Image Stability Test

For

Eastman Kodak Company

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Completed By

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RESEARCH

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1.0 Executive Summary

Eastman Kodak Company asked Torrey Pines Research (TPR) to conduct an image stability test on a number of digital print samples. Kodak defined the printers to be used. TPR printed the images, exposed them to various environmental conditions and analyzed the data.

The test images were made from commercially available printers, at retail kiosks, and from commercial minilab services. Each used the manufacturer recommended ink and media set or imaging materials. An image consisting of a number of color patches was used for most of the print samples (Appendix A.). Print samples supplied were exposed to three separate accelerated tests comprising 50 klux fluorescent light exposure with polycarbonate filtration, 80% humidity with no light, and 1 part per million ozone with no light. At periodic intervals up to 168 days total exposure, TPR measured the densitometric values of each of 57 color patches on each print sample including the media background. Values of density loss vs. time (days) for red, green and blue channels in the neutral patch and for red in cyan patch, green in magenta patch and blue in yellow patches were graphically plotted. The tables of measurements together with the detailed graphs are available in separate Excel files.

In addition to the color patch image, an image that included bleed patterns and a photo was used for the humidity test (Appendix B) and this image was evaluated at the end of the test for color change and bleed.

TPR used a density change as an endpoint to predict print life. The values and methodologies used in this calculation have been used in the industry for a number of years. TPR recommends extreme caution in interpreting print life projections in years. These projections should be regarded as a comparative evaluation rather than an absolute forecast because there are so many variables between the test methods and the typical user experience.

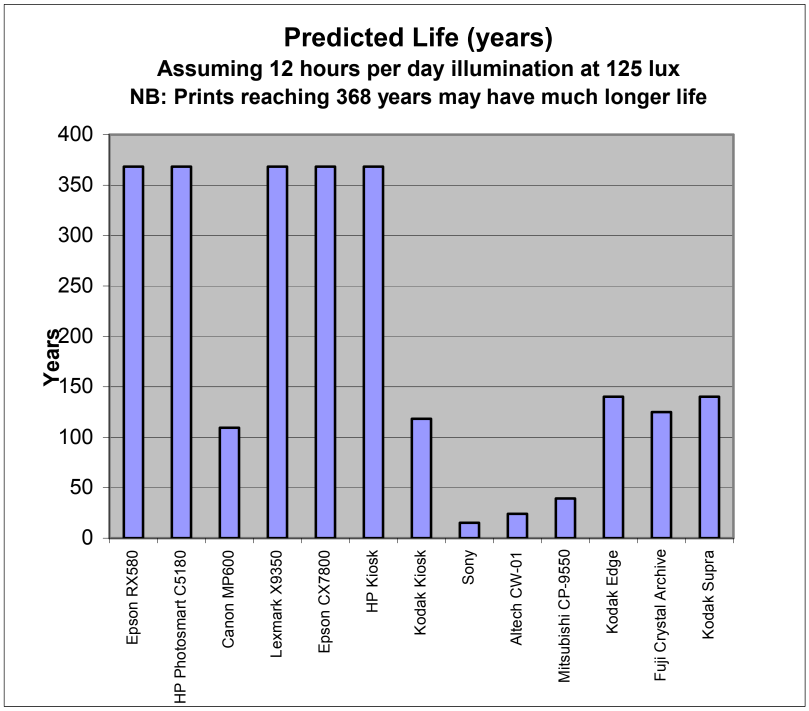


Figure 1 - Predicted Life in Years based on 50klux Accelerated Light Fade Test

In the chart for light fade, a predicted life of 368 years means that the sample did not reach an endpoint and the life prediction is then ‘at least 368 years’ under the specified conditions.

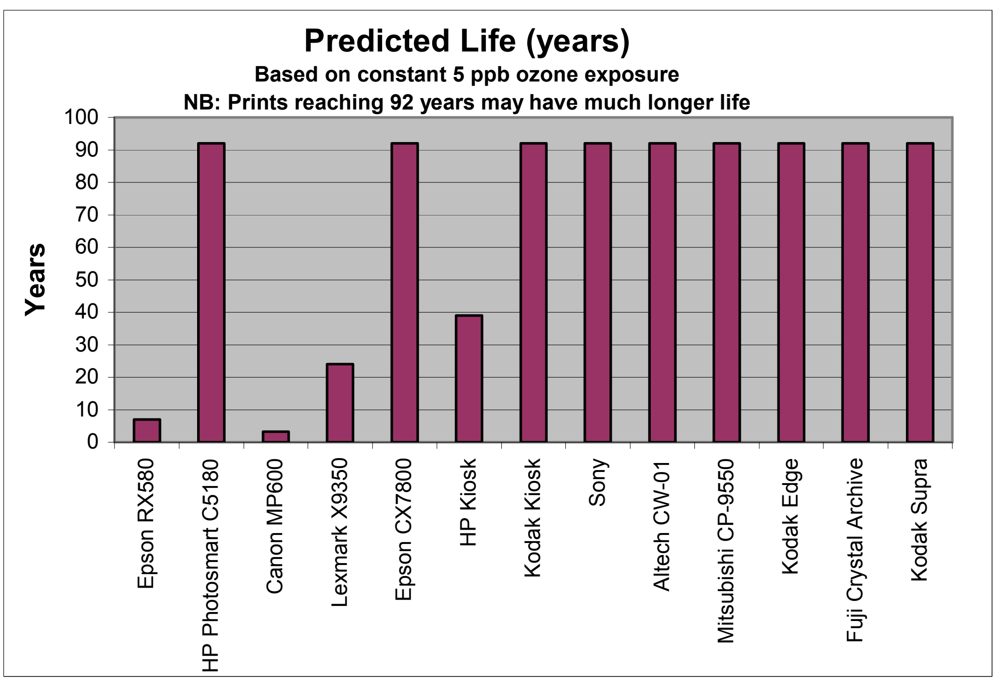


Figure 2 - Predicted Life in Years based on 1 ppm Ozone Accelerated Gas Fade Test

In the chart for gas fade, a predicted life of 92 years means that the sample did not reach an endpoint and the life prediction is then ‘at least 92 years’ under the specified conditions.

None of the print samples in the high humidity test reached the level of color change that would be unacceptable to most observers and no observable bleed or color fade was noticed in the visual examinations of the prints.

The predicted values for each of the exposures are summarized in Figure 3.

Printer	50kLux Poly Fade	Gas Fade	Humidity Fade
Epson RX580	368 +	7	90 +
HP Photosmart C5180	368 +	92 +	90 +
Canon MP600	110	3	90 +
Lexmark X9350	368 +	8	90 +
Epson CX7800	368 +	92 +	90 +
HP Kiosk	368 +	39	90 +
Kodak Kiosk	116	92 +	90 +
Sony	15	92 +	90 +
Altech CW-01	24	92 +	90 +
Mitsubishi CP-9550	39	92 +	90 +
Kodak Edge	140	92+	90 +
Fuji Crystal Archive	125	92 +	90 +
Kodak Supra	140	92 +	90 +

Figure 3 - Predicted Print Life in Years

The gas fade data for the Kodak kiosk were recast due to the fact that the sample was affected by a dye retransfer problem that is detailed in the report.

The print life predictions from all three accelerated exposure tests are summarized graphically in the following Figure:

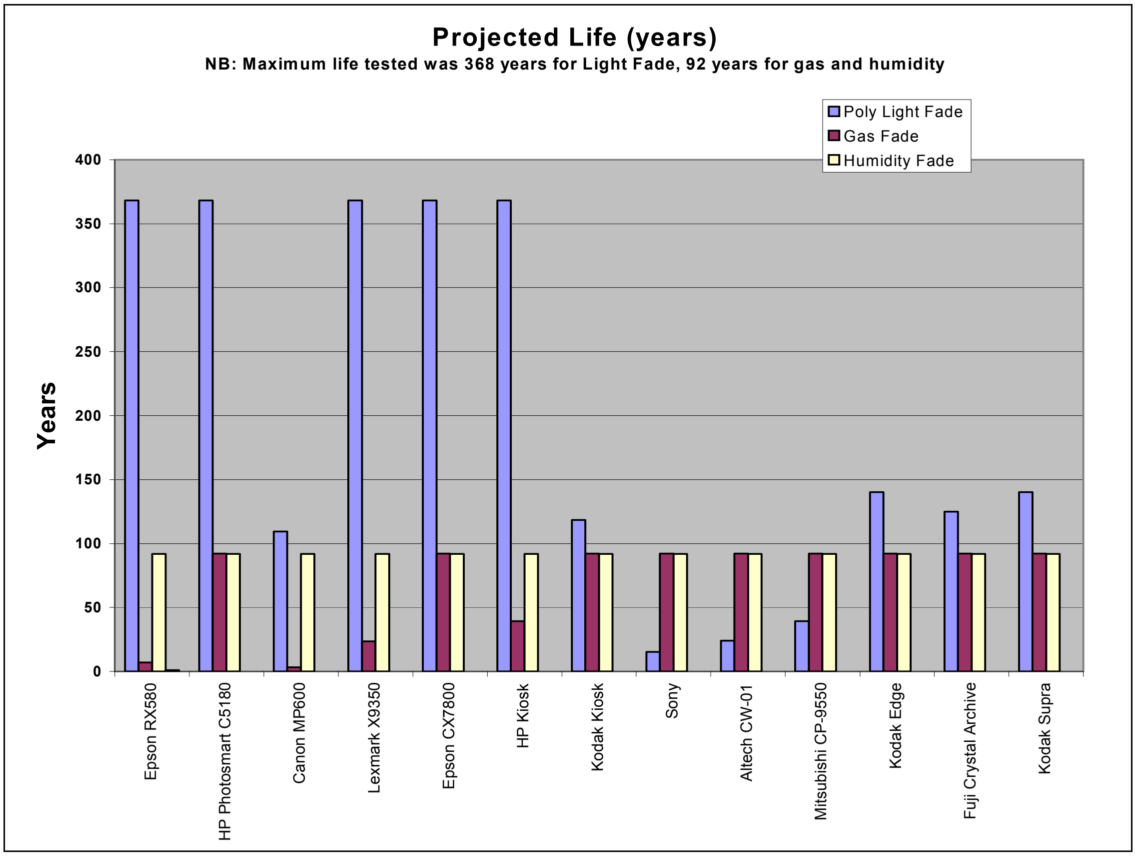


Figure 4 - Graphical Summary of Print Life Predictions

2.0 Torrey Pines Research

Torrey Pines Research is a leading independent product development, product testing, and technology consulting Company since 1986. Headquartered in Carlsbad, CA the company provides advanced technical services to companies in printing technology, materials technology, medical device and diagnostics development, and industrial/consumer product design. The Company also has turnkey manufacturing capabilities both domestically and offshore. TPR provides testing and strategy advisory consulting, often leading to advanced competitive developments, leveraging IP and industry know-how between TPR and its clients. It is common to develop significant new IP with and on behalf of the clients, and to pave new roads into revenue opportunities and untapped or under-served markets.

The Company has been testing print media, toners and inks for more than ten years for a variety of clients. TPR maintains an image stability test laboratory and has internal capabilities to perform accelerated light fade tests using xenon or fluorescent exposure, as well as gas fastness and temperature and humidity testing. Client relationships are always confidential, but in some instances our clients permit us to publish the findings. TPR personnel have presented papers at IS&T and IMI conferences in these areas.

TPR Fellows are a unique group within the company, scientists and engineers with extensive and deep subject matter knowledge, available to consult, research, and/or develop products and services on behalf of clients. They have been responsible for over 1000 patents, demonstrating a tremendous source of experience and scientific knowledge.

TPR was founded in 1986 and continues to operate independently without external investment or long-term debt. TPR has demonstrated expertise in all digital printing technologies, especially electrophotography, inkjet and thermal. To support and augment its product development capabilities, TPR has developed extensive testing capabilities for printer sub-systems and complete systems, starting with early technology feasibility verification to full scale EVT, DVT, PVT, and competitive assessment testing. The company produces scanners, printers, imaging processes (onto media, foods, pharmaceuticals, unique substrates, and more), or devices to coat, deposit or jet all kinds of fluids and materials (wet, dry, or solid).

A heritage of differentiating IP, innovation, technology, and cost-effectiveness comes from years of experience working closely on significant programs with the world's leaders such as J&J, Eastman Kodak, H-P, IBM, and many, many more. TPR people (www.tpr.com/tprfellows.htm) have deep experience in materials, process, and product development to the extent that TPR shares hundreds of patents among them with their assignees.

Contact information: Steven Beyer, VP Business Development at (585) 288-7220 x204 or at sbeyer@tpr.com.

3.0 Background and Description of Test

3.1 Image Permanence

Image permanence or image stability has become an important consideration for all involved in the development, purchase and use of photographs. In general, image permanence is the quality of a print or photo to remain unchanged for many years after its initial production irrespective of any 'normal' environmental conditions.

'Unchanged' means that the original colors, color densities, line definition and other image quality measurements do not change perceptibly to the eye of the observer.

'Normal environments' includes exposure to light from various sources including direct and indirect sunlight and artificial lights, varying temperatures and humidities, and exposure to low levels of atmospheric pollutants. All of these conditions have been shown to have a harmful effect upon the permanence of photographs made by various imaging processes.

End users would like their photographs to be unchanged in any way when exposed to these environments for long periods of time.

Suppliers of printing materials and equipment would like to assure end users that their photos will last for very long times when exposed to these environments. Unfortunately to prove this capability by exposing them to the typical environments would lead to unacceptably long test times. Therefore the industry has been developing accelerated tests that simulate the extended lifetime by exposing sample prints to higher levels of the 'normal environmental' element for short periods of time.

There are two popular standard methods for analyzing reflected color in images, based on colorimetric and densitometric measurement. Of the two methods, the colorimetric method is most likely to correspond with the consumer perception of color change. Many companies use densitometric change to measure image permanence however and this has been most commonly used by those wishing to analyze the changes in colorants. Currently densitometric analysis provides more technical information that can be used by scientists in comparing detail and in differentiating between color channels. Densitometric analysis is also widely used to predict actual print life from accelerated exposure data such as developed for this report. There is still much discussion about the specifics of these accelerated tests and the exact ratio between the accelerated test time and the expected real lifetime of the prints. However, the relative performance of prints exposed to the same accelerated tests is likely to be correct. The arguments are likely to be about the absolute extrapolated lifetimes, not the relative lifetimes.

There are a number of methods in use for projecting real print life in years using accelerated exposure life in days. These methods vary in their assumptions for the average exposure in a display environment, the number of hours per day the print is exposed, the type of light, whether the print is covered by a UV filter, density levels to be measured on the print, issues of reciprocity failure and so on. Although the industry is converging upon a consensus methodology, none has yet been finalized. The method used here is generally used in the industry and are adapted from ISO 18909-2006, which is a standard for silver halide materials.

3.2 Purpose of the Test

The purpose of this test series was to evaluate the image permanence performance of a variety of media and media/ink combinations. Prints were exposed to a number of tests, which were designed to demonstrate or measure the relative permanence of the image:

- Accelerated fluorescent light exposure at 50 klux, polycarbonate filtered
- High humidity dark keeping at 24°C / 80% RH
- Ozone exposure at 1 part per million (ppm) concentration

Specific details of the test conditions and duration can be found under the relevant sections of this report. These conditions are similar to those described in a number of independent reports.

TPR was requested to project estimated print life under the exposure conditions, using calculations that have been commonly used in the industry.

3.3 Images Used to Make Prints

Kodak provided the digital image forms used to generate prints and TPR made the prints from these images. The image used for most of the tests is illustrated in Appendix A and consists of several color blocks (57 patches total) including various densities of cyan, magenta, yellow, black, red, green, blue and neutral plus 3 D_{min} patches (unprinted media). The densities were printed as percentage of the color, 10%, 25%, 50%, 75% and 100%, this series of patches being printed for each color. Each of these color blocks was measured as part of the measurement cycle in the tests.

In addition, the high humidity dark keeping test used a second image illustrated in Appendix B. This image included bleed patterns, a photo and other sections designed to provide easier visual assessment of changes. The color densities of this image were not measured; it was used for purely visual assessment.

3.4 Test Prints

TPR acquired designated printers in the commercial retail channel together with the supplies needed to make the test prints. TPR also visited stores with kiosks where needed and had test prints made at the store using the Kodak images. Finally, TPR visited photo labs and sent the test images to them for printing the silver halide test prints. In each case, TPR was careful to insure that the prints were made in the same way that a consumer could get the prints made.

TPR completed the tests, compiled the data and compared each of the ink/media combinations and non-inkjet systems for their relative performance in each of the subject exposures. TPR then summarized the relative performance of each of the media and ink/media combinations based on the data. These results are reported in this document.

3.5 Print Identification

A total of five inkjet printers were used, including one from Canon, two from Epson, one from HP, and one from Lexmark. For each of the printers, the manufacturer's recommended ink set was used. Each printer was used to print samples on the manufacturer's recommended media for photo printing.

A total of five different kiosks were used with print/media from five different suppliers, including Altech, HP, Kodak, Mitsubishi and Sony. All of these kiosks used thermal dye transfer technology except HP, which used inkjet.

A total of three silver halide systems were tested, two using Kodak materials and one using Fuji.

Each printer/media combination was tested in duplicate. Following exposure, the results were analyzed and it was concluded that the duplicate samples performed as duplicates. Therefore, in the summary of results, duplicates are excluded. Finally, we grouped the samples into three categories as follows:

Desktop Inkjet

Photo Kiosk

Silver Halide

These changes resulted in the following summary of samples and exposure:

Poly Fade	Ozone	Hum Img 1	Hum Img 2	TYPE	Printer	Media
43	81	119	157	IJ-3	Epson RX580	Epson Ultra Premium Glossy Photo Paper
45	83	121	159	IJ-4	HP Photosmart C5180	HP Premium Plus Photo Paper
49	87	125	163	IJ-6	Canon MP600	Canon Photo Paper Pro
51	89	127	165	IJ-7	Lexmark X9350	Lexmark perfect Fnish Photo Paper
53	91	129	167	IJ-8	Epson CX7800	Epson Premium Photo Paper Glossy
47	85	123	161	IJ-5	HP Kiosk	
55	93	131	169	TH-1	Kodak Kiosk	
57	95	133	171	TH-2	Sony	
59	97	135	173	TH-3	Altech CW-01	
61	99	137	175	TH-4	Mitsubishi CP-9550	
63	101	139	177	AG-1	Kodak	Kodak Royal
65	103	141	179	AG-2	Fuji	Fuji Crystal Archive
67	105	143	181	AG-3	Kodak	Kodak Professional Super Endura

Table 1- Summary of Sample Identifications

3.6 Basis for Comparing Print Performance

The criteria that have been used in evaluating the data from this test are what is commonly referred to as ‘endpoints’. An endpoint is generally understood to mean a point where the print has changed by a measurable amount. The endpoint is used to define the end of testing so as to determine a print life estimate. The endpoint does not necessarily define a point of objectionable change in the eye of the end user however. When a print has reached an endpoint, the usefulness of the test for this application is complete. In this study we have used two endpoints, and when either endpoint is reached for a print, the test for that print is complete.

The endpoints selected were based on both neutrals and separations. The endpoint based on neutrals uses the red, green and blue densities of the neutral patch, and the separations use the red density of the cyan, green of the magenta, and blue of the yellow. These measurements yield the possibility of an endpoint in each of six measurement conditions. The endpoints selected are illustrations used in ISO 18909-2006. The value of the change in the endpoint is a change of 0.3 density in any one of the channels. For the first three conditions analyzed, we used the neutral patch of the print in Appendix A corresponding to a 1.0 density. The changes in density of the red, green and blue channels in this patch were monitored for each of the exposure conditions, and a change of 0.3 units in any of these channels was considered to be an endpoint. The same endpoint was applied to the RGB channels of the C, M and Y patches.

The other endpoint criterion is a differential of 15% in density loss from 1.0 between any two of the neutrals. Graphs of density versus time were plotted for each sample. The following graphs were developed for each sample:

Graph 1: Density vs. Time (days) for red, green and blue channels in the neutral patch (Neutrals)

Graph 2: Density vs. Time (days) for red in cyan patch, green in magenta patch and blue in yellow patches (Separations).

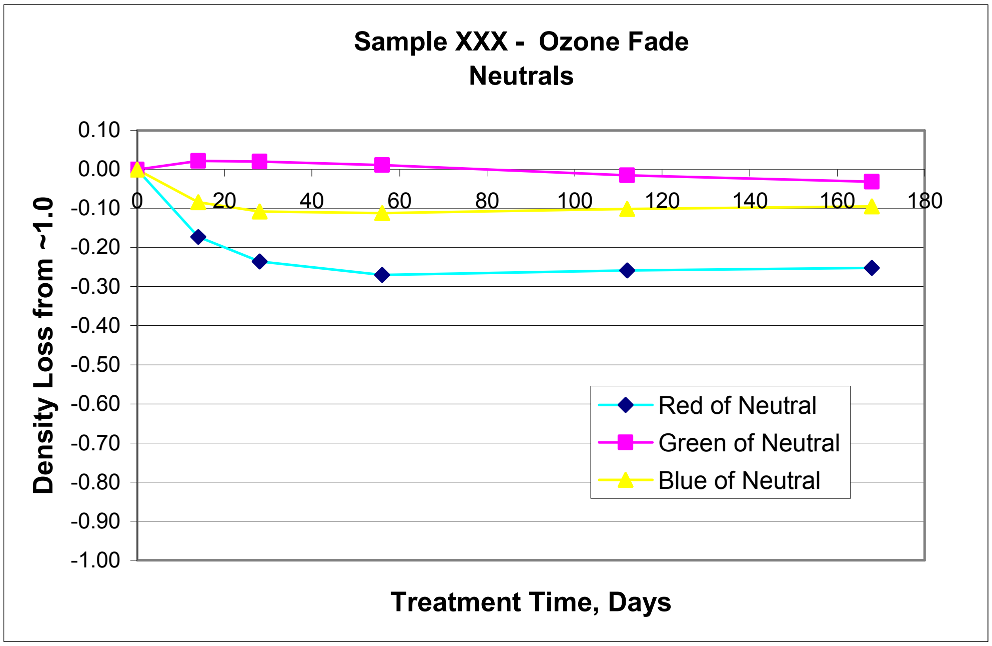


Figure 5 - Sample Chart (Graph 1) of Ozone Fade in Neutrals

The graphs were then analyzed using the above criteria to establish if and where the endpoint in density had been reached, and the corresponding number of days to reach the endpoint was tabulated for each sample. Life projections were based on the first endpoint reached in either of graphs shown in Figures 5 and 6.

In the sample chart depicted in Figure 5 it can be seen that the endpoint criterion of a density change of 0.3, did not occur during the exposure in the neutrals. However, a variation of 15% between the Green and Red channels occurred at about 14 days, so this is the value that would be used to project print life.

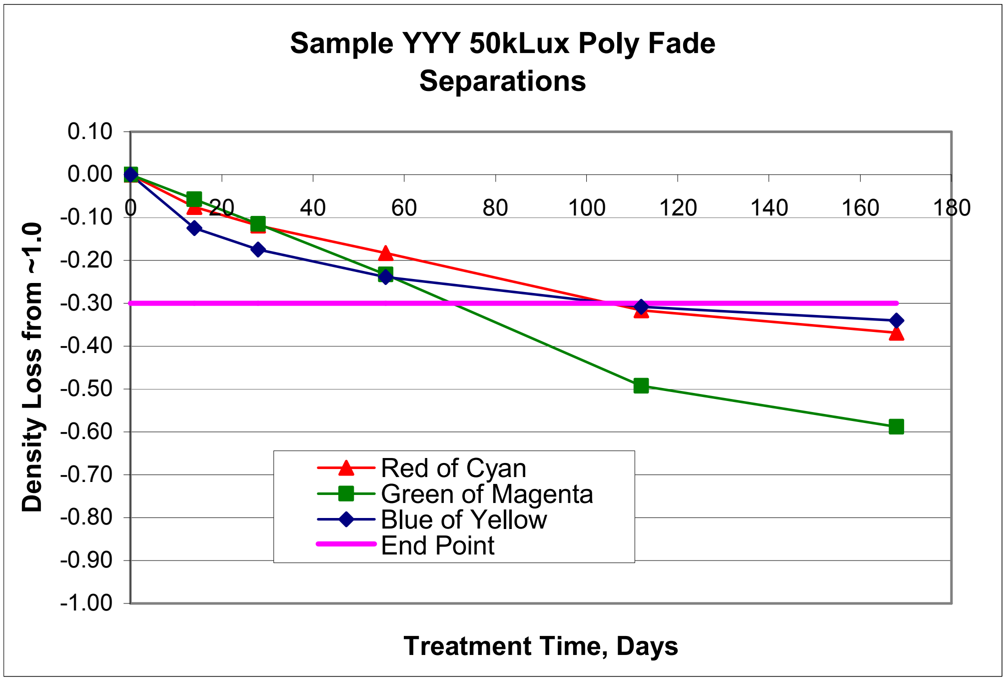


Figure 6 – Sample Chart (Graph 2) of 50klux Poly Fade Separations

In the sample chart depicted in Figure 6 it can be seen that the first endpoint, a density change of 0.3, occurred at about 69 days during the exposure in the Green channel of the Magenta patch. This was the first endpoint reached and is therefore the value used to project the print life.

TPR was asked to predict print life based on these endpoints for each of the exposures. The basis for estimating print life is a commonly used method that assumes a 'normal' exposure that might be experienced by a user and divides this into the total exposure from the accelerated test. For example, if we assume that a normal light exposure for a print hung on an indoor wall is 150 lux, we want to use the light fade results to project how long this print would take under the normal exposure conditions before it had degraded by 0.3 density units. If the accelerated test showed that a print degraded by 0.3 units in 100 days at 24 hours of exposure to 50000 lux, then we could project that it would take 50000/150*100/365*2= 182 years to degrade the print by the same amount under normal exposure conditions using 12 hour days for exposure.

For the purposes of these calculations, we have assumed the following as 'normal' exposure conditions:

Light Fastness 125 lux

Ozone Fastness 5 ppb

Furthermore, we have also assumed that there is no effect from reciprocity failure in either light or gas fade.

For the sample shown in Figure 5, the assumptions used would predict a print life of 7.7 years when continuously exposed to 5 ppb ozone.

For the sample shown in Figure 6, the assumptions used would predict a print life of 152 years when continuously exposed to 125 lux for 12 hours per day.

For the high humidity dark fastness we measured all of the density patches, but based on previous testing, decided to use a visual examination to analyze the changes.

TPR recommends extreme caution in interpreting print life projections in years. These projections should be regarded as a comparative evaluation rather than an absolute forecast for several reasons. Although the methodology for developing the life projections in this report has been in use for some years in the industry, it is becoming clear that the implied precision in the use of a single value in years cannot be scientifically supported due to variations in laboratory conditions, lamp life, measurement and control systems and so on. In addition, the predictions assume that the print is exposed to only one condition for its complete life. That is, a light fade prediction assumes no ozone exposure (or exposure to any other industrial gases), and no effects from high or low humidity. Obviously such assumptions are likely to be invalid in almost all real life exposure situations and the data for the long term effects of combined exposures is scant to say the least. Finally, actual user exposure conditions are unlikely to be an exact match for the exposure conditions used in the calculation. Even in a room where the average ambient light level is 125 lux, based on daylight measurements, the level received by a print on one wall can differ significantly from the level received by the same print when hung on the opposite wall.

4.0 General Procedures

4.1 Record Keeping

TPR used a standard PC running Windows XP operating system. The Gretag Spectralino control software read the data from the measurements directly in an extended text format into an Excel spreadsheet. These data were then compiled and analyzed for this report.

Each test sample had a unique barcode marked indelibly on a label attached to the back of the sheet.

The following data were taken using the Gretag Spectrolino – L*, a*, b* and the 4-channel V, R, G, B densities – Status A, D50, 2 deg, Reflection, White base = Abs, Filter = None, Black platform on the Spectrolino.

4.2 Material Handling During Test

All possible efforts were made to prevent contaminating the samples. All media was handled with lint free, cotton gloves before, during and after testing. Surfaces coming in contact with either surface of the print (work surfaces, instrument faces, etc.) were cleaned prior to each test with pH neutral cotton wipes. Work surfaces were covered with acid free paper during the handling of prints.

Prior to testing prints were stored in acid free storage media of the appropriate type. Each container was marked with the date printed and the job number. Each container contained only one paper/ink type. Each container was kept at 20-25^{0}C and 45-55% RH prior to testing. After printing, the prints were stored in these conditions for at least one week prior to beginning any of the initial measurements and exposure tests.

After test completion prints were stored in acid free storage media of the appropriate type. Each container was marked with the date printed, the date tested, and the job number. Each container contained only one paper/ink type. Each container contained the results of one test. Prints exposed to different tests were not mixed. Each container was kept at 20-25^{0}C and 45-55% RH.

4.3 Laboratory Facilities and Environment

All of the tests were performed at the TPR laboratory in Fairport, NY. The laboratory environment was maintained at the temperature and humidity levels required to achieve 23^0C +/- 2^0C, and 50% +/- 5% relative humidity at the print sample plane (except for the humidity testing) for the duration of the testing activity. Monitoring of these conditions was performed three times daily (morning, noon, late afternoon) to ensure conditions were acceptable.

Ambient ozone levels in the laboratory facilities were monitored twice per day for the duration of the test and verified to be at or below 3 parts per billion.

4.4 General Test Equipment

4.4.1 Viewing Booth

A Gretag-Macbeth model Judge II-S controlled lighting booth was used to observe the test prints. This piece of equipment can provide four different types of light for viewing prints:

- Artificial Daylight (fluorescent daylight – 6500K)
- Store Lighting (cool white fluorescent – 4150K)
- Home Lighting (illuminant “A” – 2856K)
- Ultraviolet

The sample viewing area is about 2.5 ft^2. For the purposes of this test Artificial Daylight was used and sample exposure was limited to no more than 5 minutes.

4.4.2 Spectrophotometer

A Gretag-Macbeth Spectrolino spectrophotometer was used to measure the different color patches on each sample before and after each exposure increment or each test. The spectrophotometer was connected through its I/O port and serial interface to the lab PC for data collection.

The Spectrolino was calibrated prior to the test and each day that test measurements were to be taken. The instrument was powered on for at least 30 minutes prior to calibration. Calibration was performed using the manufacturer supplied Calibration Standard.

4.4.3 Ozone Monitor

A 2B Technologies Model 202 Ozone Monitor was used to verify ambient ozone levels and was also used as a check on the ozone monitor in the ozone exposure chamber. The monitor was calibrated prior to the test and measurements were taken three times per day.

5.0 Accelerated Fluorescent Light Exposure Test

There are no industry standards yet available for accelerated light fade ageing of digital media such as inkjet materials. ISO 18909-2006 does define testing methodology for accelerated light fade testing of silver halide materials and TPR has used that standard as a basis for all testing reported here. Standards for digital media are expected to be issued in the next several years, and TPR will use those standards as soon as they become available.

Accelerated ageing is done using high output daylight fluorescent lamps to provide a high intensity exposure at the print surface. The tests are conducted with the prints behind a UV absorbing filter, such as glass or polycarbonate, with airspace, and at controlled temperature and humidity conditions.

The light fade test was roughly as described in the paper *High-Intensity Fluorescent Light-Fading Tests for Digital Output Materials*, by Zinn, Nishimura and Reilly of the RIT Image Permanence Institute at the IS&T 1999 International Conference on Digital Imaging Technologies.

5.1 Fluorescent Light Exposure Fixture

A custom light exposure fixture functionally equivalent to the one described in the paper by Zinn and Nishimura was used and is able to provide continuous exposure to as many as (36) 8.5"x11" prints at once. In practice, TPR limits the exposure area to the central 50% or so of the exposure plane. The reason for this constriction is to insure that the samples are exposed to a uniform intensity throughout the test. In addition, the samples were relocated daily to maintain uniformity.

The sample frames each are capable of holding eighteen 8.5"x11" sheets in landscape format. This frame can be adjusted normal to the lamp array, thus accurately adjusting the intensity of light radiated to the samples. The lamp array oscillates back and forth to eliminate cold spots from the mere spacing of each lamp. The lamps used are GE F72T12CW 1500W cool-white outdoor fluorescent tubes. Each sample plane utilizes twenty-one lamps, which, depending on how distant the sample plane is from the lamp array, will apply 35 or 50 klux at the sample plane. The appropriate distance between the sample plane and the lamp array is determined by the use of an exposure meter. As the lamps age during the test, the sample plane is moved closer to the lamps in order to maintain the exposure level and the lamps are exchanged within the fixture to maintain uniformity.

In order to maintain the required 23° ± 2° C and 50 ± 5% RH at the sample plane it was necessary to maintain the specific laboratory environment at a lower temperature and higher humidity, typically 18°C and 65% RH. In addition, small fans were added to the fixture to cool the lamps and ballasts. The temperature and humidity at the sample plane were measured several times per day.

5.2 50 klux, Polycarbonate Filtered Test

New lamps were set up on the fixture and run for two days without any print samples in place as a burn-in procedure. The sample plane on the subject side of the fixture was covered with a ¼" polycarbonate panel with a large air gap between the sample plane and the polycarbonate.

Test prints of the image shown in Appendix A were exposed for 24 hours a day, seven days a week, over the course of the testing.

Prints were removed and measured at the following intervals:

0, 14, 28, 56, 112, 168 days

5.3 Light Fade Test Measurements

The following data were taken using the Gretag Spectrolino – L*, a*, b* and the 4-channel V, R, G, B densities – Status A, D50, 2 deg, Reflection, White base = Abs, Filter = None, Black platform on Spectrolino

These readings were taken on each of the color patches on the sample noted in Appendices A and B. Samples were removed from their mounting prior to making the measurements.

For each sample, a neutral patch with density at or very close to 1.0 on day 0 has been chosen for analysis of light fade. The same procedure was used to analyze the color separations. The change in density of the selected patch with time was plotted for each of the samples. A composite graph of density loss vs time was plotted for each sample, as illustrated in Figure 5.

In addition, the separations were similarly analyzed by measuring the red in cyan patch, green in magenta patch and blue in yellow patches. A composite graph was plotted for these values for each sample as illustrated in Figure 6.

	Accelerated Light Fade - 50 klux under Polycarbonate			
	Neutrals		Separations	
Printer	Days to 0.3D Change	Days to 15% Variation	Days to 0.3D Change	Assessed Endpoint Days
Epson RX580	168+	168+	168+	168+
HP Photosmart C5180	168+	168+	168+	168+
Canon MP600	60	50	98	50
Lexmark X9350	168+	168+	168+	168+
Epson CX7800	168+	168+	168+	168+
HP Kiosk	168+	168+	168+	168+
Kodak Kiosk	92	90	54	54
Sony	8	7	72	7
Altech CW-01	20	11	92	11
Mitsubishi CP-9550	21	18	38	18
Kodak Edge	95	80	64	64
Fuji Crystal Archive	83	93	57	57
Kodak Supra	90	80	64	64

Table 2 - Summary of Days to Endpoint for 50 klux Exposure

5.4 Discussion of Accelerated Fluorescent Light Exposure Test Results

Many of the samples reached the defined endpoint of 0.3 density change before the light fade tests were completed. In these tests, the samples were not removed from the exposure but completed the test. They were all measured at each measurement point.

Samples that did not reach the endpoint after 168 days exposure to accelerated light fade were:

Epson RX580
HP Photosmart C5180
Lexmark X9350
Epson CX7800
HP Kiosk.

Based on the life projection calculation described in Section 3.6, the following print life could be expected for the samples:

Printer	Assessed Endpoint (days)	Projected Life (years)
Epson RX580	168 +	368+
HP Photosmart C5180	168 +	368+
Canon MP600	50	110
Lexmark X9350	168 +	368+
Epson CX7800	168 +	368+
HP Kiosk	168 +	368+
Kodak Kiosk	54	116
Sony	7	15
Altech CW-01	11	24
Mitsubishi CP-9550	18	39
Kodak Edge	64	140
Fuji Crystal Archive	57	125
Kodak Supra	64	140

Figure 7 - Predicted Print Life Due to Light Fade

6.0 High Humidity Dark Keeping Test

For obvious reasons, inkjet inks and media are carefully formulated so that they are dry to the touch as soon as possible after printing. This is particularly true of the micro porous papers that are now available for most printers. Some tests have shown that dye based inks used with these media can result in prints that suffer some significant color shift due to humidity effects. Humidity levels as low as 60% can cause these shifts to occur even without the presence of light. The shifts are thought to be due to dye diffusion or migration and de-aggregation in the media. These changes can be referred to as 'dark fastness' rather than humidity effects because they are best tested with light excluded from the prints in order to distinguish the effects from light fade etc.

Ink bleed is another effect that has been reported when prints are exposed to high humidity. This may be manifested as a broadening of a narrow line, wicking from the edge of a solid area, or merging of adjacent colors. In order to assess this effect, the image illustrated in Appendix B was included and submitted to the same high humidity keeping test protocol as the general test image. This image was not printed in duplicate, so the even numbers only were used.

Color fastness issues due to high humidity exposure have been observed and reported for inkjet prints, but thermal and silver halide prints have not been seen to have much problem. For the sake of continuity all of the samples were included in this humidity exposure test even though there was no expectation of problems with thermal and silver halide.

The general test image was measured in the same way as in all of the other image permanence tests and the two graphs were developed for each sample. The Appendix B image was measured in a different way. Two prints were made at the beginning of the test, one being reserved as a reference print. The reference print was kept in a dark environment at 23°C and 50% RH, the second print was exposed to the 168 day humidity test before being measured. The prints were visually compared in the

Gretag-Macbeth Judge II viewing booth using the Artificial Daylight (6500) illumination setting. The visual comparison focused upon bleed, sharpness and color shift.

No definitive standards are available for color bleed, so a subjective and relative assessment was defined by the observer and is used in the results.

6.1 Temperature Humidity Chamber

The chamber used for the dark keeping test is a Tenney Benchmaster environmental chamber. This chamber has a capacity of about 4 ft^3 and is capable of maintaining temperature in the range 15 °C to 85 °C and humidity in the range 15% to 90%.

6.2 Humidity Exposure Test

The temperature and humidity of the chamber were set to 23 °C and 80 % RH respectively and maintained at these levels for the duration of the test.

Prints were removed and measured at the following intervals:

0, 14, 28, 56, 112 and 168 days

6.2.1 Humidity Test Color Measurements

These readings were taken on each of the color patches on the sample noted in Appendix A. Samples were removed from their mounting prior to making the measurements.

For each sample, a neutral patch with density at or very close to 1.0 on day 0 has been chosen for analysis of humidity. The change in density of this patch with time was plotted for each of the samples. A second graph was developed for each sample analyzing the separations of red in cyan, green in magenta and blue in yellow.

For each graph, the two endpoints were analyzed and the length of time to reach the endpoint is listed in the table below.

	Humidity Dark Keeping - 80% RH 23C			
	Neutrals		Separations	
Printer	Days to 0.3D Change	Days to 15% Variation	Days to 0.3D Change	Assessed Endpoint Days
Epson RX580	168+	168+	168+	168+
HP Photosmart C5180	168+	168+	168+	168+
Canon MP600	168+	168+	168+	168+
Lexmark X9350	168+	168+	168+	168+
Epson CX7800	168+	168+	168+	168+
HP Kiosk	168+	168+	168+	168+
Kodak Kiosk	168+	168+	168+	168+
Sony	168+	168+	168+	168+
Altech CW-01	168+	168+	168+	168+
Mitsubishi CP-9550	168+	168+	168+	168+
Kodak Edge	168+	168+	168+	168+
Fuji Crystal Archive	168+	168+	168+	168+
Kodak Supra	168+	168+	168+	168+

Table 3 - High Humidity Dark Keeping Exposure Life

From the table it can be seen that none of the samples reached the endpoint during the test. Calculations of print life using these data are not very meaningful and so the analysis focused upon visual examination of the prints.

6.2.2 Humidity Test Visual Results

The most identifiable problem that users would see in reviewing these prints is not color change, but is color bleed. There were several areas of the subject print where this problem could be observed as illustrated in the following photos.

Figure 8 - Reverse text area of humidity image - white on black

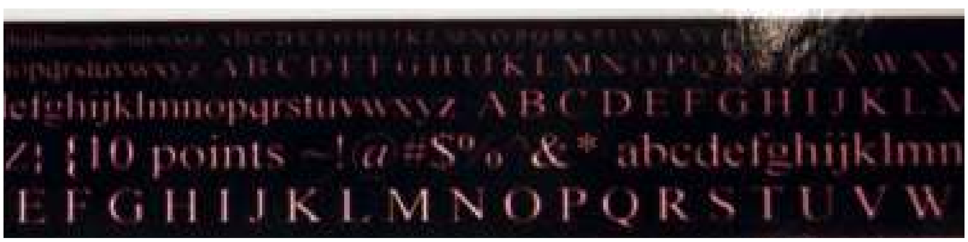


Figure 9 - Reverse text area after humidity exposure - ink bleed from black areas into white text

These photos are not of samples used in this test, but are inserted here to show the possible extent of the color bleed problem in photo prints. They show that some of the ink used to create the black background has bled into the white or non-imaged text areas and produced a red coloration.

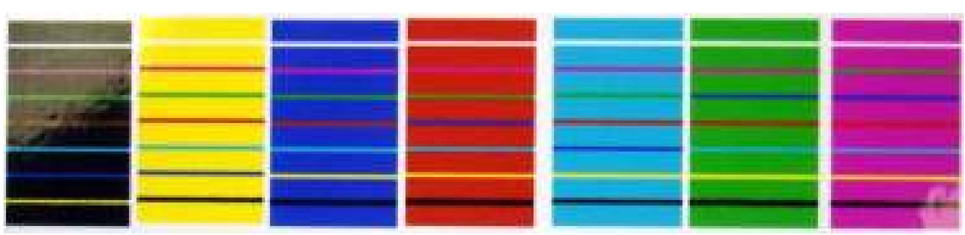


Figure 10 - Color bleed pattern from original print showing no significant bleed

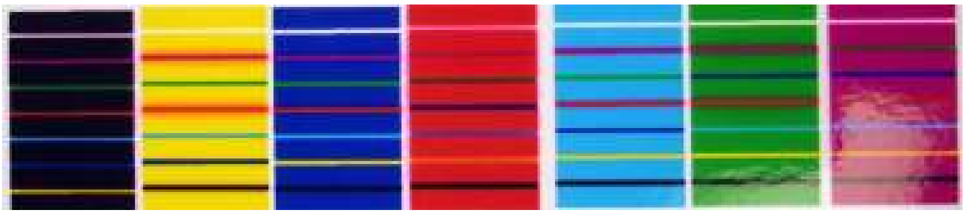


Figure 11 - Color bleed pattern showing easily observable color bleed

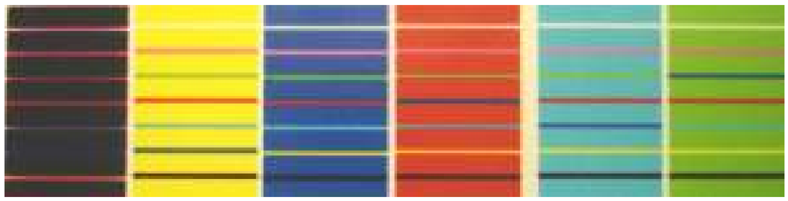


Figure 12 - Color bleed pattern showing easily observable color bleed

Patterns such as these are rarely seen in consumer photo images; however the effect of color bleed can be seen in areas of high detail sharp edges, and high contrast that are often present in photos. These types of area can also be seen in the humidity Visual Test Image depicted in Appendix B. Note in the illustration below the change in overall color caused by humidity exposure might not be noticed without the reference print. However, the red bleed around the black area would probably be noticed. Again, these photos are not of samples used in this test, but are inserted here to show the possible extent of the color bleed problem in photo prints.

Figure 13 – Detail of sample (not in this test) before and after humidity exposure

Each print was placed in one of four rating categories. All prints are rated on the difference between the room sample, and the exposed sample. If the room sample (not exposed to any conditions), showed moderate color bleed, and the exposed sample showed no further bleed, the sample would be rated as "no visible difference". The four rating categories are:

No Visual Difference (NVD) - The exposed sample looks identical to the room sample, in all ways

Slight - Requires close inspection to see any change between the exposed and the room sample.

Moderate – May not be offensive, but does not require close inspection to identify changes.

Heavy – Issues may catch the eye immediately when viewing a sample or changes are large, easily identified. Most would be considered failures or unacceptable.

6.3 Discussion of High Humidity Keeping Test results

6.3.1 Color Change

As noted above, from the table it can be seen that none of the samples reached the endpoint during the test.

6.3.2 Visual Assessment

Upon careful comparative visual observation, none of the test samples showed evidence of line bleed, and none appeared to have changed color as a result of the humidity exposure.

7.0 Accelerated Gas Fastness Test

Ozone is a gas that is found in air polluted by industrial exposure. Ozone is a strong oxidizing agent and causes chemical changes in many materials, potentially including dyes and pigments. Ozone has been shown to be one of the reasons for ink jet print fading. Typical very high ozone levels have been shown to be about 0.025 parts per million (ppm) in ambient air.

The RIT Image Permanence Institute carried out a study to develop an atmospheric pollution-aging test for the Paper and Paper Products Committee of the American Society for Testing and Materials. The test will be based on these methods and findings and is similar to that described in the paper "Effects of Pollutant Vapors on Image Permanence", by Zinn, Nishimura and Reilly of the RIT Image Permanence Institute at the IS&T 1998 PICS Conference.

7.1 Ozone Chamber

The chamber used for these tests was an Orec Model 500 Test Chamber. This chamber has an internal volume of about 3 ft^3. Ozone is generated using a two-arm UV lamp in a forced airflow. The airflow to the lamp is conditioned and the airflow after the lamp is chilled in order to maintain temperature and humidity in the chamber. The chamber is capable of maintaining ozone levels up to about 2.5 parts per million. The ozone controller system was calibrated by the supplier prior to the long-term test.

7.2 Ozone Exposure Test

The sample prints were suspended vertically in the chamber with an edge towards the direction of airflow. The viewing port on the chamber is covered with a flap so that the test was carried out in the absence of ambient light.

The chamber ozone level was maintained at 1 ± 0.03 parts per million for the duration of the test. The chamber temperature and humidity was maintained at 23 °C ± 2 °C and 50% RH ± 5% RH

Prints were removed and measured at the following intervals:

0, 14, 28, 56, 112, and 168 days

7.3 Ozone Test Measurements

Readings were taken on each of the color patches on the sample noted in Appendix A. Samples were removed from their mounting prior to making the measurements. For the purposes of this report, the values of the 4 channel density for each sample will be analyzed.

For each sample, a neutral patch with density at or very close to 1.0 on day 0 has been chosen for analysis of light fade. [As had done in previous sections (6.2.1 for example)]. The change in density of this patch with time was plotted for each of the samples. In addition, the separations were analyzed by measuring the red in cyan patch, green in magenta patch and blue in yellow patches.

For each graph, the two endpoints were analyzed and the length of time to reach the endpoint is listed in the table below.

Printer	Accelerated Gas Fade - 1ppm Ozone			
	Neutrals		Separations	
	Days to 0.3D Change	Days to 15% Variation	Days to 0.3D Change	Assessed Endpoint Days
Epson RX580	17	na	13	13
HP Photosmart C5180	168+	168+	168+	168+
Canon MP600	7	na	6	6
Lexmark X9350	76	15	43	15
Epson CX7800	168+	168+	168+	168+
HP Kiosk	72	na	78	72
Kodak Kiosk*	168+	168+	168+	168+
Sony	168+	168+	168+	168+
Altech CW-01	168+	168+	168+	168+
Mitsubishi CP-9550	168+	168+	168+	168+
Kodak Edge	168+	168+	168+	168+
Fuji Crystal Archive	168+	168+	168+	168+
Kodak Supra	168+	168+	168+	168+

Table 4 - Endpoints for Accelerated Gas Fade Test

In some instances the samples failed very early and were removed from the test. For example, the Canon MP600 sample reached a first endpoint at the first measurement point. The sample was left in place for the next measurement to confirm the analysis, but was then removed. In these cases, the second endpoint measurement was moot and so is not included, the tabular entry 'na' indicates this condition.

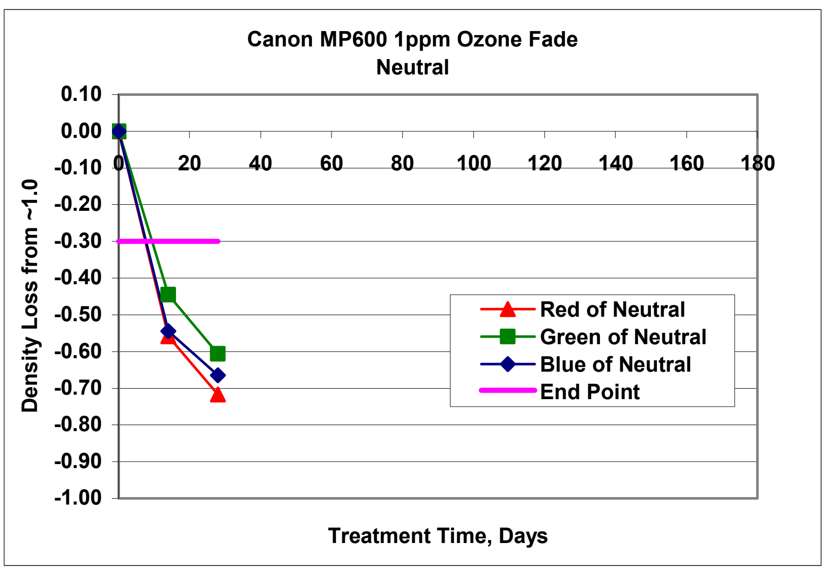


Figure 14 - Example of Early Endpoint in Gas Fade Test

In addition to these measurements, the graphs for the HP Kiosk appeared to be erratic. The following graph tracks the color separations in the ozone exposure test.

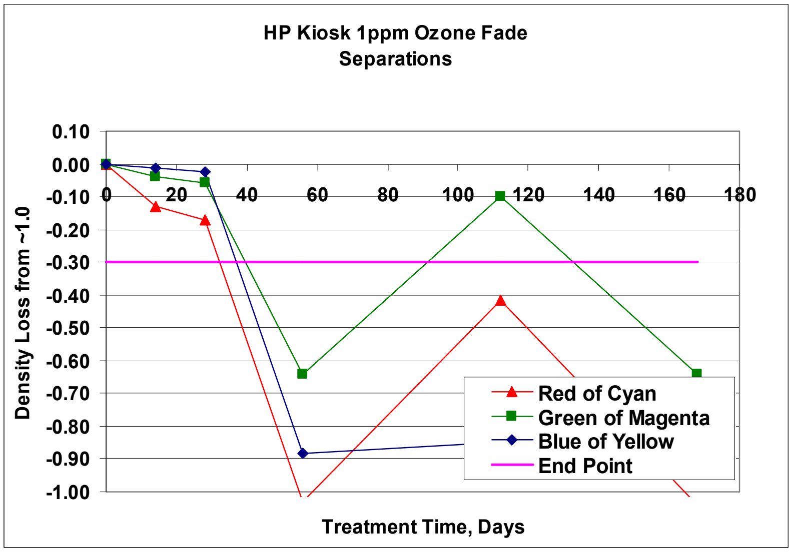


Figure 15 - HP Kiosk Ozone Exposure Anomalous Results

Both of the exposed prints were examined and both show evidence of selective color fade as shown in the Figure below:

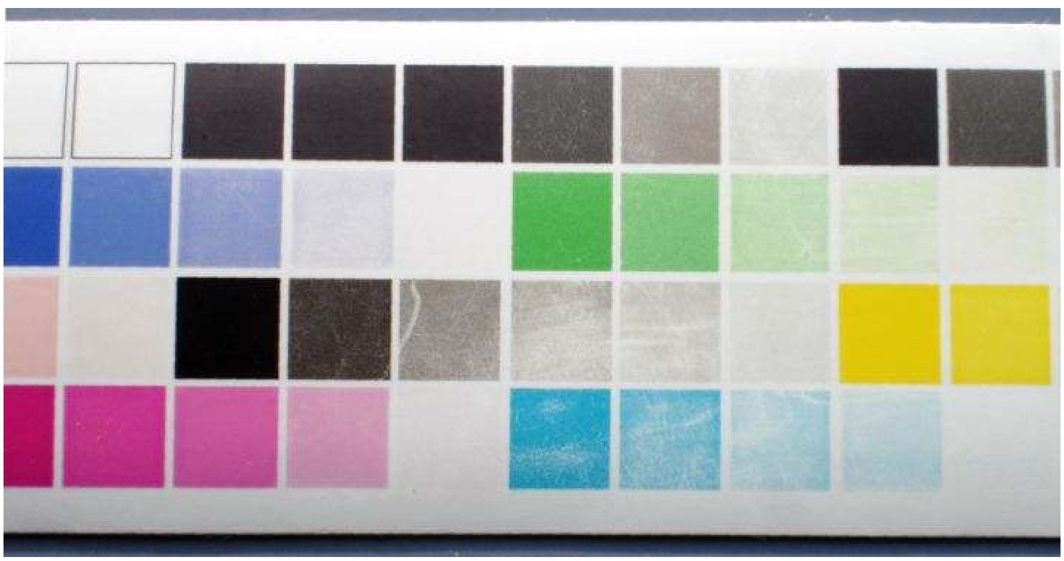


Figure 16 - Selective Fade on HP Kiosk after Gas Fade Exposure Test

The density patches shown in the figure are very non-uniform, so it appears that the explanation for the apparent 'improvement' in the color density measurement at 112 days was due to the positioning of the Spectralino probe. Obviously the effects seen on these patches would be unacceptable to a user if they appeared in a mid- or dark-tone area in a photograph. For this reason we listed the failure as the first endpoint and ignored the remainder of the chart.

Finally, another anomaly was observed when reviewing results for Kodak kiosk prints. Some time ago in other tests, Kodak noticed gas fade results for thermal materials used in kiosks were not consistent with expectations. As a result of this, an analysis was performed that showed that when this media is tightly wrapped as in a supply roll for the printer, some of the dye on one panel can transfer to other panels. The supply roll consists of sequential sets of four panels, the three primary colors plus an overlay designed to seal and protect the image. If dye is transferred to the overlay panel, it will be adhered to the layer on the air side of the image, and is thus unprotected. This condition is known as ‘dye-retransfer’. When images in this condition are exposed to pollutant gas, the dye on the exposed surface will degrade very quickly since it is not protected. In total, two distinct dye-loss rates will be observed; relatively fast loss of image density followed by a much less severe loss over a long period. This phenomenon has been reported by D.G. Foster, “Slipping Layer for Thermal Donor” in Proceedings NIP23 2007, p156.

In order to resolve this, Kodak introduced a change in the media some time ago. This change was incorporated in both the 4x6 and 8x10 printer kiosks but unfortunately some 8x10 kiosks still have the old material. In general, TPR made prints on 8x10 media wherever possible, and the Kodak kiosk prints were 8x10, therefore the exposures show the effect of this dye re-transfer problem. This effect can be seen in Figure 17.

If the first measurement point is ignored, the data are more consistent with expectations for the 4x6 media. Therefore, TPR recast the results ignoring the first data point. The new plots are shown in Figure 18 and confirm that the elimination of the dye re-transfer effect changes the results significantly to the point where there is no endpoint reached during the following 154 days of exposure.

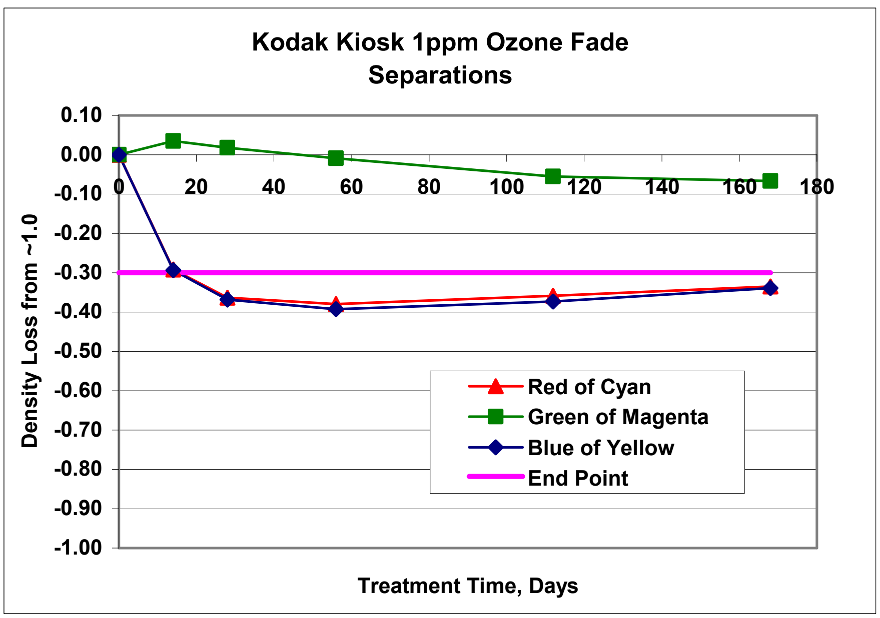


Figure 17 - Ozone Exposure of Kodak Kiosk Image Showing the Effect of Dye Re-Transfer

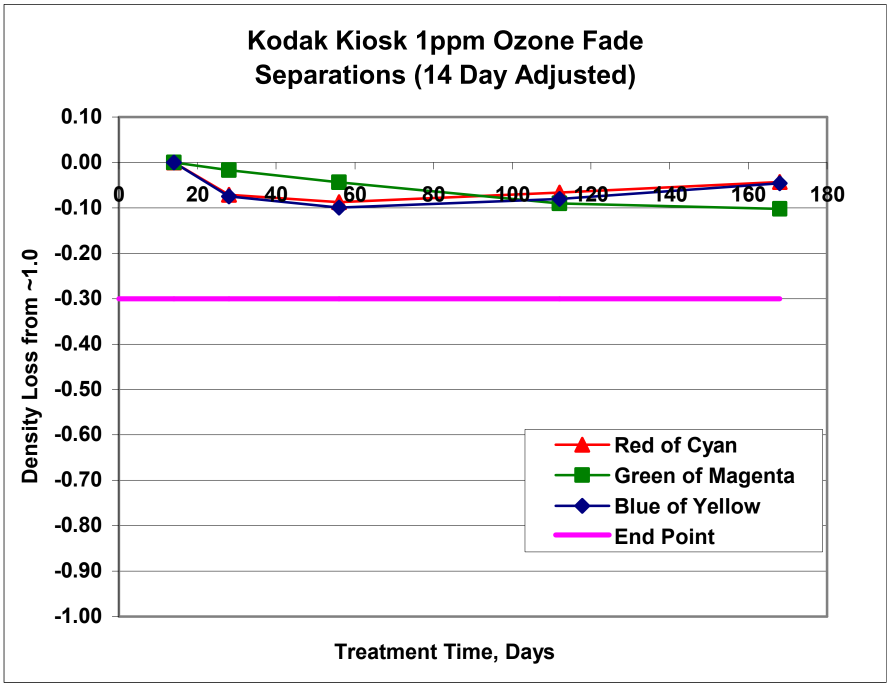


Figure 18 - Ozone Exposure of Kodak Kiosk Image with 14 Day Correction for Dye Re-Transfer Effect

7.4 Discussion of Test Results

Many of the samples reached at least one of the defined endpoints before the gas fade tests were completed. In these tests, the samples were not removed from the exposure but completed the test. They were all measured at each measurement point.

Samples that did not reach the endpoint after 168 days exposure to accelerated light fade were:

HP Photosmart C5180
Epson CX7800
Sony
Altech CW-01
Mitsubishi CP-9550
Fuji Crystal Archive
Kodak Edge
Kodak Supra

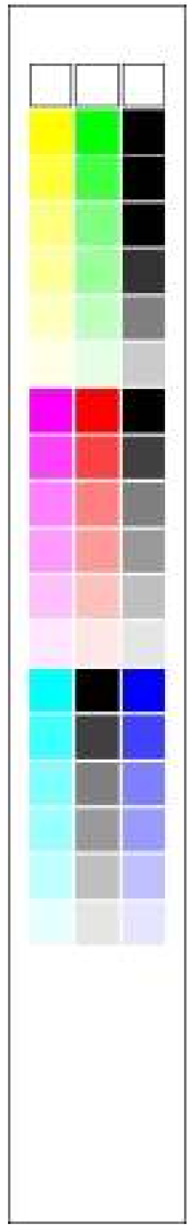
Based on the life projection calculation described in Section 3.6, the following print life could be expected for the samples:

	Gas Fade - 1ppm Ozone	
Printer	Assessed Endpoint (days)	Projected Life (years)
Epson RX580	13	7
HP Photosmart C5180	168+	92+
Canon MP600	6	3
Lexmark X9350	15	8
Epson CX7800	168+	92+
HP Kiosk	72	39
Kodak Kiosk*	168+	92+
Sony	168+	92+
Altech CW-01	168+	92+
Mitsubishi CP-9550	168+	92+
Kodak Edge	168+	92+
Fuji Crystal Archive	168+	92+
Kodak Supra	168+	92+

Figure 19 – Predicted Print Life Due to Gas Fade

* Assuming Dye Re-Transfer

Appendix A – General Test Image



Target Size = 1.25” x 8.5”

57 Patches, 0.7 mm square with 0.1 mm gap

Appendix B – Visual Test Image