The J. Paul Getty Museum, Los Angeles
© Man Ray Trust ARS-ADAGP
Man Ray, *Butterflies*, 1930-1935
Carbro print, 9¼ x 11¼ in

Advanced-level Workshop in Identification and Conservation Strategies for Color and Digital Prints

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Image Permanence Institute, Rochester Institute of Technology. 2009. *A Consumer Guide to Understanding Permanence Testing*. Rochester, NY: Image Permanence Institute. https://www.imagepermanenceinstitute.org/webfm_send/311

December 2009

A Consumer Guide to Understanding Permanence Testing

Created by Image Permanence Institute with support from the Eastman Kodak Company

COLOR PHOTOGRAPHY HAS BEEN AROUND FOR WELL OVER FIFTY YEARS, but during the last decade there have been radical changes in the way color images are created by cameras. Early digital prints sometimes faded rapidly, and this led to questions about the longevity of these modern color prints, the techniques used to evaluate their useful life, and the care that must be exercised for their preservation.

The publication is a lay-person's guide on the issues related to predicting photographic print permanence. It applies to both traditional and digitally printed images. The problem to date has been a lack of accurate and coherent information on the subject by independent experts. Most information has been published either by the material manufacturers themselves or by the popular press in a sometimes over-simplified manner. The intended audience for this guide is the home imaging consumer, though others concerned with the care of photographic prints—retailers, wholesalers, pro-labs, and advanced amateurs or "pro-sumers"—will also benefit. With this audience in mind, the guide focuses on those products and services intended for the home consumer and either printed by the consumer or for them by professional services such as processing labs, pro-photographers, or photographic suppliers. This guide will look at the effects of environmental decay forces (heat, light, humidity, and pollution) and how manufacturers test for these. It will not discuss physical stresses from handling or potentially harmful interactions with photo storage or display products. The discussion will focus on the most popular printing methods for color prints: traditional (known as silver-halide), inkjet, dye diffusion thermal transfer (also known as "dye-sub"), and electrophotographic (as in laser printers).

THE NATURE OF MODERN PHOTOGRAPHS

In order to understand how color prints are tested for permanence, it's helpful to understand the nature of these materials. Following are brief descriptions of the major printing processes being used today to print color photos. For more in-depth descriptions please refer to IPI's *A Consumer Guide to Traditional and Digital Print Stability,* which can be downloaded at www.imagepermanenceinstitute.org.

Silver-Halide Prints (AgX)

This is the technology used to make traditional photographic prints from film negatives. In this case, color dyes are formed during chemical processing in areas that have been exposed to light. What many people do not know is that a large majority of the prints made from digital images at photo-labs or from online services are still created using this same, time-tested process. Today the main difference is that instead of being exposed using light through a negative, the photographic paper is exposed using a laser or light-emitting diodes (LEDs) controlled by digital data in the image file.

Inkjet Prints (IJ)

This is the technology used by most home computer printers and some retail photo kiosks. Small droplets of ink are rapidly jetted onto the printing paper to create the image. Inkjet can be used for both documents and images. Several variations of the technology exist, and each produces prints with unique properties. The colorants in inkjet prints may be dyes or pigments. Generally the pigment inks are more stable because of their large particle size, but this is countered by the greater range of colors possible with the dye inks. Pigment inks are also less prone to smearing or image degradation when exposed to moisture. However, recent advances in dye and pigment chemistry have minimized these tradeoffs.

Electrophotographic Prints (EP)

This process (also referred to as xerography) is used in photocopiers and laser printers. In these systems color toners are deposited on the printing paper by an electrical charge (controlled by a laser, LED array, or light reflected from the original) and "fixed" by heat or pressure. The toners are usually comprised of pigments, with the black toner containing very stable carbon black. Although black-and-white EP prints on preservation-quality paper are quite stable, color EP prints, like other color systems, are sensitive to their environments and can deteriorate. This process is not widely used to make individual consumer prints, but it is commonly used to print photobooks.

Dye Diffusion Thermal Transfer Prints (D2T2; also called "thermal" or "dye-sub" prints)

In this system, the printer varies the heat energy applied to a colored donor ribbon to control the amounts of yellow, magenta, and cyan dyes that are transferred to the print paper. This technology is often used in snapshot-size home photo printers and in many instant-print photo kiosks.

FACTORS AFFECTING PRINT IMAGE STABILITY

Types of Image Loss

Original

Faded with color shift

Three types of changes are generally studied in image permanence testing: fading of the colorants that make up the image, migration or bleed of the colorants, and yellowing of the paper the image is printed on. Fading of the colorants is seen in two ways: overall fading (color is lost) and hue shift (the color changes). In overall fading, all areas of the image lighten at an even rate. Lightened images are objectionable, but the level of fading must be quite significant before it is noticeable. Hue shift, on the other hand, results in discolored images. This occurs when one of the colorants used to print the image fades faster than another. For example, in a printer that uses cyan, magenta, yellow, and black inks, if the magenta dye fades while the others do not, or do so at a lesser rate, the image will shift towards green. Small shifts in color are more noticeable and objectionable than overall fading of the image.

Original

Yellowed

Dye migration can occur when certain inkjet prints are exposed to high humidity for prolonged periods of time, or when thermal prints are exposed to high temperatures. This typically is observed as loss of sharpness, hue shift, or transfer of color to the back of an adjacent print or to an album sleeve.

Yellowing of the printing paper can also occur [1]. Note that while the shift is usually to yellow, it can also be to orange. Conversely, some prints are intentionally made on tinted or colored papers, which may fade over time.

All of these changes are measured with special color-measurement instruments. It is important to note that any image changes caused by the deterioration forces described below will likely be permanent.

Print Deterioration Forces and Test Methodologies

A variety of environmental stresses can cause the fading, bleeding, and/or yellowing of color photos. There are slow processes, such as heat-induced degradation, which can take decades to be noticeable, and there are faster processes, such as high-humidity bleed, which can cause a picture to loose sharpness or change color in weeks. Both need to be addressed. Below are descriptions of the main deterioration forces that can harm prints over time as well as short descriptions of the test methods used to examine the effects of each on print longevity.

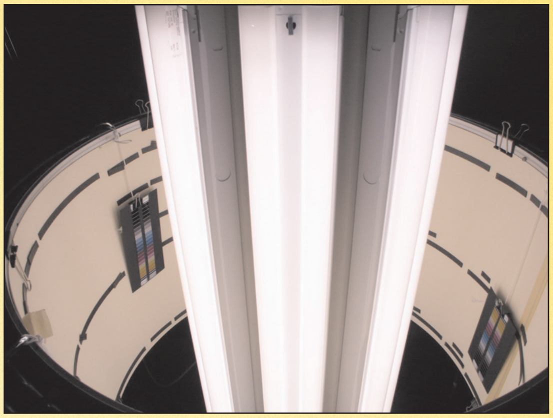
Heat

Heat amplifies chemically driven decay forces. All prints, whether on display or stored in the dark, are continually undergoing degradation due to heat. Heat, as described here, is not oven-level temperature or even a-hot-day-in-a-closed-car temperature. In this context, heat refers to the ever-present energy of the environment that can accelerate the various chemical and physical reactions that cause photos to degrade. What is hot to human beings can be *very* hot to photos. This is why it is usually recommended that photos be stored in a cool environment.

Usually the first step in assessing the long-term stability of photographic materials is to test for their heat resistance. The Arrhenius method is commonly used to determine heat resistance. Named for a Swedish chemist, this method forms the basis of a standard published by the International Organization for Standardization (ISO) [2]. IPI has used this method to determine heat deterioration rates of traditional photographic materials and, from the results, has recommended storage temperatures for traditional photographic films and color dyes. IPI believes this method can also be used to predict lifetimes for digital print materials. This complex technique requires incubating the printed materials at a series of increasing temperatures. The logarithm of times to failure of the print is graphed against inverse temperatures in degrees Kelvin, and the resulting line is extrapolated to room temperature to predict image life.

Light

Fading of color due to light exposure is a very common phenomenon—the fading of curtains and upholstery fabrics in the home, for example. The susceptibility of a color image to light is highly dependent upon the printing process as well as the nature of the light source. For example, images will show different degrees of change when exposed to fluorescent light and to sunlight. The importance of the type of light is demonstrated by the fact that sunshine will cause sunburn while indoor lighting will not. The level of light exposure is also critical. Bright lights fade images faster than dim ones.



Fluorescent light-fading unit

Until recently, most light-fade testing used high-intensity fluorescent lights. The ideas were that a) many prints were displayed in office areas that used fluorescent fixtures, b) more and more consumers were using fluorescent lights at home to reduce energy usage, and c) fluorescent is high in ultraviolet (UV) light, which is the greatest culprit in the decay of displayed images. The problem with fluorescent lighting is that the energy it produces is not evenly distributed across the visible spectrum. It is very high in certain parts of the spectrum and very low in others. Sunlight is energetic across the entire visible spectrum and also includes UV, so its total energy is greater. Recent research suggests that modified sunlight (called window-filtered daylight) and not fluorescent light is the dominant light source causing damage to consumer images in the home [3]. Therefore, predictions for image life based on high-intensity fluorescent tests may differ from the actual life of an image on display.

There is now an industry transition to high-intensity xenon arc testing because it better simulates natural daylight. During testing, prints are closely monitored over time to watch for changes. When the prints have faded or yellowed to a predetermined level, or "endpoint," they are removed from the test apparatus, and mathematical formulas are applied to estimate their lifespan in years. These methods will be further discussed below because the method chosen has a dramatic effect on the final image-life prediction.

Pollution

The presence of pollutants in the atmosphere has been of increasing concern as society has become more industrialized. Pollutants are often a greater problem in urban areas than in rural environments. While color print fading can be caused by such pollutants as sulfur dioxide and the oxides of nitrogen, the predominant impact is from ozone. These pollutants not only exist in the outdoor environment; research has shown that they also exist inside all buildings, including residential homes, and consequently pose a threat to image materials stored indoors. Some modern prints are very sensitive to pollutant gases, especially those made with some inkjet printers. Some have been known to fade in just weeks when stored in areas of high ozone. Even extremely low levels of ozone can cause significant damage over time.

In pollution testing (also called gas-fastness testing) samples are exposed to ozone and/or nitrogen dioxide. Since ozone is the more aggressive of the two, testing has concentrated on this gas. Special controlled chambers are used to ensure that the concentration of the pollutant as well as the internal air flow, temperature, and humidity remain constant. After the samples have faded or yellowed to a predetermined endpoint, image life can be estimated.

Humidity Extremes

High or low relative humidity (RH) can seriously damage both traditional and digital prints. At high humidity prints can stick together or to storage materials. They are also at risk for mold growth. At low-humidity the surface coatings that hold the image can become brittle and crack. While digital prints share these vulnerabilities with traditional prints, they also have unique sensitivities of their own. At high RH they have a potential for image flow (ink bleed). Image flow occurs when image dyes migrate either across the surface of the print (spread) or further down into a print (and occasionally all the way through to the back). The resulting effects are changes in image density (either gain or loss) and loss of image sharpness and detail.

Prints can stick together at high humidity

There are two approaches to humidity sensitivity testing. The first method exposes the materials to a specific elevated humidity level (such as 85% RH). The prints are then examined to determine if the colorants have migrated. The amount of change measured can be used to rank the materials according to their relative sensitivities or compared to a numerical rating scale that can be used to rate the materials as sensitive, slightly sensitive, or insensitive to high RH.

Image flow

The second method exposes samples of print materials to a series of increasingly elevated humidities. The humidity at which the image starts to bleed then becomes the "critical" humidity above which the print should not be displayed or stored. This second method is more time consuming, but it can lead to a specific recommendation on a humidity storage limit.

An important point about humidity testing is that the results cannot easily be extrapolated to long-term display predictions. Humidity tests are real-time tests that measure the durability of the printed image to potential extreme conditions of use, such as a very hot and humid summer. These are also often referred to as worst-case-scenario tests.

Decay Force Interactions

Finally, a word should be said about the interaction of the decay forces discussed above. No stress acts in isolation. In some cases the interaction between forces results in extending the life of prints, but more often the interactions significantly increase the rates of fading and yellowing. It would be impractical to test every possible combination or even try to understand all the ways these interactions might combine to harm or help the print. For this reason, most laboratories choose to focus on one decay force at a time.

ACCELERATED-AGING TESTS

All of the testing procedures mentioned, with the exception of humidity testing, utilize accelerated-aging techniques. Because many modern print materials are so stable, it is not feasible to wait until prints show change under normal use conditions; the aging process must be sped up in the laboratory in order to try to predict the longevity of the prints in a reasonable period of time. Simply put, aging is accelerated by increasing the intensity of the decay force for a short period of time. For example, in light-fade studies the light source used in experimentation can be as much as 1000 times the levels found in actual homes.

Comparative versus Predictive Testing

There are two broad approaches to accelerated-aging testing. The first is called *comparative testing*. This method is the simpler and less expensive of the two. In this case, the prints in question are subjected to the same stressor (heat, light, humidity, or pollution) for the same time period, measured for fading, bleed, and yellowing, and then compared or ranked in order of the severity of the damage.

There is a significant drawback to this method. Say, for example, that prints from two different manufacturers are exposed to the same light source for the same time period, and that subsequent measurements indicate that Print A faded more than Print B. It could therefore be concluded that Print A is the less stable of the two. The problem is that it isn't known how long the two prints would last in real life, but only that Print A would not last as long as Print B. In reality, it could be that Print A will fade in two months and Print B will fade in three months, and thus both would be considered disappointing products, as neither offered a significant useful life. On the other hand, it could be that Print A fades in two hundred years and Print B fades in three hundred. In that case, both would be considered permanent as they both offer very long useful lives.

The second approach is *predictive testing,* which attempts to determine how long a print will last, irrespective of the image life of other products on the market. Comparative materials are not needed for this test, only the materials under investigation. In this case, the laboratory follows a specified test method to determine by analysis a predicted number of years the image should last during normal use. While this method should be much more useful to consumers, it also has the potential to be misleading. When combined with predictions for other products tested by the same method, this technique can also be used for product comparisons, where one product with a predicted life of 50 years could be chosen over another product with a predicted life of 15 years. There are complications to the predictive method, and those will be discussed in the Issues in the Image Permanence Testing section below.

Predictive Testing

Predictive testing methods compare accelerated aging in the laboratory to natural aging in consumer homes.

As stated above, heat testing uses an existing ISO standardized method for predicting image life. While that method is different and more complicated than that used for light and pollution, it is well established and based on principles used for heat testing in many other industries. It will not be discussed further in this publication.

To make image-life predictions from light and pollution tests, scientists use a special equation, and it deserves more in-depth discussion. Here it is in plain language: *A short-term exposure at more intense experimental conditions will have the same effect as long-term exposure under normal use conditions.*

To more fully understand the above statement, the following will need to be defined:

- Endpoints
- Normal use conditions
- Experimental conditions
- Experimental duration

Endpoints

To predict image life, there needs to be agreement on what "end of life" is for prints or, at the very least, some agreed-upon measurable change to the image that can be regarded as the stopping point for the test. This indicator is called an *endpoint*. For example, it can be predetermined by the experimenters that they will run the

	Endpoint Set 1 [4]	Endpoint Set 2 [5]	Endpoint Set 3 [6]
Cyan colorant	30%	25%	40%
Magenta colorant	30%	20%	40%
Yellow colorant	30%	35%	40%

experiment until they see the beginning of image fading and then calculate their life prediction from the experimental duration at that point. An endpoint provides an agreed-upon quantitative value for when the beginning of unacceptable image fading occurs.

The industry has not yet standardized a set of endpoints. The table above shows the color fade endpoints for loss in cyan, magenta, and yellow from three published sources.

If different labs use different endpoint values to determine whether an image has reached the end of its useful life, then they will, by default, calculate different image-life predictions. This can make comparisons between products very difficult or impossible.

It should be noted that the various potential end-users of prints (such as consumers, advertisers, museums, etc.) differ considerably in what they consider an acceptable change in their images. This will be influenced by the perceived value of the print (sentimental, monetary, historical, etc.), the content of the print, its intended period of use, and the ability to easily reprint the image.

It should also be pointed out that the perceived level of change defined by the above endpoints can vary depending upon the initial appearance of an image and the expectations of the observer. In some cases, changes greater than 50%, while likely to be noticeable, may not be considered objectionable [7]. Endpoints should be used only as stopping points for testing. They are not necessarily the point at which a consumer would consider the image to be worthless.

Because visual endpoints are intimately tied to the complexities of human perception as well as the variations in scenes, the best way to establish them is through psychophysical or human factors studies in which a large group of print users evaluates a wide variety of typical images at different stages of fading [7, 8]. This is a complicated and expensive process, and not all the endpoint sets illustrated in the table above were determined by this optimal technique.

Original

Faded 30%

Faded 80%

Normal Use Conditions

Critical to predictive tests are the assumptions about what conditions the prints will be subjected to during actual use. This means that considerable data about how consumers will actually use the print materials must be collected. Until recently, most published permanence testing results have been based on anecdotal assumptions regarding consumer home conditions.

The typical home environment is created for human comfort and not photo archiving. At worst, this means that all of the decay factors will be uncontrolled. The prints will be at the mercy of nature and human activity. At best, this means that only minor attempts can or will be made to control temperature, humidity, light, and pollution. These uncontrolled or minimally controlled environments make predicting the usable life of prints exceptionally hard, as laboratories won't know to what conditions the prints will ultimately be exposed.

Recently, work has been done to statistically quantify the environments actually found in consumer homes [3].

While averages have been obtained, the range of consumer environments is rather wide, causing concern about the validity of predictions based on averages only [9].

If the conditions found in people's homes are not consistent, and because image life is dependent on those conditions, then it is obvious that there will be a real variation in actual image life from consumer to consumer, even for prints made on the same printer using the same imaging process. In a home kept at 65°F and 30% RH, some prints may remain in good condition for almost 100 years. Identical prints stored or displayed in a home kept at 75°F and 70% RH may last only 15 years before being degraded.

Experimental Conditions and Duration

The experimental conditions for testing (light, temperature, and humidity levels as well as pollutant concentrations, air flow rates, etc.) are typically based on standardized methods, data from previously published research, or laboratory experience. Some of the problems with selecting those conditions will be discussed below.

The test duration is the time the prints are exposed to the experimental conditions until the endpoints for fading and/or print-yellowing are reached. Because it cannot be known in advance how long this will take, the print samples under investigation must be periodically removed from the exposure environment and measured. Once the measurement meets or exceeds an endpoint, the exposure is stopped, and the image life for that material is calculated.

Converting Test Results to Year Predictions

After the print materials have been exposed to experimental levels of light or pollution and the fading and yellowing endpoints have been reached, the formula below can be used to convert the test results into an image-life prediction.

$$\text{Image life} = \frac{\text{experimental conditions} \ \times \ \text{experimental duration}}{\text{normal use conditions}}$$

The following is an example of an image-life calculation for a print material to be used on display. The test exposure used high-intensity fluorescent lights at 50,000 lux (*lux* is a measure of light intensity) for 24 hours a day, and it took 21 days to reach the first endpoint. It is assumed that a consumer print will actually be displayed in a well-lit office setting under fluorescent lights with an average light intensity of 500 lux for 12 hours a day (the lights would be shut off at night).

$$\text{Image life} = \frac{50{,}000 \text{ lux} \ \times \ 24 \text{ hours/day} \ \times \ 21 \text{ days}}{500 \text{ lux} \ \times \ 12 \text{ hours/day}}$$

$$\text{Image life} = 4200 \text{ days, or } 11.5 \text{ years}$$

The same approach can be used for accelerated pollution testing. Estimates of average levels of ozone in the home, as determined by manufacturers and independent testing agencies, have been used to calculate predictions for images that would be directly exposed to air that may contain ozone (such as a print hung on a refrigerator).

ISSUES WITH IMAGE PERMANENCE TESTING

There are, however, serious concerns about using these techniques. Many of the problems that occur in the testing of these materials and the interpretation of the results are reviewed below.

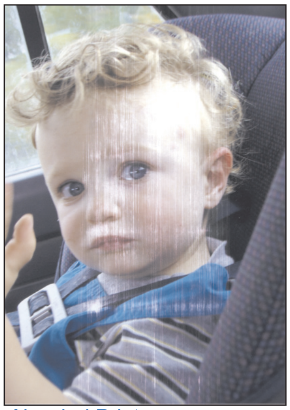
Terminology

As with every endeavor, it is critical to have a common set of terms so that all parties understand one another. In the case of image permanence testing, a few terms have been confusing to consumers.

Dark and Light Stability

Historically, the longevity of photographs has been separated into the categories of dark and light stability. It

PRINT DURABILITY


Abraded Print

Survival of the image is only part of the story. The long-term strength and cohesion of the image's support is critical and is often overlooked. Many images are sensitive to abrasion and scratch. Damage can be simply the marring of a photo's glossy surface or even the smearing of the colorant across the face of the print. Also, the print's surface coatings may be sensitive to cracking, especially at low humidities. Some coatings have even delaminated or flaked off after long-term exposure to UV-containing light. Care should be taken when handling to avoid severely flexing the print or rubbing its surface against rough materials, even the backs of other prints in stacks.

is important to remember that in dark storage (as in boxes or albums) only the dark stability forces (heat and humidity) are at work, but on display both the light and the dark forces are deteriorating the image. Modern digital images are also sensitive to pollutant decay, which occurs both in light and in the dark, so the effects of pollutants must be added to heat and humidity as a dark storage decay force.

Display Life and Image Life

Display life pertains only to the ability of a print to resist change when displayed, for example, framed on a wall. Product advertisements that indicate only display life should be questioned, because this may mean that the materials have been tested only for lightfastness and not for reactions to heat, swings in humidity, air pollutants, or framing materials. It is also important to know if testing has been performed on unprotected prints or on framed prints, as this too can have a significant impact on the display-life prediction.

Image Life and Print Life

These two terms are not synonymous. Image life is measured in terms of changes in the colorants (dyes or pigments) in the image itself or yellowing of the paper base. Image life does not include other types of damage, such as delamination of surface layers, abrasion, or prints sticking together in stacks. Print life is a broader, more inclusive term and therefore a more accurate description of what will happen to a given print material over time. However, currently there are no commonly agreed-upon methods for testing these additional factors, so it is difficult for manufactures to accurately make claims about print life.

Inappropriate Test Methods

In order to minimize the time and expense required to perform image permanence tests, some manufacturers have resorted to using inappropriate or incomplete testing methods by which to arrive at predictions of image life for their products.

Window Test

In this case an attempt is made to determine the lightfastness of a print material by placing a sample against a window in direct sunlight for a few days or weeks. While at first this method may seem logical, it is usually inaccurate. The problem is that only one question can be answered: Can this print material withstand direct sunlight through window glass for the length of time it remained in the window? This is not the kind of illumination most home prints are exposed to. No prediction should be given.

Desktop Test

This test is similar to the window test except that a sample of the print material is left on a desk and then examined again days or weeks later to see if there have been any changes. Since this is not an accelerated test, it cannot offer predictions of what will happens over years. Nor is the environment controlled. This test and the window test are both inappropriate methods that will potentially misinform consumers as to the long-term stability of their prints. Of course, if a print exhibits unacceptable levels of change while sitting on a desktop for a short period of time, accelerated test methods may not be required to judge the long-term stability of the print.

Single-Condition Test

In the single-condition test the long-term stability of a material is examined by exposing it to just one level of the accelerated condition. This is most often attempted with heat deterioration tests. Instead of the required sequence of increasing temperatures, only one temperature and one test duration are used, and it is assumed that this exposure will be equivalent to some "years in real life." Manufacturers that use single-temperature tests make the faulty assumption that all materials degrade at the same rate, but this is not true. Every material has a unique rate of degradation. Some systems may behave similarly to others, but it is not possible to use a single temperature to extrapolate a specific useful life for all print types. In a subtler variant of this testing fallacy, some manufacturers may fail to check for what is called *reciprocity failure* (see below).

Single-Factor Test

In this case a material is tested using just one factor (such as light), and then it is implied that the advertised year prediction also includes decay forces not tested, such as ozone or high humidity. This is a serious error; some prints may have high longevity when exposed to light but be so sensitive to high humidity they wouldn't last a single summer in a very humid environment like Florida. Image-life ratings should incorporate testing for all four properties—heat, humidity, pollution, and light—and the rating should be based on the most limiting of these four environmental factors.

Nonstandardized Testing

Even among those who use appropriate methods to test their materials, there are variations in procedures. These include variations in light sources and intensities, pollutant concentrations and air flows, and test temperatures and relative humidities. These differences accumulate to the point where results from one laboratory can't be compared to those from another. The ISO has been working to design and publish test methods that all labs can follow to make their data equivalent and comparable to that from other labs. This process has been slow, both because the problem is complex and because digital printing technology keeps advancing, making the target a rapidly moving one. For now it is important to know that not all results published by companies or third-party testing labs are comparable. In fact, one lab's 30-year rating may equal that of another lab's 60-year rating. Some labs have even varied their own methods over time, making their image-life ratings from years past incompatible with those they produce today.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

The International Organization for Standardization (ISO) has been working to develop quality standards to evaluate the long-term viability of modern photo printing papers and printing systems. Headquartered in Geneva, Switzerland, this standardizing body is recognized worldwide. ISO is not a marketing organization. Instead it is made up of experts from manufacturers, consumers groups, government agencies, universities, and independent laboratories.

The permanence testing of color prints is under the jurisdiction of ISO's Technical Committee 42, which has representation from twelve countries. The current program of the committee is to establish test methods to quantify the harmful effects of heat, light, humidity, water, and pollutants. Once test methods for these factors are established, ISO's next goal will be to create a material specification that can be used to calculate image-life expectancies tailored specifically for individual user groups.

ISO

Reciprocity Failure

Although accelerated aging is generally accepted by the scientific community as a feasible way to predict the long-term behavior of materials using short-term tests, it is not fool-proof. As stated above, behind this strategy is the assumption that exposing prints to high levels of environmental stresses for short periods of time will be equivalent to subjecting those same materials to low levels of stresses (normal use conditions) for long periods of time (natural aging). That assumption is called *reciprocity,* and if this assumption does not hold then reciprocity has failed. This is more commonly referred to by the term *reciprocity failure*. There are ways to test for reciprocity; however, many companies either do not perform the tests (because they take a long time and can be quite expensive) or do not publish the results.

System Testing versus Component Testing

Results of any accelerated test are valid only for the system tested. This is especially of concern for inkjet systems where the printer, the ink, and the paper may not be from the same manufacturer. Changing any one of these components may make the results invalid. Sometimes printer and ink manufacturers make claims about their inks but add the disclaimer that their predictions about image life apply only to one specific paper. This is because it is impractical to test every printer, ink, and paper combination on the market. This is understandable given that testing is expensive and time consuming. Different papers on the same printer can behave very differently in terms of image stability.

Another misleading result arises when paper manufacturers test their papers using a known stable colorant. The results make the consumer believe that all prints made using that paper will be long-lasting. Unfortunately, prints made using that same paper but with another ink may have significantly lower image-life predictions. Again, it is understandable that paper manufacturers don't want to test their paper on every printer, as that is costly; however, it is important for the consumer to know that not every printer will produce the same result with a given paper. Contacting the manufacturer directly may be helpful.

Overgeneralization of Results

It is important for consumers to avoid overgeneralizing about the potential permanence of products and technologies. This is difficult, given that information is not available about every product and system. It may be tempting to mentally fill in these information gaps by making unconscious assumptions about particular brands or product types. For example, a particular paper from a particular company is rated well in all categories for image life, but there is no information about one of their less expensive products. It's tempting to assume that the second paper is also long-lasting, since it is made by the same company. This assumption could lead to disappointment. The lack of information for the second product should be taken as a warning. Similarly, a manufacturer's claim of longevity will likely depend on several parameters, such as printer settings, which could include paper type, image quality, and speed. Claims of high stability for a given system may be true only when the printer is set to highest quality and slowest printing mode, for example.

Another overgeneralization is the assumption that since the latest print products last longer than those of the past, that all products today last longer. This just isn't true. Recent research shows that while many products are significantly improved, some current products are as poor in permanence as those manufactured and sold in the earliest days of digital printing [10].

Published Predictions versus Actual Experience

Some people are understandably concerned about whether their prints will actually last as long as predicted in advertisements or product literature. That images will fade and prints will yellow is a given. However, the number of years it will take for an individual consumer to be disappointed by the degree of change in a print is truly unpredictable. As stated above, the image-life predictions given by manufacturers and other testing laboratories are based on averages and assumptions of how the prints will ultimately be used. Since few consumer homes exactly match the conditions that were used to make the predictions, few consumers can expect their prints to last exactly as long as the ratings printed on the box or in the product's literature. The table on the right shows how varied these experiences can be.

	Ozone	Light
Assumed (test) conditions	9 ppb	250 lux
Published image-life prediction	30 yrs.	24 yrs.
Consumer A conditions	3 ppb	125 lux
Actual image-life experience	90 yrs.	48 yrs.
Consumer B conditions	30 ppb	500 lux
Actual image-life experience	9 yrs.	12 yrs.

Even if the same printer and paper are used, Consumer A's print would last 48 years while Consumer B's print would last only nine. Consumer A probably will be happy that his print lasted much longer than the manufacturer predicted, but Consumer B very likely will be disappointed that her print did not last as long as promised.

Product Quality versus Personal Practice

Many people believe that the long-term viability of their photos is purely a function of the printing products they purchase or the printing technology they select (inkjet, EP, thermal dye transfer, etc.), but this isn't true. The quality of printing materials does play a part, but by focusing solely on that aspect these consumers may never fully reach their preservation goals. It's partly their job to make their photos last. They need to recognize that preservation of important images is not something that just happens.

The most important determinant for the longevity of prints is the environment in which the images are stored—particularly the temperature and humidity. Photos should always be kept cool and dry. Mold can start to grow on prints in very humid environments. Heat and humidity can cause inks to bleed or prints to stick to adjacent materials. It is best to keep treasured photos at or below 70ºF and between 30% and 50% RH year-round. Hot attics and damp basements should be avoided. Although consumers most likely cannot control the amount of airborne pollutants (such as ozone) in their homes, pollution can be the most detrimental factor affecting permanence. Album storage or framing under glass will help, but this problem may best be addressed by initially selecting printing products that are resistant to ozone fading.

All storage and framing materials should conform to the internationally accepted standard, *ISO 18902 Imaging materials—Processed imaging materials—Albums, framing and storage materials.* Look for photo-storage and framing materials with packaging that states at the least the following:

- Passes Photographic Activity Test (PAT) ISO 18916
- Acid-free
- PVC-free (for plastic enclosures only)
- Lignin-free (for paper enclosures only)

For display, do not expose photos directly to sunlight or airborne pollutants. Always frame photos behind glass or plastic sheeting. Whether or not color prints are to be framed and displayed, it is recommended that a second print be made and kept in dark storage, even when the digital file is available to make a new print.

Keeping the digital file on hand to make a reprint if the original becomes damaged might not be a dependable approach for the long term. Without ongoing file management by the consumer, the long-term viability of the digital file is highly questionable due to inevitable hardware and software format changes. Further, depending on the quality of the chosen storage medium, loss of the digital information could occur in as little as five years or less. For more information, see www.SaveMyMemories.org, a website established by the International Imaging Industry Association (I3A) to address the long-term issues of digital file longevity.

Finally, remember to handle prints with care. Some modern prints are easily abraded or scratched. Other print types can crack or buckle. For further information on how to care for modern photos, please refer to IPI's *A Consumer Guide to Traditional and Digital Print Stability* which can be downloaded at www.imagepermanenceinstitute.org

PHOTOBOOKS

Photobooks are really just bound sets of prints made with the same technology used to make individual prints. Photobooks can be made at home using a kit or through a retail or online service. They are becoming increasingly popular and can provide the same protection and concerns as albums. Since they are in book form, the pages are not exposed to light and to a lesser extent to ozone. The main issues are their heat and humidity sensitivities and their abrasion resistance.

CONCLUSION

A variety of decay forces can cause digital prints to deteriorate. There are also many problems associated with testing digitally printed materials for permanence and interpreting the results. The variability in test methodologies currently being used, coupled with the variability in conditions to which the prints will be exposed during actual use, leads to concerns about the accuracy of advertised image-life predictions. The lesson to be learned is that, while image-life predictions can only give us a rough idea of how long prints will last, they can be used to compare products on the market as long as the test procedures used were similar. The publication of updated ISO test methods that all laboratories can use will help to improve public confidence in image-life predictions.

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