KODAK PROFESSIONAL

ENDURA Papers

Defining Print Life: The critical balance of light and thermal stability

Kodak Professional
Imaging Solutions

KODAK PROFESSIONAL ENDURA Papers

The following pages discuss light and thermal stability as they apply to Kodak's newest generation of professional color negative papers, KODAK PROFESSIONAL SUPRA, SUPRA VC Digital, and ULTRA ENDURA and ENDURA Metallic papers.

Since the earliest days of photography, people have wanted to increase the stability and extend the longevity of captured images. As the medium evolved, ongoing improvements in image stability, as well as the discovery of new challenges to image stability, have been the rule.

The introduction of KODACHROME Film for color movies and slides in the 1930s brought new stability challenges related to color. In 1942, Kodak announced KODACOLOR Film for prints, the world's first true color negative film. The advancements of color technology into prints allowed color photography to expand rapidly into the professional portrait/social and consumer environments.

It was at this time that Kodak recognized the need for dedicated testing facilities to examine the stability of images. Since then, the company has invested in and expanded its testing capability continuously for over 50 years.

As advances in technology have improved image stability and reduced major concerns, new, more subtle concerns have arisen. In the last 15 years, the silver halide-based photographic materials of all manufacturers have improved significantly, creating a need for more precise measurements of image stability over longer time periods. New technologies have also brought a need for a better understanding of these factors:

- the complexities of how images on modern photographic print materials fade
- how the different uses of images affect image life

The following pages discuss these factors as they apply to Kodak's newest generation of professional color negative papers, KODAK PROFESSIONAL SUPRA, SUPRA VC Digital, and ULTRA ENDURA and ENDURA Metallic Papers, and will cover the following topics:

- objectives in the design of photographic materials
- how materials are processed and used by finishing laboratories
- how prints are used and stored by the end-user
- what image stability means today
- the importance of the ways in which image stability is measured and interpreted

Note: In this discussion of image stability, we assume that the process conditions in the finishing lab meet specifications set by the manufacturer of the photographic material. A process that does not meet specifications can have an impact on image stability that is as large as or larger than any of the variables discussed here.

Philosophy of Product Design

Obviously image stability is a decisive factor in the design of color photographic paper. In fact, it would be possible to design a paper solely to optimize image stability. However, designing and optimizing for a single criterion such as image stability will often degrade other key factors.

During the last 20 years, the design of Kodak silver halide color papers has been driven by a three-prong strategy, coupled with continuous improvement. While a typical Kodak color paper has more than 60 individual design parameters, we follow three major design criteria:

- image quality today
- image quality tomorrow (i.e., print longevity)
- ease of use in the finishing lab

In many instances, trade-offs between the major criteria would be possible. For example, excellent image quality with accurate color and pleasing flesh reproduction depends on the image dyes formed by the paper, so color and flesh reproduction could be compromised to achieve good dye stability. Similarly, dyes optimized for image stability can be more process-sensitive, which can cause difficulties for the finishing lab.

KODAK PROFESSIONAL ENDURA Papers involve no such trade-offs. Both the dye set used and the emulsions and curve shape drive short-term and long-term image quality, as well as ease of handling and processing.

Kodak has supplemented its three-prong design philosophy with continuous improvement between major development programs. Ongoing improvements keep products fresh by adding new technology as it becomes available. Over the last 20 years, we have made a multitude of improvements in image quality and lab operations in addition to image stability.

KODAK PROFESSIONAL ENDURA Papers, however, are truly revolutionary. Made with advanced dye technology, they represent a major leap forward in image stability and print life without sacrificing image quality, while also enhancing ease of use in the lab.

In the professional market, flesh reproduction is the paramount image-quality criterion. In many color papers optimized for image stability, image quality and flesh reproduction suffer. But the three new dyes in KODAK PROFESSIONAL ENDURA Papers have been optimized for excellent image stability without degrading color reproduction or flesh reproduction. SUPRA ENDURA Paper has additional patented technologies specifically designed to optimize flesh reproduction through modifications to the image dyes combined with precise curve-shape control in the emulsions.

Testing Methodology and Modern Paper Components

Stability testing of color papers focuses on the major degradation pathways, and includes testing for light fade, thermal fade (degradation due to heat, often referred to as “dark fade”), and base degradation. Although we will not discuss the specifics of image-stability testing here, it’s important to understand the major challenges in performing the tests correctly and in interpreting the test data.

As the stability of papers improves, the testing becomes more complex. Predictions of image stability are based on accelerated testing, and the accuracy of predictions depends entirely on generating test data that are low in noise. Figures 1 and 2 show a hypothetical example of two different papers tested for thermal stability. One paper is more stable than the other, but because of time limitations, both samples were tested for one year.

Figure 1

Four-Point Prediction

—Linear Fit

Linear Fit

Log Days = 13.04666 + 5229.7488 Inverse Kelvin

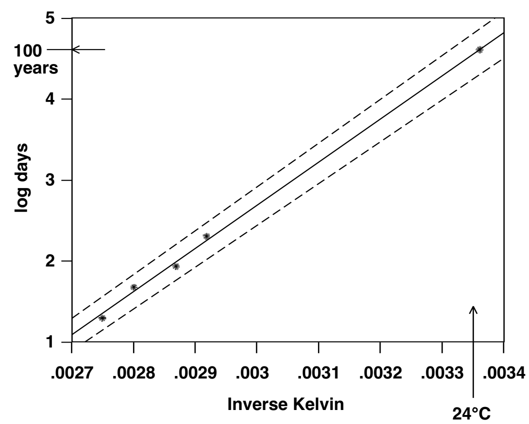
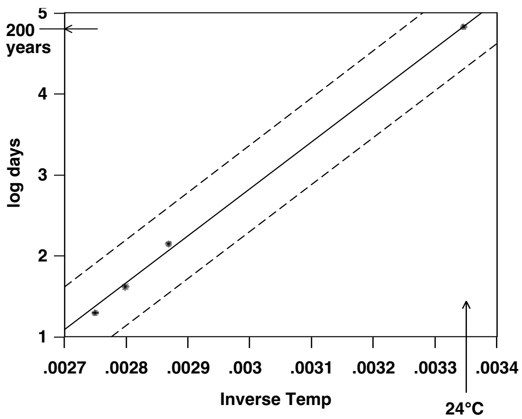


Figure 1 shows four data points based on fade generated from four high-temperature conditions. The points form a straight line with a high linear correlation coefficient, and the extrapolated prediction of room-temperature performance is 100 years. Given the correlation and the statistically calculated error from this extrapolation, the high and low limit around the predicted 100 years is plus or minus 40 years. The actual performance may be as high as 140 years or as low as 60.

Figure 2

Bivariate Fit of Log Days by Inverse Temp



—Linear Fit

Linear Fit

Figure 2 shows a straight-line extrapolation to 200 years. However, because the paper is more stable than that in Figure 1, only three data points are available. Because of noise, the three points are scattered around the predicted straight line. With only three points and the higher noise, the correlation is lower and the error band is higher. So while the straight-line extrapolation predicts a performance of 200 years, the statistically calculated error is very wide and quite nonlinear. According to the plot, the paper could last as long as 600 years or as few as 50. In this example, running the test for a longer period of time would eventually generate a fourth data point to give a more precise prediction with less error around the prediction.

In light-fade testing, using only highly accelerated tests can lead to significant errors because of reciprocity and other external factors. For example, we now know that some inkjet materials are highly susceptible to image fading due to very low levels of ambient ozone in the atmosphere.[1] Consider the outcome when only high-intensity light-fade testing, which predicts a material's stability over 100 years, is used. Because the test is so highly accelerated and run in such a short time, it cannot detect the impact of ambient ozone. Only after images were displayed in the real environment, which included low levels of ambient ozone, was the true stability determined. Then it turned out that product stability was measured in weeks, not years.

As Kodak added new resin stabilizers to increase the stability of the paper base, Kodak scientists encountered another example of a test becoming difficult to use because of noise in the data. The then-current accelerated test to measure cracking and crazing of the resin was no longer generating the normal response of cracks that would predict long-term resin stability. Instead of trying to accelerate the test further and risk the creation of even more noisy, possibly erroneous data, Kodak scientists looked to the molecular level for a predictive mechanism. They made measurements of the actual decay of the resin molecules and found that those measurements provided a good correlation to the prediction of long-term resin stability.

In these times when companies, including Kodak, introduce new products at a faster pace, it is tempting to run image-stability tests for shorter times with greater acceleration and noisier data. It would be even worse to use the high end of the statistical noise to promote a product as more stable than it really may be.

At Kodak we do neither. We continue to run highly accelerated light- and thermal-fade screening tests, using high light levels and high temperatures. However, we verify the results with less accelerated tests by using lower light levels and lower temperatures. Although these tests take significantly longer, often more than a year, the data is much more reliable. We use only this data to support product claims for image stability. We take the extra time to generate reliable data because

[1] D.E. Bugner, D. Kopperl, and P. Artz, "Further Studies on the Apparent Reciprocity Failure Resulting from the Accelerated Fade of Inkjet Photographic Prints," *Proceedings of IS&T's 12th International Symposium on Photofinishing Technology,* 2002, pp. 54–57.

of our commitment to report image-stability data accurately and to maintain integrity and credibility with our customers.

Kodak is very confident in the revolutionary image stability of KODAK PROFESSIONAL ENDURA Papers. To further demonstrate this confidence we commissioned a major study with the Image Permanence Institute at the Rochester Institute of Technology. Through this study, we not only achieved independent substantiation of Kodak's own internal testing, but learned that in fact our intrnal claims were conservative.

Defining Print Life—

Degradation Mechanisms

Defining print life requires information on the mechanisms that degrade prints and which mechanism first becomes limiting. This often requires knowledge of the environment in which the image is stored or displayed, because different degradation mechanisms may outweigh others in different environments.

In silver halide-based color papers, four mechanisms contribute to determining print life:

- degradation of the dyes caused by heat
- degradation of the dyes caused by light
- yellowing of the minimum densities (D-min) due to light or heat
- degradation of the resin base

For example, a resin-based color paper may have very high light stability but only mediocre resin stability in the base. It will perform very well in tests for light stability. However, if it is stored in an environment where the base degrades faster than the dyes, excellent light stability becomes meaningless. In this example, degradation of the resin base is the limiting mechanism.

These same four degradation mechanisms also apply to inkjet materials. However, we must also consider other mechanisms:

- ambient moisture (relative humidity)
- atmospheric pollutants
- direct water contact
- fingerprinting

A multitude of tests, reports, and conclusions from many sources have described the significant advancements made in inkjet light stability. However, while the thermal stability of most inkjet systems is quite good and very significant improvements in colorant stability due to light exposure have occurred, promotion of products based on light-stability testing is extremely misleading when it ignores the other important degradation mechanisms. To describe print life accurately requires taking all degradation mechanisms into account. A material could have excellent light- and thermal-fade performance but poor print life if the colorant stability is poor when exposed to moisture or atmospheric pollutants.

For a more detailed discussion of the degradation mechanisms and image-stability performance of Kodak inkjet materials, see the references[2,3] below as well as the technical papers found at: **http://www.kodak.com/eknec/PageQuerier.jhtml?pq-locale=en_US&pq-path=98#technical_papers.**

It is extremely important to recognize that the life of the image may not necessarily be limited by the stability of the image dyes. A manufacturer who talks about "dye stability" or "light stability" alone, or who uses only light-fade data to describe the performance of a product, is very likely not presenting an accurate prediction of print life.

[2] D.E. Bugner and C.E. Romano, "Printing Memories to Last a Lifetime: Understanding Image Stability for Ink Jet Prints," Recharger Magazine, 13(1), 2001, pp. 134–140.

[3] D.E. Bugner and P. Artz, "A Comparison of the Image Stability of Digital Photographic Prints Produced by Various Desktop Output Technologies," Proceedings of the International Conference on Imaging Science 2002, 2002, pp. 308–310.

Criteria for Defining Print Life

It is very important to know which degradation mechanism is the limiting mechanism in any given storage environment. It is also important to know the print-life criteria being used in reporting print life. The print-life criteria determine "how bad is bad"—for example, when a consumer would take a print down and throw it away.

Kodak uses the illustrative criteria stated in the ANSI/ISO standard, which places dye-fade limits at 30 percent.[4,5] Internal studies done by Kodak indicate that 30-percent fade is a conservative limit.

Table 1 compares dye-fade limits, consumer descriptors, and consumers' perceptions or reactions.[6]

Table 1

Approximate Correlation of Color Descriptors to Dye Loss from 1.0 Density

Approximate Dye Loss	Correlated Visual Impact
0 to 10%	Minimal
10 to 15%	Very slight—noticeable to an expert only in a paired comparison
15 to 20%	Slight—noticeable in a paired comparison
20 to 30%	Moderate—noticeable in single stimulus to a person familiar with original scene quality
30 to 60%	Noticeable fade with a single stimulus, but not objectionable
Greater than 60%	Very noticeable fade with a single stimulus; possibly objectionable based on use

Depending on the scene content, fade levels below about 15 to 20 percent are usually not noticeable without direct comparison to an unfaded reference image. A fade level between 20 and 30 percent could be considered noticeable without a non-faded comparison, but typically would not be considered objectionable. Fade levels between 30 and 60 percent would not be objectionable; consumers would continue to value the image based on scene content and emotional involvement.

Additional research continues to confirm that the use of the 30 percent endpoint criteria is quite conservative, and that levels of 60 percent or higher can still be considered to fall within the acceptable category. Generally, at fade levels above 70 percent, the psychophysical studies behind this research found that most prints would fall into the marginally unacceptable category or worse.[7]

Although it would be possible to use a fade limit greater than 30 percent and report longer print life, Kodak takes a conservative approach with the 30-percent upper limit. It is also important to note that using a fade limit lower than 30 percent would result in under-predictions of print life. For example, a fade limit of 15 percent may be appropriate for images in a museum, but is far too conservative for typical consumer environments because a print at this endpoint would only be slightly changed from the original. Using a 15% endpoint would predict print life that is only half of that predicted using a 30% criteria and would be very misleading. Many consumers would see little or no change in a single stimulus situation and calling this an endpoint could cause needless concern and worry.

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[4] *Stability of Color Photographic Images—Methods for Measuring,* ANSI IT9.9-1996, and ISO 10977.

[5] Stability of Colour Photographic Images—*Methods for Measuring, ISO Publication 18909-2006.*

[6] D. Oldfield and G. Pino, R. Segur, J. Twist, "Assessment of the Current Light-Fade End-Point Metrics Used in the Determination of Print Life: Part I", Journal of Imaging Science and Technology, 48 (6), 2004, pp. 495-501.

[7] D. Oldfield and J. Twist, "Assessment of the Current Light-Fade Endpoint Metrics Used in the Determination of Print Life: Part II", Proceedings of IS&T's 2004 Conference on Archiving, pp. 36-42.

Standards for Measuring Stability

International standards for measuring the stability of color materials are contained in the ANSI/ISO *Standard Stability of Color Photographic Images—Methods for Measuring*, ANSI Publication IT9.9-1996 and ISO Publication 10977. An updated version of this standard, ISO Publication 18909-2006, was issued in 2006. Work currently under way in the standards committee includes a new set of publications to address the additional complexities and degradation mechanisms found in non-silver halide color materials.

A look through the current 60-page standard on silver halide materials quickly reveals that the testing and measurement of image stability is a very complex science. The standard also provides recommendations and guidance on interpreting and using test data generated by the testing methods. Why doesn't the standard provide specific rules and definitions on how to interpret the data? The standard provides only general recommendations and guidance because images in general have a wide range of stability requirements based on intended application, and are stored or displayed under a vast range of conditions.

The standard strongly suggests that interpretation of test data be based on the specific conditions likely to be encountered as the product is used in the real world. For example, the typical environment for prints on SUPRA or SUPRA VC Digital ENDURA Paper is a wall display or a wedding album kept in a home. This is very different from the typical environment for prints on ENDURA Metallic Paper, which is likely to be a high-intensity point-of-purchase commercial display in a mall. It is logical that the interpretation of the image-stability data for these two very different products reflect the different environments.

Design for Real-World Conditions

Kodak has long recognized the importance of product design based on customer use. KODAK PROFESSIONAL SUPRA and SUPRA VC Digital ENDURA Papers are designed to be used by end-consumers in the home. These papers are designed for "portrait and social" applications, i.e., formal portraits and wedding pictures displayed in a home or stored in albums.

Remember the three major design criteria: image quality, print life, and performance in the finishing lab. In the case of papers for portrait and social applications, product design for print longevity, without regard to real-world conditions and the other two major design criteria, could result in many trade-offs, even in print life itself. For example, excellent high intensity light stability with mediocre thermal stability would be a poor combination in prints stored and displayed where light intensity is low but thermal performance is significant. Similarly, a trade-off in finishing lab operations—such as permitting high sensitivity to chemical activity levels to achieve good print life—would be a poor choice.

KODAK PROFESSIONAL SUPRA and SUPRA VC Digital ENDURA Papers are optimized for all three major design criteria in the context of real-world portrait/social applications. The design criteria for KODAK PROFESSIONAL ULTRA and ENDURA Metallic Papers are tailored to the needs of the commercial display market.

Just as the design of KODAK PROFESSIONAL ENDURA Papers reflects real-world conditions, any testing and interpreting of stability data must also reflect the environment in which the product will be used and stored. Reporting of stability results for portrait and social papers, like SUPRA and SUPRA VC Digital ENDURA Papers, without regard to real-world conditions can mislead labs in their choice of a color paper as well as photographers and consumers in their choice of a finishing lab.

Some critics have discussed the use of independent, single-condition, highly accelerated light- and dark-fade tests as very misleading.[8] These tests are useful for rapid screening of experimental dyes, but are prone to possible errors (e.g., reciprocity in light fade or reaction-mechanism shift in dark fade), which limits their reliability in predicting print longevity. They don't reflect real-world conditions and require very careful interpretation. This is true not only because they are accelerated well beyond the normal light and heat levels found in a home, but because the data are often reported in isolation. Running stability tests in a window gives even more misleading results.

Because thermal stability is so important in the portrait and social environment, testing and reporting on light fade only, without considering the impact of thermal stability, would be relevant only to consumers who store their prints in a lighted freezer.[9]

Predominance of Thermal Stability in the Portrait/Social Environment

Thermal stability, often called "dark stability," is driven by ambient temperature. This is especially important in the portrait and social environment where light levels are low. Thermal degradation, even when prints are on display, predominates.

Note: Temperature can play a role in the commercial environment as well—for example, in transmission display materials used on warm light boxes. However, the time frame for a commercial display is relatively short (often three to 12 months). The thermal effects do not become apparent because the light-fade effects predominate.

When you see the term "dark stability," remember that it is not darkness that causes dyes to fade or D-min to turn yellow; it is heat. Therefore, even when a print is on display (unless it's in that lighted freezer), thermal degradation is taking place. Dark stability is actually the combined effects of thermal fade and everything else that is not related to light fade.[10] However, from the early history of color photography through the early 1980s, thermal fade was the principal mechanism.

Improvements to thermal stability have been infrequent; but when they do come, they have been very large:

- Kodak's introduction of 5-ethyl-4,6-dichloro-2-amidophenolic couplers resulted in a three- to fourfold improvement in print stability. KODAK EKTACOLOR Plus and Professional Papers first used this new technology.
- The use of non-yellowing pyrazolotriazole (PT) class magenta couplers virtually eliminated yellowing of print D-min caused by both temperature (thermal yellowing) and light ("print-out" due to unreacted magenta coupler). Kodak first used this technology in KODAK PROFESSIONAL PORTRA III Paper.
- It was not until the invention of 2,5-diacylaminophenol couplers that excellent thermal stability combined with desirable color hue was achieved. Kodak invented these couplers and patented them in 1997.[11] KODAK EKTACOLOR Edge 8 Paper first used them in 1999.

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[8] R.E. McComb, "Separating Facts from Fiction: Examining Photo Prints," *PhotoTrade News,* February 1998.

[9] Op. cit., R.E. McComb.

[10] M. Oakland, D.E. Bugner, R. Levesque, and R. Vanhanehem, *Proceedings Paper from NIP 17,* 2001, p. 175.

[11] U.S. Patent 5686235 (Nov. 11, 1997) and U.S. Patent 5962198 (Oct. 5, 1999).

Significant modifications of this most recent coupler allowed its use in the critical professional markets, i.e., in SUPRA and SUPRA VC Digital ENDURA Papers. The successful commercialization of these couplers produced a twofold improvement in thermal stability over all earlier papers that use the previous class of couplers.

Kodak papers that incorporate this patented coupler technology have thermal stability that is twice as good as that of any other silver halide-based color photographic paper. For portrait and social applications, which have a totally thermal-driven environment (e.g., dark album storage), this means that prints will last over 200 years before noticeable fade occurs. In a typical home display environment, it means that prints will last over 100 years before noticeable fading occurs.

Light Levels

Because the large majority of prints in portrait and social applications are stored in the dark, strong thermal performance is a must. However, images are displayed as well, and simultaneously undergo both thermal fade and light fade. The longevity of the paper will depend on the light levels that will be encountered and the paper's stability to thermal fade and light fade. Therefore, the design process includes the balancing of thermal- and light-fade mechanisms.

A study to measure actual light levels in homes has documented 120 lux as the representative light intensity for the home display category. This study was first published in 1987[12] and repeated in 1991.[13] The conclusions were confirmed through a 10-year study in which prints were placed in people's homes around the United States, kept in places where people typically display prints, and measured at regular intervals. After 10 years, the level of fade verified the predicted level based on 120 lux, confirming that the 120 lux level is typical.

[12] S. Anderson and G. Larson, "A Study of Environmental Conditions Associated with Customer Keeping of Photographic Prints," *Journal of Imaging Technology,* 13, 1987, pp. 49–54.

[13] S. Anderson and R. Anderson, "A Study of Lighting Conditions Associated with Print Display in Homes," *Journal of Imaging Technology,* 17 (3), 1991, pp. 127–131.

How bright is 120 lux? Consider a typical suburban middle-class home in the United States, with images displayed in a living room with two west-facing windows and one south-facing window. Taking into account the seasonal cycle of short (winter) and long (summer) days, with daylight periods averaged over a 12-hour "daylight period," the light levels in the room might range from 50 to 100 lux at the low times of the day (morning in this example) to 150 to 200 lux at the high times of the day (afternoon/evening in this example). The average 12-hour "daylight period" would include times of only indirect sun illumination, times with direct sun illumination, and times with only artificial illumination. Over the course of these daily and seasonal periods, the average level would typically be 120 lux.[14,15]

If the living room had two south-facing windows and one west-facing window, the light levels would average somewhat higher, perhaps up to 150 lux. If the living room had only north- and east-facing windows, the levels would average somewhat lower, perhaps only 100 lux.

Apartments or condominiums with only one or two outside-facing walls would have fewer windows and might have lower average illumination levels. A house with very large windows and skylights could have intensity levels of 1000 lux at a peak point during the day, depending on the room orientation to the sun and the number of windows and skylights.

Based on the published studies and the 10-year verification study, we believe the average intensity of 120 lux is a good one for the typical suburban home, and a good average of the higher and lower light levels in homes and apartments typically found in the United States. Of course, the actual range can be quite large. From prints displayed in the apartment bedroom with no windows to prints displayed in the sunroom of a lavish home in southern California, the range of the daily high and low points widens from near zero to as high as 4000 or 5000 lux.

[14] Op. cit., S. Anderson and G. Larson.

[15] Op. cit., S. Anderson and R. Anderson.

Taking into account the income-weighted population distributions in the U.S., the darker rooms would be much more prevalent than the very bright rooms. However, to be conservative, the studies defining 120 lux as the typical home display condition considered neither of these extremes.

A very recent multi-year study covering homes in cities around the world has again verified the 120 lux light level as typical, if not conservative. Findings of this study indicated that the 90th percentile of light levels studied was 137 lux. That is, fully 90% of the homes would have light levels **below** 137 lux. This study was done over a two-year time period, covering homes in North and South America, Asia, Europe, and Asutralia, and included well over 100,000 discrete measurements.[16]

In commercial applications, the light intensity of typical display conditions covers a range much wider than that of typical home display conditions. Typical home conditions are clustered over a relatively narrow range of intensities. Commercial conditions are not clustered at all, and the difference between the lower and higher light levels can be a factor of 1000 or more. The range would cover museum conditions at 50 to 100 lux to outdoor displays at 50,000 to 100,000 lux. This wide range makes it impossible to pick one light intensity level to represent all commercial conditions. Using a single light intensity for predicting commercial print life would be extremely misleading.

In developing the new KODAK PROFESSIONAL ENDURA Papers for commercial applications, Kodak acknowledged the extremely wide range of commercial conditions. It is rare when any two commercial applications, even in relatively similar display environments, have the same ambient light, temperature, and humidity conditions. Nevertheless, various studies have been done to quantify commercial conditions and several broad categories have been recognized.[17] These are summarized in **Table 2**. By establishing typical light levels in the broad categories, it is possible to provide a broad estimate of print life. A more accurate estimate would require quantifying ambient conditions of light intensity and temperature at a minimum.

Table 2

Commercial Display Categories and Approximate Light Levels

Display Category	Approximate Light level (Lux)
Museum	150
Office	450
Moderate-Intensity Commercial Reflection Display	1000
High-Intensity Commercial Reflection Display	5000

As a guide for estimating print life in the commercial environment, **Table 3** adds an average estimate for ULTRA ENDURA Paper in commercial reflection display situations.

Table 3

Approximate Print Lifetimes for KODAK PROFESSIONAL ULTRA ENDURA Paper in Commercial Applications

Display Category	Approximate Light level (Lux)	Approximate Print Life
Museum	150	Over 100 years
Office	450	35 years
Moderate-Intensity Commercial Reflection Display	1000	8.5 years
High-Intensity Commercial Reflection Display	5000	20 months

Note: All light conditions assume illumination for 12 hours on and 12 hours off. Thermal conditions, used for the low-intensity levels, assume 24°C and 50% RH.

[16] D. Bugner, J. LaBarca, et. Al., "A Survey of Environmental Conditions Relative to the Storage and Display of Photographs in Consumer homes", Journal of Imaging Science and Technology, 50 (4), 2006, PP. 309-319.

[17] D.F. Kopperl, unpublished results.

Balance of Light and Thermal Mechanisms

As mentioned earlier, balancing the rate of dye fade due to light degradation and dye fade due to thermal degradation is important in optimizing print life. This is especially so in the portrait and social environment, where light levels are low. **Figures 3 and 4** show examples of the relationship of light and thermal fade. (For ease of illustration, the data come from an earlier generation of Kodak color papers.) In low-light situations, the two degradation mechanisms contribute nearly equally to overall print life **(Figure 3)**. Under higher-intensity lighting, such as commercial displays, the light-fade mechanism outweighs thermal fade **(Figure 4)**.

Figure 3

Relationship of Light and Dark Fade with Typical Home Illumination

Years to a Given Fade

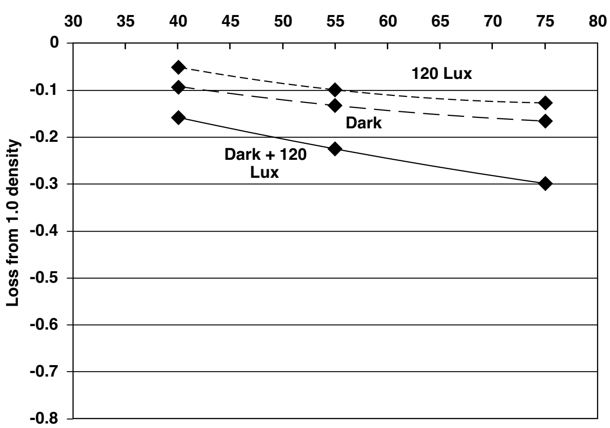
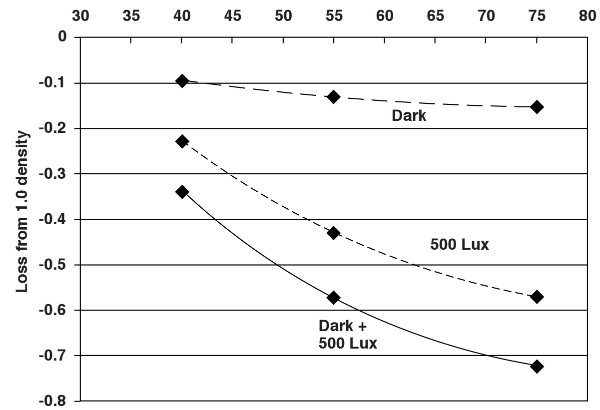


Figure 4

Relationship of Light and Dark Fade with Typical Commercial Illumination

Years to a Given Fade



Through the mid-1970s, thermal stability had been the prime fade mechanism. Then product improvements permitted a catch-up of thermal stability to light stability. By the mid-1990s, many manufacturers had achieved a good balance between light and thermal fade. However, for various reasons, the industry paid more attention to the light-stability improvements than to thermal-stability improvements. This is unfortunate for both the portrait/social and the commercial markets, because all images in both environments undergo thermal degradation, whether displayed in the light or stored in the dark. Especially in the portrait/social environment (including both consumer snapshots and professional portraits), the vast majority of images are stored in the dark—in albums, shoeboxes, closets, etc.[18]

In balancing light and thermal stability, it is important to evaluate the combination of both effects, rather than just one or the other individually. An improvement in light stability without a corresponding improvement in thermal stability, or vice versa, will not necessarily improve print life.

Kodak has long recognized the need to improve both light and thermal stability, and it was a key factor in creating the new dye technologies that are now used in KODAK PROFESSIONAL ENDURA Papers. The result of nearly six years of research, technology

[18] D.S. Hachey, unpublished report.

development, testing, modeling, and commercialization, these new papers represent dramatic improvements in print life for all professional market segments.

For more information on design and balancing of light and thermal degradation mechanisms, see the Kodak Research and Development Web site Tech Brief from January 2002 at

http://www.kodak.com/US/en/corp/researchDevelopment/productFeatures/balance.shtml.

For an in-depth discussion, see "The Importance of the Balance of Light and Thermal Image Stability Effects in the Design of Photographic Color Paper."[19]

Habits in Image Usage—Practical Print-Life Examples for the End-User

All KODAK PROFESSIONAL ENDURA Papers are designed to last for more than 200 years before noticeable changes occur in typical home dark-storage environments, such as albums. In the typical home display environment, the new papers will last over 100 years before noticeable changes occur.

Although the vast majority of end-user images in the portrait and social environment are stored in the dark, many images are displayed. In the mid-1990s an informal survey asked U.S. professional portrait finishing labs about practical print-life expectations for displayed images. Specifically, it asked how many of the images made for display would still be on display after various times. The data from the survey are shown in **Table 4**.

Table 4

Informal Survey of Length of Display of Professional Prints

Image Age (Years)	Approximate Images Still on Display
5	54 percent
10	42 percent
20	21 percent
40	1.9 percent
60	Virtually none

For various reasons, such as home redecorating and divorce, the majority of images placed on display are often taken down after 10 years.

Considering the balance of thermal and light fade in the portrait/social environment, the additive effects of thermal and light degradation, and the fact that many images displayed initially are eventually stored in the dark, it is possible to calculate practical print-life estimates. The estimates are based on the combined rates of display and dark-storage fade. **Table 5** gives several estimates.

[19] J. LaBarca and S. O'Dell, "The Importance of the Balance of Light and Thermal Image Stability Effects in the Design of Photographic Color Paper," *Proceedings of IS&T's 12th International Symposium on Photofinishing Technology,* 2002, pp. 38–47.

Table 5

Practical Print-Life Estimates Based on Combined Home Display (120 Lux) and Eventual Dark Storage (24°C and 50% RH)

Image Display Time (Years)	Estimated Remaining Dark Life After Display (Years)	Total Estimated Print Life (Years)
0	Over 200	Over 200
10	Over 180	Over 190
20	Over 160	Over 180
40	Over 120	Over 160
60	Over 80	Over 140
80	Over 40	Over 120

After a print is removed from display, the degradation mechanism reverts to the slower thermal effect and provides a jump in remaining print life during dark storage.

Conclusions

Clearly, the science of measuring, interpreting, and estimating print life is very complex. Print life depends on many external variables that can cover wide ranges of conditions.

While newer imaging technologies have revealed additional degradation mechanisms (and more mechanisms may be discovered in the future), silver halide-based color photographic paper has been around for more than five decades. The key degradation mechanisms of light fade and thermal fade are very well understood. Product improvements have made other degradation mechanisms from earlier days, such as base stability, inconsequential.

Because color silver halide-based paper has existed for so long, it is unlikely that any undiscovered degradation mechanisms will suddenly arise. For all these reasons, it is possible to predict print life accurately and with a very high degree of confidence.

As stated earlier, the accuracy of predictions depends on the quality of test data, and statistically good data take a long time and a high degree of testing precision to generate. Also, designing for optimum print life and predicting print life accurately require a thorough understanding of the degradation mechanisms in the real-world environment where products will be used.

Finally, it is critically important not to design a product exclusively for image stability and print life at the expense of other design criteria, i.e., image quality and performance in the finishing lab. The design of KODAK PROFESSIONAL ENDURA Papers has successfully improved all three major design criteria. The new papers provide excellent print life, excellent image quality, and excellent performance in the lab, all in the context of the real-world requirements of end-users in the portrait/social and commercial display markets.

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