7. Monitoring the Long-Term Fading and Staining of Color Photographs in Museum and Archive Collections

Similar Procedures Can Be Employed with Black-and-White Prints

> Douglas Severson's findings confirm a fact that has long been suspected and dreaded, that is, that the exhibition of photographs is incommensurate with their preservation.
>
> The exhibition Severson monitored [made up of some of the finest photographs in the collection of the Art Institute of Chicago, and sent to Japan for 3 months in 1984] was mounted at the highest level of practice and was of relatively short duration, yet dramatic changes were recorded. The few other monitoring projects which have been conducted show similar results. If one contemplates the probable effects upon the majority of photographs displayed for longer periods, under less controlled conditions without monitoring systems, the implications are sobering.
>
> . . . We must accept the conclusion that we are squandering the largely unrenewable resources of our photographic heritage in an ignorant fashion. It is sadly ironic that this is being done under the banner of promoting the appreciation of photographs.[1]
>
> Grant B. Romer, Conservator
> International Museum of Photography
> at George Eastman House
> Rochester, New York – September 1986

People go to museums and galleries to see original works of art — whether they are paintings, photographs, drawings, or sculptures. Viewing a *copy* of a 1653 Rembrandt painting — no matter how perfect the copy — is simply not the same intellectual or emotional experience as looking at the original work of art. The desire to see originals certainly extends to color photographs: it is accepted practice to exhibit original color prints despite the fact that exposure to light during display causes gradual image deterioration in the form of fading, changes in color balance, and, with most types of color photographs, formation of low-level yellowish stains.

See page 241 for Recommendations

Compared with most other types of artistic media, color photographs generally fade and/or stain fairly rapidly when exposed to light on display. And, unlike the dyes and pigments in watercolors, paints, and fabrics — almost all of which have very good stability when protected from light and stored under normal room-temperature conditions — most kinds of color photographs slowly fade and develop overall yellowish stains even when kept in the dark.

When the fading of a color print is not severe, it is difficult to visually assess the deterioration of the image over periods of many years, and subtle changes are usually not noticed at all; this is particularly true when the viewer sees the print frequently during the months and years while fading is progressing. Most people have a rather poor recollection of exactly how a color image appeared many years past, and often a person will not have seen a particular faded print in its original and unfaded state. As an example, most people have never seen an albumen black-and-white print from the late 1800's that has not suffered significant image deterioration. The faded and yellowed albumen print has come to be accepted as "normal." People are usually shocked when they first view an albumen print that has remained in pristine condition, with its rich purple-brown tones and wealth of highlight detail with bright, neutral whites.

More extreme is the example of Kodacolor prints from the 1940's and early 1950's; all prints of this type that this author has seen have faded. Worse, the serious loss of image density is accompanied by severe orange-yellow staining. It is no longer possible to view an early Kodacolor print in a state that even remotely resembles its original condition. In a more recent disaster, untold millions of prints made on Agfacolor Type 4 paper in the 1970's have now lost most, if not all, of the cyan dye component of their color images. Even if stored in the dark, these prints now have a ghastly red-yellow appearance.

A moderately faded and/or stained image may evoke feelings that "the image is weak," or "it lacks brilliance," or "something is wrong with it." Most people will, however, be at a loss to describe in specific or quantitative ways the changes that have taken place in the image. Often a person will speculate that the print was never very good, that the highlights were washed out, or that "the color balance was off a bit" when the print was made.

October 1987

Douglas G. Severson, conservator at the Art Institute of Chicago, monitors a color print by Joel Meyerowitz on Kodak Ektacolor 74 RC paper. Severson's monitoring of a selection of photographs from the Art Institute collection that were shipped to Japan for a 9-week exhibition in 1984 showed that some historical photographs suffered significant deterioration even during short-term travel and exhibition. Particularly disturbing was the severe staining that occurred in a number of prints, including a 1919 palladium print by Alfred Stieglitz, an 1892 albumen print by William Henry Jackson, an 1874 albumen print by Julia Margaret Cameron, and an 1857 albumen print by Francis Frith.

Recommendations

- **What should be monitored:** Museums and archives should monitor all valuable color and black-and-white photographs in their collections. It is particularly important to monitor photographs made with processes that are known to have poor fading and/or staining characteristics (e.g., almost all types of color prints, albumen prints, salted paper prints, and silver-gelatin prints made on printing-out papers).

- **Limits of fading and staining:** The limits given in **Table 7.1** are recommended. With experience, an institution may decide to adopt limits that are different from those given here. In general, museums with fine art collections will tolerate less change than institutions emphasizing historical photographs. Regardless of the type of collection, however, it is best to adopt fairly tight limits of change. Over time, densitometer errors may understate the amount of change that has actually taken place. In addition, the perceived value of many photographs will increase as the years go by, and future caretakers will wish that such prints had been better preserved.

- **Available display time should be used only gradually.** A curator should not use up all of the available display time for a particular print during his or her tenure — as much display time as possible should be left for the future. This means that display of original color prints and other unstable types of prints should be infrequent, and then only for short periods. Between display periods, the prints should be kept in humidity-controlled cold storage. Facsimile color copies should be made for routine display.

- **Facsimile color copies should always be made before a fading or staining limit is reached.** It should be emphasized that with the exceptions of UltraStable Permanent Color prints, Polaroid Permanent-Color prints, and properly processed fiber-base black-and-white prints, photographs cannot be displayed for extended periods without damage. Unless kept in humidity-controlled cold storage, most types of color prints gradually fade and stain even when kept in the dark. Therefore it is simply a matter of time before most photographs will reach one or more of the specified limits of change.

- **Prints believed to have reached a fading or staining limit before the start of monitoring should not be displayed at all.** It may safely be assumed that albumen prints and most other types of historical photographs years ago exceeded the fading and staining limits given here. Most types of color prints that have been displayed or stored in the dark at normal room temperatures for more than 5 or 10 years also have probably exceeded one or more fading or staining limit (Polaroid Spectra prints, Polaroid 600 Plus prints, and Polaroid SX-70 prints generally will exceed the stain limits only a few months after they are made). To prevent further damage, such prints must be kept in cold storage and not displayed. Facsimile copies should be made for display and study purposes.

- **Densitometers:** At the time this book went to press in 1992, Macbeth TR924 densitometers with specially installed Kodak Wratten 92, 93, 94A, and visual 102 filters were recommended. The user should purchase the filters in 5-inch-square sheets from Kodak and forward the filter sheets to Macbeth for installation in the densitometer filter wheels; leftover filter material should be stored in the original Kodak packages in a cool, dry place (if possible, in humidity-controlled cold storage). The normally supplied ANSI Status A and Status M filters have poor stability and are unsuitable for monitoring applications.

- **Long-term densitometer calibration:** At the start of a monitoring program, a new densitometer should be purchased. The densitometer should be reserved for print monitoring and not used for process control or other routine darkroom applications. In addition to the porcelain calibration plaque supplied by the densitometer manufacturer, a Kodak Reflection Densitometer Calibration Plaque should be used to assess changes in spectral response of the instrument. But most important for long-term densitometer calibration are color photographic calibration prints made on each type of color material in the collection; to keep the prints unchanged, they must be preserved in 0°F (–18°C) humidity-controlled cold storage.

With older prints, there is likely to be doubt about the color and tone-reproduction characteristics of the materials with which the prints were made. Ilford Cibachrome prints made on the materials available in the 1970’s sometimes have washed-out highlights and look very much like prints subjected to significant light fading; the appearance of such prints is most likely due to excessive contrast and poor tone-scale reproduction of the older Cibachrome materials and is probably *not* the result of light fading. On the other hand, these prints may also have been subjected to light fading, making evaluation of their condition more difficult. Only rarely is an identical but unfaded print available for a side-by-side comparison with the displayed print.

Reasons for Monitoring Color Prints

With the singular exception of pigment color prints made by the UltraStable Permanent Color process or the Polaroid Permanent-Color process, a museum cannot responsibly display color photographs for the extended periods

May 1982

The 1982 show **Color as Form: A History of Color Photography** at the Corcoran Gallery of Art in Washington, D.C. was the first photography exhibition to be densitometrically monitored for image fading and staining. Curated by John Upton for the International Museum of Photography at George Eastman House, the show was the first major survey of color photography as an art form. Consisting of vintage prints made by a wide variety of color processes — most with unknown stability characteristics — the exhibition was at the Corcoran for 3 months and was later shown at George Eastman House.

February 1982

Conservation technician Peter Mustardo (left) and conservator Grant Romer monitor a group of color prints in the George Eastman House conservation laboratory. An Electronic Systems Engineering Company Speedmaster TRC-60D densitometer was used for the monitoring project.

May 1982

Lumiere Autochromes and transparencies made by other early processes were copied on Ektachrome sheet film for display in light boxes in the Corcoran exhibition; the originals were deemed too unstable for display.

common with modern fiber-base black-and-white prints. Once this unfortunate limitation of color photography is accepted, the question then becomes: "How long *can* a color print be displayed before objectionable fading takes place?" The purpose of monitoring a print is to provide a quantitative record of the print's original condition and of the complex changes that take place over the months and years of display or storage. Monitoring makes it possible to establish a set of criteria for permissible changes in an image and to do what is necessary to prevent fading and staining from progressing beyond those limits. Monitoring allows prints to be treated individually in terms of display times and light intensities; it permits prints made on the more stable materials such as Ilford Ilfochrome (called Cibachrome, 1963–1991) to be displayed much longer than prints made on less stable materials such as Polaroid Polacolor ER, with the assurance that no print will exceed the predetermined limits of fading.

If a print is made on a material subject to fading and/or staining when stored in the dark, such as Kodak Ektacolor paper, long-term deterioration can be arrested only by placing the photograph in low-temperature, low-humidity storage. At normal room temperatures, dark-storage changes — often referred to as *dark fading* — will continue whether or not a print is on display. Thus, when a print is displayed, the total change that takes place is a complex combination of dark fading/staining and light fading/staining. Light fading is caused by both visible light and ultraviolet radiation. For most types of color prints in normal museum display conditions, image deterioration caused by ultraviolet radiation is much less significant than changes caused by visible light.

Illumination conditions for color photographs vary widely from one museum to another, and even within a given institution (see **Table 17.1** in Chapter 17). Typically, color prints in museums are illuminated with incandescent tungsten lamps of about 2800 K; intensity on the print surface is in the range of 130–430 lux for about 12 hours per day. The small ultraviolet component of the illumination, below about 330 nanometers, is normally absorbed by the glass sheet in the picture frame.

Low illumination levels of about 50 lux (4.7 footcandles) have frequently been recommended for displaying works of art on paper in general, and color photographs in particular.[2] This level is much too low, however, for proper viewing of color prints — indeed, it is much too low for adequate viewing of black-and-white photographs as well. Under low illumination, visual perception of the image is impaired; it may not be possible to see details in darker areas of a print, and perception of color also suffers. Eastman Kodak states: "The intensity of the light source influences that amount of detail that can be seen in a print. For good viewing, a light source should provide an illuminance of 1,400 lux ± 590 lux (130 fc ± 55 fc)."[3] (For further discussion of the relationship between illumination levels and visual perception of color and tone reproduction in photographs, see Chapter 17.)

Inevitably, a compromise must be made between the high illumination levels required for optimal appreciation of a color photograph, the desire for extended display periods, and the need to minimize fading. For museum applications, this author recommends glass-filtered incandescent tungsten illumination with an intensity of about 300 lux (28 fc). Tungsten illumination of this intensity should also be available in darkrooms, print study rooms, and other areas where color prints are evaluated.

With many common types of color photographs, such as prints made on Kodak Ektacolor, Fujicolor, Konica Color, and Agfacolor chromogenic papers (sometimes incorrectly called "Type C" papers) manufactured prior to 1985, dark fading reactions may predominate when the prints are displayed under low-level tungsten light; low-level tungsten illumination on the order of 50 lux (4.7 fc) may result in little if any gain in print life with these materials.

In April 1984, Konica Color Paper Type SR (also known as Konica Century Print Paper) was introduced; Type SR paper was the first of a new generation of chromogenic color negative print papers with significantly improved dark fading stability. By the end of 1985, Kodak, Agfa, and Fuji had also introduced similar papers with improved dark fading stability. With these new papers, unfortunately, the light fading stability and the tendency toward stain formation on display and in dark storage were only marginally better than previous papers.

At the time this book went to press in 1992, stain formation with Kodak Ektacolor and most other chromogenic print materials in dark storage was a more serious problem than dye fading itself. The only exceptions to this are Fujichrome Type 34 and Type 35 papers (introduced in 1986 and 1992) for printing color transparencies, Fujicolor Super FA and Fujicolor SFA3 papers for printing color negatives (introduced in 1990–92), and Konica Color QA Paper Type A5 (introduced in Japan in 1991). These papers have markedly reduced rates of dark-storage stain formation compared with similar products made by Kodak and Agfa.

Because dark fading reactions in displayed prints are much less of a factor with current papers, longer display times under low-level illumination are possible. Nevertheless, this author believes a higher illumination level is necessary to properly view color prints.

Extrapolations based on fading and staining observed in high-intensity accelerated light fading tests often underestimate the amount of deterioration that actually occurs during long-term display under normal conditions (called "reciprocity failure," this characteristic of light fading and light-induced staining is discussed in Chapter 2), and estimates of long-term fading and staining rates in dark storage currently are not available for many of the numerous types of color print materials found in museum and archive collections. It is therefore usually quite difficult to predict accurately the rates at which changes will take place for a given color print. Current color print materials manifest an extremely wide range of differences in light fading, dark fading, and stain formation characteristics.

Procedures for Monitoring Prints

To determine what changes take place over a period of months or years, it is necessary to monitor a color print — that is to periodically measure the color and optical density of a print directly. Alternatively, the changes can be measured indirectly with a "fading monitor" made of the same type of color print material as the photograph in question and subjected to the same light, temperature, and relative-humidity conditions. Measurements of a print or fading monitor are made with an accurate electronic color densitometer designed for photographic applications. The quantitative data thus obtained can indicate at what point in time small — but visually significant — changes have taken place so that the photographer or custodian knows when to retire the original print to cold storage, substituting copy prints for study and display purposes. **Table 7.1** shows the quantitative limits of "tolerable" fading, shifts in color balance, and stain formation suggested by this author for critical museum and archive applications.

Because of reciprocity failures in light fading, the complex relationship between dark fading/staining and light fading/staining of the dye sets in the many types of color photographic materials, and variables having to do with processing or the materials themselves (many of these factors are not well understood), measurement of the total light exposure received by a print by means of Blue Wool Fading Standards, NBS Fading Papers, integrating photometers, and so forth will generally not indicate accurately the degree of deterioration of a color photograph during long-term display and/or dark storage.

The general procedures described here for monitoring color prints can also be applied to color transparencies, color motion picture films, color negatives, and so forth. Black-and-white silver-gelatin photographs, albumen prints, salted paper prints, and other types of monochrome photographs can also be monitored in a manner similar to that used for color photographs.[4] Likewise, yellowing and other forms of visual deterioration in works of art on paper and in other paper objects can be monitored during long-term display and storage. The measurement techniques are applicable in documenting changes in objects after conservation treatments, too.

Changes in watercolors and paintings can also be measured with a densitometer, but because of the wide variety of colorants in paints, a spectrophotometer may have to be employed[5] in addition to, or in place of, a color photographic densitometer to ensure accuracy. Color photographic images are composed of cyan, magenta, and yellow colors that have spectral absorption peaks within a fairly narrow range; photographic densitometers are designed to measure colors with these spectral characteristics.

Although the concept of predetermined limits of change is directly applicable to paper objects, watercolors, paintings, and so forth, the limits selected for these media will probably differ from those suggested here for color photographs. Still, it is important to measure quantitatively and record the visual characteristics of all objects of these types so that any changes in future years can be determined with reasonable accuracy.

The National Archives Document Monitoring System for the "Charters of Freedom"

In 1987 the National Archives and Records Administration in Washington, D.C. installed a sophisticated electronic document monitoring system designed to detect and quantify changes in the condition of the United States Declaration of Independence (1776), the Constitution (1787), and the Bill of Rights (written in 1789 and ratified in 1791).

Known collectively as the "Charters of Freedom of the United States," the parchment documents have suffered significant ink flaking and other deterioration over the years because of mishandling and poor storage and display conditions. The Declaration of Independence is in particularly poor condition, with the ink inscriptions now deteriorated so much as to be almost unreadable. In the early years the Declaration traveled frequently and was stored and displayed in a number of different locations. The document suffered partial ink loss during an ink-transfer copying process in the early 1800's. Further damage is believed to have occurred in the late 1800's, particularly during the period of 1877 to 1894 when it was displayed at the old State-War-Navy building in Washington, D.C. and was subjected to intense daylight illumination from a large window across from the display cabinet.

Since 1952, in an effort to minimize further deterioration, the documents have been housed at the National Archives building in bullet-proof, helium-filled display cases fitted with yellow filters that absorb wavelengths below about 500 nanometers; the documents are displayed under low-level tungsten illumination.

With the Archives' new document monitoring system, a high-resolution electronic camera with a scanning charge-coupled device (CCD) sensor and computerized image-analysis system are used to record a series of 30-millimeter-square digitized images (1024 x 1024 pixels) from selected areas of the documents once each year.[6] After the images are recorded, the image analysis system electronically compares the new images with images made in previous years. Even minute changes in the physical condition or reflectance of the ink inscriptions and the parchment upon which the documents are written can be detected. As an example of the kinds of things that can be monitored, on the first page of the Constitution the first "e" of "We the people . . . " has partially flaked off, and the letter is being monitored yearly to detect any further degradation.

The imaging camera is mounted on a 3-ton optical bench with solid granite risers supported by four nitrogen-filled cylindrical legs to eliminate ground vibrations from road traffic and a nearby subway. The system was designed to image the documents through the glass cover sheets of the display cases, thus making it unnecessary to open the helium-filled cases.

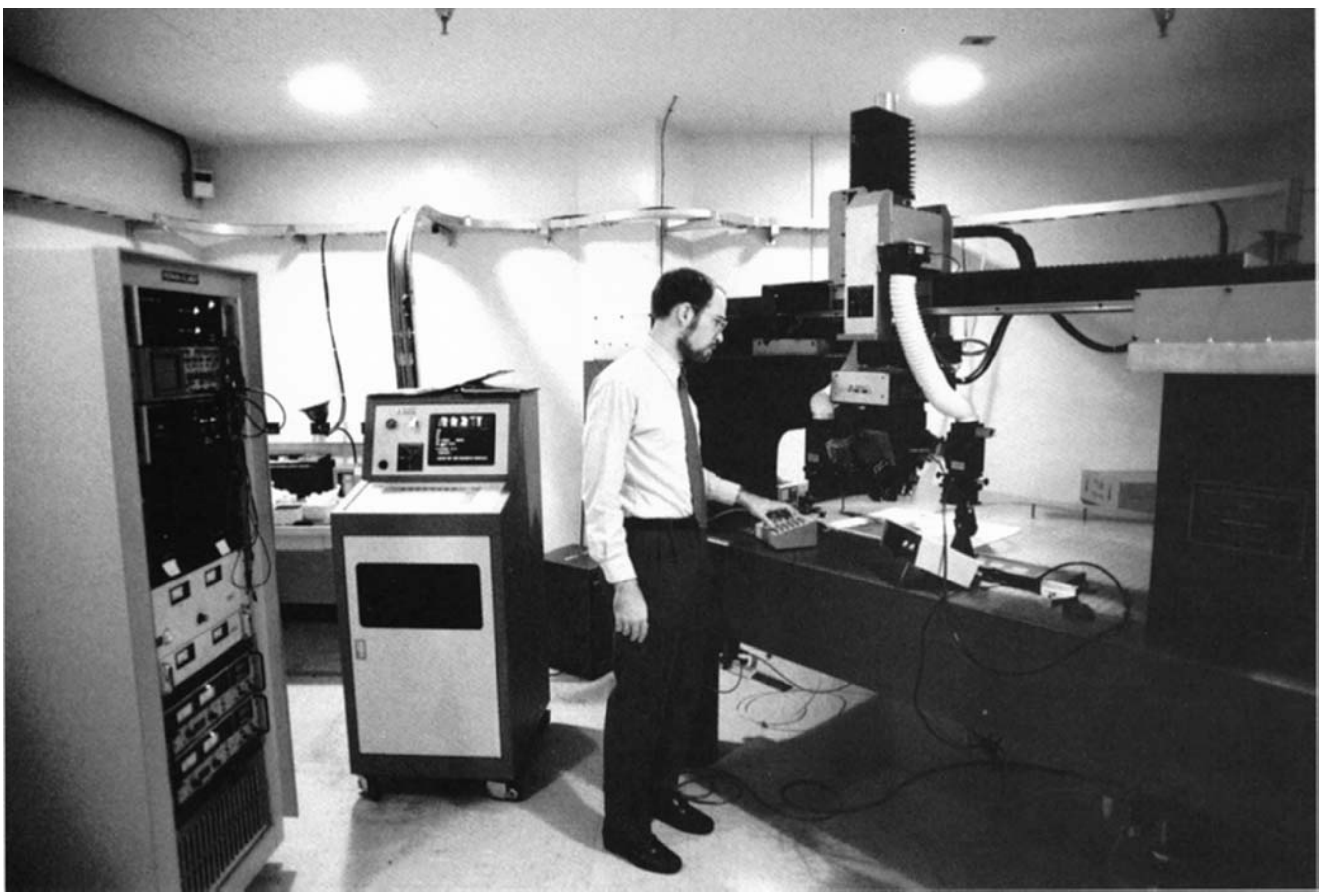
Technologically related to the electronic remote-imaging devices employed in space satellites for intelligence gathering, Earth survey work, weather forecasting, and in-space telescopes, the Archives' electronic camera and associated computer system were designed by the Jet Propulsion Laboratory at the California Institute of Technology in Pasadena and constructed by Perkin-Elmer Corporation. The Jet Propulsion Laboratory is associated with the National Aeronautics and Space Administration (NASA). The system cost $3.4 million and took 5 years to develop.

Although designed specifically for monitoring textual documents, the system could be adapted for detecting changes in the physical condition (e.g., surface cracking and flaking) and the staining and fading of photographs, oil paintings, pastels, watercolors, and other works of art.

November 14, 1989

In the central rotunda of the National Archives and Records Administration building on Constitution Avenue in Washington, D.C., long lines of people wait to see the United States Declaration of Independence (1776), the Constitution (1787), and the Bill of Rights (written in 1789 and ratified in 1791). Because of inadequate care during the 1800's, the 200-year-old documents have suffered serious deterioration. In particular, the ink inscriptions on the Declaration of Independence are now faded so badly that they are almost unreadable.

November 20, 1991

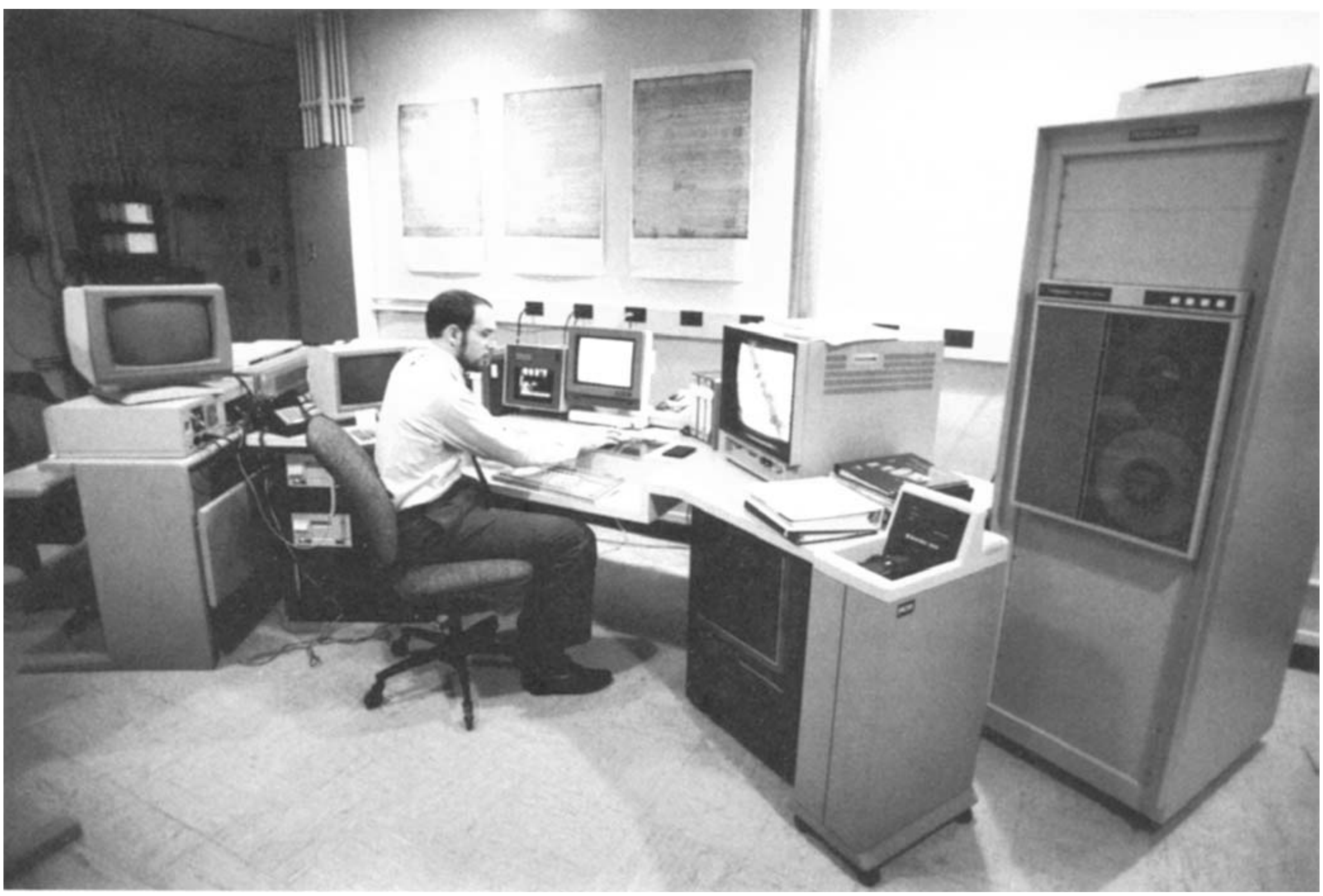


Mark Ormsby, a physicist with the Archival Research and Evaluation staff of the U.S. National Archives, is shown with the Archives' sophisticated $3.4 million computer-based document monitoring system designed to detect physical and visual changes in the U.S. Declaration of Independence, the Constitution, and the Bill of Rights. Although designed specifically for monitoring textual documents, the equipment will be used experimentally to monitor some of the photographs in the National Archives' vast collections.

November 20, 1991

Mounted on a 3-ton optical bench, the unit's electronic camera utilizes a scanning charge-coupled device (CCD) sensor to produce high-resolution digitized images of one or more 30-millimeter-square ($1^3/_{16}$ inch) sections of the object being monitored. A computer-controlled mechanism precisely positions the CCD camera. Scanning time required for each image is about 5 minutes.

November 20, 1991



Located in a room next to the electronic CCD camera, a computerized image-analysis system compares the initial digitized images of a document with images made in subsequent years and detects any changes in physical or optical properties that have taken place (e.g., ink flaking, movement of ink and dust particles, or tear propagation in the parchment on which the documents are written).

Photographic Densitometers

Reflection densitometers suitable for color and black-and-white print monitoring are available from the Macbeth Division of Kollmorgen Instruments Corporation, X-Rite, Inc., and a number of other firms.[7] The Macbeth TR924 Color Transmission/Reflection Densitometer, specially equipped by Macbeth with Kodak Wratten filter numbers 92 (red), 93 (green), 94A (blue), and 102 (visual), is at present this author's primary recommendation for print-monitoring applications. The Status A and M filter sets normally supplied by Macbeth are not acceptable because these filters have proven to be very unstable and likely will require replacement every 3 or 4 years; problems with densitometer filters are discussed in detail later in this chapter.

To ensure maximum life of the instrument, a densitometer for print monitoring should not also be assigned to other functions, such as photographic process control. In general, readings are taken with the red-green-blue filters; the 102 (visual) filter is not necessary when monitoring most types of color prints, although it should be used *in addition* to the color filters for monitoring monochrome prints. Density data should always be recorded in the standard red-green-blue sequence to avoid confusion.

Basic to any monitoring system is a calibration procedure that assures the continued accuracy of the densitometer or other measuring instrument as well as the comparability of measurements even after old equipment has been replaced by new instruments of different design. Maintaining accuracy of the system for hundreds or thousands of years will require careful planning as well as the very-long-term preservation of color photographic calibration standards in an unchanged state by means of humidity-controlled cold storage. As discussed later, preserved color photographic calibration standards are likely to provide more accurate densitometer calibration than would be possible from porcelain plaques or stable pigment standards, which usually have only two or three neutral densities and which have spectral characteristics different from those of the cyan, magenta, and yellow dyes in color photographs.

Direct Monitoring of Color Prints

Of the two methods described in this chapter for monitoring the fading and staining of color prints, institutions generally will choose to measure image changes directly on the prints. Separate fading monitors are useful chiefly for research in cases where the fading monitor's unique ability to distinguish between light-induced changes and dark-storage deterioration can provide important information in the design of better storage and display facilities.

The difficulties involved in preparing and using fading monitors, as well as the fact that monitors cannot be made for print materials that are no longer commercially available, will limit their routine application for indirect monitoring of pictorial color prints in institutional collections. In many cases it may be impossible to identify precisely the type of color material on which a print was made. There may also be uncertainty as to how an original print was processed and washed — this is especially true today, with ever more frequent introduction of new products and the proliferation of processing chemistries supplied by various manufacturers for "washless" and conventional processing of Ektacolor, Fujicolor, and similar papers. To be accurate, a separate fading monitor must be made with materials processed and washed exactly as was the print being monitored. These and other requirements will generally restrict the application of fading monitors to contemporary color prints, where the monitor's gray patches can be made at the same time as the print. A valuable color print should, if possible, be monitored directly from time to time, even when it is accompanied by a separate fading monitor.

Polyester Overlays to Locate the Densitometer Head on the Print

It is not possible to measure image density accurately when a print is framed under glass, so such a print should be removed from the frame when density readings are to be made. To avoid direct contact of the densitometer head with the surface of the print, and to provide an exact record of the densitometer reading locations on the print, a thin, matte-surface *polyester* overlay sheet[8] must be prepared for each print (cellulose acetate or polyvinyl chloride sheets are not satisfactory because curling and dimensional instability are potential problems), with the print image locations traced on the sheet so that the densitometer head can be registered accurately on the image during each series of readings. The matte surface of the polyester sheet accepts ink and pencil lines readily; ink will not adhere to the surface of ordinary clear polyester and may smear or wear off. This author has found that polyester sheets with one matte side and one glossy side are more satisfactory for this application than sheets with both sides matte. The sheet should be cut about 2 inches larger than the print in both dimensions; space on the edges is available for writing identification data, date of preparation, and other information. The polyester sheet material should be 3 or 4 mil (0.003 or 0.004 inch) thick for general applications; thinner material is adequate for prints 8x10 inches and smaller.

The corners of the print image and the densitometer head locations must be precisely marked on the overlay sheet using a technical pen with a medium point and a suitable stable black ink.[9] The glossy side of the polyester sheet is placed down, against the surface of the photograph; the matte side of the sheet is on top. All ink markings and notations should be on the matte side. Great care should be taken to keep ink away from the photograph. It is usually satisfactory to mark the densitometer head locations by tracing the outer edges of the densitometer base plate onto the polyester sheet; in addition, at each location, a dot of ink should be placed on the polyester sheet in the center of the densitometer reading aperture to aid in locating the holes to be cut later. After all of the densitometer head locations have been selected and marked, the polyester sheet should be removed and a hole about ½ inch (1.3 cm) in diameter should be cut at each reading location.[10]

All ink markings on the overlay sheet should be completed before cutting any holes; otherwise, the pen point might accidentally slip through a hole and deposit ink on the photograph. To avoid confusion, the overlay sheet should be marked (e.g., "Top," "Bottom") to indicate proper orientation. The sheet should bear a serial number that identi-

1988

Density measurements of a color print are read with a Macbeth TR924 densitometer (left). Data are transmitted by the densitometer to this author's microcomputer (center) and recorded on disk (right). The computer is programmed to analyze data in terms of specified densitometric limits of change.

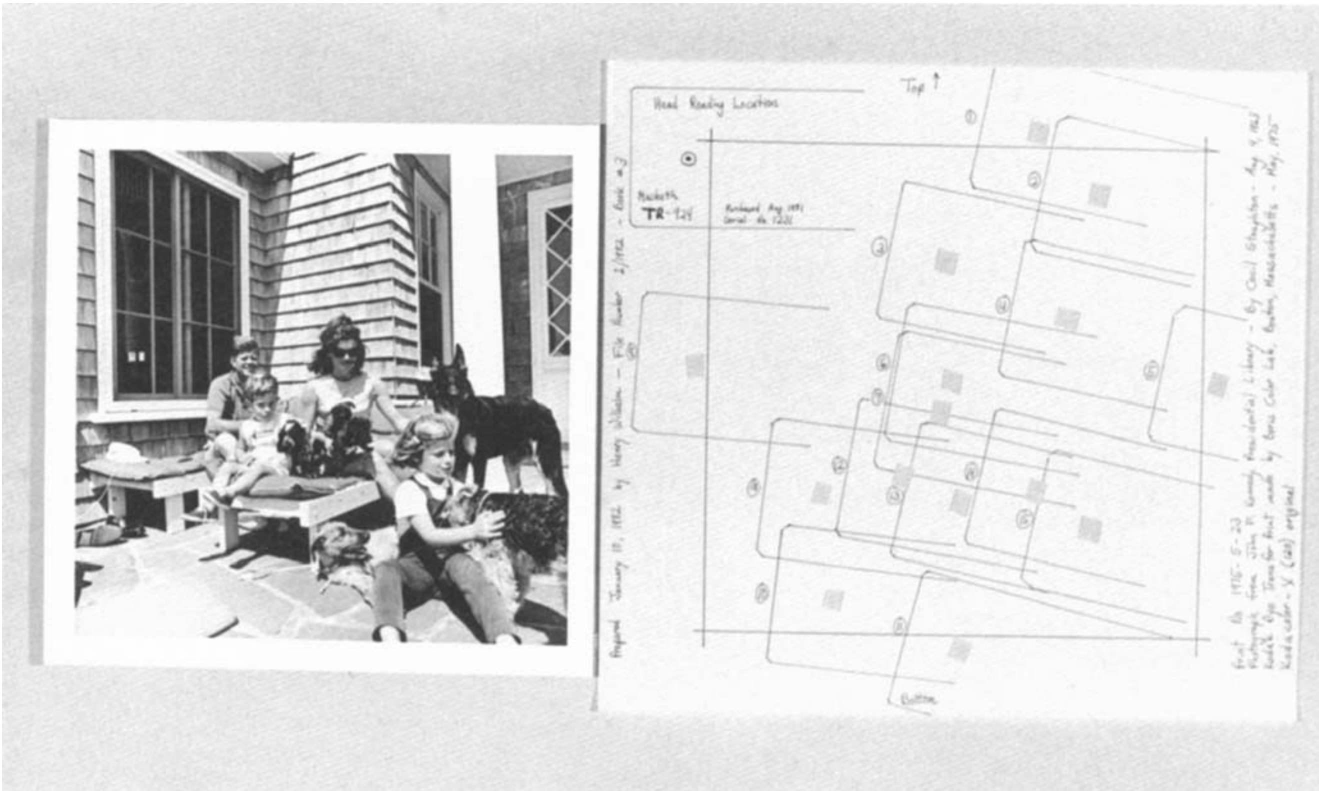
fies the print, and densitometer calibration data should be recorded in a notebook made of reasonably stable paper.

The overlay sheet must remain in exact registration with the print during all readings; smooth-surfaced weights placed on the edges of the sheet will help keep it in position. Because of localized density variations in most color prints, subsequent readings must be taken at precisely the same locations as the original readings if the measurements are to be meaningful. When densitometer heads are changed, a method must be devised for positioning the new head using the old tracings. The importance of taking future readings at the *exact* locations of the original readings cannot be overemphasized — accurate data cannot otherwise be obtained. The person taking the readings should test his or her technique by seeing whether readings by a second person produce identical results.

As an alternative to marking the densitometer head locations on the overlay sheet with ink, Douglas G. Severson, conservator at the Art Institute of Chicago, has suggested locating the point at which a reading is to be taken and then cutting a round hole in the sheet which is slightly larger in diameter than the reading aperture of the densitometer. Severson has found a #7 ($^{13}/_{64}$-inch) leather punch of the type manufactured by C. S. Osborne & Company to be satisfactory.[11] After marking the locations of each hole with a dot of ink, the polyester sheet is flipped over and placed on a sheet of Masonite; the punch is struck with a hammer to cut the holes. Severson cautions that to avoid scratching the delicate print surface, the holes must be punched from the *bottom* side of the sheet so that the slightly rough edges of the holes lift away from the print rather than toward it. To take readings, the densitometer head reading aperture is centered over each hole.

Making Density Readings

Work areas should be clean, and cotton gloves should be worn by the operator to avoid putting fingerprints on the photographs. A sheet of bright white mount board or opaque white glass should be placed on the work table and prints placed on this white surface while densitometer readings are made. Since most print support materials transmit some light, the reflectance of the surface beneath a print may have a significant effect on densitometer readings made in low-density areas of a photograph. For example, readings taken on a dark work surface will usually indicate somewhat higher densities than readings taken on a white work surface; such discrepancies may be quite large with albumen prints and other types of photographs made on thin paper supports. The same type of work surface should



A color print is shown here with a matte-surface polyester overlay sheet marked with the densitometer head locations. The Kodak Dye Transfer print, with an image size of 10 x 10 inches, is of the John F. Kennedy family; it was taken August 4, 1963 by Cecil Stoughton. The original Ektacolor negative is preserved in humidity-controlled cold storage at the John F. Kennedy Library in Boston, Massachusetts.

be used for making all readings, and densitometer readings of the work surface itself should be recorded each time the work surface is changed.

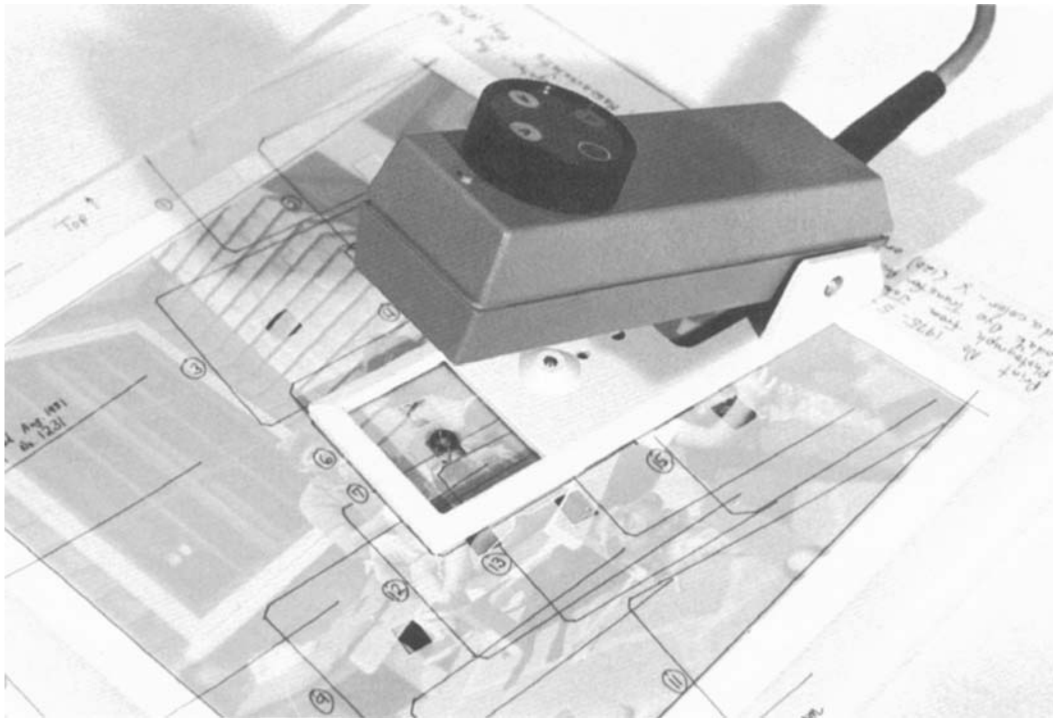
Density readings through the red, green, and blue densitometer filters (which respectively indicate changes in cyan, magenta, and yellow dyes) should be made at minimum-density (white) locations, low-density locations of about 0.45, and maximum-density locations. Normally, readings in each density range should be taken in at least three locations (for a total of at least nine reading locations), and the readings should always include near-neutral (gray) colors, assuming such colors are present. Some of the readings should be taken near the top of the print, where the intensity of illumination during display is usually somewhat higher than it is near the bottom. If possible, fairly large areas of uniform tones should be selected for reading locations. In many photographic images, however, such areas may not be present, so a large number of readings will be required for accurate representation. After readings have been taken, the polyester overlay sheets should be stored *flat* in polyester sleeves[12] or in high-quality paper envelopes.

When prints are subject to light fading on display, it is particularly important that low-density (approximately 0.35 to 0.60) areas be carefully monitored, as dye losses in the low-density areas will be much greater proportionally than dye losses in high-density areas (see **Table 7.2**). This relationship between dye loss and density is typical of many types of color print materials; however, some types of prints, such as Polaroid Spectra prints (called Polaroid Image prints in Europe), Polaroid 600 Plus prints, and Polaroid SX-70 prints, develop overall yellowish stain during storage which may obscure fading of yellow image dye in low-density areas. With these prints, density losses resulting from light fading may be larger — even on a percentage basis — than losses in lower-density portions of the image.

With dark fading, unlike light fading, most types of color prints exhibit dye losses that are more or less proportional throughout the density range of the color image. Prints which have faded in dark storage do not suffer the loss of highlight detail that is characteristic of prints which have faded because of exposure to light.

Cautions

Although a fading monitor or direct monitoring of an original color print will give an accurate indication of dye fading and stain formation, it may or may not indicate the physical deterioration that can occur in the print. Common examples of physical deterioration include cracking of the top polyethylene and emulsion layers of RC (polyethylene-resin-coated) prints, cracking of emulsions on fiber-base prints, and cracking of the internal image-receiving layer or formation of small "snowflakes" in Polaroid SX-70 prints from the 1970's. Retouching and corrective "dust spotting" may produce irregular fading or staining such as



The reading position of the densitometer head is indicated by an ink tracing of the head's base on a polyester overlay sheet.

August 1981

the orange discolorations sometimes seen on Kodak Ektacolor prints. Storage in conditions of high humidity can result in fungus growth on print emulsions. All prints should be carefully examined on a regular basis so that any physical defects or other irregularities can be documented and photographed for future reference.[13]

Fading Monitors for Color Prints

Use of a separate fading monitor allows indirect measurement of the changes that take place in a color photograph. The colors and tones in conventional color photographs are obtained by varying the concentrations of cyan, magenta, and yellow image dyes which are in three or more emulsion layers coated on the surface of the support material — the same three dyes form all of the different colors in a color print. A neutral-gray patch serving as a fading monitor consists of nearly equal concentrations of the three image dyes. A minimum-density patch contains little or no dye.

It is possible to measure changes in neutral-gray patches of minimum density, low density, and maximum density and thereby to obtain a reasonably accurate indication of changes occurring in any area of a color print if the three patches are made on the same print material and are processed in the same way as the original print. A single fading monitor consisting of three patches should be matched with only one color print, and the monitor should be permanently assigned to that print with a serial number.

Potential disadvantages of fading monitors include possible differences in print and monitor fading/staining rates caused by differences in print materials, processing, framing, and other conditions. Furthermore, as noted previously, monitors can be prepared only with print materials and processes which are available in the marketplace; monitors therefore cannot be prepared for most, if any, older color print materials in a collection. Institutions generally will find it more practical and accurate to monitor their color prints directly and to reserve fading monitors for special situations; for example, in some cases it may be undesirable to remove a print from its frame repeatedly for direct measurements.

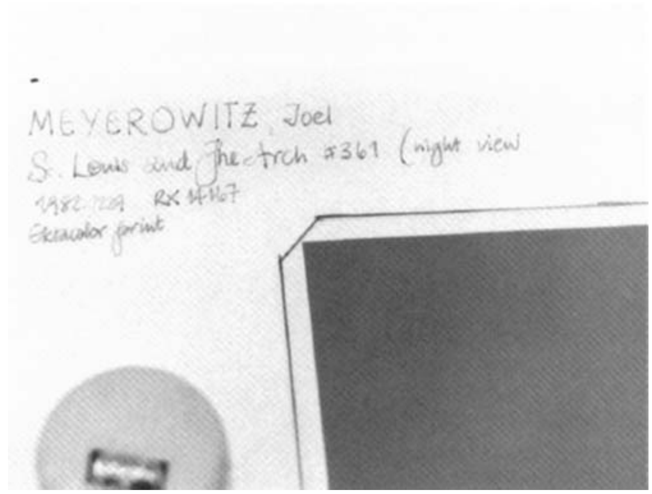
Used by themselves, fading monitors can provide important information on the stability behavior of specific color print materials in actual long-term display and storage conditions. Data thus obtained can be compared with changes observed in controlled, accelerated tests. Fading monitors can also function as low-cost "integrating photometers" for estimating accumulated light exposure in a display area over time, although this author believes that the Blue Wool Standards, which are standardized and appear to have little reciprocity failure in accelerated light fading tests, are probably better suited for this application.[14]

Preparing a Fading Monitor

Three test patches, about ½ x 1¼ inches (1.3 x 3.2 cm) each, should be prepared with the same color print material, processing chemicals, and processing procedures as those used to make the original print. Any variation in processing between the original print and its monitor may affect the fading characteristics of the monitor and may reduce its accuracy. One patch should be minimum density (white), one should be a neutral gray close to 0.45 density, and one should be maximum density (black). The three patches can be optically printed to the proper size on a sheet of print material. As an alternative, entire sheets of material can be printed to the desired density and the sheets cut to the proper sizes after processing.

The three print monitor patches should be mounted, as

An alternate system for locating the densitometer head is preferred by Douglas G. Severson of the Art Institute of Chicago. His method is to punch a small hole that is slightly larger than the densitometer reading aperture at each reading location in the overlay sheet; the small diameter of the holes assures sufficiently accurate positioning of the densitometer head.



To position a polyester overlay sheet on a print, Severson marks all four corners with diagonal lines that nearly touch the corners of the image. Chamois-covered weights hold the overlay sheet in place while densitometer readings are made.

indicated in the accompanying photograph, on the same type of board used to mount the photograph being monitored, and should be attached with the same type of adhesive or mounting system. The monitor should be covered with a mat made of the same type of board that overmats and supports the original print. The overmat should have an opening in the center so that only half of the patch is exposed to light; this keeps the light fading and dark fading functions of the monitor separated (the overmat must be opaque — 4-ply mount board is recommended — for the monitor to give an accurate indication of dark fading). The monitor should then be placed in a small frame[15] with the same type of glass or plastic covering and backing materials that were used with its companion print.

Fading monitors for integral instant materials, such as Polaroid Spectra and SX-70 prints, should be prepared by optically printing the three density patches in the center of a sheet of the material. Since cutting or trimming such prints may alter their stability characteristics, fading monitors made on these instant materials should remain intact. Polaroid has made changes in its instant color materials on a fairly frequent basis, and some of these changes have altered the fading and staining characteristics of the prints. One should therefore ascertain that a monitor for an instant color print is actually made on the same material as the companion print.

In the preparation of fading monitors for chromogenic materials, such as Ektacolor papers, every effort must be made to duplicate exactly the processing and washing procedures followed in making the original print. If the original processing conditions are unknown or uncertain, the original print should be monitored directly as well as by a separate fading monitor. Polacolor 2 and Polacolor ER instant prints can be treated in the same manner as conventional color print materials.

If the primary purpose of a monitor is to function as an integrating photometer, Ektacolor, Fujicolor, or a similar chromogenic paper printed with a pure color magenta patch of about 1.0 density is suggested; the magenta dyes of these papers have good dark fading stability, and their rate of light fading is not greatly affected by varying relative humidity or temperature. With current papers, the relative ultraviolet content of the illumination has little influence on the fading rate.

A minimum-density (white) patch should also be included to allow for later "stain-correction" of the magenta patch readings. Fading monitors can be "calibrated" with controlled, accelerated light fading tests; if, for example, a 0.25 density loss is measured in a magenta patch on the monitor, the lux-hour exposure required to produce this amount of fading can be estimated from the exposure time that results in a 0.25 density loss with a magenta patch on the same print material in an accelerated test of known light intensity. When used as integrating photometers, the magenta patches need be read only with the green-density densitometer filter.

Using a Fading Monitor

A print and its monitor should be kept in the same temperature and relative humidity conditions at all times. When a print is on display, its monitor should be exposed to the same intensity of light of the same spectral distribution for exactly the same length of time. The monitor can be exposed to light in a room separate from the display area only if all conditions are identical. The light level on the monitor can be adjusted by varying the distance of the monitor from the light source; the level chosen should be equal to the light intensity on the *most brightly illuminated* portion of the print. Most gallery and museum display areas do not provide uniform illumination over the entire surface of a print.

If the display areas receive any daylight, it will probably be necessary to place the monitor on the wall adjacent to the print, as it is difficult to obtain identical lighting conditions at all times of the day in a different location. When the print is shipped to another location (for example, when it is loaned to another institution), the monitor must accompany the print during transit and storage; the print and its monitor must be kept together at all times. The borrowing institution must be instructed as to the proper use of the monitor.

Initially, the densities of the fading monitor should be measured at least once a year to see how much change has taken place; experience with each type of print material and with the dark-storage and display conditions to which the prints are subjected will indicate whether the monitor should be measured more or less frequently.

Maintaining Long-Term Accuracy of a Monitoring System for Color Prints

The most difficult aspect of a monitoring program is maintaining long-term accuracy of the system; the ultimate success of a monitoring program will depend on the accuracy of initial and future instrument calibrations. Especially in fine art applications, very small changes in the visual characteristics of color prints must be measured accurately over many decades or centuries.

The calibration system must not be affected by changes in color densitometers or in other measuring equipment. It is obvious that present densitometers will become obsolete and will be replaced many times during the next several hundred years with new instruments. Because any two color densitometers may give significantly different readings from the same print samples (**Table 7.3**), the data obtained with one piece of equipment will have to be translated accurately to permit comparisons with readings taken with another instrument.

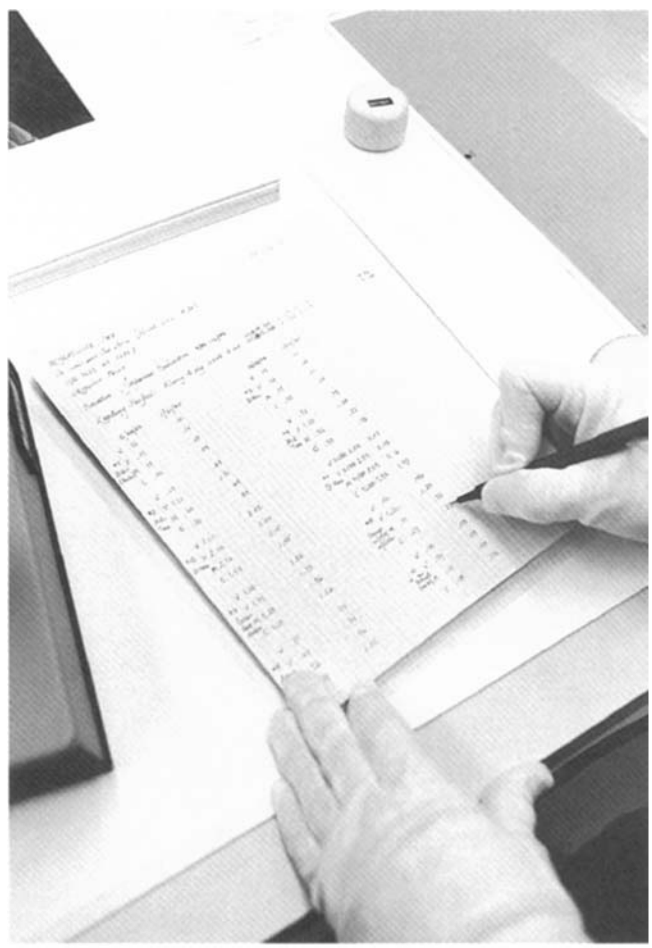
A specific densitometer should be dedicated for a monitoring program, and it should not be assigned to any other project. Densitometer readings should be taken in an environment with reasonably constant temperature and relative humidity. All photographs to be read should be brought to the work area in which the densitometer is located. The instrument should be allowed to warm up until calibration readings stabilize (with modern densitometers having solid-state sensors, a warm-up period of about 15 minutes should be adequate). Prior to each reading session, the porcelain calibration plaque supplied with the densitometer should be cleaned with Windex or a similar wax-free glass cleaner and then immediately wiped dry with paper towels. Fingerprints or other slight soiling can cause a significant deviation in readings taken on the high-density (black) patch on the plaque. Cleaning should be done in an area away from the densitometer and away from where photographs are stored; should tiny droplets of cleaner spray fall on a print, serious damage to the image may eventually occur.

After the densitometer has warmed up, the unit should be calibrated with the low- and high-density patches on the porcelain plaque, carefully following the manufacturer's instructions. Before density measurements are made of each print (or each fading monitor), the densitometer should be recalibrated ("zeroed") on the low-density (white) patch on the porcelain plaque. With most modern densitometers, it is sufficient to perform the high-density calibration just once at the beginning of the session; experience with a particular instrument will indicate whether more frequent high-density calibrations are necessary.

Repeated low-density calibrations should be performed even if there is no indication that the instrument is drifting following the initial calibration. Most densitometers have only two figures to the right of the decimal point; when the instrument calibration is checked with the porcelain plaque, the digital readout of such instruments may always indicate 0.04, for example, whereas a densitometer may in fact drift over time between 0.036 and 0.043 — such a drift is not apparent to the operator. It has been this author's experience with several different densitometers that recalibrating a densitometer before reading each print can significantly improve the repeatability of the measurements.

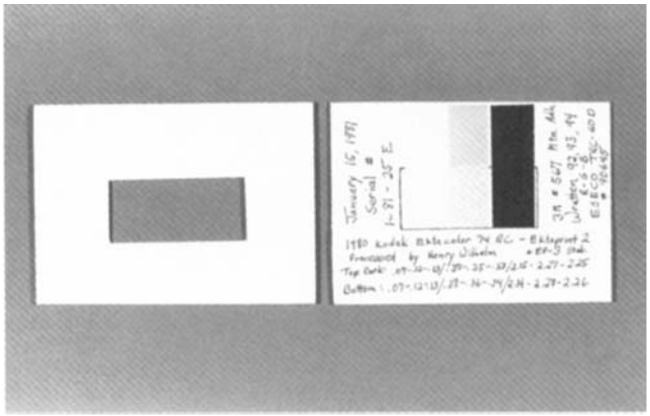
Before each measurement session, or at least once each day the densitometer is used, the accuracy of the instrument should be checked with a Kodak Reflection Densitometer Check Plaque and the readings recorded;[16] this plaque will indicate changes in spectral response of the densitometer that result from fading of the filters or from other causes. The Kodak plaque should be permanently assigned to the densitometer and should be stored carefully between uses.

In addition, measured gray scales and color scales made of each type of color photographic material in the collection should be kept in cold storage at 0°F (–18°C) or lower

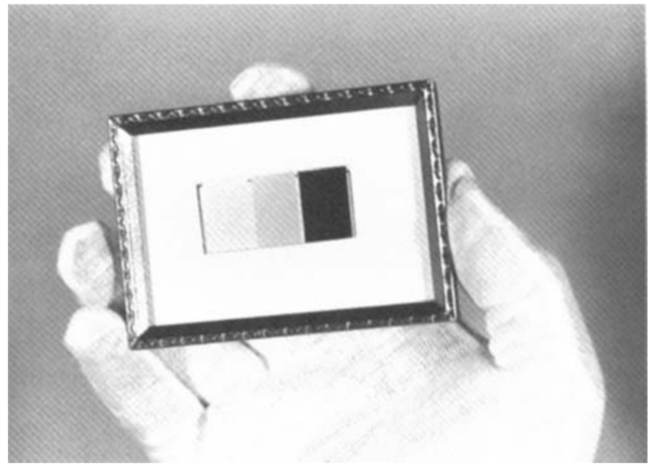


October 1987

Severson enters readings into a notebook.



Fading monitor with an overmat. The three pieces of color print material are mounted on the upper center of the board; the mount board and overmat measure 2 1/2 x 3 1/2 inches.



1981

Fading monitor covered with a sheet of glass in a small metal frame.

and at a relative humidity of 30–40%; storage at very low temperatures will reduce changes in these photographic calibration standards to a negligible amount during the next 1,000 years or more, according to current estimates based on accelerated test data.[17]

A Macbeth ColorChecker[18] is recommended as a suitable original gray scale and color patch image for preparing the calibration standards for photographic materials; the standards should be printed about 3x5 inches (7.6x12.7 cm), including a border of at least 3/8 inch (1 cm) to protect the image area. A minimum-density (white) area and all of the color patches, including those with low-saturation colors, should be read and the data recorded. Although the porcelain calibration plaques will generally be adequate for continued calibration of a specific densitometer, they will not necessarily produce accurate readings after an instrument has been repaired or if the filters have faded or been replaced; instrument response may also change if the photodiode or photomultiplier tube light sensor has been replaced. Each dye of each type of color photographic print has a distinct set of spectral absorption characteristics; for this reason, any change in the spectral response of a densitometer will produce different readings from a given photographic sample even if the instrument has been calibrated with the same porcelain plaque.

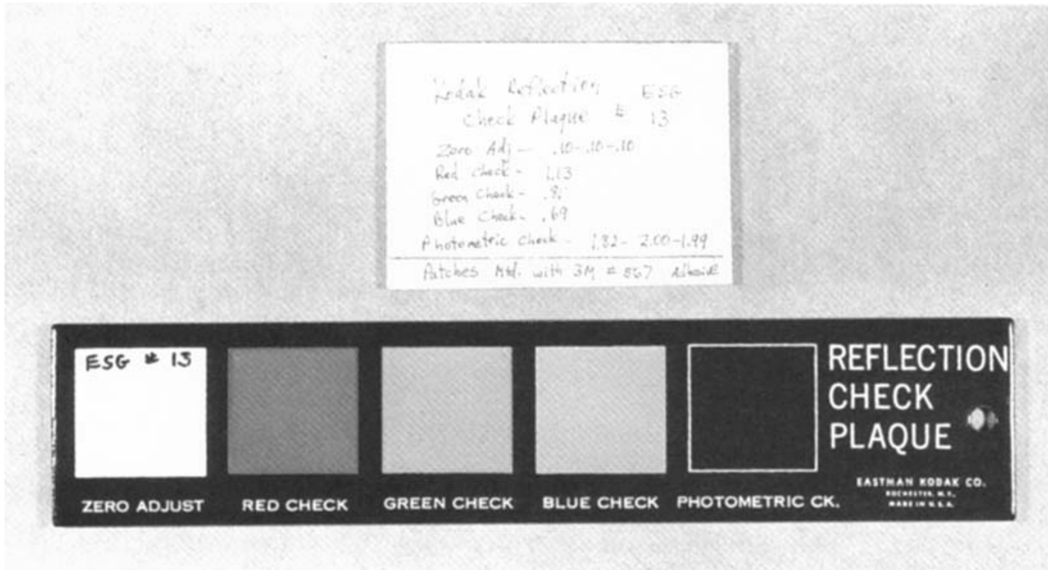
When the color photographic calibration standards are needed, the packages containing the standards should be removed from cold storage and allowed to reach room temperature before they are opened. After the densitometer has been calibrated with the porcelain plaque, readings should be taken with the color photographic calibration standards and numerical corrections determined for each gray-scale density and color patch of each material; these calibration corrections will ensure continued accuracy of the overall system during the lifetime of the color prints. The photographic calibration standards must be handled with great care, especially when readings are being made with a densitometer, to avoid surface abrasion and other physical damage that could affect the accuracy of readings. As an added degree of protection when densitometer readings are being made, the calibration standard can be covered with a thin polyester overlay with a reading hole cut in it. Because the calibration standards will be read periodically over the next several hundred years — or perhaps even several thousand years — the need for careful handling cannot be overemphasized.

While other long-term calibration procedures may be devised in the future, this author believes that, at present, long-term system accuracy can be maintained with certainty only by preserving photographic calibration standards for each type of material in a collection. It is presumed that in the near future most institutions with significant color photographic collections will install humidity-controlled cold storage facilities for preserving their color collections; the calibration standards can be kept in these cold storage areas. (See Chapters 19 and 20 for information on refrigerated storage.) If humidity-controlled cold storage is not available, the photographic calibration standards should be carefully double-sealed in suitable vapor-proof envelopes[19] and placed in a regular 0°F (–18°C) household-type or commercial freezer.

Deterioration of Densitometer Filters and Gradual Drift in Densitometer Response

In an unplanned demonstration of the need for an accurate long-term calibration procedure, this author's Macbeth TR924 densitometer suffered a significant drop in red-density reflection readings in *less than 5 years* after it was purchased in 1981. As an example, for a polyester-base Ilford Cibachrome print stored in the dark as a photographic reference standard (accelerated aging tests indicate that polyester-base Cibachrome prints have extremely good dark fading stability), the densitometer indicated a 0.03 loss in red density from an original neutral density of 1.0 and a 0.02 loss from an original neutral density of 0.60 by the end of the 4-year period. Measurement of a cyan patch with an initial red density of 1.43 indicated a loss of 0.06. In other words, the densitometer indicated that the print had *faded*, when in fact it had not.

That it was the densitometer and not the Cibachrome print that was changing was verified by similar drops in



Kodak photographic Reflection Densitometer Check Plaque for detecting changes in the spectral response of a densitometer.

1981

red-density readings from a Kodak porcelain Reflection Densitometer Check Plaque as well as from refrigerated Ektacolor, Fujicolor, Konica Color, and Agfacolor calibration prints. The response of the instrument had been checked frequently over the 5-year period, and no significant change had been detected in either the green- or blue-filter readings. Most of the change in the densitometer's red-filter response took place in the final 6 months of the 5-year period.

The reflection head of this densitometer is equipped with Status A red, green, and blue filters, in addition to a Wratten 102 (visual) filter. The transmission head, which is equipped with both Status A and Status M filters, also suffered significant changes in filter response. Macbeth supplies replacement visual, red, green, and blue filters in a filter wheel that is installed in the densitometer head; thus all the filters are replaced at the same time. Macbeth recommends that new Status A and M filters be installed about every 3 years; but, because of tests in progress, this author was reluctant to do so and kept on using the original filters until the red filter in the reflection head began to deteriorate so rapidly that there was no choice but to replace it.

At that point this author installed a new filter wheel and much to his distress found that the green filter gave readings higher by 0.05 on the green check patch of the Kodak Reflection Densitometer Check Plaque than did the previous Status A green filter (which still gave stable readings). The red and blue filters in the new wheel gave readings on the Kodak Check Plaque that were almost identical to those of the original filters. In order not to upset the green-density readings (the accuracy of which is crucial in the long-term light fading evaluation of magenta-limited papers like Ektacolor), it was decided to remove the red filter from the new wheel and install it in the original filter wheel, leaving the original visual, green, and blue filters in place. The densitometer head was then reassembled and aligned with the reading aperture (taking a densitometer head apart and replacing the filters is not a simple task, and the reader is advised not to attempt this procedure). The unit checked out well with the Kodak Check Plaque; but it was discovered that for refrigerated *photographic* calibration prints, the new red filter was giving high readings (typically 0.04 higher with 1.0 densities).

When there is a change in response in a print monitoring densitometer, even if the change is only slight, it requires that new readings from ongoing work be corrected, which not only requires additional labor but also increases the potential for error. A most unwelcome complexity!

Status A and M densitometer filters appear to be made with dichroic coatings on one side (to block infrared radiation), and examination of this author's defective red filter showed clearly that this reflective coating had seriously deteriorated, reducing its light transmission and giving it a yellowish, "cloudy" appearance. It is not known how much longer the green and blue filters will last before they also will require replacement; that the red filter was the first to fail may be only a coincidence. It is indeed distressing for one attempting to measure long-term fading of color photographs to find that current densitometer filters are themselves so unstable that they last only 3 or 4 years! The unsatisfactory experience with the Status filters supplied by Macbeth does not necessarily mean that *all* Status filters are unstable; the Kodak "Certified" Densitometer Filter sets AA and MM (the original Status filters) may be more stable; however, Kodak discontinued these filters in 1986.

This author also has an older-model Electronic Systems Engineering Company (ESECO) Speedmaster densitometer equipped with Kodak Wratten 92 (red), 93 (green), 94 (blue), and 106 (visual) filters. Although the unit does not have a computer interface, it continues to be used for a number of tests that were started about 14 years ago. The filters are still giving stable responses once the unit has fully warmed up and is properly calibrated. These four Wratten filters were the "traditional" densitometer filters until the advent of the Status A and M filters, which were designed to have an improved spectral match to chromogenic transparencies and prints (Status A) and chromogenic color negatives (Status M). It should be noted, however, that the spectral characteristics of Status A filters are not well matched to some other types of photographs, including Ilfochrome and Polaroid prints.

In print monitoring and long-term stability research, one is primarily interested in *changes* that take place in a photograph, and the specific spectral characteristics of a set of filters are not nearly so important as the need for filters that will remain absolutely unchanged over time. The Status A and M filters, which are supplied with most current photographic densitometers, are unquestionably the weakest link in their design.

It would be of great benefit if the photographic industry would produce *permanent*, standardized filters for densitometers; it is not unlikely that red, green, and blue technical glasses exist that would be suitable for this purpose.

This author strongly advises that Status A and M filters not be used in monitoring programs; instead, Kodak Wratten 92, 93, 94A, and 102 filters are recommended. These filters can be purchased from Kodak in large sheets (e.g., 125mm, 5-inch, squares), and it is suggested that two sheets of each filter be obtained.[20] These four polyester-base dyed gelatin Wratten filters appear to be essentially permanent in dark storage. In a high-temperature accelerated dark aging test conducted by this author, the filters were subjected to 144°F (62°C) and 45% RH for five years (1987 to 1991) with no significant changes occurring in either their transmission characteristics or in their physical properties. The filters are, however, subject to light fading and fading may occur over time in the course of using a densitometer.

On special order, Macbeth will install Wratten filters cut from sheets in TR924 densitometers.[21] (Not all densitometer manufacturers are willing to install customer-supplied filters in their instruments, and if the reader is contemplating the purchase of other than a Macbeth densitometer, the manufacturer should be consulted prior to making the purchase.) In the transmission head, the 92, 93, and 94A filters should be installed *only* in the Status A filter positions; the Status M filter positions should be blocked with an opaque material.

This author recommends that at the time the densitometer is purchased, five additional transmission and reflection filter wheels fitted with filters cut from the same sheets of filter material be obtained from Macbeth. These filter wheels should be carefully packaged in a completely opaque container to protect them from light, and stored in a cool, dry place. Unused filter material should be kept in the original Kodak packages and also stored in a cool, dry place (if possible, in humidity-controlled cold storage).

When it is determined that one or more filters require replacement, new reflection and transmission filter wheels and the densitometer should be shipped to Macbeth for installation (replacement of filter wheels in a Macbeth densitometer is a complex procedure and should not be attempted by the user). This procedure will eliminate spectral changes in the densitometer filters as a variable in a long-term monitoring program; a 5-inch square of filter sheet contains enough material for at least 24 filter replacements.

At the time of this writing, X-Rite said that the company was not in a position to install customer-supplied filters in its X-Rite 310 Color Transmission/Reflection Densitometer. This is unfortunate because this apparently otherwise excellent densitometer reads and displays density measurements through all four filters simultaneously, thus greatly speeding monitoring operations when the densitometer is connected to a computer or accessory printer. In 1989 Macbeth introduced the Macbeth TR1244, which also reads all four filter channels simultaneously, but because the reflection head of this instrument is attached to the top of the unit and cannot be removed, it is not suitable for monitoring prints.

The X-Rite 310 has the option (in the "10X Mode") of displaying readings with *three figures* to the right of the decimal point; this not only permits somewhat more precise readings, especially when reading low densities and minimum densities, but also allows the operator to more accurately assess drift of the instrument over time. (Because of short-term instrument drift, which unfortunately appears to be inherent with the X-Rite 310, the "10X Mode" does not actually afford a 10X increase in precision; however, with frequent recalibration, the "10X Mode" is somewhat of an improvement over the normal mode with two figures to the right of the decimal point.) At the time of this writing, this author had been using an X-Rite 310 for less than 6 years and could not yet assess the long-term stability of the instrument; however, the X-Rite 310 calibration procedure — which calls for both low-density and high-density calibrations of *each* densitometer filter — appears to give better long-term repeatability than densitometers such as the Macbeth TR924 that allow a high-density (slope) calibration for the visual filter only.

X-Rite has said that in the approximately 8 years the company has been supplying densitometers with Status A and Status M filters, "no deterioration" has been noted with the filters (with a different design than other densitometers, the filters in X-Rite densitometers are sealed to plastic light pipes and photodiodes with epoxy cement and are thus protected on both sides from the atmosphere). Nevertheless, this author recommends that for long-term print-monitoring applications, Status filters also be avoided with X-Rite densitometers. It is hoped that at some point in the future the company will be able to supply 92, 93, and 94A filters with its instruments.

This author has been engaged in discussions with several densitometer manufacturers in an effort to devise a set of permanent filters, and institutions engaged in print-monitoring programs should contact this author for current information.[22]

Recommended Limits for Deterioration of Color Print Images

Examination of large numbers of deteriorated color prints — including samples that were faded in accelerated light fading and dark-storage tests as well as prints that slowly faded during long-term display and dark storage under normal conditions — has led this author to propose the set of limits for deterioration of color print images given in **Table 7.1**. These limits are for *critical* applications in museums and archives. A number of print materials displayed under a typical tungsten-illuminated museum display condition and

A filter wheel from a Macbeth TR924 densitometer. On special request, Macbeth will install the Kodak Wratten 92, 93, 94A, and 102 filters recommended by this author in place of the normally supplied Status A filters (which are too unstable for long-term print monitoring).

evaluated with these fading and staining limits are included in **Table 3.4** in Chapter 3. For general commercial and home purposes, this author has proposed less stringent limits; these are discussed in Chapter 2 and have been used for most of the light fading comparisons in Chapter 3.

The four groups of criteria that comprise the fading and staining limits describe all of the significant visual changes that can take place in a color print in dark storage and/or during exposure to light and ultraviolet radiation. Such changes include stain formation, changes in overall density and contrast, loss of highlight detail, shifts in color balance, and various combinations of these.

For ease of understanding by persons not familiar with photographic densitometry, the limits for dye fading and color imbalances are specified in terms of changes in the cyan, magenta, and yellow image dyes even though, strictly speaking, the limits should be stated in terms of red, green, and blue density (changes in cyan dye density, for example, are measured with the *red* densitometer filter because the absorption peak of cyan is in the red portion of the spectrum). However, for stain formation at minimum density (where no image dyes are present), the limits are stated in terms of red, green, and blue density (see Chapter 2 for further discussion).

The specific limits given here (e.g., not more than 9% magenta dye [green density] loss is specified instead of, for example, a 10% magenta loss) were selected in part to correlate with actual density units at the target density of 0.45 — a critical density to indicate small changes caused by light fading. A 9% density drop from 0.45 is a loss of 0.04 (0.0405, actually), whereas a 10% loss would be 0.045. Most densitometers give readings to only two decimal places, resulting in uncertainty whether a specified 10% loss should be read as a 9% loss (0.04) or as an 11% loss (0.05). Were it not for this practical consideration, limits such as 7%, 11%, and 13% would have been given as 8%, 12%, and 14% respectively.

Density losses measured at about 0.45 initial density are of interest primarily in terms of light fading and reflect a loss of image detail, especially noticeable in low-density highlight areas of a photograph. Initial densities of about 0.45 are best for these measurements; however, densities from 0.35 to 0.6 can be used if necessary. Within this range, the limits are given as losses of ***density units*** (i.e., 0.04 for cyan and magenta dye losses and 0.06 for yellow dye losses), and are ***not*** calculated from percentage losses (although for reference the percentage losses are given in **Table 7.2**). In a displayed print made on Ektacolor paper, for example, a 0.08 magenta dye loss measured at an initial neutral density of 0.45 will be approximately the same as the magenta losses at 0.35 and 0.6. That is, the losses at all three densities will be 0.08 (or close to that figure), while the *percentage* (and visual) losses at the three densities are quite different — being greatest at 0.35 and least at 0.6.

For evaluation of shifts in color balance, it is necessary to measure changes in near-neutral colors. When subjected to light fading on display, the "pure" cyan, magenta, and yellow colors of most types of color prints fade more rapidly than when all three colors are present in approximately equal amounts (forming near-neutral or gray colors). It is not uncommon for the separate "pure" colors to fade two or even three times faster than when combined to form a neutral gray. On the other hand, a pure magenta can lose considerable density and still be "magenta" — it will simply be a lighter magenta. The same degree of magenta lost from a neutral gray would cause a decided color shift toward green. With most types of pictorial scenes, this author has found it satisfactory to monitor near-neutrals of about 0.45 density. Within the limits suggested in **Table 7.1**, losses of pure yellow, magenta, and cyan colors will not often be visually excessive; many scenes do not even contain significant areas of such colors.

If, however, a photograph contains important areas of relatively pure, saturated colors, and especially if the colors are of a low density to begin with (e.g., a light pink sky), it is certainly appropriate to monitor these areas as well and to apply the same limits as suggested for near-neutral colors. Density losses from saturated colors should be determined using the densitometer filter (or filters) showing the highest initial density; for example, the green filter indicates the highest density for magenta and pink colors. In portraits and other photographs where people are an important part of the scene, flesh tones must also be monitored.

If there is any doubt about the relative significance of density losses measured in different parts of an image, or if a decision has to be made about how much change is tolerable in a particular photograph, it is best to be conservative. If one must err, it is better to allow too little display time than too much. Remember, the intent here is to keep the print as close to its original condition as possible.

With most types of color prints, density losses measured at d-max (maximum density) give a more accurate assessment of dark fading than measurements made at lower densities, such as 0.45. At or near d-max, the limits are given as *percentage losses*, as computed from the actual measured initial densities. Some prints have no high-density dark areas, and in such cases the highest densities available in the print should be chosen for d-max measurements. When monitoring pictorial prints, it is generally not possible to accurately "stain-correct" the density readings based on changes measured in minimum densities (see Chapter 2 for an explanation of "stain-corrected" densitometry). In pictorial prints, true minimum-density areas frequently are not present; if white borders are included, they are generally covered with overmats that shield the borders from exposure to light on display and therefore could be used only for stain-correction of dark fading data.

Separate values are given for blue density *increases* and the resulting color-balance shifts toward yellow caused by the yellow stain that occurs in many materials, particularly in dark storage. Some people feel that a fairly significant degree of yellow stain is tolerable — especially in instant photographs — and they may wish to assign higher numbers to the limits of stain formation and minimum-density color imbalance. Such higher limits would not normally be acceptable, especially in a color imbalance between red and green densities, or even as a loss in blue density (the opposite of a yellow stain).

Yellow stain, however, does not significantly affect the sense of visual image contrast; in addition, so many common materials — such as low-grade book papers — yellow with age that many people have developed a tolerance for this particular type of deterioration. Indeed, for some people, a moderate degree of yellow stain — the "patina of age" — provides assurance that an article is old, and may even impart an added degree of value. Such views have no validity: the goal here is to preserve color photographs in their original condition. The yellow stain formation common to many types of prints is undesirable and should be prevented if at all possible.

Polaroid SX-70, Polaroid 600 High Speed, Polaroid Spectra (Image prints in Europe), and Polaroid 600 Plus prints are almost certain to have exceeded the suggested low-density stain formation limits given in **Table 7.1** even before they arrive in a museum collection. To obtain an approximation of the stain level reached by a particular print, it should be measured in the area of lowest density, and this reading compared with measurements taken from the identical material shortly after processing (initial readings should generally be made about 24 hours after the processing of an instant print).

To further complicate matters, the stain that occurs in these types of Polaroid prints in dark storage is less stable in light fading than the image dyes themselves. For example, when a Spectra print that has developed a low-level yellowish stain during a year or two of dark storage is put on display, the blue density can drop very rapidly.

The limits proposed here allow only for relatively small amounts of deterioration — appropriate to museum and archive collections — and require that the monitoring densitometry be done with a high degree of accuracy. It should be possible to make measurements in low- to medium-density areas with a repeatability of ± 0.01, although in practice a deviation of ± 0.02 may be more realistic. In high-density areas of an image, a repeatability of ± 0.03 to 0.05 should be possible; at high densities, an error of ± 0.03 is of much less consequence than it is at low densities. The *percentage* (and visual) difference of a ± 0.02 error is far greater at a low density than it is at a high density (e.g., a density of 1.80).

One reason for specifying small amounts of permissible change is that densitometer reading errors and/or densitometer calibration errors may result in significantly greater change taking place in the print than indicated by the density readings. For example, with a minimum-density stain color imbalance limit of 0.04, a density measurement error of ± 0.02 could result in an actual color imbalance of 0.06 (usually caused by yellow stain) — a rather noticeable change — before the limit is reached. Setting tight limits on permissible density changes will assure that even with significant densitometer calibration and reading errors, large changes in print condition will almost certainly be detected.

However, even with careful use of a densitometer and precise calibration procedures, the accuracy and repeatability of readings will probably not be as good as one would like, especially if the instrument must be replaced and the new densitometer is calibrated from photographic color print samples kept in cold storage. Accurately detecting small changes in print densities over long periods of time strains the capabilities of even the best equipment currently available; one must expect a certain amount of "noise" in the readings and be content with less than exact repeatability. This is not a perfect system.

Potential difficulties aside, however, careful monitoring of prints is certainly an improvement over past museum practice in which there was no way to know whether, much less how much, a print had faded or stained, even if rather large changes had occurred over the years. Monitoring prints allows one to know when a print has been subjected to excessive display and eliminates the uncertainty of how to properly handle prints made on paper of an unknown type or processed under unknown conditions (more often

Table 7.1 Recommended Limits of Color Print Fading and Staining for Museums, Galleries, Archives, Artists, and Collectors

Print density changes should not exceed the following:

Overall density losses from near-neutral colors:

Cyan dye (red density) loss from about 0.45:	**0.04**	**(9%)**
Magenta dye (green density) loss from about 0.45:	**0.04**	**(9%)**
Yellow dye (blue density) loss from about 0.45:	**0.06**	**(13%)**

Density losses measured at about 0.45 initial density are of interest primarily in terms of light fading and reflect a loss of image detail that is especially noticeable in low-density highlight areas of a photograph. Initial densities of about 0.45 are best for these measurements; however, densities from 0.35 to 0.60 can be used if necessary. Within this range, the limits are given as losses in *density units* (i.e., 0.04 for cyan and magenta dye losses and 0.06 for yellow dye losses) and are *not* calculated as percentage losses.

Cyan dye (red density) loss from d-max:	**9%**
Magenta dye (green density) loss from d-max:	**9%**
Yellow dye (blue density) loss from d-max:	**13%**

With most types of color prints, density losses measured at d-max (maximum density) give a more accurate assessment of dark fading than measurements made at lower densities, such as 0.45. At d-max and near d-max, the limits are given as *percentage losses,* as computed from changes in measured densities. Some prints have no high-density dark areas, and in such cases the highest densities available in the print should be chosen for d-max measurements.

Cyan-magenta-yellow color imbalances in near-neutral image areas:

Cyan/Magenta (red/green density) imbalance at about 0.45:	**0.03**	**(7%)**
Cyan/Yellow (red/blue density) imbalance at about 0.45:	**0.05**	**(11%)**
Magenta/Yellow (green/blue density) imbalance at about 0.45:	**0.05**	**(11%)**

Color imbalances measured at about 0.45 initial density are of interest primarily in light fading. Initial densities of about 0.45 are best for these measurements; however, densities from 0.35 to 0.60 can be used if necessary. Within this relatively low range, it is more practical to determine color imbalances as imbalances in *density units* (i.e., 0.03 between cyan and magenta, and 0.05 between yellow and either cyan or magenta) than it is to calculate them as percentage imbalances. Stain formation frequently contributes to medium- and low-density color imbalances.

Cyan/Magenta (red/green density) imbalance at d-max:	**7%**
Cyan/Yellow (red/blue density) imbalance at d-max:	**11%**
Magenta/Yellow (green/blue density) imbalance at d-max:	**11%**

With most types of color prints, density imbalances measured at d-max (maximum density) are of interest primarily in terms of dark fading. At d-max and near d-max, the limits are given as *percentage imbalances,* as computed from the actual measured densities. Some prints have no high-density dark image areas, and in such cases the highest densities available in the print should be used for d-max measurements. Stain formation generally has little visible effect on d-max color imbalances.

Minimum-density stain formation:

Red Density increase at d-min:	**0.04**
Green Density increase at d-min:	**0.04**
Blue Density increase at d-min:	**0.08**

D-min (minimum-density) changes may occur in dark storage and/or as a result of exposure to light on display; an increase in blue density (as a result of yellowish stain) is the most commonly observed change. In some cases, as a result of exposure to light, the minimum density (most commonly red density) will decrease somewhat, instead of increasing. Such losses may be ignored in terms of the stain-formation limits; however, d-min losses will probably contribute to the generally more significant minimum-density color imbalances, the limits for which are given below.

Minimum-density color imbalances:

Red/Green density imbalance at d-min:	**0.03**
Red/Blue density imbalance at d-min:	**0.04**
Green/Blue density imbalance at d-min:	**0.04**

D-min (minimum-density) color imbalances may occur in dark storage and/or as a result of exposure to light on display. Minimum-density color *imbalance* limits will almost always be reached before minimum-density increase limits are reached.

Note: Many pictorial scenes do not have near-neutral colors throughout the density range; readings should be taken from important colors, such as flesh tones, sky areas, etc. Readings may be taken throughout the range of tones in a print, from the lightest to the darkest; however, the emphasis should be on image areas with densities close to d-min, 0.45, and d-max. With Polaroid instant prints, which have higher minimum densities than conventional prints, measurements at about 0.60 may prove to be more useful than measurements at 0.45. A typical print should be monitored in five to ten different locations. Small color (density) imbalances may be visually apparent on prints only in large areas of near-neutral colors.

Table 7.2 Percentage Losses of Magenta Dye (Green Density) in Kodak Ektacolor Professional Paper in an Accelerated Light Fading Test

21.5 klux (2,000 fc) Glass-Filtered Cool White Fluorescent Illumination
75°F (24°C) and 60% RH at Sample Plane
From Neutral-Gray Patches (Base + Fog Density = 0.10)

Start	Loss After 60 Days	% Loss	% Loss Minus Base + Fog	Start	Loss After 120 Days	% Loss	% Loss Minus Base + Fog
0.25	–0.09	–36%	–60%	0.25	–0.10	–40%	–67%
0.35	–0.13	–37%	–52%	0.35	–0.18	–51%	–72%
0.45	–0.16	–36%	–46%	0.45	–0.24	–53%	–69%
0.60	–0.16	–27%	–32%	0.60	–0.31	–52%	–62%
1.00	–0.16	–16%	–18%	1.00	–0.36	–36%	–40%
1.50	–0.16	–11%	–11%	1.50	–0.35	–23%	–25%

than not, this is the case even with prints in museum collections). Being told that a certain print is a "Type C" print means very little in terms of its stability in dark storage or on display!

A color print may be considered to have reached the limit of acceptable deterioration when the *first* of the numerically expressed criteria has been attained. With any given color print material, the particular changes involved depend on the specific conditions of display or dark storage. For example, in Polaroid Spectra, Spectra HD, Polaroid 600 Plus, and Polaroid SX-70 prints stored in the dark, the "minimum-density color imbalance" limit will always be reached first. In Kodak Ektacolor Professional, Ektacolor Plus, Ektacolor Supra, and Ektacolor Portra and Portra II prints on long-term display, the "overall density loss" limit for magenta dye (green density) will likely occur first. When these types of modern Ektacolor prints are stored in the dark at normal room temperature, the prints slowly develop yellowish stain and the "minimum-density color imbalance" limit probably will be reached first.

In Ilford Ilfochrome prints (called Cibachrome prints, 1963–1991) on display under low-level tungsten illumination, the "cyan/yellow color imbalance" limit will probably come first, because of the comparatively inferior light fading stability of the cyan dye in relation to the yellow dye when the prints are displayed under these conditions. (Displayed under low-level fluorescent illumination, the Ilfochrome yellow dye is *less* stable than the cyan dye — the very opposite of what occurs under tungsten illumination!)

Compared with the "10% density loss of one or more dyes at an initial density of 1.0," a criterion which has sometimes been used in the technical literature of Kodak and a few other manufacturers,[23] the more complex analysis of color image deterioration proposed here correlates much better with visually observed changes. The "10% density loss" criterion also ignores stain formation, which is the principal factor in color image deterioration in materials like Polaroid Spectra and SX-70 prints stored in the dark.

The "30% density loss," upon which Konica, Agfa, and Kodak have based their claims for the 100-year life of their respective color prints kept in dark storage, is *far* too much change to be acceptable for museum and archive collections. In light fading, a 30% dye loss measured at an initial density of 1.0 will result in total destruction of important highlight detail, as well as a severe loss of magenta in low- and medium-density portions of the image. (Other than reporting basic accelerated light fading test data, Konica has made no specific claims for its color papers in terms of how long the prints may be expected to last on display.)

Most photographic manufacturers would prefer a rather broad interpretation of what constitutes "objectionable fading." American manufacturers in particular tend to believe that the general public is particularly tolerant of yellow stain formation and loss of highlight detail common to light fading. By allowing a large amount of change to occur before it is said that a print has reached the end of its useful life, the manufacturers' projections of the average life of a given print material can be greatly extended, and the public's perception of the stability — and quality — of the print material can be influenced accordingly.

This author suggests, of course, that the *limits* of color

Table 7.3 Response Variations of Four Color Densitometers

Near-neutral patches of various color print materials were read with a Macbeth TR924 densitometer equipped with Status A filters; for ease of interpretation, readings with the other densitometers are given as ± deviations when compared to measurements made with the Macbeth TR924 (this is not to imply that the Macbeth is more accurate than, for example, the X-Rite 310 densitometer). One of the Electronic Systems Engineering Company Speedmaster TRC-60D densitometers was equipped with Kodak Certified AA filters (Status A response), which were discontinued by Kodak in 1986; the other Electronic Systems Engineering Company Speedmaster TRC-60D densitometer was equipped with Kodak Wratten 92, 93, and 94 filters. The ESECO densitometers are of an older design that is no longer manufactured. Each densitometer was calibrated using the porcelain plaque supplied by the manufacturer.

Type of Print	Macbeth TR924 Status A Filters Red-Green-Blue	X-Rite 310 Status A Filters Red-Green-Blue	ESECO TRC-60D Kodak AA Filters Red-Green-Blue	ESECO TRC-60D Wratten Filters Red-Green-Blue
Ektacolor Professional	0.99 1.02 1.07	+.03 +.00 –.01	–.01 +.05 +.04	+.05 +.07 +.03
Fujichrome Type 34	1.35 1.28 1.21	+.04 +.00 –.02	+.10 +.06 +.02	+.01 +.11 +.03
Cibachrome II Glossy	1.52 1.33 1.16	–.05 –.01 –.04	–.39 +.08 +.04	–.37 +.09 –.01
Kodak Dye Transfer	1.20 1.27 1.04	+.03 –.01 +.01	–.15 +.02 +.00	–.03 +.08 –.02
ArchivalColor Pigment Print	0.74 1.02 1.00	+.00 +.01 –.02	–.06 +.02 +.02	–.07 +.08 +.06
Polaroid Spectra	1.29 1.34 1.56	+.05 –.01 –.03	–.07 +.08 –.07	+.13 +.22 +.09
Polacolor ER	1.50 1.29 1.23	+.06 +.02 –.01	–.17 +.09 –.01	+.10 +.22 –.02

image deterioration given here should not be reached during any single exhibition period and that color prints should not normally be placed on continuous display long enough to reach the limits. Most types of pre-1985 chromogenic color prints, such as Kodak Ektacolor 74 RC prints, will pass these limits of deterioration in less than 10 years, even when kept in the dark at room temperature, because of their poor dark storage stability; this can be prevented only by placing the prints in low-temperature, humidity-controlled storage. Each curator will have to decide how much of the useful life of a print he or she will allow to be consumed during a particular exhibit, or during the curator's tenure, and how much will be left for future curators.

For example, given this set of deterioration criteria, and knowing the stability characteristics of Kodak Ektacolor 74 RC Paper, one could conclude that under moderate tungsten illumination of 300 lux (28 fc) and nominal conditions of 75°F (24°C) and 50% RH, a print made with this now-obsolete paper will have a display-life expectancy of about 6 years; this would allow twelve 6-month exhibitions if the print is kept in cold storage between display periods. If the print is *not* kept in cold storage, but instead is kept at room temperature, the acceptable life would probably be less than 8 years even if it were never exhibited. If the print is put in cold storage between exhibitions, and is displayed for a single 3-month period each 5 years, the final showing of the print could take place about 120 years after the first exhibition. Other print materials (such as those made with many of the early color processes) are much less stable than Kodak Ektacolor 74 RC prints and could tolerate only a small fraction of this total display time.

Museum Exhibitions of Color Photographs That Have Been Monitored

Grant Romer, conservator of photographs at George Eastman House in Rochester, New York, working in conjunction with this author and Ronald Emerson, at the time a curator at George Eastman House, and John Upton, guest curator at the museum, employed the basic color print monitoring procedures described here for *Color as Form: A History of Color Photography*, an exhibition at the Corcoran Gallery of Art in Washington, D.C. from April 10 to June 6, 1982 and at the International Museum of Photography at George Eastman House from July 2 to September 5, 1982. This was the first exhibition of color photographs to be monitored densitometrically during the display period. (Some of the photographs chosen for the exhibition, including a number of Lumiere Autochrome glass-plate transparencies, were not shown in their original form because of physical problems and/or the potential instability of their color images; instead, color copy prints or transparencies were shown.)

Sergio Burgi, who was in charge of densitometry and data analysis for the exhibition, has reported that whereas none of the photographs reached the set of limits adopted for the project, a number of prints came close to the limits. Among the images that showed significant changes were Kodak Kotavachrome and Minicolor prints from the period 1941–1945 (these prints were made on pigmented cellulose acetate film base using a variation of the external-coupler Kodachrome process — see Chapter 1). During the 4-month period of the display, the photographs had been exposed to only 110–160 lux (10–15 fc) of tungsten illumination for approximately 10 hours a day. Burgi commented on the results of his examination of the densitometry data:

> In a Kotavachrome print there were some areas with quite a significant loss — which was not necessarily consistent throughout the print. I found some staining and some dye loss going on simultaneously in the print; one area stained a lot.
>
> Some of the prints have already lost 0.02 density and this would increase on further exhibition. It certainly points out that we should think twice about having some of the prints in another exhibition.
>
> However, the recent Ektacolor prints didn't present any significant change and they could certainly tolerate more exhibition time. I plan to go through the data so as to be able to separate the more stable prints from the less stable.
>
> I think monitoring is a very useful method for control of exhibition time — and to reassure us that we are not harming prints by putting them on display.[24]

Burgi said that in general he believes the monitoring procedure gave reliable data, adding, "It can be very accurate if you work carefully." The museum has prints made on a number of materials — including Kodak Dye Transfer, Ektacolor 74 RC, and Ilford Ilfochrome (Cibachrome) — and placed them in freezer storage as aids in future calibration of their monitoring system.

An Important Illustration of Print Monitoring by the Art Institute of Chicago

In what turned out to be a dramatic illustration of the value of print monitoring, Douglas G. Severson, assistant conservator for photography at the Art Institute of Chicago, monitored 38 prints from the 180 photographs in the 1984 exhibition *The Art of Photography: Past and Present, From the Collection of the Art Institute of Chicago*. The exhibition was put together by David Travis, curator of photography at the Art Institute, and was shown at the National Museum of Art in Osaka, Japan from October 6 to December 4, 1984.

According to Severson, "The selection represented a broad cross-section of photographic history and technique, with prints dating from 1842 to 1982." Among the 38 prints monitored, 13 photographic processes and works by 24 different photographers were represented. The exhibition included Kodak Dye Transfer prints by Eliot Porter, Ektacolor 74 RC prints by Joel Meyerowitz and John Pfahl, and Polacolor 2 prints by Paolo Gioli.

For the Osaka exhibition, the Art Institute placed the following restrictions on display conditions:

1. Temperature: Not in excess of 75°F (24°C).
2. Relative Humidity: 40% RH. A range of 35–55% RH is permitted if rapid changes in humidity are avoided.
3. Light Level: Not to exceed 325 lux (30 footcandles).
4. No sunlight or daylight permitted in exhibition area.
5. No TV or film crew lights permitted.

A calotype negative made by Fox Talbot in the exhibit was covered with brown cloth to protect it from exposure to light except when the cloth was lifted by a person viewing the print.

The prints were away from the Art Institute for a total of 12 weeks, with the actual exhibition lasting 9 weeks. During the exhibition period, the gallery temperature ranged from 56 to 77°F (13–25°C) and the relative humidity was recorded over a range of 39–66%. The photographs were matted with 100% cotton fiber mount board and framed with Acrylite OP-2 ultraviolet-filter acrylic plastic sheet. The exhibit was illuminated with tungsten lamps (presumed not to exceed 325 lux [30 fc]), and no daylight or fluorescent light was present.

Before air shipment of the exhibit to Japan, density measurements were made on the 38 selected prints, and the prints were measured again upon their return to Chicago; the measured density changes are given in **Table 7.4**. Severson made the following observations about the changes that took place in the prints during the time they were away from the Art Institute:

> Overall, of the 38 prints monitored, 17 did not change, 15 changed 10% or less, and 6 changed more than 10%. Of the 13 different processes monitored, only 5 were immune to change and 4 of those are rather unusual or hybrid materials (silver-gelatin being the only common process to remain unchanged).
>
> With regard to albumen prints, the most common type of 19th-century photographic material, several points can be noted. Support can be found here for the notion that the rate of image deterioration in these materials is closely related to their condition. Without exception, the prints in better condition [at the time the exhibit was shipped from the Art Institute] showed more density change than those in poor condition. For instance, the most stained and faded albumen print in the exhibit (#7 by Baldus) was unchanged, while that with the richest tonalities (#14 by Jackson) changed considerably. Also, the pattern of results in prints #10–13 would indicate that staining may appear first in the shadows, where it is the least detectable by the human eye.
>
> Perhaps the most surprising result to be found here is the change that occurred in photograph #21 by Stieglitz. Platinum and palladium prints have a reputation for extreme stability, but this image yellowed considerably in the midtones and shadows. One might assume the change is a yellowing of the paper base due to the acidic nature of the process, but the absence of highlight yellowing tends to contradict that notion. There may be other deterioration mechanisms operating here.

Table 7.4 Density Changes Measured in Photographs from "The Art of Photography: Past and Present, From the Collection of the Art Institute of Chicago" Following Their Return After a 9-Week Exhibition in 1984 at the National Museum of Art in Osaka, Japan

Prints monitored by Douglas G. Severson, Assistant Conservator for Photography, the Art Institute of Chicago

	Photographer	Date	Process	Original Condition	% Density Change in Shadows	% Density Change in Midtones	Initial d-min Density	d-min Density after Exhibition and Trip to and from Japan	d-min Density Change
1)	Fox Talbot	1842	calotype negative	fair	0	0	0.42	0.44	NS
2)	Salzman	1854	salted paper print	good	0	+6%	0.24	0.25	NS
3)	Cameron	1857	albumen print	fair	0	0	0.41	0.43	NS
4)	Cameron	1874	albumen print	good	+5%	0	0.31	0.31	NS
5)	Cameron	1867	albumen print	good	+7%	+15%	0.37	0.48	+0.11
6)	Frith	1857	albumen print	good	+7%	+10%	0.41	0.46	+0.05
7)	Baldus	1855	albumen print	fair	0	0	0.27	0.28	NS
8)	LeGray	1856	albumen print	fair	0	0	0.42	0.43	NS
9)	MacPherson	1867	albumen print	fair	0	0	0.31	0.31	NS
10)	Bourne	1865	albumen print	good	+5%	0	0.36	0.36	NS
11)	Bisson Freres	1863	albumen print	good	+5%	0	0.44	0.45	NS
12)	Atget	ND	albumen print	good	+5%	0	0.28	0.30	NS
13)	Watkins	c.1865	albumen print	excellent	+5%	0	0.25	0.26	NS
14)	Jackson	1892	albumen print	excellent	+5%	+15%	0.21	0.29	+0.08
15)	O'Sullivan	1863	albumen print	good	0	–10%*	0.26	0.26	NS
16)	Fenton	1856	dilute albumen	fair	0	0	0.33	0.34	NS
17)	Tripe	1858	dilute albumen	fair	0	0	0.31	0.33	NS
18)	Atget	c.1910	matte-albumen	good	0	–14%*	0.24	0.24	NS
19)	Atget	c.1910	gelatin p.o.p.	good	–5%	–10%*	0.48	0.43	–0.05
20)	Steichen	1904	multiple gum print	good	0	0	0.50	0.50	NS
21)	Stieglitz	1919	palladium print	good	+15%	+30%	0.40	0.44	NS
22)	Stieglitz	1931	silver gelatin	good	0	0	0.18	0.18	NS
23)	Strand	1928	silver gelatin	good	0	0	0.28	0.28	NS
24)	Hine	1909	silver gelatin	fair	0	0	0.26	0.26	NS
25)	Hine	1920	silver gelatin	fair	0	0	0.22	0.21	NS
26)	Meyerowitz	1978	Ektacolor 74 RC	excellent	0	0	0.14	0.14	NS
27)	Meyerowitz	1978	Ektacolor 74 RC	excellent	0	+10%	0.29	0.28	NS
28)	Meyerowitz	1978	Ektacolor 74 RC	excellent	–3%	+5%	0.17	0.18	NS
29)	Pfahl	1981	Ektacolor 74 RC	excellent	–5%	0	0.25	0.27	NS
30)	Pfahl	1980	Ektacolor 74 RC	excellent	0	+5%	0.18	0.18	NS
31)	Porter	1951	Dye Transfer	good	0	0	0.32	0.33	NS
32)	Porter	1963	Dye Transfer	good	0	0	0.45	0.42	NS
33)	Porter	1967	Dye Transfer	excellent	–3%	0	0.32	0.33	NS
34)	Porter	1969	Dye Transfer	excellent	–6%	0	0.20	0.20	NS
35)	Porter	1974	Dye Transfer	excellent	0	–20%	0.62	0.62	NS
36)	Gioli	1982	Polacolor 2	excellent	0	0	0.11	0.10	NS
37)	Gioli	1982	Polacolor 2	excellent	+3%,–8%	0	0.11	0.10	NS
38)	Josephson	1969	color litho, etc.	good	0	0	0.15	0.17	NS

*** measured at edge of image** **NS = Not Significant**

Important to Note:

1) Changes are reported as percentage of initial density in whichever densitometer color channel changed most (generally blue density).
2) Reliability of the readings was estimated quite conservatively, with a margin of error of ± 0.02. Thus, only changes greater than 0.04 were considered significant.

David Kolody, a photographic conservator, demonstrates his system of print monitoring at a meeting of the Photographic Materials Group of the American Institute for Conservation in Rochester, New York (see Note No. 4). Kolody has employed the system primarily to measure changes that result from conservation treatments.

> The color photographs, on the other hand, may have changed less than one would anticipate, given their reputation for instability. One might also note the inverse relationship of age to deterioration with the five Eliot Porter Dye Transfer prints — the newest print changed most, while the oldest was stable.
>
> . . . One principal conclusion seems inescapable — namely, that some photographs do indeed change when [shipped and/or] exhibited, sometimes in ways that are difficult to understand or predict, and sometimes more than one would anticipate.
>
> . . . This method of print-monitoring can be a very time-consuming and exacting activity. But for those in a position to make decisions or give advice about exhibiting photographs, the information it provides can be extremely useful and important.[25]

Severson noted that according to this author's "Recommended Limits of Print Image Deterioration,"[26] which constitutes a somewhat simplified version of the limits given in **Table 7.1**, "21 of the 38 prints monitored would have exceeded those limits in this one exhibition period."

The total light exposure experienced by the prints during the 9-week exhibition was relatively small, and this author would be surprised if light exposure alone could account for the large changes observed in some of the prints. If low-level air pollutants were present where the prints were exhibited (information about air quality could not be obtained), they could have contributed to the changes that were measured. Because the prints were matted and framed before leaving Chicago, and were exhibited for only a relatively short 9-week period, low-level air pollution was probably not a significant factor, however.

The fading and staining of the prints in this exhibit were more likely caused by the uncontrolled environmental conditions to which the prints were subjected during shipment to and from Japan. Severson reports that "the photographs may have been exposed to excessive or rapidly fluctuating temperatures and humidities in transit. For instance, the baggage compartment of a jet plane can be as cold as –40°F [–40°C], while that of a truck on a hot day can reach as high as 120°F [50°C]. Uncontrolled humidity can be even more damaging, and it is known that the crates in this exhibit experienced at least one major rainfall in the course of their journey. Conditions in transit are always one of the most difficult aspects of any traveling exhibition to control and measure, but they may be a more likely cause of damage than any other even in the full course of the exhibit." The shipping crates themselves may also be implicated in the damage that occurred to the prints; plywood and other common packaging materials are known to evolve formaldehyde vapors and other potentially harmful substances (see Chapter 15).

It should be noted that the large changes noted by Severson in the 1919 Stieglitz palladium print (#21) likely are not representative of what is to be expected with *all* palladium prints under similar exhibition and transit conditions. The fact that the changes did occur with this particular print, however, underscores the importance of monitoring valuable photographs. Particularly with older photographs, merely being able to identify the process does not make it possible to predict how a print will be affected by display and storage. The specific material with which a print is made, its processing, its history of storage (temperature, relative humidity, and exposure to contaminants from storage materials or the atmosphere over the years), prior exposure to light (duration, intensity, and spectral distribution), and so forth, can singly or in combination influence future changes that take place in a given photograph. With further experience in monitoring various types of photographs, it will become apparent which types of prints are particularly vulnerable to damage as a consequence of exhibition or shipment under uncontrolled conditions; but with historical photographs it probably never will be possible to predict with certainty the behavior of a specific print.

When significant changes in a photograph have been noted — for example, in the 1867 Cameron albumen print (#5) and the 1892 Jackson albumen print (#14), both of which suffered substantial image and highlight staining as a result of the trip to Japan — great care must be taken to ensure that no further deterioration takes place. Future display should be restricted (or eliminated, if monitoring indicates that further changes are taking place), and travel outside of the museum should not be permitted. The Art Institute is fortunate in having a temperature- and humidity-controlled storage facility for its collection, and the prints will have the best chance of survival if they remain there — in the dark.

This author considers Severson's study to be an extremely important contribution to our presently limited knowledge about what changes can take place in historical photographs when they are exhibited and/or shipped considerable distances under uncontrolled conditions. Severson's experience with the Osaka exhibition leaves no doubt that the practice of routinely shipping valuable photographs around the country — or around the world — in traveling exhibitions must be carefully re-examined.

Under the direction of conservator John McElhone, the National Gallery of Canada also maintains an extensive monitoring program.[27]

Notes and References

Note: This chapter is based on an article by this author published in the Fall 1981 issue of the **Journal of the American Institute for Conservation,** Vol. 21, No. 1, pp. 49–64, entitled "Monitoring the Fading and Staining of Color Photographic Prints." This author discussed the design and use of fading monitors and presented a preliminary version of the "Recommended Limits of Color Print Image Deterioration," given in this chapter, as part of a paper entitled "Light Fading Characteristics of Reflection Color Print Materials" at the **31st Annual Conference of the Society of Photographic Scientists and Engineers**, Washington, D.C., May 1, 1978. Additional information on print monitoring was included in a paper entitled "Special Topics: Pigment Color Prints, Fading Monitors for Color Prints, Special Display Techniques, and Cold Storage Facilities," given at the International Symposium on the Conservation of Contemporary Art, sponsored by the National Gallery of Canada, Ottawa, Ontario, July 9, 1980; and in a presentation entitled "Monitoring the Fading and Staining of Color Photographic Prints" at the Summer Meeting of the Photographic Materials Group of the American Institute for Conservation, held as part of the Annual Conference of the American Institute for Conservation, Philadelphia, Pennsylvania, May 31, 1981.

1. Grant B. Romer, "Can We Afford to Exhibit Our Valued Photographs?", **Topics in Photographic Preservation — 1986** (compiled by Maria

S. Holden), Vol. 1, pp. 23–24, 1986. American Institute for Conservation Photographic Materials Group, American Institute for Conservation, Suite 340, 1400 16th Street, N.W., Washington, D.C. 20036; telephone: 202-232-6636; Fax: 202-232-6630. The article was reprinted in **Picturescope,** Vol. 32, No. 4, Winter 1987, pp. 136–137. For a related discussion, see: Paul Lewis, "Preservation Takes Rare Manuscripts From the Public," **The New York Times,** January 25, 1987, p. H1.

2. A review of museum lighting recommendations has been given by Garry Thomson in **The Museum Environment,** second edition, Butterworth & Co., Ltd. (in association with the International Institute for Conservation of Historic and Artistic Works), London, England, 1986, pp. 22–35. A maximum illuminance of 50 lux (4.7 fc) is recommended for "objects especially sensitive to light, such as textiles, costumes, watercolours, tapestries, prints and drawings, manuscripts, miniatures, paintings in distemper media, wallpapers, gouache, dyed leather. Most natural history exhibits, including botanical specimens, fur and feathers." A maximum illuminance of 200 lux (18.6 fc) is recommended for "oil and tempera paintings, undyed leather, horn, bone, and ivory, oriental lacquer." (p. 23).

   See also: Stefan Michalski, "Towards Specific Lighting Guildelines," **Preprints of the 9th Triennial Meeting of the ICOM Committee for Conservation,** Dresden, German Democratic Republic, August 26–31, 1990, pp. 583–588. (Published by the International Council of Museums Committee for Conservation, Los Angeles, California.)

   See also: James M. Reilly, **Care and Identification of 19th-Century Photographic Prints,** Kodak Publication No. G-2S, Eastman Kodak Company, Rochester, New York, 1986. Reilly concurred with the 50 lux (4.7 fc) recommendation, saying it applies to "all photographic print materials that have exposed paper fibers (salted paper prints, platinotypes, cyanotypes, gum bichromate prints, and carbon prints), to all photomechanical print materials, and to albumen prints. It also applies to all prints that have applied color in any form. Prints with baryta coatings (most gelatin developing-out papers, gelatin printing-out papers, and collodion printing-out papers) may tolerate up to 100 lux (10 foot-candles)." p. 105.

3. Eastman Kodak Company, **Kodak Color Films and Papers for Professionals,** Kodak Publication No. E-77, Eastman Kodak Company, Rochester, New York, March 1986, p. 49.

4. A project to monitor albumen prints was begun in 1979 at the International Museum of Photography at George Eastman House in Rochester, New York by James Reilly, Douglas Severson, and Grant Romer. Both 19th-century and freshly made albumen prints (the latter in the form of gray scales) were included in the project in an effort to better understand the stability characteristics of this type of print. The project was continuing at the time this writing.

   David Kolody, a conservator in Stow, Massachusetts, adapted the method of direct monitoring of prints described in this chapter to the routine monitoring of black-and-white photographs, lithographs, watercolors, and etchings. Kolody prepared a polyester overlay sheet marked with a grid consisting of numbered lines drawn ¾ inch (2 cm) apart and with holes cut at each intersection of lines. Density readings can be quickly taken at points of line intersection which correspond to high-density, medium-density, and low-density parts of the image; the line coordinates and density data are recorded in a notebook. Only one overlay sheet is needed in this procedure; the same sheet is used for all of the prints being monitored. Although the pre-drawn grid overlay sheet does not offer the flexibility of being able to locate the densitometer head precisely at any desired point on a print, Kolody believed that the method was adequate for routine monitoring of work before and after conservation treatments. Kolody developed the system in early 1982. He gave a brief demonstration of his monitoring techniques at the Winter Meeting of the Photographic Materials Group of the American Institute for Conservation in Rochester, New York, February 3, 1982, and a more detailed demonstration at the Winter Meeting of the Photographic Materials Group, at the Art Institute of Chicago, January 31, 1983.

   Also at the 1983 Photographic Materials Group Winter Meeting, Siegfried Rempel, who at the time was conservator of photographs at the Humanities Research Center (HRC), University of Texas, Austin, Texas, described an ongoing project to monitor calotypes from the HRC collection that were included in the exhibition **Paper and Light — The Calotype in France and Great Britain 1839–1870.** The exhibition was on display at the Art Institute of Chicago from December 15, 1982 to February 13, 1983, after which it traveled to several other institutions.

   In 1984 Douglas G. Severson monitored a selection of black-and-white and color prints from the exhibition **The Art of Photography: Past and Present, From the Collection of the Art Institution of Chicago,** which was exhibited at the National Museum of Art in Osaka, Japan from October 6 to December 4, 1984. This monitoring project is discussed in the text (also see Note No. 25).

5. In 1966, Garry Thomson, scientific adviser to the National Gallery in London, started an investigation of methods to record changes in paintings and arranged for a specially designed spectrophotometer to be built for this purpose; certain paintings are now being measured once every 5 years. See: Linda Bullock, "Reflectance Spectrophotometry for Measurement of Colour Change," **National Gallery Technical Bulletin,** Vol. 2, 1978, pp. 49–56. See also: R. M. Johnson and R. L. Feller, "The Use of Differential Spectral Curve Analysis in the Study of Museum Objects," **Dyestuffs,** Vol. 44, No. 9, 1963, pp. 1–10; and R. L. Feller, "Problems in Spectrophotometry," **1967 London Conference on Museum Climatology,** second edition, Garry Thomson, editor, IIC, London, 1968, pp. 196–197.

6. Alan R. Calmes, "Monitoring the U.S. Charters of Freedom by Electronic Imaging," a chapter in: **Proceedings of the International Symposium: Conservation in Archives**, published by the National Archives of Canada, 1989, pp. 243–251. The Symposium, which took place May 10–12, 1988 in Ottawa, was jointly sponsored by the National Archives of Canada and the International Council on Archives. Copies of the Proceedings are available from the International Council on Archives, 60, rue des Francs-Bourgeois, 75003 Paris, France. See also: Jet Propulsion Laboratory, **Conceptual Design of a Monitoring System for the Charters of Freedom**, JPL Publication 83-102, Jet Propulsion Laboratory through an agreement with the National Aeronautics and Space Administration, California Institute of Technology, Pasadena, California, 1984. See also: Alfred Meyer, "Daily Rise and Fall of the Nation's Revered Documents, **Smithsonian**, Vol. 17, No. 7, October 1986, pp. 135–143.

7. Manufacturers of high-quality photographic densitometers include: Macbeth Division, Kollmorgen Instruments Corporation, P.O. Box 230, 405–417 Little Britain Road, Newburgh, New York 12550, telephone: 914-565-7660; X-Rite, Inc., 3100 44th Street S.W., Grandville, Michigan 49418, telephone: 616-534-7663; and ESECO Speedmaster (Electronic Systems Engineering Company), 1 Eseco Road, Cushing, Oklahoma 74023, telephone: 918-225-1266. Good-quality transmission/reflection densitometers cost between $3,000 and $5,000, depending on the model. Kodak Wratten 92 (red), 93 (green), 94A (blue), and 102 (visual) filters are currently recommended by this author instead of the normally supplied Status A and Status M filters (see discussion in text).

8. Matte-surface polyester (such as DuPont Mylar or Cronar) sheets of a type intended for drafting with technical pens can be obtained from stores that sell drafting and engineering drawing supplies. Matte DuPont Mylar Type EB-11, or other matte polyester with an incorporated matting agent of silicon dioxide or other abrasive material, should be avoided because the abrasive can easily damage the delicate surface of a photograph.

9. Densitometer head locations can be marked with a technical pen (such as a Koh-I-Noor Rapidograph) with a No. 1 point (medium) and a suitable stable black ink (such as Koh-I-Noor Rapidograph "Universal" Waterproof Black Drawing Ink No. 3080-P, Koh-I-Noor Rapidomat Black Ink No. 3074-F, or Higgins Professional India Ink for Film No. 4465 Black).

10. Holes in the polyester overlay sheet are best cut by placing the sheet on a large piece of glass and cutting out a circle with an X-Acto Craft Swivel Knife No. 3241. As an alternative to round holes, square holes may be cut with a straight-blade knife. Be certain that the knife blade is very sharp, and cut the holes carefully to avoid rough edges that might scratch the surface of a print. Holes can also be punched with a suitable leather punch (see Note No. 11).

    This author gratefully acknowledges the suggestion by Grant Romer, conservator at the International Museum of Photography at George Eastman House, Rochester, New York, that holes be cut in the polyester overlay sheet. Eliminating the polyester from the densitometer optical path improves the long-term accuracy of this system; it also permits the use of matte-surface polyester, to which ink adheres far better than it does to high-gloss polyester. In the original version of the monitoring system proposed by this author in 1978, readings were made through a clear polyester overlay sheet.

11. The punch used by Douglas Severson at the Art Institute of Chicago is manufactured by C. S. Osborne & Company, 125 Jersey Street, Harrison, New Jersey 07029; telephone: 201-483-3232. The #7 punch cuts a 13⁄64-inch hole, which accommodates the 3⁄16-inch head aperture of the Macbeth TR924 and similar Macbeth densitometers. Severson cautions that after marking the polyester overlay sheet, it **must** be inverted for punching so that the slightly rough edges of the hole lift away from the print rather than toward it, to prevent scratching delicate print surfaces.

12. Suitable transparent polyester (DuPont Mylar D or ICI Melinex 516) sleeves which open along one edge so it is not necessary to slide a print or film in and out (thus minimizing the risk of scratching the

surface) are available from: Talas Inc., Ninth Floor, 213 West 35th Street, New York, New York 10001-1996; telephone: 212-594-5791.

13. Documentation photography is most effectively done with color reversal films (recommended is Fujichrome 64T Professional Film [Tungsten] or, as a second choice, Kodak Ektachrome 64T Professional Film [Tungsten]). After processing, the color transparencies can be preserved almost indefinitely by placing them in humidity-controlled cold storage. This author believes that in most cases, color films stored under the proper conditions (0°F [–18°C], 30% RH) will greatly outlast archivally processed black-and-white films stored under typical room-temperature conditions. It is assumed here that an institution engaged in a monitoring program will have cold storage facilities for its collections, densitometer photographic calibration standards, and color documentation photographs.

14. When a fading monitor is used as an "integrating photometer" to study environmental conditions in which photographs are displayed, density losses measured with the fading monitor are correlated with density losses of the same type of photographic material that result from low-level accelerated light fading tests in which the light exposure is known.

    The application of photographic materials for "integrating photometers" has been reported by Stanton Anderson and George Larson of Eastman Kodak Company in "A Study of Environmental Conditions Associated with Customer Keeping of Photographic Prints," **Second International Symposium: The Stability and Preservation of Photographic Images,** (Printing of Transcript Summaries), Ottawa, Ontario, August 25–28, 1985, pp. 251–282. Available from: IS&T, Society for Imaging Science and Technology, 7003 Kilworth Lane, Springfield, Virginia 22151; telephone: 703-642-9090.

    This author believes, however, that Blue Wool Standard test cards are more satisfactory than photographic materials for use as "integrating photometers." Blue Wool Standard test cards are available from: British Standards Institution, 10 Blackfriars Street, Manchester M3 5DT, England; Beuth-Vertrieb, Burggrafenstr, 4-7, D-1000 Berlin 30, Germany; Japanese Standards Association, 1-24 Akasaka 4, Minatoku Tokyo, Japan. In the U.S. the cards may be purchased from: Talas Inc., Ninth Floor, 213 West 35th Street, New York, New York 10001-1996; telephone: 212-736-7744.

    The Blue Wool Standards are described in **BS 1006:1978, British Standard Methods of Test for Colour Fastness of Textiles and Leather,** British Standards Institution, 2 Park Street, London W1A 2BS, England; telephone: 01-629-9000. See also: **ISO 105/ A-1978 Textiles – Tests for Colour Fastness – Part A: General Principles** and **ISO 105/ B-1978 Textiles – Tests for Colour Fastness – Part B: Colour Fastness to Light and Weathering,** published by ISO, 1, rue de Varembe, Case postal 56, CH-1211 Geneve 20, Switzerland; telephone: 41-22-34-12-40. ISO Standards are available in the U.S. from American National Standards Institute, Inc., 11 West 42nd Street, New York, New York 10036; telephone: 212-642-4900; Fax: 212-302-1286. The Blue Wool light-fastness Standards (numbered 1–8) should not be confused with the "L Blue Wool Standards," (numbered L2–L9) supplied by the American Association of Textile Chemists and Colorists.

    A significant problem with the use of color photographic papers as "integrating photometers" is that new color papers are introduced and older versions discontinued on a fairly regular basis, and this will make long-term continuity difficult. In addition, manufacturers sometimes make unannounced changes in a material and/or its processing, which can affect its stability and possibly its light fading reciprocity characteristics. Because of these uncertainties, each new batch of color paper will have to be retested for "calibration" purposes — a time-consuming process. Unlike photographic papers, the Blue Wool Standards are standardized and should provide good repeatability from year to year. The eight steps of the Blue Wool Standards afford measurement over a very wide range of accumulated exposure and, in this author's tests, the Blue Wool Standards exhibited minimal reciprocity failure in long-term "natural" tests compared with short-term accelerated tests (see Chapter 2). For discussion of the Blue Wool Standards as "integrating photometers" see: Robert L. Feller and Ruth Johnston-Feller, "Use of the International Standards Organization's Blue Wool Standards for Exposure to Light. I. Use as an Integrating Light Monitor for Illumination Under Museum Conditions," **AIC Preprints of Papers Presented at the Sixth Annual Meeting,** Forth Worth, Texas, June 1–4, 1978, pp. 73–80. Also see: Robert L. Feller and Ruth Johnston-Feller, "The International Standards Organization's Blue-Wool Fading Standards (ISO R105)," **Textile and Museum Lighting,** published by the Harpers Ferry Regional Textile Group, 1985, pp. 41–57.

    For more accurate measurement of light exposure accumulated over time than is possible with the Blue Wool Standards, various electronic integrating photometers are available. Recommended is the Minolta Illuminance Meter (Model T-1), a moderate-cost lux/footcandle meter with an integration function, available for about $600 from Minolta Corporation, 101 Williams Drive, Ramsey, New Jersey 07446; telephone: 201-825-4000 (manufactured by Minolta Camera Company, Ltd., 30,2-Chome, Azuchi-Machi, Higashi-ku, Osaka 541, Japan).

15. Inexpensive metal frames of appropriate size can be obtained at many variety stores and, for large-quantity purchases, directly from a manufacturer such as Intercraft Industries Corporation, Chicago, Illinois 60614. Backing materials supplied with such frames should be discarded and replaced with high-quality mounting board.

16. Kodak Reflection Densitometer Check Plaque, Kodak Catalog No. 140-5026, for use with reflection densitometers. For transmission densitometers, obtain a Kodak Transmission Densitometer Check Plaque, Catalog No. 170-1986. Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.

17. See, for example: Robert J. Tuite, "Image Stability in Color Photography," **Journal of Applied Photographic Engineering,** Vol. 5, No. 4, Fall 1979, pp. 200–207. For stability information on specific Kodak color materials, see: Eastman Kodak Company, **Evaluating Dye Stability of Kodak Color Products,** Kodak publication CIS No. 50, and CIS No. 50 series data sheets for Kodak color papers, January 1982 and later dates.

18. The Macbeth ColorChecker chart can be purchased from photographic suppliers or from Kollmorgen Instruments Corporation, Macbeth Division, P.O. Box 230, 405-417 Little Britain Road, Newburgh, New York 12550; telephone: 914-565-7660; toll-free: 800-622-2384.

19. Heat-sealable vapor-proof envelopes called Light Impressions Heat Seal Envelopes, which are suitable for storage of photographs in uncontrolled humidity conditions, are available in two sizes from Light Impressions Corporation, 439 Monroe Avenue, Rochester, New York 14607-3717; telephone: 716-271-8960 (toll-free: 800-828-6216). Similar vapor-proof envelopes, called Containers for Freezing Photographic Material, are supplied (minimum purchase of 500 envelopes) by Conservation Resources International, Inc., 8000-H Forbes Place, Springfield, Virginia 22151; telephone: 703-321-7730 (toll-free: 800-634-6932). These heat-sealable envelopes are made with an aluminum-foil vapor barrier which is laminated between sheets of polyethylene and paper; ordinary plastic bags are not suitable.

20. Kodak Wratten densitometer filters in 125mm (5-inch) square sheets may be ordered from Kodak as follows: Visual No. 102 (Catalog No. 166-8318); Red No. 92 (Catalog No. 176-4513); Green No. 93 (Catalog No. 186-0261); and Blue No. 94A (Catalog No. 148-2413). (In 1985 Kodak replaced the traditional Wratten No. 94 densitometer filter with the Wratten No. 94A densitometer filter.) Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.

21. Jeanne Boddin, product manager, Macbeth Division, Kollmorgen Instruments Corporation, telephone discussion with this author, December 4, 1986.

22. For current recommendations on densitometers and densitometer filters for photographic print-monitoring applications, contact Henry Wilhelm at Preservation Publishing Company, 719 State Street, P.O. Box 567, Grinnell, Iowa 50112-0567; telephone: 515-236-5575; Fax: 515-236-7052.

23. Robert J. Tuite, see Note No. 17.

24. Sergio Burgi, International Museum of Photography at George Eastman House, telephone discussion with this author, August 5, 1983. Burgi was tentatively using the set of limits previously proposed by this author in an article in the **Journal of the American Institute for Conservation** (see Note No. 26). The limits suggested in that article are a somewhat simplified version of the limits given in this chapter (**Table 7.1**).

25. Douglas G. Severson, "The Effects of Exhibition on Photographs," **Topics in Photographic Preservation – 1986** (compiled by Maria S. Holden), Vol. 1, pp. 38–42, 1986. American Institute for Conservation Photographic Materials Group, American Institute for Conservation, Suite 340, 1400 16th Street, N.W., Washington, D.C. 20036; telephone: 202-232-6636. Slightly revised, the article was reprinted in **Picturescope,** Vol. 32, No. 4, Winter 1987, pp. 133–135.

26. Henry Wilhelm, "Monitoring the Fading and Staining of Color Photographic Prints," **Journal of the American Institute for Conservation,** Vol. 21, No. 1, Fall 1981, pp. 49–64.

27. John McElhone (National Gallery of Canada), "Determining Responsible Display Conditions for Photographs," presentation at The Centre for Photographic Conservation Conference '92: **The Imperfect Image: Photographs their Past, Present and Future**, Windermere, Cumbria, England, United Kingdom, April 6–10, 1992.