UltraChrome inks. WIR testing to date with UltraChrome K3 inks indicates that significant increases in Display Permanence Ratings for black-and-white prints can be expected because the three-level, highly-stable carbon pigment based black inks in the UltraChrome K3 inkset largely replace the cyan, magenta, and yellow color inks in B&W prints when they are made with the “Advanced Black and White Print Mode.” Very high stability inks such as these require extended test times; tests are continuing and this webpage will be updated regularly. “> 150 Years” means “greater than 150 years,” and that tests are continuing.

For much of his photography, James Nachtwey has long preferred black-and-white and, when assignments and deadlines permit, he still shoots B&W film. The “Advanced Black and White Print Mode” provided with the Epson R2400 and other Epson UltraChrome K3 printers gives subtle control of the hue and tonescale of black and white images. In the picture to the right, Nachtwey and staff members Ichiyo Ikezaki, Erin Siegal, and Will Sterns discuss prints being prepared for an upcoming exhibition.

Note: The Display Permanence Ratings given here are based on long-term testing with the previous generation of UltraChrome inks. WIR testing to date with UltraChrome K3 inks indicates that significant increases in Display Permanence Ratings for black-and-white prints can be expected because the three-level, highly-stable carbon pigment based black inks in the UltraChrome K3 inkset largely replace the cyan, magenta, and yellow color inks in B&W prints when they are made with the “Advanced Black and White Print Mode.” Very high stability inks such as these require extended test times; tests are continuing and this webpage will be updated regularly. “> 150 Years” means “greater than 150 years,” and that tests are continuing.

---
## Epson Stylus Photo R2400 – Print Permanence Ratings

Black-and-white prints made with Epson UltraChrome K3 inkset and the “Advanced Black and White Print Mode”

( . . . . continued from previous page)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epson Double-Sided Matte Paper</td>
<td>now in test</td>
<td>now in test</td>
<td>now in test</td>
<td>185 years</td>
<td>now in test</td>
<td>now in test</td>
<td>moderate(10)</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson</td>
<td>&gt;105 years</td>
<td>&gt;150 years</td>
<td>&gt;76 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(10)</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson w/PremierArt™ Print Shield Spray(12)</td>
<td>&gt;150 years</td>
<td>&gt;150 years</td>
<td>&gt;100 years</td>
<td>&gt;200 years</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(10)</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>PremierArt™ Water Resistant Canvas for Epson w/PremierArt™ Eco Print Shield Coating(12)</td>
<td>&gt;150 years</td>
<td>&gt;150 years</td>
<td>&gt;100 years</td>
<td>now in test</td>
<td>now in test</td>
<td>very high</td>
<td>moderate(10)</td>
<td>no</td>
<td></td>
</tr>
</tbody>
</table>

---

1. WIR Print Permanence Ratings Published on www.wilhelm-research.com

---

2. Display Permanence Ratings and Album/Dark Storage Permanence Ratings (Years Before Noticeable Fading and/or Changes in Color Balance Occur)
Epson Stylus NX400 – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Epson Stylus NX400 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/epson/nx400.html>
The Epson Stylus NX400 is an all-in-one 4-ink printer which uses Epson DURABrite Ultra pigmented inks and includes a built-in high-resolution flat-bed scanner for stand-alone copying of documents and photos. ©2008 Henry Wilhelm

Ink System: Four inks. Epson DURABrite Ultra pigmented Cyan, Magenta, Yellow, and Black. Four individual Epson No. 69 ink tanks (also Epson No. 68 and No. 88 ink tanks). The piezo inkjet heads are a permanent part of the printer. Resolution: up to 5760 x 1440 dpi; minimum ink droplet size: variable, as small as 3 picoliters.

Maximum Paper Width: Single sheet: 8.5 inches; maximum printable area: 8.26 x 10.76 inches. Paper sizes: U.S. letter; legal; A4; statement; executive; user definable (4" to 44" in length); 4"x6"; 5"x7"; 8"x10"; borderless photo sizes: 4"x6"; 8"x10"; 8.5"x11".

Operating Systems: Windows Vista, XP, 2000; Mac OSX 10.3.9–10.5 or later. The NX400 also operates as a stand-alone printer and copier which can reduce or enlarge photos without the need for an attached computer. Index sheet printing from camera cards with simple image selection and printing features.

Connectivity: USB 2.0. Integrated camera memory card slots with front Pictbridge and DPOF support.

Special Features: Built-in 48-bit 1200 x 2400 dpi color flatbed scanner (24-bit output). Auto Photo Correction software with face detection. Features a 2.5-inch tilt color LCD display and multiple memory card slots. Stand-alone copier with "fit-to-page" and 100% functions. The Epson Stylus NX400 and other Epson printers using DURABrite inks are among the few general purpose 4-ink printers on the market that offer a fully pigmented inkset – a major advantage with plain papers because pigmented inks are water-resistant on plain paper and also provide good light stability with a wide variety of media. Users of Epson DURABrite ink printers should be aware that most third-party non-genuine (“compatible”) inks supplied by others substitute low-stability dye-based inks that have poor water resistance, very poor ozone resistance, and very poor display permanence.

Price: Epson Stylus NX400: $99.99 (USA) Epson Model No. C11CA20201. The NX400 is sold as the Epson Stylus SX400 in Europe and the Epson Stylus TX400 in Asia, Latin America, Pacific, Middle East, and Russia.

Epson DURABrite Ultra pigmented inks, an improved version of the DURABrite inks first introduced with the Epson C80 printer, are water-resistant on plain papers and photo papers and also have good light stability and resistance to high humidity.
Kodak ESP Office 6150 – Print Permanence Ratings

General descriptions of the test methods used in the preparation of this report can be found on pages 5–10 of the document: “Epson Stylus Pro 11880 – Print Permanence Ratings” (reproduced in this publication).

Detailed test method descriptions are normally included with all “WIR Print Permanence Ratings” reports but have been omitted here to conserve space. The complete report for the Kodak ESP Office 6150 printer can be downloaded at no charge from: <http://www.wilhelm-research.com/kodak/ESP6150.html>
# Kodak ESP Office 6150 Printer – Print Permanence Ratings

**Ink System:** Six inks in two Kodak cartridges. Kodak pigmented Photo Black, Cyan, Magenta, Yellow, Clear Protective inks in a 5-ink Kodak 10C cartridge. Document Black ink is supplied in a separate high-capacity Kodak 10XL cartridge. The Clear Protective Ink produces more uniform gloss levels on glossy, semigloss, and lustre photo papers. The MEMS inkjet heads are a permanent part of the printer, dual drop size.

**Maximum Paper Width:** Single sheet: 8.5 inches. Paper sizes: U.S. letter; legal; A4; 3.5”x5”; 4”x6”; 4”x8”; 4”x12”; 5”x7”; 6”x9”; 8”x10”; 8.5”x11”; 8.5”x14”; A4.

**Operating Systems:** Windows XP, Vista, Windows 7; Mac OSX 10.4.11; 10.5 or later. PC-free copying.

**Connectivity:** Wi-Fi; USB 2.0; Ethernet; DPOF; MIPC; PTP/IP. PC-free printing from camera memory cards.

**Special Features:** Wi-Fi enabled; direct printing from Blackberry smartphones, Apple iPhones and iPod Touch. 2.4-inch LCD. Built-in duplexer for double-sided printing. Built-in 8.5’x11’’ scanner with 30-page document feeder and scan over network with Wi-Fi. One-touch document and photo copying for sizes up to 8.5’x11’’. rotate or crop images with or without a PC. Printer detects paper type codes on back of Kodak photo papers and plain papers and automatically selects the correct printer driver settings. The Kodak ESP-7250 and other Kodak inkjet printers offer a fully pigmented inkset which is water-resistant on plain paper and also provides very good light stability with a very wide range of media; most third-party ("compatible") inks and cartridge refilling services supplied by others substitute low-stability dye-based inks that have poor water resistance, poor humidity resistance, very poor ozone resistance, and very poor light stability.


### Display Permanence Ratings and Album/Dark Storage Permanence Ratings

<table>
<thead>
<tr>
<th>Paper Printed With Kodak No. 10 Pigmented Inks</th>
<th>Displayed Prints Framed Under Glass</th>
<th>Displayed Prints Framed With UV Filter</th>
<th>Displayed Prints Not Framed (Bare-Bulb)</th>
<th>Album/ Dark Storage Rating at 73°F &amp; 50% RH (incl. Paper Yellowing)</th>
<th>Unprotected Resistance to Ozone</th>
<th>Resistance to High Humidity</th>
<th>Resistance to Water</th>
<th>Are UV Brighteners Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak Ultra Premium Photo Paper, High Gloss</td>
<td>132 years</td>
<td>&gt;300 years</td>
<td>43 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>some</td>
</tr>
<tr>
<td>Kodak Ultra Premium Photo Paper, Studio Gloss</td>
<td>148 years</td>
<td>264 years</td>
<td>34 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>some</td>
</tr>
<tr>
<td>Kodak Ultra Premium Photo Paper, Semi Gloss</td>
<td>259 years</td>
<td>&gt;300 years</td>
<td>55 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>some</td>
</tr>
<tr>
<td>Kodak Premium Photo Paper, Gloss</td>
<td>120 years</td>
<td>300 years</td>
<td>45 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>some</td>
</tr>
<tr>
<td>Kodak Premium Photo Paper, Matte</td>
<td>234 years</td>
<td>&gt;300 years</td>
<td>70 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>high</td>
<td>some</td>
</tr>
<tr>
<td>Kodak Photo Paper, Gloss</td>
<td>163 years</td>
<td>243 years</td>
<td>60 years</td>
<td>&gt;200 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>Kodak Photo Paper, Matte</td>
<td>221 years</td>
<td>&gt;300 years</td>
<td>67 years</td>
<td>&gt;150 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
<tr>
<td>Kodak Ultimate Paper (&quot;plain paper&quot;)</td>
<td>290 years</td>
<td>&gt;300 years</td>
<td>81 years</td>
<td>&gt;300 years</td>
<td>&gt;100 years</td>
<td>very high</td>
<td>moderate</td>
<td>yes</td>
</tr>
</tbody>
</table>

©2010 by Wilhelm Imaging Research, Inc. As long as this document remains complete and unaltered, it may be freely distributed to your associates, customers, and friends. This PDF may also be reproduced in magazine articles, books, and other hardcopy print publications; however, it may not be posted on websites without written permission. Links to <www.wilhelm-research.com> are welcomed. Address e-mail inquiries to: <info@wilhelm-research.com> Wilhelm Imaging Research, Inc., Box 775, Grinnell, Iowa 50112 U.S.A.
Annex 8

WIR Subzero Newspaper Preservation Collection: p. 213
Cold Storage Publications:


*Imaging Science and Technology* 2008: “Long-Term Preservation of Photographic Originals and Digital Image Files in the Corbis/Sygma Collection in France” p. 222

An overview of how original newspapers are preserved and archived in the WIR/Smithsonian Subzero Preservation Vault. On the right: the publication detailing the digital preservation vacuum table concept planned and built at WIR. This document is published and available for free download on www.wilhelm-imaging.com.
Examples of newspapers which are preserved and archived in the WIR/Smithsonian Subzero Preservation Vault.
High-Security, Sub-Zero Cold Storage
For the PERMANENT Preservation of the
Corbis-Bettmann Archive Photography Collection

Henry Wilhelm* with Ann C. Hartman, Kenneth Johnston, and Els Rijper (Corbis), and Thomas Benjamin (Iron Mountain/National Underground Storage Vital Records)

*Wilhelm Imaging Research, Inc.
Grinnell, Iowa U.S.A.

Abstract
Consisting of more than 13 million B&W and color photographs, the Corbis-Bettmann Archive photography collection spans almost the entire technological history of photography. When the collection was acquired by Bill Gates in 1995, the condition of the materials ranged from almost pristine, in the case of contemporary B&W negatives and color transparencies, to older, seriously faded color images and B&W negatives in which the acetate film base had deteriorated to the point that they were no longer recoverable. To halt further deterioration of this extraordinary collection—and ensure its survival for many thousands of years into the future—it was moved from New York City to an underground home where it would be protected from man-made and natural disasters and, literally, be frozen in eternity in secure sub-zero humidity-controlled storage.

Introduction
"When we acquired the Bettmann Archive in 1995, both Bill and I immediately recognized not only its commercial potential, but even more important, our stewardship obligation. The Corbis Film Preservation Facility, dedicated to the memory of Dr. Otto Bettmann, performs two vital functions. First, it ensures that the collection, one of the most important visual records of the 20th century, will be preserved for generations into the far-distant future. Second, the on-site digitization lab and expert photo researchers on staff who fulfill client requests daily have made the Archive collection accessible to people throughout the world in a way that was simply not possible in the past.”

Steve Davis
President and CEO, Corbis
Seattle, Washington <www.corbis.com>

In the Corbis sub-zero preservation vault are (L to R) Ann Hartman, Manager of Library and Records Management, and Dina Keil and Rhinnya Roberts, Image Library Associates. At the time this photograph was taken, parts of the collection were still being moved into the vault and, during this interim period, it was being maintained at 45°F (7.2°C) and 35% RH. In late 2004, the vault temperature will be lowered to –4°F (–20°C) at 35% RH to assure the permanent preservation of the collection.

Dina Keil in the film, print, and glass plate negative scanning facility equipped with Heidelberg Topaz and Creo Scitex EverSmart scanners and located adjacent to the sub-zero vault. Individual images can be brought out of the vault in moisture-protective packaging, warmed to room temperature, and scanned in less than 45 minutes. High-speed data links allow the images to be sent to any location in the world—and the precious originals need never leave the safety of their secure underground home.
Storage Temperatures and Relative Humidity

Like other historical still photographic and motion picture collections, the Corbis-Bettmann collection – which contains materials dating back more than 100 years – has suffered significant deterioration. The temperature of the storage environment is the major determinant of both color fading and degradation of cellulose acetate film base negatives and color transparencies. As shown in Table 1, lowering the storage temperature to 0°F (–18°C) and below will drastically slow deterioration processes. Relative humidity also plays a roll in both the fading of traditional photographic color images (see Table 2) and in acetate and nitrate film base deterioration, but the gains that can be achieved with controlled RH environments (e.g., 35% RH) are small compared with what can be achieved with very low temperature storage.

Storage at 32°F (0°C) is Not Cold Enough

Storage temperatures in the range of 30°F to 35°F (–1°C to 1.7°C) are simply not low enough to provide adequate long-term preservation of historical photographic and motion picture collections. For example, as shown in Table 3, Kodak Process E-3 Ektachrome Professional films, which were in widespread use until around 1980, will suffer from a “just noticeable” (10%) fading of the least stable dye in only five years when stored at a room temperature of 75°F (24°C) and 40% RH, and are predicted to fade this amount in approximately 100 years when stored at 35°F (1.7°C) provided that they are placed in 35°F storage immediately after processing. By dropping the storage temperature another 35°F to –4°F (–20°C), however, the predicted storage time for a 10% dye loss increases from 100 years to 2,100 years! In other words, lowering the temperature the additional 39°F (18°C) added approximately 2,000 years to the predicted storage time.

With a well-engineered humidity-controlled sub-zero cold storage facility, the additional capital equipment and yearly operational costs to lower the temperature from 35°F to –4°F are relatively small – but the long-term preservation benefits to a collection will be absolutely enormous!

Table 1 Effect of Temperature on Dye Fading Rates at 40% Relative Humidity*

<table>
<thead>
<tr>
<th>Storage Temperature</th>
<th>Relative Storage Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>86°F (30°C)</td>
<td>½X</td>
</tr>
<tr>
<td>75°F (24°C)</td>
<td>1X</td>
</tr>
<tr>
<td>66°F (19°C)</td>
<td>2X</td>
</tr>
<tr>
<td>55°F (13°C)</td>
<td>4X</td>
</tr>
<tr>
<td>45°F (7°C)</td>
<td>10X</td>
</tr>
<tr>
<td>40°F (4°C)</td>
<td>16X</td>
</tr>
<tr>
<td>32°F (0°C)</td>
<td>28X</td>
</tr>
<tr>
<td>14°F (–10°C)</td>
<td>100X</td>
</tr>
<tr>
<td>0°F (–18°C)</td>
<td>340X</td>
</tr>
<tr>
<td>–15°F (–26°C)</td>
<td>1000X</td>
</tr>
</tbody>
</table>

* Derived from: Charleton C. Bard et al., “Predicting Long-Term Storage Dye Stability Characteristics of Color Photographic Products from Short-Term Tests,” Journal of Applied Photographic Engineering, Vol. 6, No. 2, April 1980, p. 44 (with permission). Fading rates of many dyes can be significantly greater when stored where relative humidities are higher than 40%.

Table 2 Effect of Relative Humidity on Fading Rates of Certain Kodak Chromogenic Yellow Dyes*

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Relative Dye Fading Rate at a Specified Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>2X</td>
</tr>
<tr>
<td>40%</td>
<td>1X</td>
</tr>
<tr>
<td>15%</td>
<td>½X</td>
</tr>
</tbody>
</table>

Table 3  Estimated Number of Years for “Just Noticeable” Fading to Occur in Various Kodak Color Materials Stored in the Dark at Room Temperature and Three Cold-Storage Temperatures (40% RH)\(^7\)

<table>
<thead>
<tr>
<th>Time Required for the Least Stable Image Dye to Fade 10% from an Original Density of 1.0</th>
<th>Years of Storage at: 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75°F (24°C)</td>
</tr>
<tr>
<td><strong>Color Papers</strong></td>
<td></td>
</tr>
<tr>
<td>Ektacolor 37 RC Paper (Process EP-3)</td>
<td>10</td>
</tr>
<tr>
<td>(&quot;Kodacolor Print&quot; when processed by Kodak)</td>
<td></td>
</tr>
<tr>
<td>Ektacolor 78 and 74 RC Papers (Process EP-2)</td>
<td>8</td>
</tr>
<tr>
<td>(&quot;Kodacolor Print&quot; when processed by Kodak)</td>
<td></td>
</tr>
<tr>
<td>(&quot;Kodacolor Print&quot;)</td>
<td></td>
</tr>
<tr>
<td>Ektachrome 2203 Paper (Process R-100)</td>
<td>7</td>
</tr>
<tr>
<td>Ektachrome 22 Paper (R-3)</td>
<td>8</td>
</tr>
<tr>
<td><strong>Color Transparency Films</strong></td>
<td></td>
</tr>
<tr>
<td>Ektachrome Films (Process E-3)</td>
<td>5</td>
</tr>
<tr>
<td>Ektachrome Films (Process E-4)</td>
<td>15</td>
</tr>
<tr>
<td>Kodak Photomicroscopy Color Film 2483 (Process E-4)</td>
<td>3</td>
</tr>
<tr>
<td>Ektachrome Films (Process E-6)</td>
<td>52</td>
</tr>
<tr>
<td>(&quot;Group II&quot; types since 1979)</td>
<td></td>
</tr>
<tr>
<td>Ektachrome Plus &amp; &quot;HC&quot; Films (1974)</td>
<td>110</td>
</tr>
<tr>
<td>Ektachrome 64X, 100X, &amp; 400X Films</td>
<td></td>
</tr>
<tr>
<td>Ektachrome 64T and 320T Films (&quot;Group II&quot; types since 1988) (Process E-6)</td>
<td>95</td>
</tr>
<tr>
<td>Kodachrome Films (Process X-14)</td>
<td></td>
</tr>
<tr>
<td>(all types)</td>
<td></td>
</tr>
<tr>
<td><strong>Color Negative Films</strong></td>
<td></td>
</tr>
<tr>
<td>Kodacolor II Film</td>
<td>6</td>
</tr>
<tr>
<td>Kodacolor VR 100, 200, 400 Films</td>
<td>17</td>
</tr>
<tr>
<td>(&quot;initial type&quot;)</td>
<td></td>
</tr>
<tr>
<td>Kodacolor VR-G 100 Film (&quot;initial type&quot;) (Kodacolor Gold 100 Film in Europe)</td>
<td>12</td>
</tr>
<tr>
<td><strong>Color Negative Films</strong></td>
<td></td>
</tr>
<tr>
<td>Vericolor II Prof. Film Type S</td>
<td>6</td>
</tr>
<tr>
<td>Vericolor II Prof. Film Type L</td>
<td>3</td>
</tr>
<tr>
<td>Vericolor II Commercial Film Type S</td>
<td>3</td>
</tr>
<tr>
<td>Vericolor III Prof. Film Type S</td>
<td>23</td>
</tr>
<tr>
<td>Ektacolor Gold 160 Prof. Film</td>
<td></td>
</tr>
<tr>
<td>Vericolor Internegative Film 6011</td>
<td>5</td>
</tr>
<tr>
<td><strong>Motion Picture Color Negative Films</strong></td>
<td></td>
</tr>
<tr>
<td>Eastman Color Negative II Film 5247 (1974)</td>
<td>6</td>
</tr>
<tr>
<td>Eastman Color Negative II Film 5247 (1976)</td>
<td>12</td>
</tr>
<tr>
<td>Eastman Color Negative II Film 5247 (1980)</td>
<td>28</td>
</tr>
<tr>
<td>Eastman Color Negative II Film 5247 (1985 name change)</td>
<td>28</td>
</tr>
<tr>
<td>Eastman Color Negative II Film 7247 (1974-83)</td>
<td>6</td>
</tr>
<tr>
<td>Eastman Color Negative II Film 7291</td>
<td>50</td>
</tr>
<tr>
<td>Eastman EXR Color Negative Film 5245 and 7245</td>
<td>22</td>
</tr>
<tr>
<td>Eastman EXR Color Negative Film 5248 and 7248</td>
<td>30</td>
</tr>
<tr>
<td><strong>Motion Picture Laboratory Intermediate Films</strong></td>
<td></td>
</tr>
<tr>
<td>Eastman Color Reversal Intermediate Film 5249 &amp; 7249</td>
<td>8</td>
</tr>
<tr>
<td>Eastman Color Intermediate II Film 5243 and 7243</td>
<td>22</td>
</tr>
<tr>
<td><strong>Motion Picture Print Films</strong></td>
<td></td>
</tr>
<tr>
<td>Eastman Color Print Film 5381 &amp; 7381</td>
<td>5</td>
</tr>
<tr>
<td>Eastman Color SP Print Film 5383 &amp; 7383</td>
<td>5</td>
</tr>
<tr>
<td>Eastman Color Print Film 5384 &amp; 7384</td>
<td>45</td>
</tr>
</tbody>
</table>

\(^7\) Boldface Type indicates products that were being marketed at the end of 1992; the other products listed had either been discontinued or replaced with newer materials. These estimates are for dye fading only and do not take into account the gradual formation of yellowish stain. With print materials in particular (e.g., Ektacolor papers), the level of stain may become objectionable before the least stable image dye has faded 10%.
“Zero-Tolerance” for Further Deterioration

The storage temperature recommendations for prints and films given in applicable ISO standards are for optimally processed photographs that are placed in controlled storage almost immediately after they are made. In practice, with historical and other collections that are assembled over long periods of time, many photographs will have already exceeded the “maximum” acceptable limits of deterioration by the time cold storage is even considered. To prevent further, unacceptable changes in the images, sub-zero cold storage is essential. One of the goals of the Corbis sub-zero preservation effort is to permanently preserve important historical artifacts such as these Ektachrome transparencies in their original, unchanged form.

A critical part of every historical collection is the identifying information found on deteriorating negative envelopes, caption sheets, rubber stamp impressions, and pressure sensitive stickers on the backs of prints. Sub-zero storage preserves not only the photographic originals, but also the “metadata” that supplies the essential information about “when, where, and who?”

The Corbis-Bettmann collection of 13 million original and duplicate negatives, prints, glass plates, and color transparencies is also a museum of the era of traditional photography which will, essentially, be at an end by 2010. Sub-zero storage preserves everything, including blue “Ditto” spirit duplicator caption slips, card catalogs, magazines, newspapers, and books.

Henry Wilhelm (4)

The guarded entrance to the Iron Mountain/National Underground Storage Vital Records facility, located in a secluded area about an hour’s drive northeast of Pittsburgh, Pennsylvania.

The home to a large number of paper-based, film-based, and digital records centers serving the U.S. government, business, and Hollywood motion picture industry, armed guards and electronic surveillance systems provide security 24 hours a day.

Housed in a former limestone mine that at one time served the Pittsburgh steel industry, new areas in the mine are being cleared for construction of additional records preservation centers.

With an LCD video display showing photographs from the Corbis collection, the entrance to the Corbis Film Preservation Facility has a somewhat otherworldly appearance when one first encounters it deep within the underground limestone mine.

In the newly-named Otto Bettmann Preservation Vault are (L to R) Henry Wilhelm (Wilhelm Imaging Research, Inc.); Thomas Benjamin (Vital Records Product Manager, Iron Mountain); Ann Hartman (Records Management, Corbis); Charles Doughty (Vice President of Engineering, Iron Mountain); and Thomas Roth (General Manager, Vital Records, Iron Mountain).

Refrigeration, dehumidification, and air-filtration systems are located outside the vault for non-disruptive servicing. The year-round 55°F (12.8°C) ambient temperature in the mine provides a steady-state environment for energy-efficient HVAC systems.
References


3. Els Rijper joined the Bettmann Archive in 1984 and served as Preservation Coordinator at the 902 Broadway location in New York City until she left her position in 2001. Els established the Corbis “Very Important Photographs” (VIP) collection to protect and preserve particularly valuable photographs. Rijper’s work culminated in a report submitted to Corbis in November 1997 (with minor revisions, the final report was submitted in September 1999) entitled: A Strategy for the Permanent Preservation of the Corbis-Bettmann Photographic Collections. A key recommendation in the report was that the collection be placed in sub-zero storage as quickly as possible, and that this could only be accomplished by moving the collection out of New York City to the Iron Mountain/National Underground Vital Records Facility, where a suitably humidity-controlled cold storage facility could be constructed for the collection. After considering a range of possible alternatives, Corbis management accepted the plan as the best long-term solution – and also the most cost-effective solution – to the permanent preservation of this historically, culturally, and technologically important collection. The official opening of the new humidity-controlled, sub-zero Corbis Film Preservation Facility took place on April 26, 2002. Henry Wilhelm continues to advise Corbis on preservation and handling issues related to the collection.


5. Henry Wilhelm of Wilhelm Imaging Research, Inc. serves as the lead consultant to Corbis on the preservation of its photographic collections. Responding to an invitation in 1994 from Els Rijper, Wilhelm began an examination of the condition of the wide variety of black-and-white and color film and print materials that make up the collection – and of the then quite inadequate environmental conditions in which the photographs had long been housed on the 5th floor of a older building located at 902 Broadway, near 20th Street in New York City. After Bill Gates acquired the Bettmann Archive in late 1995, an expanded study of the collection was undertaken with the goal of developing a plan for its very-long-term preservation. This work culminated in a report submitted to Corbis in November 1997 (with minor revisions, the final report was submitted in September 1999) entitled: A Strategy for the Permanent Preservation of the Corbis-Bettmann Photographic Collections. Among the key recommendations in the report were that the collection be placed in sub-zero storage as quickly as possible, and that this could only be accomplished by moving the collection out of New York City to the Iron Mountain/National Underground Vital Records Facility, where a suitably humidity-controlled cold storage facility could be constructed for the collection. After considering a range of possible alternatives, Corbis management accepted the plan as the best long-term solution – and also the most cost-effective solution – to the permanent preservation of this historically, culturally, and technologically important collection. The official opening of the new humidity-controlled, sub-zero Corbis Film Preservation Facility took place on April 26, 2002. Henry Wilhelm continues to advise Corbis on preservation and handling issues related to the collection.


8. The estimates given here have been derived from data in Evaluating Dye Stability of Kodak Color Products, Kodak Publication No. CIS-50, January 1981, and subsequent CIS-50 series of dye-stability data sheets through 1985; Kodak Ektachrome Plus and Professional Papers for the Professional Finisher, Kodak Publication No. E-18, March 1986; Dye Stability of Kodak and Eastman Motion Picture Films (data sheets); Kodak Publications DS-100-1 through DS-100-9, May 29, 1981; Image Stability Data: Kodachrome Films, Kodak Publication E-105 (1985); Image Stability Data: Ektachrome Films, Kodak Publication E-106 (1988); and other published sources. For many products, including Process E-6 Ektachrome films; Vericolor III, Vericolor 400, Kodacolor VR, Kodacolor Gold (formerly Kodacolor VR-G), Kodak Gold, and Kodak: Gold Plus color negative films, approximately 40% RH will result in fading rates of the least stable dye (yellow) approximately twice as great as those given here for 40% RH; that is, the estimated storage time for reaching a 10% dye-density loss will be cut in half. Furthermore, the dye stability data given here were based on Arrhenius tests conducted with free-hanging film samples exposed to circulating air. Research published by Eastman Kodak in late 1992 showed that storing films in sealed or semi-sealed containers (e.g., vapor-proof bags and standard taped or non-taped metal and plastic motion picture film cans) probably consider-

**Final Program and Proceedings: IS&T Archiving Conference**

ISBN: 0-89208-251-8

©2004 The Society for Imaging Science and Technology

April 20–23, 2004
The Hyatt Regency San Antonio Hotel
San Antonio, Texas  U.S.A.

Published by:

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org
Long-Term Preservation of Photographic Originals and Digital Image Files in the Corbis/Sygma Collection in France

Henry Wilhelm, Wilhelm Imaging Research (USA); Cédric Gressent, Corbis/Sygma (France); and Drew MacLean, Corbis (USA)

Abstract
Corbis/Sygma in France is one of the most important documentary photography collections in the world. The Corbis “Sygma Preservation and Access Initiative” project began in 2004 to ensure that the collection’s more than 50 million individual objects, including prints, negatives, contact sheets, and color transparencies, will be carefully preserved for thousands of years into the future in a new high-security cold storage facility located in Garnay, France (45 minutes from Paris by train). The second major goal of the project was to make the collection more widely accessible to publishers, the creative community, historians, photographers, students, and others around the world.

Beginning in 2005, a team of Corbis editors and archivists became engaged in the initial phases of the project, leading up to the relocation of the collection from its original home in Paris to the new “Sygma Preservation and Access Facility” in Garnay, scheduled to open on May 14, 2009. This process has involved changing the archive classification system to organize pictures by photographer, rather than by theme, and to better systematize tracking and payment of royalties.

Corbis has been collaborating closely with the many photographers represented in the Sygma collection to make their work more widely available by researching, identifying, and digitizing the most significant photographs in the collection – and making the images available on the Corbis website. During the period from 2002 to 2008, Corbis technicians digitized more than 80,000 prints, negatives, and color transparencies from the Sygma collection to bring the total number available in 2008 at on-line at Corbis.com to more than 850,000 searchable images.

The comprehensive analog and digital preservation program will utilize –20°C (–4°F), humidity-controlled cold storage to preserve the irreplaceable photographic originals in essentially their present condition for many thousands of years into the future. To preserve the high-resolution digital scans of the photographs – and to preserve the digital camera captures made in recent years – Corbis utilizes secure servers which are backed up offsite and has developed a long-term data format migration strategy. Corbis is a private corporation owned by Bill Gates.

The History of the Sygma Photography Collection
In 1973, photographer Hubert Henrotte and other photographers left the photo agency Gamma with their archives and set out to create their own organization. Shortly thereafter they acquired Apis, the agency which gave them access to iconographic material along with the agency’s premises and its photographic laboratory, thus giving birth to Sygma.

The Sygma photographers covered most major international conflicts of this century, including the Vietnam War, the Iranian Revolution, wars in Lebanon, Afghanistan, former Yugoslavia, the events of Tiananmen Square, the fall of the Berlin Wall, and the first Gulf War. In the 1980’s, a new approach to entertainment photography was inaugurated with ‘rendez-vous,’ in which dedicated photographers devoted themselves exclusively to photographing celebrities and other famous personalities. It was during this period that Sygma entered into its golden age.

The 1990’s witnessed a turning point with the digital transmission of photographs during the first Gulf War. Sygma’s own technological evolution continued in 1993, when the agency decided to digitize its images and launch www.sygma.com, with about 750,000 images online. Hubert Henrotte left the agency in June 1998. In 1999 Corbis purchased Sygma, thereby adding an invaluable collection to its worldwide archives. The Sygma collection now represents a photographic heritage of inestimable value, grouping together the collections of three agencies:

• Sygma: photojournalism, news, editorial, magazine photography, celebrities, and portraits
• Kipa: television and movie sets
• Temporsport: sporting events

It also includes other collections dating from the late 1940’s to the 1960’s such as Apis, Universal Photo, Reporters Associés, and Interpress. Together, these collections represent an archive
Imaging Science & Technology 2008: “Long-Term Preservation in the Corbis/Sigma Collection”

of more than 50 million elements, including negatives, contact sheets, slides and prints.

The Sygma Preservation and Access Initiative

In 2004, Corbis announced its “Sygma Preservation and Access Initiative.” Recognizing the richness of the Sygma archive, Corbis set out to find a suitable site for the long-term preservation of the prints, negatives, and color transparencies that comprise one of the largest photography collections in the world. An ambitious project representing significant long-term investment, the initiative would involve reorganizing and relocating more than 50 million images in a new archiving site designed to provide optimum storage conditions, scanning capability, ready access, and ensure the continuity of the collection.

Phase 1: From 2005 to 2008

To launch the initiative, Corbis decided to restructure its archiving system, classifying pictures by photographer rather than by theme. The task was daunting, but deemed necessary, as the new system would allow for a regularization of royalties, as well as facilitate the promotion of the collection and its digitization. This sorting was carried out in conjunction with the signing of archive agreements with photographers. Every Sygma image is the property of its author who alone can decide whether it will be entrusted to Corbis or reclaimed. In the last four years, Corbis has contacted more than 10,000 contributors, offering them an “archive agreement” which enables them to entrust the archiving and commercial development of their work to Corbis.

Publishing the core of the Sygma collection is a multifaceted task. Corbis developed a team of editors who work in close collaboration with the photographers, choosing the very best images for digitization, and bringing the collections to life. Since 2002, more than new 80,000 images from the Sygma collection have been added on the www.corbis.com website, revealing once unknown treasures to the public for the first time, and adding to the wealth of material already available in digital format.

Phase 2: 2008 and Forward

Corbis’ commitment to preserve the Sygma archive involved finding a suitable site which would follow strict criteria for long-term preservation and maximum security in a facility dedicated strictly to Corbis, while providing easy access to the archive by researchers and photographers. Corbis decided to entrust its collection to Locarchives, one of France’s leading archiving and record management firms.[1] The site, located in Garnay near Dreux, is only 45 minutes from western Paris, offering easy access by car or train from the capital.

Locarchives managed the construction of the 800 m² site for the exclusive use of Corbis. It is equipped with sophisticated humidity and temperature controls, an airtight environment, and has optimal fire safety and intrusion protection.

With such an extensive inventory, the relocation of the archive was indeed complex. For that reason, Corbis again called upon Locarchives for the safe transfer of the archive from the Paris location to the preservation site. The move will take place in two phases. In the summer of 2008, the material will be safely packed into boxes, tracked and stored in a temporary location while the seven linear kilometers of shelving at the Paris office is dismantled and upgraded for the new facility, where it will be reassembled. The archive will then be moved into its new home.

In order to ensure optimal preservation of the Sygma collection, Corbis asked Henry Wilhelm of Wilhelm Imaging Research, Inc. to serve as a consultant and advisor on preservation.[2-4] As the Sygma collection is a working collection with high demands on accessibility, the difficulty for Corbis lay in finding the right balance between preserving these archives in an unchanging environment and granting quick and easy access with minimal impact to the material.

To satisfy these conflicting requirements, the preservation facility is divided into three vaults, each of which operates at a different temperature depending on the nature of the material, and the anticipated frequency of access.

• The first section, with a maximum temperature of –3°C (26°F) and 40% relative humidity (RH), houses the oldest collections of negatives and prints, complying in full with the applicable ISO 18911 and ISO 18920 storage standards.[5-6]

• The second section, with a temperature of 14°C to 16°C (57°F to 61°F) and 40% RH, is provided for the core of the collection including the original selects, which are often subject to requests for immediate digitization.

• The third section, set at 18°C (65°F) and 40% RH, is provided for the rest of the archives, composed mostly of duplicates, prints, and non-selects for which there remains a great deal of work to be done in terms of organization and indexing. These conditions allow the staff to work comfortably for extended periods dressed in normal office clothing.

After organization and indexing are completed, the temperature in the new facility will be gradually lowered to –20°C (~4°F) and 40% RH. This will stop the slow but inexorable deterioration of the collection. The color images, prints, and acetate base black-and-white negatives and transparencies will be preserved essentially unchanged – in their original form – for many thousands of years into the future.[7-9]

If the collection had remained in the uncontrolled, room temperature conditions where it had been kept in Paris for so many years, it would have perished before the end of this century.

The Sygma/Corbis collection will continue to be freely accessible to photographers, iconographers, historians and researchers in the future, with scanning capabilities onsite. The formal opening of the new facility is scheduled for May 14, 2009.
Table 1 Maximum temperatures and relative humidity ranges for extended-term storage specified in ISO 18911 (2000)

<table>
<thead>
<tr>
<th>Image</th>
<th>Base</th>
<th>Maximum temperature</th>
<th>Relative humidity range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>°C</td>
<td>%</td>
</tr>
<tr>
<td>Black-and-white silver-gelatin&lt;sup&gt;d&lt;/sup&gt; (see ISO 10602)</td>
<td>Cellulose esters&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2</td>
<td>20-50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Black-and-white silver-gelatin&lt;sup&gt;d&lt;/sup&gt; (see ISO 10602) Thermally or processed silver (see ISO 18919) Vesicular (see ISO 9718) Silver dye bleach</td>
<td>Polyester</td>
<td>21</td>
<td>20-50</td>
</tr>
<tr>
<td>Colour (chromogenic)</td>
<td>Cellulose esters&lt;sup&gt;e&lt;/sup&gt;</td>
<td>–10</td>
<td>20-50</td>
</tr>
<tr>
<td></td>
<td>Polyester</td>
<td></td>
<td>–3</td>
</tr>
<tr>
<td>Diazoo (see ISO 8225)</td>
<td>Polyester</td>
<td>2</td>
<td>20-30</td>
</tr>
</tbody>
</table>

<sup>a</sup> See annex H for storage of historic still photographic records.
<sup>b</sup> Cycling of temperature shall not be greater than ± 2 °C over a 24 h period.
<sup>c</sup> Cycling of relative humidity shall not be greater than ± 5 % RH over a 24 h period.
<sup>d</sup> If there is concern about the possibility of silver image oxidation due to atmospheric contaminants, poor quality enclosures, and/or excessively high temperature and humidity levels, a post-process chemical conversion treatment can be used to provide added protection (see ISO 18915).
<sup>e</sup> This includes cellulose triacetate, cellulose acetate butyrate, and cellulose acetate propionate.

Older black-and-white and color films and prints, such as those found in the Corbis/Sygma collection, should be stored at a very low temperature to halt further deterioration. ISO 18911:2000 (Informative Annex H “Historic photographic records”) states: “Since the colour images of most types of older colour files (for example, incorporated coupler transparency films manufactured prior to around 1980) are intrinsically less stable than the films being manufactured at this time and because of changes as a result of storage over the years, storage temperatures significantly lower than the maximum temperatures specified in Table 1 (above) should be provided to prolong their life. This is also true for older black-and-white films on acetate film base that may be showing evidence of degradation.”[5]

Table 2 Effect of Temperature on Dye Fading Rates at 40% Relative Humidity*

<table>
<thead>
<tr>
<th>Storage Temperature</th>
<th>Relative Storage Time</th>
<th>Effect of Temperature on Dye Fading Rates at 40% Relative Humidity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>86°F (30°C)</td>
<td>1⁄4X</td>
<td></td>
</tr>
<tr>
<td>75°F (24°C)</td>
<td>1X</td>
<td></td>
</tr>
<tr>
<td>66°F (19°C)</td>
<td>2X</td>
<td></td>
</tr>
<tr>
<td>55°F (13°C)</td>
<td>4X</td>
<td></td>
</tr>
<tr>
<td>45°F (7°C)</td>
<td>10X</td>
<td></td>
</tr>
<tr>
<td>40°F (4°C)</td>
<td>16X</td>
<td></td>
</tr>
<tr>
<td>32°F (0°C)</td>
<td>28X</td>
<td></td>
</tr>
<tr>
<td>14°F (–10°C)</td>
<td>100X</td>
<td></td>
</tr>
<tr>
<td>0°F (–18°C)</td>
<td>340X</td>
<td></td>
</tr>
<tr>
<td>–15°F (–26°C)</td>
<td>1000X</td>
<td></td>
</tr>
</tbody>
</table>

<sup>*</sup> Derived from: Charleton C. Bard et al., “Predicting Long-Term Storage Dye Stability Characteristics of Color Photographic Products from Short-Term Tests,” Journal of Applied Photographic Engineering, Vol. 6, No. 2, April 1980, p. 44 (with permission). Fading rates of many dyes can be significantly greater when stored where relative humidities are higher than 40%.

Table 3 Effect of Relative Humidity on Fading Rates of Certain Kodak Chromogenic Yellow Dyes*

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Relative Dye Fading Rate at a Specified Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>2X</td>
</tr>
<tr>
<td>40%</td>
<td>1X</td>
</tr>
<tr>
<td>15%</td>
<td>1⁄4X</td>
</tr>
</tbody>
</table>

Table 4  Estimated Number of Years for “Just Noticeable” Fading to Occur in Various Kodak Color Materials Stored in the Dark at Room Temperature and Three Cold-Storage Temperatures (40% RH)<sup>8</sup>

Time Required for the Least Stable Image Dye to Fade 10% from an Original Density of 1.0

Boldface Type indicates products that were being marketed at the end of 1992; the other products listed had either been discontinued or replaced with newer materials. These estimates are for dye fading only and do not take into account the gradual formation of yellowish stain. With print materials in particular (e.g., Ektacolor papers), the level of stain may become objectionable before the least stable image dye has faded 10%.

<table>
<thead>
<tr>
<th>Color Papers</th>
<th>Years of Storage at:&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Color Negative Films</th>
<th>Years of Storage at:&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24°C</td>
<td>7.2°C</td>
<td>1.7°C</td>
</tr>
<tr>
<td></td>
<td>(75°F)</td>
<td>(45°F)</td>
<td>(35°F)</td>
</tr>
<tr>
<td>Ektacolor 37 RC Paper (Process EP-3)</td>
<td>10</td>
<td>95</td>
<td>200</td>
</tr>
<tr>
<td>Ektacolor 78 and 74 RC Papers (Process EP-2) (“Kodacolor Print” when processed by Kodak)</td>
<td>8</td>
<td>75</td>
<td>160</td>
</tr>
<tr>
<td>Ektacolor Plus Paper (Process EP-2) (“Kodacolor Print”) (“Kodalux Print”)</td>
<td>37</td>
<td>350</td>
<td>750</td>
</tr>
<tr>
<td>Ektacolor Professional Paper (Process EP-2) (“Kodacolor Print”) (“Kodalux Print”)</td>
<td>8</td>
<td>75</td>
<td>160</td>
</tr>
<tr>
<td>Ektachrome 2203 Paper (Process R-10G)</td>
<td>7</td>
<td>65</td>
<td>140</td>
</tr>
<tr>
<td>Ektachrome 22 Paper (R-3)</td>
<td>8</td>
<td>75</td>
<td>160</td>
</tr>
<tr>
<td><strong>Color Transparency Films</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ektachrome Films (Process E-3)</td>
<td>5</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>Ektachrome Films (Process E-4)</td>
<td>15</td>
<td>140</td>
<td>300</td>
</tr>
<tr>
<td>Kodak Photomicrography Color Film 2483 (Process E-4)</td>
<td>3</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td>Ektachrome Films (Process E-6) [“Group II” types since 1979]</td>
<td>52</td>
<td>500</td>
<td>1, 100</td>
</tr>
<tr>
<td>Ektachrome Plus &amp; “HC” Films 110</td>
<td>1,000</td>
<td>2,200</td>
<td>45,750</td>
</tr>
<tr>
<td>Ektachrome 64X, 100X, &amp; 400X Films</td>
<td>52</td>
<td>500</td>
<td>1, 100</td>
</tr>
<tr>
<td>Ektachrome 64T and 320T Films [“Group II” types since 1988 (Process E-6)]</td>
<td>52</td>
<td>500</td>
<td>1, 100</td>
</tr>
<tr>
<td>Kodachrome Films (Process K-14) [all types]</td>
<td>95</td>
<td>900</td>
<td>1,900</td>
</tr>
<tr>
<td><strong>Color Negative Films</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kodacolor II Film</td>
<td>6</td>
<td>55</td>
<td>120</td>
</tr>
<tr>
<td>Kodacolor VR 100, 200, 400 Films</td>
<td>17</td>
<td>160</td>
<td>340</td>
</tr>
<tr>
<td>Kodacolor VR-G 100 Film (“initial type”)</td>
<td>12</td>
<td>115</td>
<td>240</td>
</tr>
<tr>
<td>Kodacolor Gold 100 Film in Europe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

©2008 Society for Imaging Science and Technology
Between 2000 and 2008, the Corbis/Sygma collection was stored in rented office space in the Lumiere Building in Paris. Without refrigeration or humidity-control, the storage conditions were not adequate to preserve the films and prints in the collection. Corbis planned to move its office to a new location in Paris in 2009.

Cédric Gressent inspecting a shelf of new flat file negative and transparency storage boxes, in preparation for packing them for transport to Garnay in 2008. Many thousands of the new boxes were required, and all had to be cataloged, labeled, and entered into the collection’s database so that the physical location of each box, and every item in the box, could be tracked.

To move the entire collection, approximately 14,000 shipping boxes were filled, and information for both the contents and the boxes themselves was carefully entered into the tracking system.

In preparation for the move to Garnay, prints, negatives, and color transparencies were carefully removed from the shelves and placed in shipping boxes. A sophisticated barcoded tracking system was developed to make certain that none of the 50 million items involved in the move could be misplaced. The collection consists of more than 7 kilometers of linear shelf space.

More than 48 truck loads of boxes were required to move the collection from Paris to the new preservation facility in Garnay.
The Corbis world headquarters and central computer operations are located in a renovated former bank building in Seattle, Washington. Corbis also maintains regional offices throughout the world.

A large-scale EMC data storage system provides on-line storage for high-resolution scans of analog films and prints, as well for digital camera files. Secure, offsite back-up is also provided.

Drew MacLean (left), Corbis vice president for media services and operations, in the high-bandwidth server facilities at Corbis headquarters. The clustered servers deliver on-line search, image access, and purchase transactions for www.corbis.com.

High-bandwidth Internet support systems are housed in this room. These 24/7 systems with backup power supplies serve Corbis regional offices, Corbis customers, and other visitors to the Corbis website throughout the world.

Long-Term Preservation of Digital Image Data

While Corbis is carefully implementing a sophisticated preservation and access program, it is also simultaneously digitizing and marketing thousands of new images each month. With the consent of the photographers who have signed agreements with Corbis, many of these images are from the Sygma collection.

Corbis is a creative resource for editorial, advertising, marketing and media professionals worldwide, providing high-quality photography, video footage, and rights services. Corbis offers a diverse collection of more than 100 million creative, entertainment and historic images, a comprehensive video footage library, one of the world’s most wide ranging rights and clearances services, and a sophisticated media management solution. Corbis also operates SnapVillage, an innovative microstock web site. It is Corbis’ mission to not only preserve photography and video footage, but also to digitize, enhance the search metadata, market, and display the images for Corbis customers. The Corbis collection is constantly growing, providing an increasingly broad range of high quality and historically significant photographs to people around the world.

To facilitate this, Corbis follows strict sourcing, production, and archiving guidelines to insure that the photography and footage are available in the most suitable format – and in the highest quality – for Corbis clients. This standards-based process of converting analog images to searchable digital files requires professional editing, high-end scanning equipment, advanced digital imaging software, a comprehensive, controlled vocabulary, and a team of skilled and dedicated professionals. This combination of technology and visual sensitivity to im-
A Note on Storage Temperature and Relative Humidity

Because the materials in the Corbis/Sygma collection are relatively recent – with the majority of the photographs made after around 1950 – the overall condition of the films and prints is still reasonably good. The goal of the Corbis/Sygma Preservation and Access Initiative is to keep the collection that way – to preserve the photographers’ films and prints in their original form – far into the future. The temperature of the storage environment is the major determinant of the rates of both color fading and degradation of cellulose acetate film base negatives and color transparencies. As shown in Table 2, lowering the storage temperature to –18°C (0°F) and below will drastically slow the deterioration process. Relative humidity also plays a roll in both the fading of traditional photographic color images (Table 3) and in acetate and nitrate film base deterioration, but the gains that can be achieved with controlled RH environments (e.g., 35% RH) are small compared with what can be achieved with very low temperature storage.

For example, as shown in Table 4, Kodak Process E-3 Ektachrome Professional films, which were in widespread use until around 1980, will suffer from a “just noticeable” (10%) fading of the least stable dye in only five years when stored at a room temperature of 24°C (75°F) and 40% RH, and are predicted to fade this amount in approximately 100 years when stored at 1.7°C (35°F) provided that they are placed in 1.7°C storage immediately after processing. However, by lowering the storage temperature another 18°C to –20°C (–4°F), the predicted storage time for a 10% dye loss increases from 100 years to 2,100 years. In other words, lowering the temperature the additional 18°C (39°F) added approximately 2,000 years to the storage time before a 10% dye loss is predicted to occur!

With a well-engineered humidity-controlled subzero cold storage facility, the additional capital equipment and yearly operational costs to lower the temperature from 1.7°C to –20°C are relatively small – but the long-term preservation benefits to a collection will be enormous!

References
[1] Locarchives headquarters are located near Paris at 5, rue Jean Martin, 93582 Saint-Ouen Cedex, France; tel: 01.49.33.78.00; www.locarchives.fr.
[3] Henry Wilhelm has served as an advisor to Corbis on the preservation of its photographic collections since 1997. He has been a consultant on the preservation of the Corbis/Sygma collection in France since 2005. Wilhelm’s initial work on preservation of what are now the Corbis collections began in 1994, in response to a request from Els Rijper, who was with the Bettmann Archive before it became part of Corbis. Rijper asked Wilhelm to conduct an examination of the condition of the wide variety of black-and-white and color film and print materials that made up the Bettmann Archive collection – and of the then quite inadequate environmental conditions in which the photographs had long been housed on the 5th floor of an older office building located at 902 Broadway, near the corner of 20th Street, in New York City. After Bill Gates ac-
quired the Bettmann Archive in late 1995, an expanded study of the collection was undertaken with the goal of developing a plan for its very-long-term preservation. This work culminated in a report submitted to Corbis in November 1997 (with minor revisions, the final report was submitted in September 1999) entitled: "A Strategy for the Permanent Preservation of the Corbis-Bettmann Photographic Collections." Among the key recommendations in the report were that the collection be placed in sub-zero storage as quickly as possible, and that this could best be accomplished by moving the collection out of New York City to the high-security Iron Mountain/National Underground Vital Records Facility (located in rural Boyers, Pennsylvania, north of Pittsburgh) where a suitable humidity-controlled cold storage facility could be constructed for the collection. After considering a range of possible alternatives, Corbis management accepted the plan as the best long-term solution—and also the most cost-effective solution—to the permanent preservation of this historically, culturally, and technologically important collection. The official opening of the new humidity-controlled, sub-zero Corbis Film Preservation Facility took place on April 26, 2002.


[8] The estimates given here have been derived from data in Evaluating Dye Stability of Kodak Color Products, Kodak Publication No. CIB-30, January 1981, and subsequent CIB-30 series of dye-stability data sheets through 1985; Kodak Ektacolor Plus and Professional Papers for the Professional Finisher, Kodak Publication No. E-18, March 1986; Dye Stability of Kodak and Eastman Motion Picture Films (data sheets); Kodak Publications DS-100-1 through DS-100-9, May 29, 1981; Image-Stability Data: Kodachrome Films, Kodak Publication E-105 (1988); and other published sources. For many products, including Process E-6 Ektachrome films; Vericolor III, Vericolor 400, Kodacolor VR, Kodacolor Gold (formerly Kodacolor VR-G), Kodak Gold, and Kodak Gold Plus color negative films; and Eastman color motion picture films, storage at 60% RH will result in fading rates of the least stable dye (yellow) approximately twice as great as those given here for 40% RH; that is, the estimated storage time for reaching a 10% dye-density loss will be cut in half. Furthermore, the dye stability data given here were based on Arrhenius tests conducted with free-hanging film samples exposed to circulating air. Research published by Eastman Kodak in late 1992 showed that storing films in sealed or semi-sealed containers (e.g., vapor-proof bags and standard taped or non-taped metal and plastic motion picture film cans) could substantially increase the rates of dye fading and film base deterioration. Therefore, the estimates given here for color motion picture films probably considerably overstate the actual stabilities of the films when they are stored in standard film cans under the listed temperature and humidity conditions. See: A. Tulsi Ram, D. Kopperl, R. Sehlin, S. Masaryk-Morris, J. Vincent, and P. Miller [Eastman Kodak Company], “The Effects and Prevention of ‘Vinegar Syndrome’,” presented at the 1992 Annual Conference of the Association of Moving Image Archivists (AMIA), San Francisco, California, December 10, 1992.


Authors’ Biographies

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-S/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-S/TG-3 Technical Subcommittee on test methods for 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 recipient of the Photographic Imaging Manufacturers and Distributors Association (PMBA) “2007 Lifetime Achievement Award” for his work on evaluation of the permanence of traditional and digital color prints and for his advocacy of very low temperature cold storage (minus 20 degrees C [minus 4 degrees F]) at 40% RH for the permanent preservation of black-and-white and color prints, color negatives, transparencies, and motion picture films.

Cédric Gressent served as the original Project Manager for the “Sygma Preservation and Access Initiative.” In 2008 he was appointed Corbis’ Manager of Services for Europe, Middle East, and Africa (EMEA) region. Cédric joined the photographic industry in 1999 at Kipa Interpress just before the company entered into the Corbis Group, which includes such famous agencies and collections as Sygma and Tempoprint. Cédric held various positions in the financial and sales departments of Corbis before becoming Project Manager for the Sygma Initiative. As Manager of Services, Cédric currently leads the Archive Department and Media Production in Paris, as well as the Office Operations of various facilities in Europe. Cédric holds a DEUG in English studies and a BTS in Business Management.

Drew MacLean serves as Corbis Vice President of Operations. Drew has been a member of the Corbis team since 2000 and works out of the Seattle headquarters. He is responsible for both media production, film preservation, and all Corbis facilities. Prior to coming to Corbis, Drew was a production manager for the Boeing Company in Seattle where he held various positions in manufacturing and manufacturing support in the Commercial Airplane Division. Early in his career he was a helicopter pilot in the U.S. Marine Corps.
The abstract for this paper by Henry Wilhelm (Wilhelm Imaging Research, USA); Cédric Gressent (Corbis/Sygma, France); and Drew MacLean (Corbis, USA), entitled: “Long-Term Preservation of Photographic Originals and Digital Image Files in the Corbis/Sygma Collection in France” appeared on page 257 in:

Archiving 2008 Final Program and Proceedings

General Chair: Rudolf Gschwind, University of Basel


©2008 The Society for Imaging Science and Technology

June 24–27, 2008
The University of Bern
Bern, Switzerland

The full paper with supporting materials was presented at the conference on June 26, 2008

Published by:

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151  U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org
The Design and Operation of a Passive Humidity-Controlled Cold Storage Vault Using Conventional Freezer Technology and Moisture-Sealed Cabinets

Mark McCormick-Goodhart and Henry Wilhelm
Wilhelm Imaging Research, Inc.
Grinnell, Iowa/USA

Abstract

This paper presents results from a research project sponsored by the Smithsonian Institution to construct and operate a low-cost subzero temperature storage vault for photographic and manuscript collections. It uses conventional walk-in freezer technology and passive moisture control methods to achieve large savings in both construction and ongoing operational costs.

Introduction

The ultimate design for a low temperature storage facility to preserve a photograph and manuscript collection would incorporate the following features:

1) Redundant compressors and dehumidification equipment combined with electrical generator back-up to provide an uninterrupted steady-state environment at approximately –20˚C (–4˚F) and 25% RH.

2) An inert fire suppression system backed up by a dry pipe sprinkler system.

3) Special cabinets to isolate the collection materials from direct contact with water in the event of sprinkler system action or other situations where water might enter the vault. At the same time the cabinets would allow ventilation with perhaps four to five air exchanges daily. Volatile gases emanating from the collection materials (e.g., residual solvents from inkjet prints, acetic acid from dye transfer prints or degraded films, etc.) would thus be prevented from building up potentially interacting with other items inside each cabinet.

4) Filtered make-up air entering the vault to completely exchange at least four times daily. The incoming air would be filtered to remove dust and air pollutants such as ozone, nitrous oxides and sulfur dioxides, etc.

5) Thermally insulated and heated windows to allow especially fragile objects to remain inside the vault while permitting viewing by patrons situated in an adjoining room maintained at human comfort levels.

6) Placement or removal of materials from the vault accomplished not by a single intermediate temperature staging room, but by a chamber or room that allows temperature to be ramped up and down according to a very gradual pre-programmed cycle. Such a controlled temperature gradient is not needed to prevent thermal shock. Thermal shock is not an issue with cold stored photographic materials. Rather, the staging room guarantees that moisture gradients do not form within archival boxes or oversized framed items that do not have uniform thermal conductivity.

7) A security system and item tracking capability as required.

The vault described above is technologically possible, but it would be very expensive to build and operate. High air exchange rates require constant cooling and conditioning of the make-up air, and operating costs would escalate dramatically. Few museums and archives will undertake this idealized specification. Large financial resources are usually allocated to high-profile exhibits that generate immediate public good will, not to the unglamorous but vital task of upgrading storage environments for important collections.

Fear of unknown or untested storage recommendations within the conservation community has also slowed the adoption of cold storage on a large scale even though the museum world can now examine an over thirty year record of low temperature storage results. The implementation of low temperature storage for photographic collections has its roots in a key paper published by Adelstein, Graham, and West in 1970.

Museums and archives must take a more pragmatic approach in order to increase the percentage of 19th and 20th century materials that will be optimally preserved.
by means of low temperature storage. Many conservators are now admirably undertaking special packaging methods to store small but important collections of photographic films and prints in reach-in refrigerators or freezers. The methods are relatively low cost and practical for small collections, particularly ones of a very modular nature such as motion picture film cans or still film collections of negatives and/or transparencies. They become far less practical for large volumes of material or for prints of varying sizes, especially ones with very large formats. For bigger collections, a walk-in vault is more appropriate, but the cost and complexity of the project increases significantly. To date, walk-in cold storage vaults for photographic collections have employed high volume desiccant dryer technology in order to actively control the relative humidity level inside the vault. Combining refrigeration equipment with high volume desiccant dryers in a way that operates efficiently and also shuts down safely upon component failure requires the hiring of contractors with specialized knowledge of this application. Construction and ongoing maintenance is significantly higher than typical walk-in refrigerators and freezers built and serviced so widely in the food industry.

In 1998, Wilhelm Imaging Research, Inc. began a cold storage research project to design, build, and operate a subzero temperature vault that passively controls moisture content of the collection materials using cabinets with sealed gaskets in lieu of active dehumidification equipment. The project was funded by a grant from the Smithsonian Institution in Washington, DC. The objective was to create an alternative method, one that combines the simplicity and cost effectiveness of conventional freezer technology with the collection management benefits of easier access to collection materials unencumbered by special packaging and repackaging requirements. Using this new approach, a conventional walk-in freezer of the type routinely installed by local refrigeration contractors was constructed. Moisture control is accomplished by sealed cabinetry as shown in Figure 1. It is important to note that the required moisture control takes advantage of the natural moisture buffering properties of the collection materials as well as the degrees of freedom afforded by more recent research into the allowable temperature and RH limits for the safe use and storage of photographic materials. The vault

Figure 1. Henry Wilhelm (left) and Mark McCormick-Goodhart stand inside the WIR cold storage vault. On the left wall (front to back) are cabinets VK2, SF1, and VK1. At center is SF2, and on the right (back to front) are cabinets DD1, DD2, and DD3. Refer to Table 1 for humidity measurements taken inside the respective cabinets. Note, also, the vinyl magnetic material covers on the recessed handles of some cabinets, the latex painted plywood for floor protection underneath the cabinets, and the acclimatization boxes made from ordinary picnic coolers.

**Freezer Construction**

Site preparation work was minimal since Wilhelm Imaging Research, Inc. (WIR) had free space with a level concrete floor in the interior of the building to locate the walk-in vault. By keeping the vault located a few feet away from the foundation exterior of the heated building, it was determined that an additional concrete pad with heated wires to prevent frost heaving of the building floor would not be necessary. The electrical hook-up cost approximately $2,000 dollars and made use of the building’s three phase wiring capability. Powering the vault with three phase electrical wiring adds approximately 30% operating efficiency over single phase wiring. Our chosen local contractor, Industrial Refrigeration Services, Inc., was given a design specification for a 12.5 ft.(W) x 15 ft(L) X 9.5 ft.(H) conventional walk-in freezer to operate at −20°C (−4°F). A 42 inch wide heated door with heated window was also specified. Dimensions are critical in the design of a vault. The door had to be wide enough to bring the chosen cabinets into the vault, and the ceiling height had to allow clearance as the tall cabinets are brought horizontally though the door and then erected to stand in their final vertical position. The cost of the freezer was quoted at $17,450 bringing the total installation cost estimate to approximately $20,000 including the electrical hook-up. The vault took only 4 days to build and become operational. The cabinets are placed on outer walls with 4-6 inch clearance behind them to ensure good circulation and a uniform temperature envelope. One concern was that the cabinets are very heavy, and especially so when fully loaded. The Viking cabinets, in particular, use very small diameter leveling castors which might exceed the punch-through load rating of the floor panels. Quarter inch stainless steel floor liners are widely available in the industry for walk-in coolers that must carry heavy loads (e.g., where forklift trucks are used). However, we did not order this additional protection. Rather, we placed one inch thick latex-primed and painted plywood underneath the cabinets as can be seen in Figure 1.

During the initial days of operation a few problems were identified and corrected. The door heaters had been inadequately equipped for the subzero temperature operation, and frost began to build at the base of the door. The contractor opened the panel and installed additional heat tape which corrected this problem. Additionally, we asked the contractor to modify the wiring to the evaporator coil fans. In normal food applications, the fans are wired to run even when the compressors are off. This has the effect of evaporating water frozen on the coils and returning it to the room. For food applications, this extra humidity is desirable. For photographs, the natural dehumidification provided by the frozen evaporator coils is desired, so the wiring was changed to turn the fans off when the compressors are not running. This modification was trivial for the contractor to accomplish, and the modified operational behavior lowered the average humidity in the walk-in freezer from over 75% to about 58% RH. Lastly, we upgraded the freezer to a digital temperature controller (readily available in the industry) and added a power meter to give us precise data on the actual operating cost of the vault over time. The modifications and additions to the project brought the final construction cost to $22,275. Compare this figure to an actively dehumidified cold vault of similar size which would have cost $55–80K.

**Passive Moisture Control At Low Temperature**

Passive climate control is a well established concept in museums. Sealed display cases containing moisture buffering materials such as silica gel are routinely used to create stable relative humidity conditions that are maintained in the display case for weeks or months at a time. Generally, for large display cases containing collection objects that may or may not have much moisture buffering capacity in their own right, a significant amount of conditioned silica gel or other buffering agent is pre loaded into the display case to create the stable climate. Such heavy use of conditioning agent would be impractical for a large cold vault with many cabinets. However, calculations based on standard psychometric principles demonstrate that at subzero temperatures the absolute amount of available airborne moisture is two orders of magnitude lower than at room temperature. This is one reason why high volume desiccant dryers become inefficient and expensive to operate at low temperature. They are trying to scavenge much fewer numbers of water molecules from the air in order to maintain the low relative humidity in the cold air. Recall that moisture content in the collection materials is proportional to relative humidity not absolute humidity. On the other hand, the properties of low temperature air work to our advantage for passive moisture control because the volume of desiccant required to offset the moisture entering the cabinets can be greatly reduced. The need to periodically replace the desiccant is also proportionately reduced. Moreover, the moisture absorbing properties of paper and photographic materials also serves as a large moisture buffering reservoir, and this capacity is enormous when the cabinet is moderately to fully loaded with items.
Sealed Gasket Cabinet Issues

Sealed gasket cabinets are available as stock items to the museums and archives community. The Smithsonian Institution, for example, uses them extensively at the Museum Support Center located in Suitland, Maryland to house natural history specimens. The cabinets feature doors that close against a silicone or elastomeric gasket, preventing among other things, insect infestation. Locking doors and easy gliding shelving features add many convenient handling and security features. One objective in this research project was to determine if stock cabinets would provide satisfactory moisture control performance in a subzero temperature environment without requiring serious modifications. Three vendors kindly donated samples of their cabinets.

One cabinet featured glass viewing doors and had stationary but adjustable shelves. Two were designed to hold large flat files on sliding shelves (e.g., matted photographic prints as large as 35 x 50 inches) and were countertop height. Two were small storage cabinets also of countertop height. Two cabinets were tall double-door units with convenient retractable shelving that glided on smooth bearings. The tall vertical cabinets required the 9.5 ft. high ceiling to erect once inside the vault. The total storage capacity of the donated cabinets is 367 cu. ft. With net capacity utilization factored at 50% the WIR cold vault presently has a net storage capacity of 183 cu. ft. Had we purchased cabinets for the vault, the net storage capacity could have been optimized in excess of 250 cu. ft. It would take approximately 24 domestic reach-in freezers to achieve this storage volume, and, of course, large photographic prints would be difficult if not impossible to fit into reach-in style freezers.

Moisture vapor transmission rate (MVTR) studies were conducted to determine the moisture buffering performance of the cabinets. One surprising result of this investigation was that two of the three cabinet manufacturers’ products required a significantly re-engineered seal design. Both vendors use a silicone seal that did not adequately seal when the doors were closed no matter how carefully the cabinets were aligned and leveled. This fact could be seen by simple visual inspection of the cabinets, and it is therefore surprising that the problem went unnoticed by the manufacturers. We retrofitted the offending cabinets with a new gasket that was made using elastomeric automotive gasket material obtained at a local auto supply store. This task was time consuming, but we succeeded in bringing these cabinets up to the MVTR performance level we were looking for. The third vendor, Viking Metal Cabinet Company, uses an elastomeric seal design neatly trapped in a metal channel of the cabinet. The two cabinets donated by Viking Metal Cabinet Company required no modification to the seals, and were determined to function very successfully.

Support Center located in Suitland, Maryland to house natural history specimens. The cabinets feature doors that close against a silicone or elastomeric gasket, preventing among other things, insect infestation. Locking doors and easy gliding shelving features add many convenient handling and security features. One objective in this research project was to determine if stock cabinets would provide satisfactory moisture control performance in a subzero temperature environment without requiring serious modifications. Three vendors kindly donated samples of their cabinets.

Moisture vapor transmission rate (MVTR) studies were conducted to determine the moisture buffering performance of the cabinets. One surprising result of this investigation was that two of the three cabinet manufacturers’ products required a significantly re-engineered seal design. Both vendors use a silicone seal that did not adequately seal when the doors were closed no matter how carefully the cabinets were aligned and leveled. This fact could be seen by simple visual inspection of the cabinets, and it is therefore surprising that the problem went unnoticed by the manufacturers. We retrofitted the offending cabinets with a new gasket that was made using elastomeric automotive gasket material obtained at a local auto supply store. This task was time consuming, but we succeeded in bringing these cabinets up to the MVTR performance level we were looking for. The third vendor, Viking Metal Cabinet Company, uses an elastomeric seal design neatly trapped in a metal channel of the cabinet. The two cabinets donated by Viking Metal Cabinet Company required no modification to the seals, and were determined to function very successfully at subzero temperature after one minor correction was made. Our MVTR tests revealed that key hole in the door lock on most cabinets was a significant source of air leakage into the cabinets (one company’s cabinet design uses a double panel door construction that isolates the lock mechanism from the cabinet interior which eliminates the problem). We simply taped the keyholes closed with an aluminum foil tape on the cabinets with standard door handles, and also covered the larger recessed style handles with easily removable vinyl magnetic signage material. The reason a small hole increases MVTR in the cabinets so dramatically relates to barometric pressure. As the air in the vault cycles in temperature by a few degrees while the interior temperature of the cabinets remains more stable due to thermal mass, a small but significant pressure differential between the vault air and the cabinet air occurs if the cabinets are truly sealed. This pressure differential serves to “push” air in and out of a key hole thus equalizing the pressure and in turn more rapidly exchanging

Acclimatization

The WIR vault was deliberately designed without a staging room. Our approach to bringing materials in and out of the vault was also to once again use cost-effective passive climate control methods. Dehumidified cold vaults have traditionally made use of an antechamber or “staging” room that operates at an intermediate temperature halfway between the cold zone and the ambient room temperature in the user environment. This staging room is also dehumidified to low RH levels. The use of a temporary vapor barrier such as a recloseable polyethylene bag has also been recommended as a practical method for item transfer, the theory being that condensation is kept to the outside surface of the bag. We had never questioned either methodology until we conducted some staging experiments that brought to light a potential problem with both approaches. The intermediate temperature/low RH approach may prevent condensation for cold vaults operating at above freezing temperatures, but may fall short of that mark when subzero vaults are employed. Furthermore, the low RH in the staging room only has relevance to the outside of the container or box that houses the collection material. Internally, the RH may be higher, especially when a document box, for example, has not had the often lengthy time needed to equilibrate to a dehumidified cold vault climate. When a steep temperature gradient forms across a container that has hygroscopic walls (e.g., a document box made of mat board) the walls will warm faster than the contents of the box, and moisture can then be released from the box walls, increase the RH inside the free space in the box, and in a worse case scenario condense on the colder contents inside the box. Neither a staging room with low RH nor a vapor barrier surrounding the box can prevent this from happening. The key to eliminating the problem is to reduce the temperature gradient. This can be passively accomplished by creating a thermal barrier as well as a vapor barrier around the collection materials. An inexpensive thermocouple can be installed in the transfer box to notify the user when the materials have acclimated to the vault temperature or room temperature prior to opening the box. For larger objects, the “picnic cooler” concept can be scaled to make a larger transfer box using materials such as Styrofoam and wood to provide thermal mass and insulation. Again, slowing the cooling or warming time is not necessary to avoid what many conservators fear to be “thermal shock.”
Thermal shock to materials generally requires extremely rapid temperature changes within the bulk of an object, an unsustainable event in this application. Rather, the need to lower the temperature gradient is specifically to address the problem of high humidity or condensation layers forming at collection material surfaces. This stratification is due to the thermal gradient spread across a group of materials such as those housed in a document box where continuity of thermal mass is disrupted by pockets of free space surrounding the materials. To summarize:

1) For thin, single items of contiguous mass, a polyethylene vapor barrier is more than adequate to safely remove items from the cold vault. Such items generally have low thermal mass, and will warm safely in minutes to room temperature (or cool to vault temperature). This is an efficient way to bring single matted prints, negative, slides, etc., in and out of the vault.

2) Larger items housed in non-hygroscopic containers (e.g., motion picture film in plastic or metal containers) may also be safely removed or returned to a vault by tape sealing the container or enclosing it in a polyethylene bag.

3) Items grouped in document boxes, Solander boxes, or other larger containers made of materials that are in themselves hygroscopic, must be brought to and from a vault in a transfer box or package that has sufficient thermal mass and insulation to slow the rate of temperature change and reduce the temperature gradient across the collection materials to a satisfactorily low level. These types of transfer boxes can be easily designed, constructed, and verified for proper performance. An alternative approach is to design a temperature programmable chamber that can be ramped slowly between vault temperature and room temperature.

WIR has made very successful and routine use of thermally insulated boxes (as per Figure 4). However, on two separate occasions we moved very large quantities of materials into the cabinets, and a simple and effective approach was simply to use the walk-in freezer itself as the staging room. By shutting off the power, the thermal mass of the vault contents and the insulating properties of the walls allowed the vault to rise gradually to room temperature whereupon the collection materials were immediately stocked in the cabinets and the vault then turned back on. We don’t recommend this method as a normal course of action, but it can be useful on planned occasions when very large quantities of materials must be added or removed from the vault.

**Overall Performance Results**

After the modifications to the cabinets with poor seals, the MVTR of the cabinets was held to less than 150 grams per year calculated at a constant interior RH level of 30% with exterior RH level at 60%. When a door is opened, a large empty cabinet will have an additional uptake of up to 2 grams of water. Factoring one weekly entry per cabinet, one needs to compensate for a total yearly increase in moisture content of about 250 grams in the largest cabinets. This can be accomplished with little difficulty by exchanging about two pounds of silica gel per cabinet per year. However, in our practical use of the vault over the past four years we have not exchanged any desiccant, and all cabinets have remained easily within the desired RH limits. The relative humidity in the cabinets is continuously monitored by data loggers made by Pace-Scientific, Inc., and we also have a very effective low cost monitor in the form of a cobaltous chloride humidity plug installed on the door of each cabinet. There are three basic reasons why we have not had to do any cabinet maintenance whatsoever. First, the cabinets are moderately to fully loaded with collection materials at this point in time which gives enormous moisture buffering capacity. Second, we do routinely open cabinet doors to add or retrieve items, but not on a repetitious daily or weekly schedule. Third, as materials are removed and later returned to the vault their moisture content gets “reset” to equilibrium with the normal display environment which is maintained within safe allowable limits. Thus, during the routine use of the vault the collection materials dominate the moisture buffering function, and we have had no cause to add or replenish any additional desiccants. Table I lists the average internal RH of all seven cabinets during the most recent year of operation, 2003. The cabinets have remained at similar levels during the entire 3.5 years that the vault has housed the WIR collection, some increasing slightly and others decreasing slightly in response to various collection materials added or removed from each cabinet. At this rate, the cabinets will likely stay in control for decades without ever needing further maintenance.

Of particular importance to any cold vault design is whether the vault fails safely when equipment failures occur. To test the behavior of the WIR vault, we simulated a power failure that would cause complete loss of the cooling compressors and total warming of the vault to room temperature. This failure path is very obvious compared to the multiple ways in which a vault with both compressors and dehumidifiers may fail. One surprising result of the test was that water droplets formed and fell from the vault’s ceiling beginning several hours after the power was lost. Typical panels for walk-in freezers are joined by tongue-and-groove construction and a vinyl gasket to form the seal between the panels. The large temperature gradient between the freezer’s interior and exterior surface allows some moisture to penetrate and reside within the panel joints. When the power failed, this water accumulated and leaked into the vault. Small puddles were noted on cabinet tops and on the floor. However, the cabinets did their required job. They controlled the RH within the allowable limits as the cabinets warmed to room temperature, and they kept the water droplets away from the collection...
materials. Foil taping the outside seams of the vault would likely have reduced the water droplet problem within the vault, and we would recommend this simple procedure for any new vault construction because this panel behavior is not unique to our vault design. Actively dehumidified vaults operating at low temperatures may experience a similar situation. Thus, open shelving presents a risk to collections stored in cold vaults unless steps are taken to add a “roof” to the shelves. However, such a modification may not be enough to prevent damage to the collection in the event of burst pipes or sprinkler discharge. The cabinets clearly provide better protection against water and smoke damage.

In the last couple of years we have had two actual incidents of sustained power failure, the longer of the two caused by a winter storm. Again, the cabinets maintained excellent humidity control throughout the cycle including when the power was restored and the vault immediately commenced cooling.

Conclusion

The WIR cold vault has performed flawlessly for nearly four years and we continue to monitor its performance by collecting humidity and temperature data in all cabinets and the vault itself on a 2 measurement/hour basis with the data loggers. No effort to date has been made to readjust the humidity levels in the cabinets as they remain comfortably within specification of 21–42% RH at −20°C operating temperature as can be seen in Table I. The vault uses 23.5 kilowatt-hours per day in energy consumption, and WIR pays $0.63/kwh. Thus, the daily cost of energy to keep the WIR collection stored in an optimal subzero temperature environment with passive moisture control is $1.46 per day or $531.38 per year. A comparably sized dehumidi-

Table I - Cabinet RH Control

<table>
<thead>
<tr>
<th>Cabinet</th>
<th>Dimensions (inches)</th>
<th>Ave. Daily RH Year 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK1</td>
<td>51.5L x 22.5W x 78H</td>
<td>29 ± 1 %RH</td>
</tr>
<tr>
<td>VK2</td>
<td>56.75L x 38.5W x 39.5H</td>
<td>31 ± 1 %RH</td>
</tr>
<tr>
<td>DD1</td>
<td>58L x 32W x 76H</td>
<td>26 ± 1 %RH</td>
</tr>
<tr>
<td>DD2</td>
<td>58L x 32W x 39H</td>
<td>28 ± 1 %RH</td>
</tr>
<tr>
<td>DD3</td>
<td>58L x 32W x 76H</td>
<td>31 ± 1 %RH</td>
</tr>
<tr>
<td>SF1</td>
<td>58L x 32W x 37H</td>
<td>33 ± 1 %RH</td>
</tr>
<tr>
<td>SF2</td>
<td>29L x 32W x 37H</td>
<td>28 ± 1 %RH</td>
</tr>
</tbody>
</table>

Note: Ave. daily vault RH = 58% RH, RH range = 55–78% RH

References


The Design and Operation of a Passive Humidity-Controlled Cold Storage Vault Using Conventional Freezer Technology and Moisture-Sealed Cabinets

Mark McCormick-Goodhart and Henry Wilhelm
Wilhelm Imaging Research, Inc., Grinnell, Iowa/USA
Presented at the IAFIT Conference, San Antonio, Texas, April 22, 2004

Acknowledgments: We wish to thank the National Science Foundation, Washington, D.C., for sponsoring this research project. We also want to thank the following companies: Sartorius Bioanalytical Company, and Viking Metal Cabinet Company for kindly donating equipment.

Construction...

Begin Construction...

...Time to Complete — 4 days

Freezer modifications...

Cabinet Installation...

...Time to Complete — 1 day

Cabinet modifications, methods, and experiments...

Over four years of trouble-free operation, $1.46/day energy costs!

Final Program and Proceedings: IS&T Archiving Conference

ISBN: 0-89208-251-8

©2004 The Society for Imaging Science and Technology

April 20–23, 2004
The Hyatt Regency San Antonio Hotel
San Antonio, Texas U.S.A.

Published by:
IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151 U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org
FIFTEEN YEARS AGO, two fraud cases sent shock waves through the world of photography, helping to trigger a revolution in photo conservation science. Long dismissed by the art establishment as a second-tier medium, “photography used to fight for space in galleries,” says James M. Reilly, director of the Image Permanence Institute in Rochester, N.Y. But by the 1990s the prestige—and price tags—of photographs began to approach those of paintings and sculpture. During that decade, collectors increasingly paid out hundreds of thousands and then the first million dollars for vintage and contemporary photographs. Yet, as in all coming-of-age stories, life’s dark side made an appearance, this time by means of back-to-back fraud cases.

In 1998, researchers in Germany discovered that a collection of prints by the avant-garde American photographer Man Ray had not been made by the artist himself. A year later, a team in the U.S. began to scrutinize a collection of 20 prints by Lewis Hine, an early-20th-century American documentary photographer. They discovered that the iconic collection of photos of Empire State Building construction sites and child laborers, purported to have been printed by Hine himself, were made decades after his death. Both cases led to million-dollar settlements that helped stimulate the photo conservation research, transforming a niche field into a mature science.

“The market drives conservation research,” Reilly says. “If you said, ‘Would you please analyze my $5.00 photograph with a $300,000 machine?’ the answer would be, ‘Well no, not today.’ But the...
COVER STORY

market has reached a point where a photograph that was made in the 20th or 21st century sells for $3 million.”

Interest in photo conservation research has grown to reflect this trend. Scientists are now teasing apart the intricate marriage of chemistry and physics that is to blame for the deterioration of a wide variety of photographs, everything from historical daguerreotypes and silver gelatin masterpieces to common color snapshots found in family albums. Understanding the molecular makeup and the ailments of precious images can help owners fight both the insults of time and counterfeit crime.

THE FRAUD CASES were both “a real shock and a revelation,” says Paul Messier, a photograph conservator involved in uncovering the Hine fakes. In 1999 Messier was approached by a collector and physicist, Michael Mattis, who was very eager “to get to the bottom of rumors about counterfeited Lewis Hine prints,” Messier says.

The question was not whether Hine had taken the photos; the question was whether he himself had produced the prints of the image. This detail is inherent to the value of a print. If Hine hadn’t printed the photographs himself, they were almost worthless. If he had, each of the 75 fake prints Messier eventually caught could have been sold for tens of thousands of dollars.

Although Messier had been working for more than a decade in photograph conservation when he was first approached about the suspected counterfeits, there were no established ways to authenticate the Hine prints—nor any other famous works of photography. “I just didn’t have the tools,” Messier says. “Here I was a photograph conservator, an expert in the field, and I couldn’t tell you whether the objects in front of me pre- or postdated Hine’s death,” Messier says.

So Messier teamed up with a private forensic scientist and Mattis to uncover three pieces of evidence showing the photographs couldn’t possibly be authentic Hine prints.

All the damning data came from the paper. The black-and-white images were so-called silver gelatin prints, the 20th century’s most popular form of professional photography, and one that Hine had also favored. When the team looked at the paper, they found it contained optical brighteners. These molecules, often based on a stilbene backbone, absorb ultraviolet radiation and reflect it in the blue area of the spectrum, giving images a brighter look. But photopaper companies only began using optical brighteners in the late 1950s, nearly two decades after Hine’s death.

Another clue came from the paper fiber. Messier’s team discovered it was not made from cotton rag fibers common during Hine’s era, but from more modern wood pulp instead. Furthermore, the team caught sight of a small backprint stamp from the photo paper maker that corresponded to stock issued after Hine’s death.

“It was clear that they were fakes,” Messier says.

The irony, Messier says, is that the German research team working to discover the Man Ray fakes had independently “come up with the exact same three criteria” for their authentication.

These cases galvanized the field. Hoping to develop a vision for photo conservation science, the Getty Conservation Institute sponsored a workshop the following year in Rochester. “Everybody was invited,” Messier says. “We were all asked to stand up by one and present what we thought the most important research topics for the field should be.”

The key idea that came out of that meeting was that the field should focus on identifying and characterizing every photographic process, Reilly says. Participants agreed that sophisticated understanding of the chemical and physical makeup of different kinds of photos could inform future authentication issues; it would help conservators monitor the degradation of photographs; and it would help museum staff choose the best conditions for storing and displaying photos in exhibitions so that further degradation could be mitigated.

This may sound like a pretty straightforward—possibly even a simple—plan of action. In practice, it is anything but.

Since the Frenchman Joseph Niépce...
Saving Endangered Photographs

To add another layer of complexity for researchers, “photographers were often mixing processes,” says Bertrand Lavédrine, director of the Research Center for Collections Conservation, in Paris. So sometimes a photograph is a hybrid or superposition of techniques. Particularly in the early days of photography, before there were commercial companies and photographic studios, “people were really doing kitchen chemistry,” Kaplan says. “People were just starting to realize they could capture permanent images and so there was a lot of experimentation happening in back rooms.”

TO MAKE THINGS even more challenging for researchers “a lot of photographs made with different processes can look remarkably similar,” Kaplan says. “And if you don’t know what you have, you don’t know how to display, conserve it, or store it without causing some sort of damage to the image.”

A case in point, Norris says, is the difference between gelatin-based silver prints and collodion-based silver prints. Both are printed on paper, and both rely on silver salts to produce a black-and-white image. The only difference is whether the silver salts are suspended in gelatin on the paper or whether they are suspended in collodion, which is a solution of cellulose nitrate in ether and alcohol. Say conservators want to clean dust from the surface of a collodion print. If they erroneously think it is a gelatin print, they might use acetone, causing irreversible damage to the image, Norris says. To distinguish between collodion and gelatin, conservators can use Fourier transform infrared spectroscopy (FTIR) to look at the fingerprint spectrum produced by vibrating bonds in the different materials. Another workhorse technology used in photo research is X-ray fluorescence, which can identify the heavy elements used to create or change the tint of a photograph. For example, XRF is the only tool capable of determining whether a photograph is made from a platinum process or a palladium one. Researchers can also use the technique to detect trace mercury on the image. Its presence stems from mercury bichloride in the chemical baths used to intensify the image on some black-and-white prints. But its long-term presence is sometimes to blame for the brownish tinge, called sepia, found on old black-and-white photographs.

XRF has also been useful in dating and authenticating silver gelatin prints. Early on in commercial photography, around 1880, many companies began adding a barium sulfate and strontium-based coating known as a baryta layer to their photo paper, Norris says. This layer provides a reflective surface that improves the look of photos. It also creates a boundary between the image layer and the paper layer, so that no trace contaminants in the paper can migrate into the image layer and discolor or damage it.

Although the baryta layer was common across many manufacturers, the relative concentration of barium and strontium in the layer can finger a particular manufacturer in a particular era, explains Dusan Stulik, a Getty Conservation Institute researcher who developed an XRF-based technique for measuring such ratios in...
Photographic film is made from cellulose nitrate or cellulose acetate, polymers that have been dubbed “malignant plastic” by conservators. As the material degrades, it releases gaseous nitric and acetic acid that catalyze further degradation of nearby film. But absorbent materials placed in the canisters can trap the offending vapors.

Collaboration with Messier. This ratio can be useful in authentication because many photographers were loyal to certain brands. Furthermore, given that some manufacturers changed their baryta formulations over time, barium-to-strontium ratios can help date a paper.

Radiocarbon dating can also be used to figure out whether a silver gelatin image was produced before or after the 1950s. That’s when aboveground nuclear testing changed carbon-14 levels in gelatin, which is typically taken from animal sources, Messier says.

But microscopy is the real tool of choice among photo researchers. For example, if you can clearly see paper fibers on an image using an optical microscope, this indicates that the image is embedded in the paper rather than suspended in albumen or gelatin binder layers, Norris says.

Another kind of microscopy, electron microscopy, is useful for observing degradation processes, which can in turn help identify the process used to make the image. For example, it’s common for silver to precipitate out of aging silver gelatin prints, Norris says. A wide variety of factors—from high humidity to airborne pollutants—can oxidize the elemental silver in the photograph, turning it into a form that can migrate through the gelatin layer until it reaches the photo’s surface where it gets reduced back to elemental form. The result is shiny silver “mirrors” or blemishes in the image. “There’s no unscrambling that egg,” Reilly says. “Once the particles have rearranged themselves, who’s going to put them back to where they were?”

Conservators have various ways of removing the silver mirroring or masking the distracting shine with microcrystalline wax. But many are increasingly circumspect about treating heavily mirrored photos because some interventions are not reversible, and thus permanently alter an object of cultural value. What’s more, a photograph can also lose financial value when significant changes to the original have been made.

For example, sensual photographs of peppers made by Edward Weston can sell for as much as a half-million dollars, Reilly says. A few years ago, a vintage Weston print went on the market. But the print was eventually withdrawn from auction when potential buyers balked after reading conservation papers, which detailed extensive and ill-advised treatments to remove silver mirroring.

To avoid silver mirroring and other deg-
radation in silver gelatin prints in the first place, the best idea is to keep the photos in a dry environment at room temperature, Lavédrine says. Scientists are also trying to fight fading in color prints, such as so-called chromogenic photographs, which dominate prints in family photo albums—and some artists’ catalogs—from the 1950s through the 1990s. Lavédrine notes these photographs are so fragile that they “fade in the dark and they fade in the light.”

It’s actually two different fading processes, he says. When exposed to light, chromogenic photos often take on blue tones. When kept in the dark, the cyan dyes in such photos degrade, shifting the photo tint to a reddish purple. “The exact color shift depends on the dye chemical used by a particular manufacturer,” he says. Although the dyes vary from manufacturer to manufacturer, this problematic fading exists for most brands that existed in the second half of the 20th century.

**Given that degradation** of these popular color photographs is inevitable, the only real solution is slow down the process through cold storage, Lavédrine says. “This is feasible for a big museum, but it may not be feasible for smaller museums or museums in developing countries that can’t afford the high energy bills,” he says. As for family photographs, “most people are not going to store their family album between the cheese and the milk,” even if that’s the safest idea, he says. “So we are losing a huge part of the cultural heritage.”

Meanwhile, most people have turned to digital photography. Although the general public now prints only a tiny fraction of their photos, professional photographers still make prints. And when either wants a physical copy, the common technique is to use ink-jet printers. The big question in photography circles is defining the vulnerabilities of these prints, Reilly says.

“We still don’t know exactly how well these things are going to hold up,” he says. But initial research suggests that one potential problem has to do with the fact that the photograph’s dye lies on top of the paper. The printers “squirt the ink, which is water soluble, onto a mineral-gel layer on the paper. The water drains down through the mineral-gel layer quickly, but the colorants stay on top,” Reilly explains. The problem is that the dyes remain on top and are not encased in anything like gelatin. So the image is easily rubbed or abraded.

Furthermore, because the dyes are water soluble, moisture is a problem. Even nearly invisible droplets of saliva from someone speaking too close to the image can cause havoc, Reilly says. “Or if you are in Florida and it’s humid, the photos can bleed so that images lose their definition.”

Some people choose to spray images with polymer coatings, Reilly says. The problem, he says, is that the exact recipe for the polymer coatings “are proprietary, and so you are not sure what you are dealing with. Some haven’t performed well in the past.”

In fact, the continued secrecy of many companies about their materials and processes frustrates many conservators. “After photography ceased to be a ‘do it yourself’ activity and became a large-scale industry,
In the early 20th century, tintype photos were that era’s photo booth. A photographer would set up a booth on a beach and snap your photo, with development taking only a few minutes. The image is a tin-based emulsion backed by a magnetic iron plate. Current-day counterfeiters sell fake tintypes backed with plastic instead of iron. So when you’re scouring flea markets for vintage tintypes, the Getty Conservation Institute’s Art Kaplan recommends you bring a little magnet with you to ensure the picture is magnetic. “It’s the cheapest way to authenticate,” Kaplan says.

Conservation researchers have made enormous headway in their quest to decode the secrets of vintage photographs. Nevertheless, they face new challenges, such as how to use the vast amounts of information garnered about existing photographic processes to inform museum collecting, authenticating, storing, and exhibiting practices, Messier says. At the Getty Conservation Institute alone, “we’ve analyzed 10,000 images of a variety of processes,” Kaplan says. He says he’s working with colleagues to organize the profusion of data into a tome that will be a comprehensive reference for all forms of photography and that will hopefully be a resource to museum research staff, Kaplan says. “The whole idea is to change [museum] practices,” Messier says. “Gathering thousands of spectra is not the end but just a start.”

Then there’s the challenge of how to preserve “the billions of digital images” created since the advent of digital photography and which are stored in a variety of formats and on memory hardware that could eventually become obsolete and thus lost to history, Lavédrine says.

As photo researchers work hard to keep up with the evolving nature of the medium and its conservation challenges, the overarching goals of the photo conservation community are perhaps best spelled out by Henry Wilhelm, a pioneer of photo research:

“The mere act of taking a picture is preserving a moment in time,” he said. “Our work is to preserve that moment as long as possible in the best possible condition.”

**2012 Special Award in Synthetic Organic Chemistry, Japan**

2012 Prize winner and his contribution in chemistry

KUNIAKI TATSUTA (Waseda University)
Total Synthesis and Medicinal Developments of Diverse Bioactive Natural Products

Kuniaki Tatsuta is Honorary Fellow and Professor Emeritus of Waseda University. He received Ph.D. from Keio University in 1969 before doing postdoctoral studies with the late Professor R. B. Woodward at Harvard University (1973-1975). In 1985 he became Professor of Keio University and then moved to Waseda University in 1993 as Professor.

His research interests focus on the developments of innovative concept and methodologies in total syntheses of natural products, and on the investigation of their medicinal profiles to produce biologically significant compounds. Tatsuta has already accomplished the total syntheses of 102 diverse bioactive natural products including the big four antibiotics, and medicinally practical developments. He has received many awards including the Award of Chemical Society of Japan, the National Medal with Purple Ribbon of Japan, the Japan Academy Prize. He also received the Ernest Guenther Award in 2012. Special Award in Synthetic Organic Chemistry was founded by SSOCJ in 1983 to praise remarkable achievements in organic synthesis. Up to present, 29 Chemists have won this prize.
Annex 10

*IS&T NIP29 International Conference on Digital Printing Technologies, Seattle, Washington, September 30, 2013: “Automated Surface Texture Classification of Inkjet and Photographic Media” p. 248*
Automated Surface Texture Classification of Inkjet and Photographic Media

Paul Messier; Paul Messier LLC, Boston, MA USA; Richard Johnson; Cornell University, Ithaca, NY USA; Henry Wilhelm; Wilhelm Imaging Research, Inc., Grinnell, Iowa USA; William A. Sethares; University of Wisconsin, Madison, WI, USA; Andrew G. Klein; Worcester Polytechnic Institute, Worcester, MA USA; Patrice Abry; Ecole Normale Superieure de Lyon, Centre National de la Recherche Scientifique, Lyon FR; Stéphane Jaffard; University of Paris, Paris FR; Herwig Wendt, Institute de Recherche en Informatique de Toulouse, Centre National de la Recherche Scientifique; Toulouse, FR; Stephane Roux, Ecole Normale Superieure de Lyon, Lyon FR; Nelly Pustelnik, Ecole Normale Superieure de Lyon, Centre National de la Recherche Scientifique, Lyon FR; Nanne van Noord, Laurens van der Maaten, and Eric Postma; Tilburg University, Tilburg, NL

Abstract

Digital imaging and signal processing technologies offer new methods for inkjet and photographic media engineers and manufacturers, and those responsible for product quality control, to classify and characterize printing materials surface textures using new and more quantitative methods. This paper presents a collaborative project to systematically and semi-automatically characterize the surface texture of inkjet media. These methods have applications in product design and specification, and in manufacturing quality control.

Surface texture is a critical feature in the manufacture, marketing and use of inkjet papers, especially those used for fine art printing. Raking light reveals texture through a stark rendering of highlights and shadows. Though raking light photomicrographs effectively document surface features of inkjet paper, the sheer number and diversity of textures prohibits efficient visual classification.

This work provides evidence that automatic, computer-based classification of texture documented with raking light photomicrographs is feasible by demonstrating an encouraging degree of success sorting a set of 120 photomicrographs made from diverse samples of inkjet paper and canvas available in the market from 2000 through 2011.

The samples used for this study were drawn from the Wilhelm Analog and Digital Color Print Materials Reference Collection. Using this dataset, four university teams applied different image processing strategies for automatic feature extraction and degree of similarity quantification. All four approaches were successful in detecting strong affinities among similarity groupings built into the dataset as well as identifying outliers. The creation and deployment of the algorithms was carried out by the teams without prior knowledge of the distributions of similarities and outliers. These results indicate that automatic classification of inkjet paper based on texture photomicrographs is feasible. To encourage the development of additional classification schemes, the 120 inkjet sample “training” dataset used in this work is available to other academic researchers at www.PaperTextureID.org.

Figure 1. Microscope and light configuration for producing raking light photomicrographs.

Figure 2. Raking light photomicrographs: Hahnemuhle Fine Art William Turner; Germany, ~1909 (top) and Canson Museum Canvas Water Resistant Matte Canvas; France, April 2008 (bottom).
Collaborative Competition

As part of a materials-based characterization project of modernist silver gelatin photographs at the Museum of Modern Art (MoMA) in New York, raking light photomicrographs were made from each print from the Thomas Walther Collection to document surface texture. This work stimulated interest in developing an automated scheme to cluster like prints based on surface texture. An appeal was made to university teams with signal processing experience to initiate a collaborative competition to develop methods for sorting texture images.

Four university teams joined this project:

- **University of Wisconsin**: William A. Sethares
- **Worcester Polytechnic Institute**: Andrew G. Klein, Christopher Brown, Anh Hoang Do, and Philip Klausmeyer
- **Ecole Normale Superieure de Lyon**: Patrice Abry, Stephane Jaffard, Herwig Wendt Stephane Roux, and Nelly Pastechnik
- **Tilburg University**: Nanne van Noord, Laurens van der Maaten, and Eric Postma

Each team adopted a different approach to the development of the two standard parts of an automatic classifier: (1) feature vector extraction and (2) degree of similarity quantification. These strategies stem from a broad variety of basic approaches to texture image classification and are described in the following section.[7]

Prototype algorithms were constructed by the four teams using a training set of 50 silver gelatin samples with some known texture matches. This preliminary work established the orientation of the primary paper fiber direction relative to the raking light had no significant impact on results. This finding does not exclude a priori that silver gelatin surfaces possess other forms of anisotropy. This initial work proved effective in providing a basis for sorting silver gelatin prints by surface texture. Since inkjet surfaces were not included in this preliminary test and some surfaces appear to exhibit anisotropy based on fiber direction, a natural expansion of the scope of this work, immediate interest was expressed in testing the applicability of the data collection method and sorting strategies on other paper surfaces including inkjet paper and canvas.

To forward these goals, a dataset containing 120 raking light photomicrographs of inkjet papers with known metadata including manufacturer, brand, date, gloss, and texture classification, and offering varying degrees of self-similarity was prepared (the Appendix lists all samples used in this study). The dataset delivered to the teams for testing was largely composed of nine groups of ten paper samples each. Within these groups, there were three similarity subsets: (1) images made from the same sheet of paper, (2) images made from sheets taken from the same manufacturer package of paper and, (3) images from papers made to the same manufacturer specifications over a period of time. The remaining thirty samples were picked without concern for texture similarity but instead were selected to span the large range of textures associated with inkjet paper and canvas.

Conventional wisdom suggests that any raking light photomicrograph taken from different spots on a single sheet of paper would appear nearly identical. Likewise, texture images from different sheets of paper taken from the same manufacturer package also should show strong similarity. Furthermore, raking light images from papers manufactured to the same specifications but made at different times should show strong similarity, but to a somewhat lesser degree. For the thirty remaining samples, selected to demonstrate diversity, some would appear similar to the group of ninety textures and some would appear to be unique. The challenge posed to the teams was to discover these similarity groupings and isolate unique textures by producing a system of texture affinities that described the entire set.
Technical Approaches

The approaches taken by the four teams can be divided into two categories [8] based on the approach to feature definition: (1) non-semantic / Wisconsin and Tilburg and (2) multiscale / Lyon and WPI. The fundamental difference is that non-semantic features are derived directly from the image data where multiscale features are based on a structural model presupposed as relevant to the encountered data.

1. Eigentextures (Wisconsin)

In the eigentexture approach, a collection of small patches are chosen from each photographic image. These patches are gathered into a large matrix and then simplified to retain only the most relevant eigendirections using a singular value decomposition (SVD). The preparation stage consists of two steps:

1. For each imaged paper, randomly pick N p × p pixel patches \( X_{ij} \in \mathbb{R}^{p \times p} \) for \( i = 1, 2, \ldots, N \) (with \( N = 2000 \) and \( p = 25 \) in this case). Lexicographically reorder the \( X_{ij} \) into column vectors \( a_{ij} \in \mathbb{R}^p \).

2. Create matrices \( A_j = [a_{j1}, a_{j2} \ldots a_{jn}] \) consisting of the \( N \) column vectors and calculate the SVDs \( A_j = U_j \Sigma_j V_j \) for all \( j \). Extract the \( m \) columns of \( U_j \) corresponding to the \( m \) largest singular values and call this \( U_j \) (with \( m \) selected as 15 in this case).

The \( U_j \) are the representatives of the classes and may be thought of as vectors pointing in the most-relevant directions. During the classification stage, a number of similarly-sized patches are drawn from the tested photographic paper. Each of these patches is compared to the representatives of the classes via a least squares (LS) procedure.

3. Select Q (with \( Q = 2000 \) used here) \( p \times p \) pixel patches \( Q_i \), from the tested paper and reorder into vectors \( q_i \in \mathbb{R}^p \). Calculate the distance from the \( j \)th patch to the \( j \)th class:

\[
d(i, j) = \left\| U_j^T q_i - a_{ij} \right\|
\]

Every patch is closest to one of the classes, and the number of patches closest to the \( j \)th class is recorded.

4. For each patch \( i \), \( f_i = \arg \min_{j} d(i, j) \) locates the smallest of the \( d(i, j) \), indicating that class \( j \) is the best fit for patch \( i \). Tally the set of all such \( f_i \), \( i = 1, 2, \ldots, Q \).

The commonest entry among the \( f_i \) is the most likely class for this image. The second most common entry is the next most likely class for this image, etc.

2. Random-feature texton method (Tilburg)

This method combines random features and textons, i.e., the random-feature texton method. This method was developed by Liu and Fieguth [10] and is an adaptation of the texton approach [11] using random features. Textons are prototypical exemplar image patches capturing the “essence” of the texture of an image. Random-features (RF) are random projections of image patches with \( N \times N \) pixels to vectors with \( D \) elements (\( N = 9, D = 20, D < N^2 \)). More specifically, a random feature (RF) is defined as a \( D \times N^2 \) matrix, the elements of which are sampled from the standard multivariate normal distribution \( N(0, 1) \).

The application of the random-feature texton method on the 120-sample dataset is conducted as follows. A set of \( X \) sub-images of \( M \times M \) pixels is selected for each gray-value texture image in the 120 sample dataset (\( M = 512 \)). The sub-images are defined to be the central regions of \( M \times M \) pixels of which the intensity distributions are normalized to zero mean and unit variance. A sample of 45,000 randomly selected \( N \times N \) (\( N < M \)) patches (represented as vectors of length \( N^2 \)) of the normalised sub-images are contrast-normalised and subsequently multiplied with RFs, yielding RF vectors of length \( D \).

Subsequently, a texton dictionary is created by applying k-means clustering to all RF vectors of the \( X \) sub-images of each texture image of the 120-sample dataset. Each image of the dataset is transformed into a texture histogram by comparing all of its patches (represented as RF vectors) to the entries in the texton dictionary. Finally, the histograms are classified using a k-nearest neighbor algorithm using the \( \chi^2 \) similarity measure.

3. Anisotropic wavelet multiscale analysis (Lyon)

This method relies on the use of the Hyperbolic Wavelet Transform (HWT) [12–13] which is a variation of the 2D Discrete Wavelet Transform (2D-DWT) [14]. The HWT explicitly takes into account the possible anisotropic nature of image textures. Indeed, instead of relying on a single dilation factor \( a \) used along both directions of the image (as is the case for the 2D-DWT), HWT relies on the use of two independent factors \( a_1 = 2^h \) and \( a_2 = 2^h \) along directions \( x_1 \) and \( x_2 \) respectively. The Hyperbolic Wavelet coefficients of imaged paper are denoted as \( T_j((a_1, a_2), (k_1, k_2)) \).

The area-scale analysis is a technique which has been applied to various problems in surface metrology [15]. Much as the measured length of a coastline depends on the scale of observation and therefore the resolvability of small features, the measured area of a surface is also a function of the scale of observation. The area-scale approach uses fractal analysis to decompose a surface into a patchwork of triangles of a given size. As the size of the triangles is increased, smaller surface features become less resolvable and the ‘relative area’ of the surface decreases. The topological similarity of two surfaces is computed by comparing relative areas.

4. Pseudo-area-scale analysis (WPI)

Area-scale analysis is a technique which has been applied to various problems in surface metrology [15]. Much as the measured length of a coastline depends on the scale of observation and therefore the resolvability of small features, the measured area of a surface is also a function of the scale of observation. The area-scale approach uses fractal analysis to decompose a surface into a patchwork of triangles of a given size. As the size of the triangles is increased, smaller surface features become less resolvable and the ‘relative area’ of the surface decreases. The topological similarity of two surfaces is computed by comparing relative areas.
at various scales. The technique has traditionally been employed on topographic data sets containing height information over a surface. Though lacking a direct measure, area-scale analysis can be applied to the photomicrographs using light intensity as a proxy for height.

The proposed approach proceeds in three steps: (1) preprocessing, (2) feature extraction, and (3) classification. The preprocessing step extracts a square $N \times N$ region from the center of the image (where $N$ was chosen to be 1024), and normalizes the intensity of the resulting extracted image. The $N \times N$ grid of equally spaced points (representing pixel locations) is decomposed into a patchwork of

$$2 \left( \frac{N-1}{s} \right)^2$$

isosceles right triangles where $s$ is a scale parameter representing the length of two legs of each triangle. The pixel values at each of the triangle vertices are then taken as the ‘pseudo-height’ of each of the vertices. The area of each triangle in 3-D space is then computed and the areas of all triangular regions are summed, resulting in the relative area $A_s$ at the chosen scale $s$. To conduct feature extraction, the relative area for an image is computed over a range of scale values; in this study, 8 scale values were used ranging from 1 pixel to 34 pixels, which correspond to lengths of 6.51 $\mu$m to 0.221 mm, respectively. Finally, to classify and compare the similarity of two images $i$ and $j$, a $\chi^2$ distance measure $d(i, j)$ is computed via

$$d(i, j) = \sum_{s \in S} \left( \frac{A_s^{(i)} - A_s^{(j)}}{A_s^{(i)}} \right)^2$$

where $A_s^{(i)}$ is the relative area of image $i$ at scale $s$ and $S$ is the set of chosen scale values. Small values of $d(i, j)$ indicate high similarity between images $i$ and $j$, while large values indicate low similarity.

Results as Affinity Maps

From the metadata and each of the teams’ automatic classifiers, the degree of similarity (affinity) was tabulated for each possible pairing of images in the 120-sample dataset. These scores were then converted to a grey-scale with the darkest intensities indicating the greatest affinity and the lightest the least affinity. To visualize these values a table containing 120 rows and 120 columns was created, one row and column for each sample in the data set. Each of the resulting 14,400 cells in the table was shaded according to the similarity of compared samples with black describing an exact match, white a total mismatch and gray-scale values in between describing a range of better or worse similarities. For example, the top diagram in Figure 3, shows predicted similarities within the sample group suggested by the metadata listed in the Appendix, including manufacturer, texture, brand, and date (these affinities were prepared solely on the metadata and not on direct examination of the surfaces). As expected, the six dark blocks starting in the upper left and continuing down along the diagonal, show a high degree of affinity (dark gray and black) as these blocks depict the groups derived from the same sheet or package. Lesser degrees of similarity are scattered throughout the figure with the 30 samples selected to show diversity (poorer levels of similarity) falling in the lower right quadrant and along the right side and bottom edge.

Gray-scale affinity maps produced to display the results from each of the four teams are also shown in Figure 3. The principal similarity among the five affinity maps in Figure 3 are the six dark squares
along the upper left to lower right diagonal. Given the construction of the dataset, these blocks should be dark due to the similarity between the samples in these groups. The light stripes in the right and bottom quarters of the affinity maps, due to some relatively matchless texture among samples 91-120, are also shared by all five affinity maps.

While small local differences among the five maps indicate that work remains to find an ideal automated scheme, striking fundamental similarities between the metadata-based affinity map and the four produced by automated schemes validate ranking light photomicrographs as having sufficient texture information to support the automated classification of inkjet paper.

Observations

As shown in Figure 3, there is a relatively high level of agreement between the affinity pairings prepared by the classification algorithms and those derived from metadata and subject-matter expertise. As discussed in the previous section, the principal correspondence among the five affinity maps is the six dark squares along the diagonal running from upper left to lower right. Given the construction of the dataset, the samples in these blocks are very similar and these texture affinities were recognized both by a subjective metadata sort and by the four automated solutions. In addition, both “human” and automated solutions are sensitive to the increased levels of diversity within samples 61-90 that track a manufacturer’s surface over time.

These findings are reinforced by Figure 4, which shows a normalization of the distances between each texture pairing within the tested groups. The shape of the curves are remarkably consistent with the automated solutions and the human metadata-based classification detecting very similar degrees of affinity across the groups. The chart confirms there is no measurable difference between texture images made from the same sheet of paper as compared to images made from different sheets from the same manufacturer package. Further, textures produced to same manufacturing standard over time show fair to good levels of similarity (blocks 7, 8 & 9). These results, though not a surprise given high levels of manufacturing regularity, are important for the possible development of future systems that rely on indices of known “exemplar” textures to identify unknowns.

Compared with the 120 silver gelatin surfaces assessed in the previous study, the inkjet materials were found to be more diverse. Smooth inkjet papers were observed to be significantly more uniform as compared to smooth (non-ferrotyped) silver gelatin papers. On the other end of the scale, the rougher inkjet canvas finishes showed significantly more dimensionality than any of the tested silver gelatin surfaces. Another difference is the relative lack of stronger affinities within diagonal blocks 7, 8 & 9 in Figure 3. Silver gelatin papers showed higher levels of consistency in these groups of papers identified as having the same manufacturer specifications over a period of time. Aside from these differences, the results for both the inkjet and silver gelatin surfaces are highly comparable especially for the generally good alignment between the human expert’s affinity expectations and the measured affinities generated by the teams.

Conclusions and Next Steps

This project opens a path toward a machine vision system that provides meaningful results for the study of inkjet prints. To have meaning, an automated classification system cannot produce results simply based on an internal, self-referential “sameness/difference” parameter but instead must render results that are relevant to trained practitioners, such as media manufacturers, conservators and curators. For example, the photomicrographs made from ten spots on the same sheet of paper, though totally different images, need to be recognized as the “same.” Likewise the two other similarity groups made from different sheets from the same manufacturer’s package and from papers manufactured to the same standard must be recognized as related.

A useful system needs to reliably cluster these groups together while at the same time be discriminating enough to set these groups apart from others made to different manufacturer specifications. Using different techniques, each of the four teams met this standard. The fundamental outcome of this experiment is the intuitive “human / expert observer” conception of a classification system based on sameness/difference can be replicated through imaging and signal processing techniques.

The techniques described in this work could engender new modes of scholarship based on the discovery of materials-based affinities. Work at the Museum of Modern Art is under way to determine how these techniques might meaningfully be applied to silver gelatin prints in its Thomas Walther Collection. Moving forward, reference libraries of surface textures, containing papers grouped by photographer or paper manufacturer can be assembled and used as a basis of comparison.

This work has already begun through the assembly of large photographic and inkjet paper and canvas reference collections categorized by manufacturer, brand, surface finish, and date as well as for individual photographers and artists. When used together with image and dot structure photomicrographs, spectral reflectance data in the UV, visible, and IR regions, gloss and DOI measurements, surface characterization is an important tool in the identification, dating, and authentication of inkjet prints. With standardized imaging techniques and a networked infrastructure, conservators and others could query such texture libraries to detect similar paper held by others and potentially characterizing and identifying works in their collection as well as revealing relationships within an photographer’s body of work and between photographers. Having shown promise for both silver gelatin papers and inkjet, these methodologies are being applied to other media, including the platinum papers of F. Holland Day (1864-1933). A website, www.PaperTextureID.org, has been created to distribute the dataset of silver gelatin and inkjet textures used as the basis for this study. The availability of these image sets should encourage and assist other image processing and programming teams to develop their own automated classification and sorting schemes.
Appendix: Inkjet Paper and Canvas Samples Used in the Dataset

The number is the sequential numbering system suggested by the teams following image processing. The papers are further identified by manufacturer, brand, manufacturer location and date (date generally refers to the acquisition date of papers). Other descriptors, such as surface finish designations, are taken directly from the manufacturer packaging. All samples were drawn from the Wilhelm Analog and Digital Color Print Materials Reference Collection.

10 samples from the same sheet (X 3 sheets)
1-10. Canon Platinum Pro, Smooth, Glossy: Japan, Purchased 4/2012
11-20. Ilford Gallerie Gold Fibre Silk, Smooth, Glossy: Germany, ~ 2009

10 samples from the same package (X 3 packages)
41-50. Epson Ultra Premium Photo Paper Luster (Formerly called Epson Premium Photo Paper Luster), Smooth, Semi-Glossy: Japan, Purchased 7/2011
51-60. Epson Sample Roll Premium Luster Photo Paper, Smooth, Semi-Glossy: Japan, ~ 2001

10 samples from the same (or similar) manufacturing standard (X 3 sets)
62. HP Premium Plus, Glossy Photo Paper, Smooth, Glossy: Switzerland, 2002
64. HP Premium Plus Photo Paper, High gloss, Smooth, Glossy: United States, 2005
65. HP Premium Plus High gloss Photo Paper, Smooth, Glossy: Switzerland, 2004
66. HP Premium Plus Photo Paper, High gloss, Glossy, Smooth, Glossy: Switzerland, 2005
69. HP Premium Plus Photo Paper, Glossy, Smooth, Glossy: Switzerland, 2002
70. HP Premium Plus Photo Paper, Glossy, Smooth, Glossy: Switzerland, 2007
71. Epson Photo Quality Glossy Film, Smooth, Glossy: Japan, ~ 1996
72. Epson Photo Paper Glossy, Smooth, Glossy: Germany, Purchased 2/2008
73. Epson Premium Photo Paper Glossy (Formerly Premium Glossy Photo Paper), Smooth, Glossy: Japan, Purchased 03/29/2008
74. Epson Premium Photo Paper Glossy (Formerly Premium Glossy Photo Paper), Smooth, Glossy: Japan, Purchased 03/08/2008
75. Epson Ultra Premium Glossy Photo Paper, Smooth, Glossy: Japan, Purchased 03/07
76. Epson Ultra Premium Photo Paper Glossy (Formerly Ultra Premium Glossy Photo Paper), Smooth, Glossy: Japan, Purchased 02/2008
77. Epson Ultra Premium Glossy Photo Paper, Smooth, Glossy: Japan, Purchased 02/2007
78. Epson Photo Paper Glossy (Formerly Glossy Photo Paper), Smooth, Glossy: Germany, Purchased 2002
79. Epson Premium Glossy Photo Paper, Smooth, Glossy: Japan, Purchased 06/2004
82. Kodak Premium Photo Paper, Gloss, Smooth, Glossy: Germany, Purchased 06/2011
84. Kodak Photo Paper, Gloss, Smooth, Glossy: Germany, Purchased 03/2009
86. Kodak Professional Inkjet Photo Paper, Smooth, Glossy: USA, Purchased 7/2004
89. Kodak Premium Photo Paper, Gloss, Smooth, Glossy: Germany/USA, Purchased 03/2007

30 samples showing diversity
91. Epson Ultra Premium Glossy Photo Paper, Smooth, Glossy: Japan, ~ 2005
93. Canon Fine Art Paper Premium Matte, Smooth, Matte: Japan, ~ 2006
94. Canon Photo Paper Pro II, Smooth, Glossy: Japan, Purchased 12/2008
101. Canson Artist Canvas Water Resistant Matte, Canvas, Matte: France, Purchased 04/2008
102. Epson Water Color Paper-Radiant White, Textured, Matte: Japan, ~ 2000
103. Canson Artist Canvas Professional Gloss, Canvas, Glossy: France, Purchased 04/2008
104. Canson Mi-Teintes, Honeycomb, Matte: France, Purchased 04/2008
106. Canson Montval-Torchon, Textured, Matte: France, Purchased 03/2008
107. Epson Cold Press Bright, Cold-Press Textured, Matte: Italy, Purchased 3/2010
108. Epson Hot Press Bright, Hot-Press Smooth, Matte: Italy, Purchased 03/2011
110. Epson Photo Paper Pro (PR-101), Smooth, Glossy: Japan, ~ 2006
111. Epson Matte Photo Paper (MP-101), Smooth, Matte: Japan, ~ 2007
IS&T NIP29: "Automated Surface Texture Classification of Inkjet and Photographic Media"

References


Presenter Biographies

Paul Messier is a conservator of photographs working in Boston Massachusetts, USA. Founded in 1994, his studio provides conservation services for private and institutional clients throughout the world. The heart of this practice is unique knowledge and ongoing research into photographic papers. Messier is the corresponding author. Address: 103 Brooks Street, Boston, MA 02135. Email: pmessier.com.

Henry Wilhelm is co-founder and director of research at Wilhelm Imaging Research, Inc. Through its website, www.wilhelm-research.com, the company publishes print permanence data for desktop and large-format inkjet printers, silver-halide color papers, and digital presses. Wilhelm Imaging Research also provides consulting services to museums, archives, and commercial collections on sub-zero cold storage for the very long-term preservation of still photographs and motion pictures. Address: Wilhelm Imaging Research, Inc., 713 State Street, P.O. Box 775, Grinnell, Iowa 50112 USA. Email: hwilhelm@aol.com.

C. Richard Johnson, Jr. received a PhD in Electrical Engineering and a PhD minor in Art History Stanford University. He is currently the Geoffrey S. M. Hedrick Senior Professor of Engineering and a Stephen H. Weiss Presidential Fellow at Cornell University, Ithaca, NY. His current research interest is computational art history. Address: School of Electrical and Computer Engineering, 390 Rhodes Hall, Cornell University, Ithaca, NY 14853 USA. Email: johnson@ece.cornell.edu.

Acknowledgements

The authors are deeply grateful for the contributions of Christopher Brown and Anh Hoang Do of the Worcester Polytechnic Institute and Philip Klausmeyer of the Worcester Art Museum. We also wish to acknowledge the vital assistance of James Coddington, Lee Ann Daffner and Hanako Murata of the Museum of Modern Art, as well as Sally Wood, Mark Messier and Andrew Messier.

William Sethares examining raking light photomicrographs of paper surface textures at a meeting at the Museum of Modern Art in New York in January 2013. Sethares, who teaches at the University of Wisconsin at Madison, is one of the signal processing experts who contributed to this study. The meeting was hosted by Jim Coddington, Lee Ann Daffner, and Hanako Murata, conservators at MoMA.

A meeting held at the San Francisco Museum of Modern Art in July 2012. Richard Johnson (left) who organized this project with Paul Messier, is a professor at Cornell University. The meeting was hosted by SFMoMA conservators Jill Sterret and Theresa Andrews. (Photos by Henry Wilhelm)
Automated Surface Texture Classification of Inkjet and Photographic Media

Paul Messier; Paul Messier LLC, Boston, MA USA; Richard Johnson; Cornell University, Ithaca, NY USA; Henry Wilhelm; Wilhelm Imaging Research, Inc., Grinnell, Iowa USA; William A. Sethares; University of Wisconsin, Madison, WI, USA; Andrew G. Klein; Worcester Polytechnic Institute, Worcester, MA USA; Patrice Abry; Ecole Normale Superieure de Lyon, Centre National de la Recherche Scientifique, Lyon FR; Stéphane Jaffard; University of Paris, Paris FR; Herwig Wendt, Institute de Recherche en Informatique de Toulouse, Centre National de la Recherche Scientifique; Toulouse, FR; Stephane Roux, Ecole Normale Superieure de Lyon, Lyon FR; Nelly Pustelnik, Ecole Normale Superieure de Lyon, Centre National de la Recherche Scientifique, Lyon FR; Nan van Noord, Laurens van der Maaten, and Eric Postma; Tilburg University, Tilburg, NL

Paper presented by Paul Messier and Henry Wilhelm on September 30, 2013

Paper (monochrome, with no color) published on pages 85–91 in:

Technical Program and Proceedings:

NIP29: The 29th International Conference on Digital Printing Technologies

IS&T: The Society for Imaging Science and Technology
and ISJ: The Imaging Society of Japan

September 29 – October 3, 2013
Westin Seattle Hotel
Seattle, Washington U.S.A.

ISBN: 978-0-89208-306-0
©2013 The Society for Imaging Science and Technology

Published by:
IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, Virginia 22151 U.S.A.
Phone: 703-642-9090; Fax: 703-642-9094
www.imaging.org (e-mail: info@imaging.org)
Improved Water-Resistance Test Methods Utilizing a Multispectral Imaging System to Quantify Black and Color Ink Bleeding for Plain Paper Office and Legal Documents Printed with Pigment- and Dye-Based Inkjet Inks

Henry Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa, USA; Richard Adams, Ryerson University, Toronto, Ontario, Canada; Ken Boydston, MegaVision Inc., Santa Barbara, California, USA; Charles Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa, USA

Abstract

Current ISO standards that pertain to water-resistance testing with inkjet prints were developed for moisture-impermeable RC photo papers and do not take into account the kinds of ink diffusion behavior that can occur with inkjet printing on highly absorbent plain papers, especially with dye-based inks. Contact with water with plain paper documents can result in significant lateral ink bleeding, migration of inks through the paper to the backside of the sheet, transfer of ink from one sheet to adjacent sheets, and two-way transfer of inks with double-sided printed documents. Shipping labels and envelopes can become illegible should they become wet, and Barcodes and QR codes may be rendered completely unreadable. This study attempts to better understand the water-resistance behavior of plain paper documents printed with dye-based and pigment inkjet inks. The use of high-resolution multispectral imaging and colorimetric analysis systems to provide a quantitative assessment inkjet printing technology have led to greatly increased print speeds together with significantly reduced cost of ownership and costs per page – and this in turn has allowed inkjet to move into market areas previously dominated by monochrome and color laser printing.

As most business documents now contain critical color information – business logos, color typography, graphs and spreadsheets, and color photographs and illustrations – printing in color has become the expectation in most plain paper office printing markets. Pigment inks, dye-based inks, and “hybrid” pigment black/dye color inksets are presently being used in office markets and there is increased interest in understanding the differences in the permanence characteristics of the different types of inks with plain paper prints. This is especially true in terms of water resistance, because plain paper documents printed with inks having poor water resistance can be catastrophically damaged in just seconds or minutes by contact with water.

Water damage can be caused by hurricanes, typhoons, tornadoes, river and stream flooding, broken water pipes, faulty sprinkler systems, water inundation resulting from efforts to extinguish a fire inside a home, office, or other building, roof leaks, basement leaks, mail exposed to rain, and so on. The current ISO standards that pertain to water-resistance test-
Goals of This Project

1. A principal focus of this research is to better understand the types of water damage that can occur to inkjet-printed plain paper documents in real world conditions. This includes momentary exposure to water resulting from a spill that is wiped with a paper towel or other absorbent material, or rain drops that might contact a mailing envelope or shipping label; longer-term partial or total water exposure that could occur to an inkjet print in a plastic sleeve restaurant menu should a customer spill water on it during a meal; rain exposure on a “lost dog” or other plain paper signs posted outdoors; or prolonged, “total immersion” water exposure to documents caused by hurricanes, floods, broken water or sewer pipes, faulty sprinkler systems, and similar calamities.

2. Design new water exposure tests that take into account the specific behaviors of dye-based inkjet inks printed on plain papers and pigment-based inkjet inks printed on plain papers.

ISO 18935:2016(E) originally published in 2005, is intended primarily for use with digital and analogue printed RC-base and other photographic materials; text is not included in the test target design. ISO 11798:1999(E)[2] published eighteen years ago in 1999, was developed primarily for offset printed book papers, xerographic printing on copy papers, and manual pencil and ink writing on writing papers – and was intended for books and other documents intended to be stored in libraries, archives, and “other protected environments.”

Figure 2. A square cross-hatch-pattern water-resistance test target designed for multispectral imaging and analysis. The degree of ink bleed that fills the interiors of the cross-hatch elements in the target can be measured and quantified with the multispectral imaging and analysis system. The target, which consists of cyan, magenta, yellow, black, CMY gray, red, green, and blue segments, is printed on an 8.5 x 11-inch letter size (or A4 size) sheet of plain paper. To the left is a newly-printed target, not yet subjected to contact with water. The image to the right shows an overlay grid for 400 x 450 measurement locations – 180,000 individually addressable data points on a target. After the target has been in contact with water and dried, the “before and after” images can be compared to quantify ink bleeding. As with the circular spoke-pattern target, this target is useful to assess the amount of ink migration that takes place from the front to the back of a sheet, both sides of the sheet can be imaged and compared.

Figure 4. From the MegaVision LAB values, Delta-E was computed with Chromix ColorThink software to compare the test targets overall, or in areas of particular interest, before and after they were subjected to contact with water, including short-term or long-term total immersion in water.
Figure 5. Water resistance of envelopes, shipping labels, barcodes, and QR codes is of critical importance, as ink bleed can easily render them unreadable. In this example, a FedEx shipping label printed on plain paper with an inkjet printer is shown on the left. The label has not yet been subjected to contact with water. The image to the right shows an overlay grid for 200 x 250 measurement locations – which amounts to 50,000 individually addressable data points. After contact with water, at what point a barcode or QR code is no longer readable is a very useful way to evaluate water resistance of different plain paper printing systems, inks, and xerographic toners. A multispectral analysis provides a way to characterize barcode failure in a qualitative way.

This includes evaluation of ink “bleed-through” to the backside of a page printed on one side, and “bleed-through” of inks in two directions for pages printed on both sides. The authors designed two color targets intended to quantify the effects of water exposure to inkjet and other printed materials with a multispectral imaging and analysis system. The Multispectral Water Resistance Cross-Hatch Target consists of a series of finely-spaced, 4-point lines and squares that can be imaged in CMYK, RGB, and gray colors. The Circular Spoke- Pattern Target, with its ever-narrowing distance between the spokes toward the center of the target can also offer a sensitive indication of lateral ink bleeding or diffusion. In designing these targets, the authors sought a method of assessing water resistance through color comparisons of the solid-color lines with the white spaces in between. The presumption was that, if an ink was soluble or suspendable in water, molecules of color dye or pigment particles could migrate from solid to white areas, thereby lightening the solids and darkening the white spaces in between. Thus, the evaluation strategy was to compare the colorimetric values of the solids with those of the white areas. From the MegaVision LAB values, Delta-E was computed in Chromix ColorThink comparing the black and magenta inkered patches to the surrounding paper (see Fig. 4).

3. Develop new methods to characterize and quantify ink transfer from one printed page to an adjacent page when a stack of pages (e.g., pages in a bound report, between pages stapled together, and between multiple pages placed together in a file folder) are partially or totally immersed in water for both short or extended periods of time.

4. Develop new methods to measure color ink bleeding, intermixing, and to quantify ink spread (bleeding) using a camera-based multispectral imaging system and associated software.[3] The longer-term goal of this research is to develop

Figure 6. To simulate the effects of immersion in water of multi-page plain paper documents or of multiple pages in a file folder, lightly spraying a blank unprint- ed sheet with water and then placing a printed test target page on top of it and lightly spraying and, finally, placing another blank page on top of it and spraying it proved to provide better assessments of ink bleeding, ink migration through to the back of the page, and ink transfer to an adjacent page proved to be more meaningful than completely immersing a whole stack of pages in water at the same time.
meaningful, quantitative standards for water resistance tests with inkjet-printed plain paper documents that will replace the types of subjective evaluations currently used in water resistance tests.[1,2,4] An imaging-based measurement system can enable characterization and quantification not practical – or even possible – with single-point measurement devices.

5. Work with ISO, other standards groups, archive and library organizations, and manufacturers of inkjet and xerographic printer, ink, toner and paper manufacturers to develop improved test methods, specifications and standards.

6. In a future research project, the authors plan to conduct paired-comparison tests with selected inks and plain papers using various surface and deep-well municipal sources, seawater, and distilled water to understand what effects different kinds of water might have on water-resistance behavior in both short-term and long-term contact with water.

References


Author Biographies

Henry Wilhelm is Founder and Director of Research at Wilhelm Imaging Research, Inc. Grinnell, Iowa. With work beginning in 1971, Wilhelm and his colleagues have assembled the world’s largest reference collection of analog and digital color print materials and associated permanence data. Wilhelm has authored or co-authored more than 25 technical papers that were presented at conferences sponsored by the Society for Imaging Science and Technology (IS&T), the Imaging Society of Japan (ISJ), and the American Institute for Conservation (AIC). He has been involved with ANSI and ISO print permanence test methods standards development since 1978. With contributing author Carol Brower Wilhelm, he wrote “The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures,” published in 1993. The complete 761-page book is available in PDF-A format at no cost from www.wilhelm-research.com. Wilhelm is currently serving with Shigeo Suga of Suga Test Instruments Co., Ltd., Tokyo, Japan, as Co-Project Leaders for the development of the new ISO 18937-4 accelerated test methods standard for LED illumination sources.

Ken Boydston is the President and Chief Color Scientist of MegaVision, Inc., Santa Barbara, California. Boydston led the development of the high-resolution, MegaVision Multispectral Imaging and Analysis System which was introduced in 2007 and, with Boydston’s collaboration, has been used to image, monitor with very large colorimetric data sets, and conduct forensic analysis of The Dead Sea Scrolls in Israel, President Abraham Lincoln’s handwritten draft of the Gettysburg Address, and many other cultural heritage treasures in the United States and throughout the world.

Richard M. Adams II, Ph.D., is an Associate Professor in the School of Graphic Communications Management at Ryerson University, Toronto, Canada. He teaches courses in document design, web design, and material science for print. His research focus include color management, electronic documents, and web design. Before coming to Ryerson University, Adams was a color management specialist with the training division of X-Rite, Inc., and he was also a research scientist at the Graphic Arts Technical Foundation (now the Printing Industries of America). After completing his Ph.D., he went on to study for a master’s degree in printing technology from the Rochester Institute of Technology. Adams has recently been collaborating with Wilhelm Imaging Research on a number of research projects.

Charles Wilhelm is the manager of testing operations at Wilhelm Imaging Research in Grinnell, Iowa. Wilhelm is a 2015 graduate of Grinnell College, with a major in Chinese language and culture, and also studied Japanese language and culture, music, calculus, and statistics.
Paper by Henry Wilhelm (Wilhelm Imaging Research, Inc.); Richard Adams (Ryerson University); Ken Boydston (MegaVision, Inc.); and Charles Wilhelm (Wilhelm Imaging Research, Inc.) entitled:

**Improved Water-Resistance Test Methods Utilizing a Multispectral Imaging System to Quantify Black and Color Ink Bleeding for Plain Paper Office and Legal Documents Printed With Pigment- and Dye-Based Inkjet Inks**

Published on pages 122–125 in:


**ISBN: 978-0-89208-331-2**

Paper presented by Henry Wilhelm on November 8, 2017

Sponsored by:

IS&T: The Society for Imaging Science and Technology

and ISJ: The Imaging Society of Japan

©2017 The Society for Imaging Science and Technology

November 5–9, 2017

Hyatt Denver Hotel

Denver, Colorado U.S.A.

Published by:

IS&T: The Society for Imaging Science and Technology

7003 Kilworth Lane

Springfield, Virginia 22151 U.S.A.

Phone: 703-642-9090; Fax: 703-642-9094

www.imaging.org (e-mail: info@imaging.org)
Permanence Testing of 3D-Printed Objects Subjected to Fade Testing with Outdoor Sunlight and with High-Intensity Fluorescent Illumination and Evaluated with a Multispectral Camera and Image Analysis System

Richard M. Adams II*, School of Graphic Communications Management, Ryerson University, Toronto, Ontario, M5B 2K3, Canada; Henry G. Wilhelm, Wilhelm Imaging Research, Inc., Grinnell, Iowa, 50112 USA; and Jeremy Littler, Digital Fabrication Laboratory, Faculty of Communication and Design, Ryerson University, Toronto, Ontario, M5B 2K3, Canada

Abstract

In the past two decades, 3D printing using polylactic acid (PLA) and other plastics has become widely used for modeling, prototyping, and manufacturing for both professional and amateur applications. Statistics website <www.statista.com> predicts that the global 3D printing market will grow from $12 billion in 2018 to $20 billion in 2021. Unlike 2D-printed signs, prints, and photos, 3D-printed objects, if placed outdoors or in windows, will be exposed to visible light and UV radiation that can cause colorant fading, surface chalking, crazing, and other degradation (including a loss of brightness in the case of fluorescing colors). Little recent work has been published concerning testing of 3D-printed materials for light fading, ozone resistance, and long-term dark storage stability[1]. To develop a protocol for permanence testing of 3D-printed objects, the authors first developed a 3D-printable test target inspired by the widely-used Macbeth ColorChecker. Fade-resistance testing of samples placed in the 3D color test target was conducted under accelerated fluorescent illumination and exposed directly to outdoor sunlight.

Introduction

The authors have developed a 3D-printed color test target for assessment of color permanence in 3D-printed objects, and for use in a test that could be evaluated with a large data-set multispectral camera and analysis system. The multispectral camera records CIE LAB values similar to a spectrophotometer but measures non-flat objects more accurately – and much more quickly – than is possible with desktop or hand-held spectrophotometers. The large data-set capture time with the MegaVision EV system for 16 spectral bands is just 1 minute and 16 seconds. For capture of 26 spectral bands (including special multi-filter image captures with a filter wheel for analysis of degradation of UV-excitation of fluorescing colorants) is 3 minutes and 15 seconds. The system allows for the capture of more than 10,000 individually addressable LAB data points; capture times are the same regardless of the number of data points specified.

The 3D-printable color test target (Figure 1) was inspired by the widely-used Macbeth ColorChecker. The plastic 3D-printed target includes a holder with 6 columns and 4 rows of indentations into which 1x1-cm 3D-printed cubes or flat, square tiles can be placed. Once installed in the holder, the 3D-printed materials can be subjected to fade testing. The design also includes a protective clear lid with 0.5x0.5-cm openings that hold the test tiles in place during transport, but still allows unimpeded light exposure of the color tiles. The 3D .stl print files for the test target are posted on the Wilhelm Imaging Research website and can be freely used by anyone without cost. Although not intended for 3D printing, a conceptually similar flat customizable camera test target with individual user-installable target patches is available from Image Science Associates [2].
Permanence Testing Protocols

3D color test targets were printed at Ryerson University’s Digital Fabrication Laboratory (Digital FabLab) with a Prusa MK2 3D printer [3] and a CraftBot 3D printer [4] with a variety of polyactic acid (PLA) filaments of various colors (Figure 2).

For the “raw materials” to build 3D-printed objects, most 3D printers are capable of printing only one color (one filament) at a time. The Ryerson-Wilhelm 3D Color Test Target allows color tiles to be printed individually using separate filament colors; the color tiles can then be inserted into the 3D-printed test target frame to easily create a multi-color test target. Some printers, including the HP JetFusion 500 Series 3D printers (which uses an inkjet assisted sintering 3D printing process with CMYK color capabilities), the 3D Systems ProJet CJP 660Pro 3D printer, and the XYZprinting daVinci Color FDM 3D printer (which uses in-line CMYK inkjet printing of a special ink-receptive filament to impart colors) and is claimed to be able to print “high-resolution, full color” objects directly with the color information encoded into the printing file. Some 3D-printed objects are spray-painted or otherwise have colorants applied after printing. This is especially common with large 3D-printed objects, or where brilliant, highly-saturated colors with deep blacks are desired. Because of market demand, “Color-Capable” 3D printing systems are certain to become more commonplace in the future.

Regardless of how colorants are incorporated into 3D-printed objects – or are applied as a separate process after printing – the multispectral imaging and analysis procedures described in this paper can be used to quantify color fading, color balance shifts, yellowish staining, chalking, and other types of degradation.

Accelerated Light-Fading Tests

Fade-resistance testing of samples in the 3D color target was conducted under accelerated fluorescent illumination (Figure 3) and in outdoor sunlight (Figure 4). After being exposed to 25 klux fluorescent light for 24-hour, 1-week, and 1-month intervals, the samples were measured with a MegaVision EV Multispectral camera and image analysis system[5] as shown in Figures 5, 6, 7, 8, and 9, and delta-E color difference values were calculated.[6]

C* chromaticity and ΔC* chromaticity differences were calculated (Table 1) and graphed (Figure 5) to compare the

<table>
<thead>
<tr>
<th>Number</th>
<th>Position</th>
<th>Color</th>
<th>Fluorescence</th>
<th>ΔE2000</th>
<th>C*</th>
<th>ΔC*</th>
<th>L* UV</th>
<th>Scaled L* UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>yellow</td>
<td>low</td>
<td>88.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td>green</td>
<td>high</td>
<td>22.8</td>
<td>32</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A3</td>
<td>blue</td>
<td>medium</td>
<td>55.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A4</td>
<td>magenta</td>
<td>low</td>
<td>35.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>B1</td>
<td>white</td>
<td>high</td>
<td>3.8</td>
<td>34</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>B2</td>
<td>black</td>
<td>low</td>
<td>11.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>B3</td>
<td>red</td>
<td>high</td>
<td>46.1</td>
<td>23</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B4</td>
<td>orange</td>
<td>high</td>
<td>53.6</td>
<td>24</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fluorescent Illumination (Cool White Lamps, Bare-Bulb Exposure)

<table>
<thead>
<tr>
<th>Number</th>
<th>Position</th>
<th>Color</th>
<th>Fluorescence</th>
<th>ΔE2000</th>
<th>C*</th>
<th>ΔC*</th>
<th>L* UV</th>
<th>Scaled L* UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>A5</td>
<td>yellow</td>
<td>2.6</td>
<td>77.6</td>
<td>10.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>A6</td>
<td>green</td>
<td>15.0</td>
<td>30.7</td>
<td>-7.9</td>
<td>16</td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A7</td>
<td>blue</td>
<td>2.1</td>
<td>54.9</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>A8</td>
<td>magenta</td>
<td>7.6</td>
<td>27.8</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>B5</td>
<td>white</td>
<td>0.6</td>
<td>3.5</td>
<td>0.3</td>
<td>24</td>
<td>70.6</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>B6</td>
<td>black</td>
<td>7.8</td>
<td>4.3</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>B7</td>
<td>red</td>
<td>4.4</td>
<td>41.9</td>
<td>4.3</td>
<td>25</td>
<td>108.7</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>B8</td>
<td>orange</td>
<td>2.7</td>
<td>48.7</td>
<td>4.9</td>
<td>23</td>
<td>95.8</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>5.4</td>
<td>3.6</td>
<td>81.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Outdoor Sunlight (Weathering with Rainfall and Snow)

<table>
<thead>
<tr>
<th>Number</th>
<th>Position</th>
<th>Color</th>
<th>Fluorescence</th>
<th>ΔE2000</th>
<th>C*</th>
<th>ΔC*</th>
<th>L* UV</th>
<th>Scaled L* UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>A9</td>
<td>yellow</td>
<td>5.4</td>
<td>66.7</td>
<td>21.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>A10</td>
<td>green</td>
<td>9.5</td>
<td>19.6</td>
<td>3.3</td>
<td>17</td>
<td>53.1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>A11</td>
<td>blue</td>
<td>3.9</td>
<td>46.7</td>
<td>9.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>A12</td>
<td>magenta</td>
<td>11.1</td>
<td>18.6</td>
<td>17.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>B9</td>
<td>white</td>
<td>5.4</td>
<td>7.0</td>
<td>-3.1</td>
<td>13</td>
<td>38.2</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>B10</td>
<td>black</td>
<td>13.2</td>
<td>3.9</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>B11</td>
<td>red</td>
<td>5.5</td>
<td>34.5</td>
<td>11.7</td>
<td>21</td>
<td>91.3</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>B12</td>
<td>orange</td>
<td>7.8</td>
<td>34.6</td>
<td>19.0</td>
<td>20</td>
<td>83.3</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>7.7</td>
<td>10.8</td>
<td>66.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. Graph of the change in chromaticity ($C^*$) of color patches exposed to fluorescent light and outdoor sunlight. The samples illuminated with sunlight (red) showed the greatest decrease in chromaticity due to light fading.

Unfaded Reference Sample | 1 Year of 25 klux Fluorescent | 1 Year of Outdoor Exposure

Multiple Wavelength Captures (color-accurate rendering for human vision)

Photoshoot software measurement screen (green squares are the LAB measurement areas)

365-nm (UV) capture for fluorescing colorants

Figure 6. Top: 3D-printed color test targets captured by the MegaVision EV camera (left to right): control, fluorescent illumination, outdoor sunlight. Middle: Screen capture showing 4x2 measurement grid used to read LAB values in the MegaVision PhotoShoot software. Bottom: The same three 3D color targets (control, fluorescent, and sunlight) photographed under 365-nm UV illumination. Note that considerable degradation of the fluorescent dye has occurred in four of the most stable colors (white, green, orange, and yellow).
chromaticity differences for the fluorescent- and sunlight-faded color patches with the control.

**Testing the Degradation of UV-Excitation of Fluorescing Colorants**

Some of the PLA colors used to print the target patches for this project contained significant levels of UV-excitation components, as revealed by examination under UV illumination (Figure 6). To assess degradation of the UV-excited components, the 365-nm TIFF file created by MegaVision Photoshoot software that was opened in Photoshop. The colors that were observed to have “high” levels of fluorescence (green, white, red, and orange) were measured with Photoshop’s Grayscale Information Palette (scale, 0–100%) and the cursor. Measurements of the fade-tested target (Table 1, column 7) were scaled (column 8) with reference to the control target.

**Results**

**Accelerated Light Fading**

Table 1 shows the C* chromaticity values and ΔC* color differences between the unexposed control and the targets exposed to sunlight and fluorescent light for one year. (Positive numbers indicate a greater reduction of chromaticity.)

The ΔC* measurements (column 6) show that exposure of the 3D-printed color patches to fluorescent light and sunlight resulted in fading, as reflected in the reduction in chromaticity values. (The green patch gained slightly in chromaticity upon exposure to fluorescent light.)

**Degradation of UV-Excitation of Fluorescing Colorants**

The UV reflectance values of the 365-nm exposure (column 7) and scaled values (Column 8) show the extent to which the UV brighteners faded upon exposure to fluorescent light and sunlight. On average the fluorescing components “faded” to 81.3% of their original levels on exposure to fluorescent light and to 66.5% on exposure to sunlight.

**Permanence Testing Using a High-Resolution Multispectral Imaging and Analysis System**

MegaVision has developed a multispectral imaging system that employs a high-resolution monochrome area sensor array (50 megapixel CCD array with a file size of 100 MB at 16 bits per wavelength recorded); files are saved in uncompressed RAW format. Image capture time is 4 seconds per frame; a 16-band image capture requires about 1 minute and 15 seconds.

The MegaVision system uses narrow-band LED’s, ranging from near UV to IR, in place of white light as the illuminant (nominally covering the 350–1000 nm range of silicon detectors). This arrangement improves by one or more orders of magnitude the efficacy of the light energy illuminating the scene (important, for example, where damage to delicate museum objects from light exposure is a concern) and eliminates the many problems associated with changeable filters in the optical path. Ten of the nominally nineteen (or more) spectral bands cover the visible range; additional spectral bands, including in the UV and IR regions, can be employed if desired.

The LED illumination system typically includes 50,000-hour-rated LED’s with up to nineteen specific wavelengths, including:

- UV: 365, 385, 400 nm
- Visible: 420, 450 470, 505, 530, 560, 595, 615, 630, 655 nm
- Infrared: 700, 735, 780, 850, 940, 1050 nm
To date, the MegaVision EV multispectral camera has very accurate color reproductions of manuscripts and works of art. The camera is being used for imaging historical documents at the Library of Congress in Washington, D.C., including drafts of the United States Declaration of Independence.

The system is available at <www.antiquities.org.il> for high-resolution, multi-spectral imaging of the 2,000-year-old Dead Sea Scrolls.

The MegaVision EV multispectral camera is fitted with a specially designed 120mm f4.0 UV-VIS-IR hyperspectral lens that is apochromatic and maintains the same focus point over the full range of wavelengths from 350 to 1050 nm.

**Use of a Color Filter System in Quantifying the Degradation of UV-Excitation of Fluorescing Colorants**

MegaVision’s Color Filter Wheel (CFW, Figure 12) provides front-of-the-lens filtration for a range of color image capture and scientific imaging applications. The CFW contains either one or two coaxial filter wheels; each wheel has 4 filter ports. The 61-mm filter ports enable vignette-free use with a wide range of optics, including MegaVision’s 120-mm hyperspectral lens. Standard 67-mm rings on both wheel housing ports facilitate external interfaces with standard filters, lens shades, and other modifiers. The CFW can be fitted with a range of gel, polyester, resin, or thin (up to 2 mm) glass filters. A standard single-wheel configuration includes one clear opening and red, green, and blue color separation gel or polyester filters. In dual-wheel configurations, each wheel is independently controlled and incremented, so arbitrarily selected filters from each wheel may be super positioned.
can be detected by a silicon sensor. Alternatively, features filtering the excitation light can enable the discovery of invisible components of the color in the images.

When integrated into MegaVision’s multispectral imaging system, the CFW plays a crucial role in discovery. Features that are not visible often leave invisible traces that can be discriminated from the background by fluorescence. Often, the fluorescence is weak, and without the filter wheel the weak fluorescence signal is swamped out by the strong excitation light. Filtering the excitation light can enable the discovery of invisible features. Alternatively, some features transparent to visible light may reflect UV radiation which cannot be seen by humans, but can be detected by a silicon sensor. To this end, the CFW is commonly fitted with both a UV-pass filter and one or more UV-blocking filters.

The CFW increments to an adjacent filter position in about 1 second. Smooth acceleration and deceleration ensure minimal vibration and motion transients.

CFW control and utilization are completely integrated into MegaVision’s image capture software application, PhotoShoot. When used with MegaVision’s narrow-band multi-spectral imaging system, the CFW provides the capability to not only render color images of great accuracy, but also to quantify and discriminate between the reflectance and fluorescence components of the color in the images.

Summary

The Ryerson-Wilhelm 3D Color Test Target provides an easy-to-print color test target incorporating multiple 3D-printed colors for use in assessing the color permanence and fluorescing colorant degradation with 3D-printed objects.

The colorant degradation analysis procedures described here are also applicable for spray-painted 3D-printed objects and with other types of post-printing application of colorants. The 3D color test target was specifically designed for comprehensive, large data-set multispectral imaging and analysis systems; however, if necessary, it can also be used with desktop and handheld spectrophotometers.

The 3D-printed test targets and the multispectral imaging and analysis procedures described here can be used with a broad range of accelerated aging tests, including indoor and outdoor light exposure and weathering tests, predictive multi-temperature thermal aging (Arrhenius) tests, water-resistance tests, high-humidity and cycling humidity resistance tests, and tests for resistance to ozone and other atmospheric pollutants.

References


[3] Prusa MK2 3D printers and Prusa filament are supplied by Prusa Research SRO, Partyznska 18/B, Prague, Czech Republic 17000. Prusa also has a distribution office in the United States. https://www.prusa3d.com


Author Biographies

Richard M. Adams II is an Associate Professor in the Ryerson University School of Graphic Communications Management, where he teaches color management, document design, and web design. After completing his Ph.D. at Cornell University and contributing to scientific publications, he earned a Master of Science degree in Printing Technology at Rochester Institute of Technology. He has taught at several universities and was a research scientist at the Graphic Arts Technical Foundation (now the Printing Industries of America), where he worked on press test forms and their measurement with spectrophotometry. In the Fall of 2018 he will teach at the Stuttgart Media Academy in Stuttgart, Germany.

Henry Wilhelm is Director of Research at Wilhelm Imaging Research, Inc. in Grinnell, Iowa, USA. Wilhelm has authored or co-authored more than 30 technical papers presented at conferences sponsored by the Society for Imaging Science and Technology (IS&T), the Imaging Society of Japan (ISI), and the American Institute for Conservation (AIC) in the United States, Europe, Japan, and other countries. He was one of the founding members of American National Standards Institute (ANSI) Committee IT-3, established in 1978. The Committee is now known as ISO Working Group 5/Task Group 3 (a part of ISO Technical Committee 42). Working together with Yoshihiko Shibahara of Fuji Photo Film Ltd. in Japan, Wilhelm served as Co-Project Leader of the “Indoor Light Stability Test Methods Technical Subcommittee” of ISO WG-5/ TG-3. ISO International Standard 18937 – Imaging Materials – Photographic reflection prints – Methods for measuring indoor light stability (58 pages) was published in January 2014. Wilhelm is currently serving with Shige Suqa of Suqa Test Instruments Co., Ltd., Tokyo, Japan, as Co-Project Leader for the development of the new ISO 18937-3 accelerated test methods standard for LED illumination sources.

Jeremy Littler is the Lead for Emerging Technologies at Ryerson’s Faculty of Communication and Design (FCAD). He is a desktop 3D printing/fabrication specialist and was the lead designer of FCAD’s FabLab (fablab.ryerson.ca). Littler utilizes a wide range of FDM and SLA printers for multi-material 3D printing projects. These capabilities will be further expanded in the new Creative Technologies Lab being developed at Ryerson University.