6. Projector-Caused Fading of 35mm Color Slides

Fujichrome Films Have the Longest Life When Projected

Projecting a 35mm color slide exposes the image to a concentrated beam of extremely intense light — a Kodak Ektagraphic III projector equipped with the standard 300-watt EXR quartz-halogen lamp has a light level at the film plane of over one million lux (almost 100,000 footcandles), which is equivalent to about *ten times* the illumination intensity of direct outdoor sunlight.[1] The Kodak Ektapro 7000 and 9000 projectors, introduced in 1992, also employ EXR lamps; however, because of an improved mirror design, the Ektapro projectors have about 10% greater film plane illumination intensity than Ektagraphic III projectors. Kodak Carousel and earlier model Ektagraphic projectors equipped with 300-watt ELH quartz-halogen lamps have a light intensity that is only slightly less than that of an Ektagraphic III.

Some special-purpose projectors for large auditorium screens are equipped with powerful xenon-arc lamps which can exceed the light intensity — and fading power — of the standard Kodak projectors by as much as eight times.[2] This can equal *75 times* the intensity of direct outdoor sunlight!

"Projector-caused fading"[3] is a term used by this author to distinguish the deterioration of images caused by slide projection from other types of light fading. The usually intermittent and relatively short total exposure of slides to the extremely intense light and moderately high heat of projection is a unique fading condition to which color prints and negatives are never subjected. During projection, fading takes place at a rapid rate, and it is only because the total projection time of most slides in their lifetimes is relatively short — normally not exceeding 1 or 2 hours — that color slide images manage to survive at all.

The projector-fading and dark fading characteristics of a film often have little relation to each other. For example, Kodachrome films have the best dark fading stability of any type of camera film in the world. However, in this author's projector-fading tests, the situation was quite the reverse, with Kodachrome ranking the worst of all current color slide films. In projector-fading tests, the current Process K-14 Kodachrome films proved even less stable than the previous generation of Process K-12 films (Kodachrome II and Kodachrome-X), which were introduced in 1961 and discontinued in 1974, having been replaced that year by the Process K-14 films Kodachrome 25 and Kodachrome 64.

Assuming that a slide receives at least some projection time, the fading that takes place during its lifetime will be some combination of projector-caused fading and dark fading. The fading of many slides in recent years has been incorrectly attributed to projection when the primary cause has actually been the poor dark fading stability of the film; this has been particularly true for slides made on unstable motion picture films (such as Eastman Color Print Film 5383 and earlier versions) which were prevalent in educational and slide library markets in the United States from the 1960's until about the end of 1983.

See page 213 for Recommendations

It should never be forgotten that an original color slide is a unique, one-of-a-kind photograph. Like an instant color print, there is no negative from which to make another slide should the original fade, be physically damaged, or be lost. Unless they make their own color prints — and have a firsthand appreciation for the exasperating problems that scratches and dirt cause on reversal prints — most photographers handle their color slides with far less care than they do their black-and-white and color negatives. Minor scratches, surface dirt, fingerprints, and other defects are not nearly as noticeable when slides are projected as they are when the slides are used to make prints for display or color separations for book or magazine reproduction.

For the typical amateur photographer, the projector-fading stability of current slide films appears to be adequate for the usually limited total times of projection; dark fading stability is generally the more important consideration for amateurs. On the other hand, picture agencies, academic slide libraries, teachers, and lecturers are likely to subject slides to repeated and extended projection: 5- to 10-minute projection periods each time a slide is shown are typical for academic art slide libraries, for instance.

Generally speaking, the more valuable a particular slide is, the more likely it is to receive repeated and extended projection. Most photojournalists and stock photographers have slides for which reproduction rights are sold over and over again, year after year. In the hands of editors and art directors, the accumulated projection time may quickly become sufficient to cause subtle losses of image quality — especially in the highlights — and eventually will result in serious image deterioration. Knowledge of the fading rates of slide films will enable the user to obtain projection duplicates before the fading of originals becomes objectionable.

Light (Not Heat) Is the Primary Cause of Color Slide Fading During Projection

It is primarily light that causes fading when a slide is projected. Because slide films are subjected to projection heat for relatively short durations, projection heat in itself contributes almost nothing to slide fading. For example, an Ektagraphic III projector has a film-gate temperature of about 130°F (55°C),[4] and accelerated dark fading data (see Chapter 5) indicate that no significant fading could

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The National Geographic Society in Washington, D.C., like many facilities with important commercial and publication slide collections, houses millions of 35mm color slides (at the time this book went to press in 1992, the Geographic's collection totaled nearly 11 million slides). Ferne Dame, head librarian, describes the Geographic's slide filing system to Klaus B. Hendriks, Director of the Conservation Research Division at the National Archives of Canada. Geographic staff members are urged to keep projection to a minimum — and to avoid exposing slides unnecessarily to light from illuminated editing tables and from room lights when slides sit uncovered on desks. To protect slides from fingerprints and scratching during editing and handling, all slides in the Geographic's working library are kept in Kimac transparent cellulose acetate sleeves.

take place at that temperature during the short total times normally associated with projection. If a slide were projected long enough for heat to have an effect, the resulting light fading would be so severe as to make the heat-induced dark fading inconsequential. High heat may, however, indirectly increase the rate of light fading,[5] and for this reason — as well as to minimize buckling of slides in open-frame cardboard or plastic mounts and to avoid physical damage to the film base and emulsion — projector cooling systems should be in proper working order, and the infrared-absorbing glass filter should never be removed.

There has been a trend in projector design during the past 20 years to increase the light intensity at the film plane while employing infrared-transmitting dichroic lamp reflectors and mirrors, heat-absorbing glass filters, and high-velocity cooling systems to control slide temperature. The introduction of the ELH quartz-halogen lamp in Kodak Carousel and Ektagraphic projectors in 1971 was a major step in this direction. The new 300-watt lamps and associated optical systems provided significantly more intense light at the film plane than did the previous 500-watt incandescent lamp — and, unfortunately, more rapid fading of slides as well. According to Kodak, the Ektagraphic III has an illumination intensity which is "25% more"[6] than previous Ektagraphic models E-2 through AF-2; in normal use this means that for any given degree of fading, slides will last about 25% longer when projected in the older model Ektagraphic projectors with ELH lamps, and about 30% longer in the older model Carousel projectors that also had ELH lamps but had uncoated condensers in their illumination systems, thereby somewhat reducing their light intensity compared with the Ektagraphic models. The Kodak Ektapro projectors introduced in 1992 provide an additional 10% increase in illumination intensity compared to that in Ektagraphic III projectors.

What Is the Useful Life of a Projected Slide?

Three factors determine how long a slide can be projected before objectionable fading takes place:

1. **The projector-fading characteristics of the particular slide film.** Current films vary a great deal in their

Recommendations

Color Slide Films

- **Fujichrome is best when significant projection of originals is anticipated or when an easily processed E-6 film is required.** During projection, Fujichrome is significantly more stable than any other slide film on the market. Ektachrome (including Ektachrome Plus and HC films, and the new Ektachrome 64T, 320T, 64X, 100X, and 400X films) is the second-choice recommendation. Fujichrome Velvia Professional Film, a very sharp, extremely fine-grain 50-speed film introduced in 1990, fades somewhat more rapidly during projection than other Fujichrome films, but Velvia nevertheless is still more stable than Ektachrome when projected.

- **Kodachrome is best when little or no projection of originals is expected.** In spite of Kodachrome's unequaled dark-storage dye stability and complete freedom from d-min stain, Kodachrome has the worst projector-fading stability of any color slide film currently on the market. Kodachrome is an excellent film if projection can be avoided; but if projection of originals is sometimes a must and time or money prevents routine duplication of originals — or if the complex and time-consuming processing required for Kodachrome is not available and a Process E-6 film is needed — Fujichrome is recommended.

- **Slide films to avoid:** In terms of overall image stability — when projector-fading stability and dark storage stability are considered together — both Agfachrome and 3M ScotchChrome films are inferior to both Fujichrome and Ektachrome films. And when visually compared with Fujichrome, Ektachrome, or Kodachrome, neither Agfachrome nor ScotchChrome distinguishes itself in terms of sharpness, grain structure, or color reproduction; this author can see no compelling reason to recommend their use. Polaroid PolaChrome instant color slides should be strictly avoided unless it is essential to have a quickly processed slide. PolaChrome slides have very poor image quality, the high base density of PolaChrome results in very dark screen images when the slides are projected, and the film suffers from various other practical shortcomings.

- **Duplicating films:** Fujichrome Duplicating Film CDU, which has the same projector-fading and dark-storage stability characteristics as regular Fujichrome camera films, is recommended for duplicating slides. For printing slides via internegatives, Fujicolor Positive Film LP 8816 is best. Also recommended is Eastman Color Print Film 5384. Agfa CP1 and CP2 color print films have very poor dark fading stability and should be avoided. Kodak Vericolor Slide Film 5072 has relatively poor dark fading stability and should also be avoided if possible. Ilford Ilfochrome (formerly Cibachrome) Micrographic film, which in dark storage is the world's only permanent color film, and also has relatively good projector-fading stability, is unfortunately not yet available in a version with sensitometry suitable for top-quality slide duplication.

Projection Guidelines

- Never forget that **original** color slides are one-of-a-kind color photographs and should be treated as such. As with daguerreotypes of the 1800's, there is no negative to go back to should an original slide fade, suffer physical damage, or become lost.

- Keep the projection time of original slides or nonreplaceable duplicates to a minimum. For general applications (with Kodak Ektagraphic, Ektapro, and Carousel projectors), the **total** accumulated projection time with Fujichrome should not exceed 5½ hours; with Fujichrome Velvia do not exceed 4 hours; with Ektachrome do not exceed 2½ hours; with Kodachrome do not exceed 1 hour. For particularly important slides — or when image quality is critical — much shorter total projection times should be adhered to (see **Table 6.1**). The accumulated projection time, not the length of a particular projection, is what is important. Lecturers who project certain slides repeatedly should be especially cautious. Project expendable duplicates whenever possible.

- It is the intense light of a projector that causes color image fading; under normal circumstances, projector heat in itself makes a negligible contribution to image fading. (The temperature at the projector film gate should never get so high that buckling, blistering, or other physical damage occurs, however.)

- Unless showing expendable duplicates, avoid high-intensity xenon-arc projectors.

- Glass mounts offer no protection against fading during projection; in fact, glass mounts may somewhat increase the rate of fading.

projector-fading rates (see **Figure 6.1**). Selection of a film usually cannot be based solely on its projector-fading rates; dark fading stability is more important in many applications. Film speed, granularity, sharpness, contrast and color reproduction characteristics, batch-to-batch uniformity, and ready availability of processing are also important considerations.

2. **The intended use of the slide and, subjectively, how much fading can be tolerated.** If the slide is intended only for projection, much greater fading can usually be tolerated than if the slide is needed for making color prints or for photomechanical reproduction. The pictorial content of a particular slide can also make a great difference in how much fading is acceptable — some types of scenes show fading much more readily than others. Projection of an original slide can, of course, be reduced or avoided by making expendable duplicates for everyday purposes.

3. **The type of slide projector and projector lamp.** With the exception of special high-intensity projectors, this

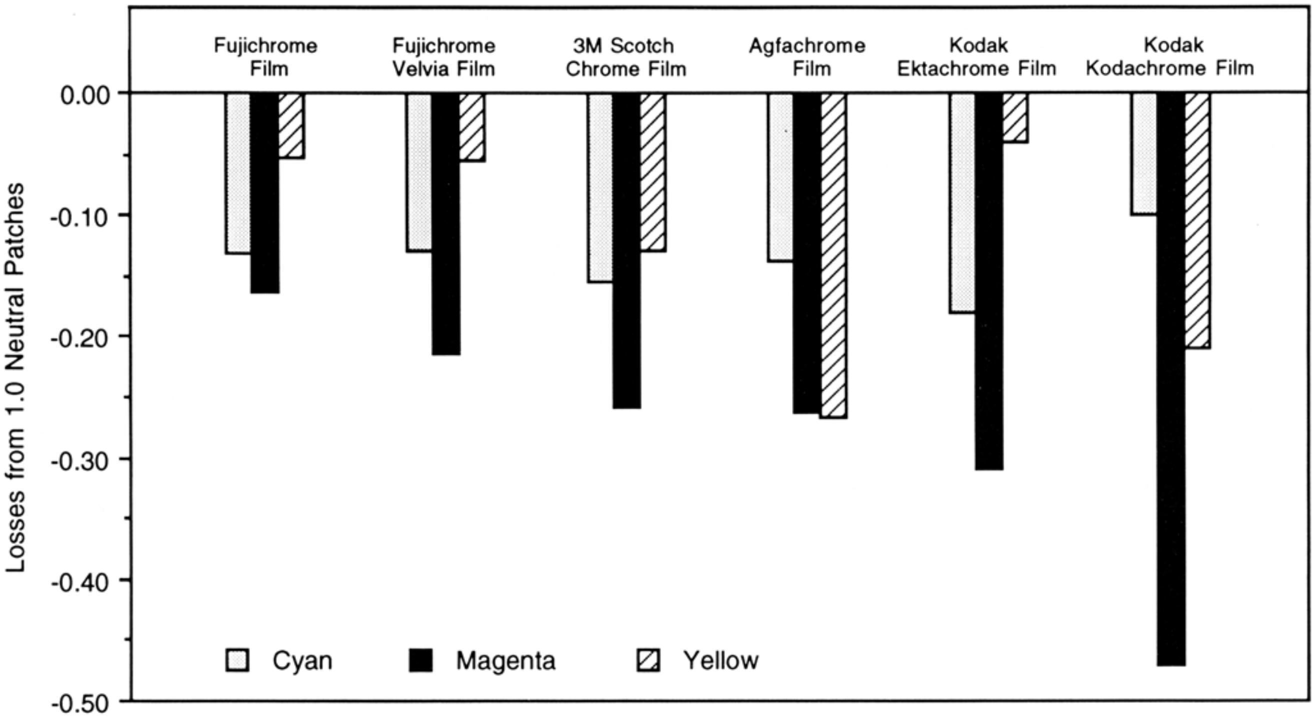

Figure 6.1 Fading of magenta dye from an initial neutral density of 1.0 in Fujichrome, Ektachrome, Kodachrome, Agfachrome, and 3M ScotchChrome films. With nearly all of these films, the magenta dye is less stable during projection than either the cyan or yellow dye. The very poor projector-fading stability of Kodachrome is obvious in this comparison.

is not usually as significant a variable as the other two factors listed here. There are important considerations related to the projector, however. For example, operating a Kodak Carousel, Ektagraphic, or Ektapro projector with the lamp-intensity switch in the "Low" position instead of "High" will slow the rate of fading by approximately 30%.

In **Figure 6.1** and other graphs that follow, it should be understood that changes indicated for cyan, magenta, and yellow dyes are actually changes in integral red, green, and blue densities, respectively, as measured by a densitometer. Red density refers to the amount of red light absorbed by the image and is determined primarily by the amount of cyan dye (which absorbs red light) present. Magenta dye primarily absorbs green light, and the amount of magenta present determines green density. Yellow dye absorbs blue light, and the amount of yellow dye (and yellow stain, if any) present determines blue density.[7] For ease of understanding by the reader who may not be familiar with photographic densitometry, this author has in general avoided reference to red, green, and blue densities and instead uses cyan, magenta, and yellow designations.

Methods of Evaluating Color Slide Fading

This author has developed two sets of criteria to be applied in the computer evaluation of fading and shifts in color balance that result from the projection of slides.[8] One set of criteria is for general amateur and commercial situations where prints are not typically made from the slides and where a fairly large amount of fading can usually be tolerated. For critical commercial and museum applications, a more stringent set of criteria has been chosen. The criteria and method of evaluation are discussed in more detail later.

In developing these criteria, slides made on a variety of films were projected in a Kodak Ektagraphic III projector for 30 seconds, six times each day (a total of 3 minutes a day) during a 140-day period in an attempt to simulate the intermittent short projections, spread out over many months or years, commonly experienced by slides. All of the *current* E-6 and Kodachrome films tested were processed by the Kodalux Processing Services Laboratory (formerly a Kodak Processing Laboratory) in Findlay, Ohio. Kodalux processing is believed to be representative of top-quality, replenished-line commercial processing and, for the purposes of this study, the films are assumed to have optimum image stability (see Chapter 5 for discussion of the influence of processing on image stability).

Older, now-discontinued films were processed by their respective manufacturers. Densitometric data accumulated during the course of the tests were then analyzed by special computer programs in terms of the two sets of criteria. The results of these tests are summarized in **Table 6.1**.

Several negative-positive print films for making slides from original negatives — or in large-quantity slide production from internegatives — are listed in **Table 6.2.** All of these films were exposed and processed by Stokes Imaging Services, Inc., Austin, Texas.[9] Ilford Ilfochrome Micrographic Film (called Cibachrome Micrographic Film,

(Continued on page 219)

Table 6.1 Comparative Stability of Projected Color Slide Films

Accumulated Times of Intermittent Projection in a Kodak Ektagraphic III Projector to Reach Specified Limits of Density Loss or Color Balance Shift

GE Type EXR Lamp – Projector on “High” Lamp Position – Slides in Open-Frame Mounts

Letters inside ( ) following projection time indicate first limit reached: C = cyan, M = magenta, Y = yellow. For example, (M–Y) means that the color-balance criterion between magenta and yellow was reached, with yellow fading more than magenta; (–C) means the cyan-dye fading limit was reached first. See Chapter 5 for data on the dark-storage stability of these films. Times for slides in Kodak Ektapro projectors are similar to those listed here.

Boldface Type indicates films that were being marketed in the U.S. and/or other countries when this book went to press in 1992; the other products listed had been either discontinued or replaced with newer materials.

Slide Film Type	General Commercial and Amateur Use	Critical Commercial and Museum Use
Fujichrome professional and amateur films, and Fujichrome duplicating films (for Fujichrome Velvia film, see below) (initial types: 1983–88/89) (improved types: 1988/89/92—) [see Note #1] (Process E-6)	**5 hr 20 min (–M)**	**2 hr 25 min (–M)**
Fujichrome Velvia Professional Film (ISO 50) (1990—) [see Note #2] (Process E-6)	**4 hr 45 min (–M)**	**1 hr 5 min (–M)**
3M ScotchChrome 100, 400, 800/3200, and 640T films **Polaroid Presentation Chrome Film** (1988—) 3M Scotch 640T Color Slide Film (1981–89) (although these films are labeled by 3M and Polaroid as “Made in U.S.A.,” they are actually manufactured in Italy by a 3M subsidiary) [see Note #3] (Process E-6)	**3 hr 30 min (–M)**	**1 hr 20 min (–M)**
Kodak High Speed Ektachrome Film Kodak High Speed Ektachrome Film Type B Kodak Ektachrome-X Film (1963–77) [see Note #4] (Process E-4)	3 hr 30 min (–M)	1 hr 10 min (–M)
Kodak Ektachrome Professional Film EP-120 (120-size transparencies) (1959–77) [see Note #5] (Process E-3)	3 hr (–M)	1 hr 10 min (–M)
Fujichrome 100 Film Fujichrome 400 Film (initial types: 1978–84) [see Note #6] (Process E-6)	2 hr 45 min (Y–M)	1 hr 45 min (Y–M)
Kodak Ektachrome professional and amateur films, and Ektachrome duplicating films (1976—) [see Note #7] (Process E-6)	**2 hr 40 min (–M)**	**1 hr 5 min (–M)**
Ektachrome 100 Plus Professional Film **Ektachrome 100HC, 50HC, and 400HC films** (100 Plus and HC: 1988—; 50HC: 1990—; 400HC: 1992—) **Ektachrome 64T, 320T, 64X, 100X, and 400X Professional films** (64X and 64T: 1991—; 100X: 1990—; 320T and 400X: 1992—) [see Note #8] (Process E-6)	**2 hr 40 min (–M)**	**1 hr 5 min (–M)**
Fujichrome R-100 Film (1968–73) [see Note #9] (Process E-4)	2 hr 15 min (–M)	1 hr 5 min (–M)
Konica Chrome R-50, R-100, R-200, and R-1000 films (1990—) (generally available only in Japan) [see Note #10] (Process E-6)	**(data not available for these films)**	

Slide Film Type	General Commercial and Amateur Use	Critical Commercial and Museum Use
Agfachrome RS 50, 50 Plus, 100, 100 Plus, 200, and 1000 professional and CT amateur films (improved types: 1988/92—) [see Note #11] (Process E-6)	**2 hr (C–M)**	**20 min (C–M)**
Agfachrome 64 and 100 films (1976–83) [see Note #12] (Process AP-41)	1 hr 35 min (–C)	50 min (–C)
Kodachrome II and Kodachrome-X films Kodachrome II Professional Type A Film (1961–74) [see Note #13] (Process K-12)	1 hr 20 min (C–M)	30 min (C–M)
Kodachrome 25, 64, and 200 professional and amateur films; Kodachrome 40 Type A (1974—) [see Note #14] (Process K-14)	**1 hr (C–M)**	**20 min (C–M)**
GAF 64, 200, and 500 films (1969–77) [see Note #15] (Process AR-1)	40 min (M–C)	25 min (M–C)
PolaChrome Instant Color Slide Film (1983—) [see Note #16] (instant process)	**(developed severe, irregular stains during test – not recommended for other than short-term applications)**	

Notes:

1. Only Fujichrome 50D and 100D Professional films were included in these tests; however, Fuji has indicated that all of the "new type" E-6 professional and amateur Fujichrome films, the first of which were introduced in early 1983, have similar projector-fading and dark fading stability characteristics. The films can be processed in Kodak Process E-6 or Fuji Process CR-56 (Fuji's equivalent to E-6). Fujichrome professional, amateur, and duplicating films are this author's primary recommendation for Process E-6 compatible films.

2. Fujichrome Velvia Professional Film is an ISO-50 Process E-6 (Fuji CR-56) film introduced in January 1990. Velvia is a high-saturation, very sharp, and extremely fine-grain film. The name Velvia was derived from the words "velvet" (smooth, long-scale, and very fine-grain tone reproduction) and "media" (the main market for Velvia is in commercial, advertising, and fashion photography intended for reproduction in printed media). The grain and sharpness characteristics of Velvia are better than Kodachrome 64 and, overall, are approximately equal to those of Kodachrome 25 film, which had long been considered the sharpest and finest-grain color slide film in the world.

3. Only 3M ScotchChrome 100 film was included in these tests; however, 3M ScotchChrome 400 and 800/3200 films probably have similar projector-fading stability. 3M ScotchChrome films formerly were called 3M Scotch Color Slide films; prior to that they were sold under the 3M ColorSlide name. In 1986 the name was changed to Scotch and the film packaging redesigned in an attempt to build stronger identification with the well-known 3M "Scotch" brand (e.g., Scotch tapes). The data given here are for the "improved type" films introduced in 1988. (At the time this book went to press in 1992, ScotchChrome 640T and 1000 films were still being sold. These films have projector-fading characteristics that are generally similar to the improved 1988 films; however, the 640T and 1000 films have inferior dark fading stability compared with the new films.) Polaroid Presentation Chrome film is a non-instant E-6 film made for Polaroid by 3M; Presentation Chrome is apparently identical to ScotchChrome 100 Film. Although labeled "Made in USA," 3M ScotchChrome and 3M Scotch Color Print films in reality are made in Ferrania, Italy by 3M Italia S.p.A. The films are only packaged in the U.S. 3M Italia is a subsidiary of the 3M Company, St. Paul, Minnesota. In spite of the relatively good projector-fading stability of 3M ScotchChrome films, they have comparatively poor dark fading stability and are not recommended. By the end of the 6-hour intermittent projection tests with 3M ScotchChrome 640T film, a "greasy" surface residue was observed on parts of the emulsion surface. The nature of this undesirable substance has not been identified, but it likely is coupler solvent or other emulsion addenda. The residue was not apparent on slides projected continuously for 6 hours. The exudation seems to be caused by the combined effects of intermittent projector light and projector heat. A similar-appearing surface residue was noted on Eastman Color Print Film 5384 slides after between 5 and 6 hours of intermittent projection (see Note #1 in Table 6.2).

4. High Speed Ektachrome Film was introduced in April 1959 as a Process E-2 160-speed film; it was converted to Process E-4 around 1966. Ektachrome-X, an ASA 64 film, was marketed in March 1963 as a replacement for the previous ASA 32 Ektachrome film. Although unknown to photographers at the time, these films had

much better dark fading stability than the Process E-3 Ektachrome Professional films widely used by professional photographers until 1977 (see Note #5), when the Process E-3 films were replaced by Process E-6 films (see Notes #7 and #8).

5. Introduced in 1959, Ektachrome Professional Process E-3 roll and sheet films have extremely poor dark fading stability — the worst of any transparency film tested by this author. Ektachrome Process E-3 120 roll film and sheet films were not supplied by Kodak in the 35mm format. However, the film was included in this study since transparencies made with it are sometimes projected using 120 slide projectors. The Process E-3 professional films replaced the original Process E-1 Ektachrome film introduced in 1946 (a tungsten-balanced Type B version was marketed in 1952). Ektachrome sheet films replaced Kodachrome sheet films that had far better dark fading stability, a fact of which Kodak was well aware but which was withheld from photographers. Process E-3 camera and duplicating films were in widespread use by commercial, advertising, and fashion photographers until the films were replaced with Process E-6 films. Perhaps surprisingly, the “amateur” Process E-4 Ektachrome films, available all through the 1960’s and 1970’s, were much superior to the “professional” Ektachrome films in terms of dark fading stability.

6. Introduced by Fuji in 1978, Fujichrome 100 and 400 films were used primarily by amateurs and had a relatively small market in the U.S. The films were replaced by “new type” E-6 compatible Fujichrome films in 1983.

7. Only Ektachrome Professional 50 Tungsten and Ektachrome 400 film were included in these tests. Kodak Publication CIS No. 50-45 (August 1982) and Kodak Publication E-106 (May 1988) indicate that these two films as well as other amateur and professional Process E-6 films (including Ektachrome 64, Ektachrome 160, Ektachrome 200, and Ektachrome Duplicating Films, but not including Ektachrome 100 Plus, Ektachrome “HC” films, and Ektachrome “X” films), have identical projector-fading and dark fading stability. Early versions of the Process E-6 Ektachrome films, introduced in 1976, were less stable in dark storage than later versions.

8. Introduced in February 1988, Ektachrome 100 Plus Professional Film has higher color saturation than Ektachrome 100 Professional Film and other older Ektachrome professional films. Ektachrome 100 HC film, also introduced in 1988, is the amateur counterpart of Ektachrome 100 Plus film. Ektachrome 50 HC film was introduced in 1990. Kodak has indicated that the earlier Ektachrome 100 Professional Film will continue to be sold. Ektachrome 64X (1991—), 100X (1990—), 400X, 400HC, 64T, and 320T (1992—) are “warm-balance,” high-saturation films with overall color and tone reproduction that are generally similar to those of Fujichrome films.

9. Fujichrome R-100 was a Process E-4 compatible film intended mostly for the amateur market; manufactured from 1968 to 1973, the film was never widely sold in the United States.

10. Konica Chrome “professional” color transparency films were introduced in late 1990. Konica has sold an ISO 100-speed transparency film in amateur markets in Japan and some other countries since 1976; this film has not been available in the U.S. and this author has not tested the film for projector-fading stability. The Konica Chrome “professional” films also are not available in the U.S. and had not been tested by this author at the time this book went to press in 1992. Unlike Kodak, Fuji, and Agfa — all of which have broad lines of both color negative and color transparency films — Konica has largely focused its efforts on color negative films and color negative papers.

11. Process E-6 compatible Agfachrome RS professional and CT amateur films were introduced by Agfa in 1984–85 as replacements for Agfachrome 64 and 100 films, which could be processed only in Agfa Process 41. The initial versions of the Agfachrome E-6 compatible films had poor dark fading stability. In March 1987 Ilford introduced Ilfochrome 50, 100, and 200 color slide films. These films were made for Ilford by Agfa-Gevaert and apparently were identical to Agfachrome films of the same ISO ratings. Ilford discontinued sale of the films in 1988. Like their Agfachrome counterparts, the Ilfochrome films had comparatively poor dark fading stability. Improved versions of Agfachrome RS and CT films with better dark fading stability were introduced in 1988.

12. Agfachrome 64 and 100 films were direct descendants of the original Agfacolor Neu transparency film introduced in 1936 (this was the world’s first incorporated coupler color film and was much simpler to process than the Kodachrome films introduced by Kodak a year earlier in 1935). Agfachrome 64 and 100 films could be processed only with Agfa Process 41; when the Kodak E-6 process came into almost universal use in the late 1970’s, the market for the Agfa films became ever more limited. Agfachrome 64 and 100 films have good dark fading stability in low-humidity conditions but fade rapidly in high-humidity accelerated tests. Agfa replaced the films with E-6 compatible Agfachrome RS and CT films beginning in 1984.

13. Process K-12 Kodachrome II Film and Kodachrome II Film, Type A [3400 K tungsten] were introduced in February 1961 as replacements for the modified Kodachrome films placed on the market in 1938. The original daylight Kodachrome 35mm film, introduced in September 1936, and Kodachrome Film, Type A, introduced in October 1936, had very poor dark fading stability, especially in terms of the yellow dye; both the film and processing technique were changed in 1938, and from that date all Kodachrome films have had comparatively good dark fading stability — in addition to almost complete freedom from stain formation. Kodachrome-X, a higher-speed version of Kodachrome II, was introduced in December 1962. The films were widely used by both professionals and amateurs.

14. Considered by Kodak primarily to be amateur slide films, Process K-14 Kodachrome 25 and 64 films were introduced in March 1974 as replacements for Process K-12 Kodachrome II and Kodachrome-X films. A Process K-14 version of Kodachrome 40 Film, Type A was marketed in January 1978. In response to numerous complaints by professional photographers about color balance irregularities and curve crossover problems of the amateur

Kodachrome 25 and 64 films, Kodak introduced Kodachrome 25 Professional Film (and special "professional" processing at Kodak labs) in 1983, and followed with Kodachrome 64 Professional Film in 1984. Kodachrome 200 Professional Film and a 120 roll-film version of Kodachrome 64 Professional Film were introduced in October 1986. All of the Process K-14 Kodachrome films have identical, poor projector-fading stability; but in dark storage Kodachrome films have outstanding dye stability and complete freedom from yellowish stain.

15. GAF 35mm slide and roll-film transparency films, which until 1969 had been sold under the Anscochrome name, were withdrawn from the market in 1977 when General Aniline and Film Corporation decided to abandon its photographic materials business. The GAF films had the worst projector-fading stability of any transparency film tested by this author. These films used the older "Agfa-type" couplers and, in common with other films of this type, have very poor stability in high-humidity accelerated dark fading tests. In low-humidity storage, however, the dark fading stability of these films appears to be reasonably good.

16. Polaroid PolaChrome instant color slide film, an ISO 40 film based on the antiquated additive-screen process, was introduced in 1983 (PolaChrome High Contrast film was introduced in 1987 for special applications such as photographs of graphs, charts, etc.). Intended for use in conventional 35mm cameras, PolaChrome films can be processed in about 1 minute with a small tabletop processing unit. During the course of these projector-fading tests, PolaChrome instant slides developed severe, irregular yellow stains; non-uniform staining of this type cannot be corrected by adjustments in color balance or exposure during duplication or printing and is one of the worst types of flaws a photographic product can have. Because of the stain problem, coupled with very poor stability in high-humidity accelerated dark fading tests, this film is not recommended for applications requiring other than short-term stability. Had the irregular yellow stains not occurred, PolaChrome film would have been given about a 6-hour projection life based on the "General Commercial and Amateur Use" criteria (with density measurements made in lesser-stained areas of the image). If one were to ignore the stain problem, the projector-fading stability of PolaChrome film is in a general way similar to that of Fujichrome film (it is difficult to compare directly the projector-fading stability of PolaChrome film with conventional films because PolaChrome has a very high base density, and a distinctly different manner of fading and staining).

Table 6.2 Comparative Stability of Projected Negative-Positive Slide Print Films and Ilford Ilfochrome Color Microfilm

Accumulated Times of Intermittent Projection in a Kodak Ektagraphic III Projector to Reach Specified Limits of Density Loss or Color Balance Shift

GE Type EXR Lamp – Projector on "High" Lamp Position – Slides in Open-Frame Mounts

Letters inside ( ) following projection time indicate first limit reached: C = cyan, M = magenta, Y = yellow. For example, (M–Y) means that the color-balance criterion between magenta and yellow was reached, with yellow fading more than magenta; (–C) means the cyan dye fading limit was reached first. See Chapter 5 for data on the dark-storage stability of these films. Times for slides in Kodak Ektapro projectors are similar to those listed here.

Boldface Type indicates films that were being marketed in the U.S. and/or other countries when this book went to press in 1992; the other products listed had been either discontinued or replaced with newer materials.

Film Type	General Commercial and Amateur Use	Critical Commercial and Museum Use
Ilford Ilfochrome Micrographic Film (called Ilford Cibachrome, 1984–1991) [see Note #1] (P-5 process)	**7 hr (–C)**	**1 hr 40 min (–M)**
Vericolor Slide Film 5072 [Eastman Kodak] (C-41 process)	**5 hr (–M)**	**1 hr 50 min (–M)**
Eastman Color Print Film 5384 (ECP-2A motion picture process) [Eastman Kodak] [see Note #2]	**4 hr 20 min (C–M)**	**3 hr 10 min (C–M)**
Eastman Color Print Film 5383 (ECP-2 motion picture process) [Eastman Kodak] [see Note #3]	3 hr 30 min (C–M)	2 hr 15 min (C–M)
Gevacolor Print Film 982 (ECP-2A motion picture process) [Agfa-Gevaert] [see Note #4]	2 hr 30 min (C–M)	1 hr 45 min (C–M)

Table 6.2 Notes:

1. Ilford Ilfochrome Micrographic films are manufactured in Fribourg, Switzerland by Ilford AG (a subsidiary of International Paper Company, headquartered in New York City). The films were introduced in 1984, and from that date until 1991 they were called Ilford Cibachrome Micrographic films. Ilfochrome Micrographic films, which utilize the silver dye-bleach color system, are made on a polyester base. In dark storage, the films are essentially permanent; they should last many hundreds of years without noticeable fading or staining. No other type of color film can even approach the dark storage stability of Ilfochrome Micrographic films. The films are supplied in two versions: Type M, a high-contrast film for copying reflection materials, and Type P, a moderate-contrast film for reproducing transparent originals and for use as a duplicating film. The films are processed by the user in Ilfochrome Process P-5. Ilfochrome Micrographic films are distributed in the U.S. by Microcolor International, Inc., 85 Godwin Avenue, Midland Park, New Jersey 07432; telephone: 201-445-3450. Microcolor also offers various micrographic services including processing of Ilfochrome Micrographic films.

2. Between the fifth and sixth hour of intermittent projection, the Eastman Color Print Film 5384 slide of a Macbeth ColorChecker was noted to have significant amounts of a "greasy" residue on the emulsion side of the film in sections of the high-density parts of the image; the residue probably became apparent prior to the fifth hour of projection, but was not noticed during routine densitometry during which only the base side of the film was visible to this author. The substance has not been identified, but it appears to be coupler solvent or other emulsion addenda. The residue, which smears easily when touched, would create problems with glass-mounted slides. To date, a similar residue has been seen only on 3M Scotch Color Slide 640T and 1000 films (see Note #3 in Table 6.1). The residue on 5384 was not observed in accelerated dark fading tests with the film; the residue seems to be caused by the combined effects of intermittent exposure to projection light and projection heat. Continuous projection for 6 hours did not produce the surface residue. Eastman Color Print Film 5384 was introduced in 1981–82 as a replacement for 5381 and 5383. Eastman 5384 is widely used as a slide print film by low-cost labs offering Eastman Color Negative Film 5247 and 5294 motion picture films respooled in 35mm cassettes for still cameras (use of these negative films in still camera applications is not recommended by this author). Eastman Color 5384 has much better dark fading stability than Vericolor Slide Film 5072, and this author recommends 5384 as a better film for making slides from color negatives, in spite of the projector-caused emulsion exudation observed with 5384.

3. Eastman Color Print Film 5383 has very poor dark fading stability and for this reason was not suitable for color slide production, although it was extensively used for this purpose. 5383 and a similar motion picture print film, 5381, were discontinued in 1983 and replaced by Eastman Color Print Film 5384, which has much better dark fading stability than 5383 and 5381 (see Note #2 above concerning 5384). Eastman Color 5383 was widely used as a slide print film by low-cost labs offering Eastman Color Negative Film 5247 motion picture film respooled in 35mm cassettes for still cameras. Both the negative and resulting slides have very poor dark fading stability.

4. The Gevacolor Print Film 982 in these tests (obtained in 1983) had very poor dark fading stability. In 1984 Agfa-Gevaert introduced a new version of Gevacolor Print Film 982 (the name of the product remained the same). This motion picture print film was replaced with Agfa CP1 print film in 1990 (which was supplemented with Agfa CP2 film in 1992). Information is not available on the projector-fading stability of CP1 and CP2 films, but it is probably similar to the discontinued 982 film tested here. Both CP1 and CP2 have very poor dark fading stability and should be avoided.

1984–91), a low-speed (about ISO 1), high-resolution silver dye-bleach color microfilm designed for copying maps and other documents but sometimes also used as a slide film and slide-duplicating film, was also included in this study because of its essentially permanent dark-storage characteristics. This film was processed by Microcolor International, Midland Park, New Jersey.[10]

Fujichrome Film: The Best Projector-Fading Stability of Any Color Slide Film

In terms of projector-caused fading, this author's tests showed clearly that Fujichrome films are the most stable slide films currently available. When projected, standard Fujichrome films were *twice* as stable as Ektachrome films and more than *five times* as stable as Kodachrome films. In this author's dark-storage tests, standard Fujichrome films and Ektachrome films had similar stability characteristics. Fujichrome Velvia Professional Film, a very sharp and extremely fine-grain 50-speed E-6 film introduced in 1990, is somewhat less stable when projected than standard Fujichrome; however, Velvia is significantly more stable than Ektachrome or Kodachrome. Current Agfachrome RS and CT professional and amateur films, although significantly improved compared with earlier Agfachrome E-6 films, are inferior to Fujichrome and Ektachrome in both projector-fading and in dark storage. (The dark fading characteristics of color transparency films are discussed in Chapter 5.)

For most photographers, Fujichrome and Kodachrome professional films should be the slide films of choice. Fujichrome is available in a comprehensive line of 35mm, 120 roll-film, and sheet-film formats, with ISO speeds from 50 to 1600; Fujichrome films can be processed easily by the user or by any lab offering E-6 processing. In the late 1980's many experienced professional photographers came to believe that Fujichrome films had generally better color saturation and more pleasing color and tone-scale reproduction than Kodak's analogous Ektachrome films. Thom O'Connor, writing in New York City's *Photo District News* in 1987, said: "Since their introduction in America just three years ago, Fujichrome Professional transparency films have significantly eroded both the professional sales and prestige of Kodak's Ektachrome and Kodachrome emulsions."

In the article, veteran *Time* magazine photographer Bill Pierce, a recent convert to Fujichrome, cited a number of reasons why he and many other top photojournalists had come to prefer the Fuji films:

> Fujichrome has a magical quality. Everywhere I've worked in the past few years, in or out of the country, photographers were using Fuji as an alternative to Ektachrome. Fuji is a warmer film, it's punchier, it has exciting colors, it makes skies majestically blue. Especially on overcast days, it delivers. In the beginning we all used Fuji for pictures that were important to us — of our kids and girlfriends — the pictures that we weren't being paid for. Now Fuji has become a bread-and-butter film.[11]

O'Connor reported, "[P]hotographers are switching from Kodachrome and Ektachrome not because of price differences, fancy packaging, or expensive ad campaigns, but because they simply feel Fujichrome gives better results."

> Photographers and editors at *Time, Playboy, Sports Illustrated,* and the *Los Angeles Times Sunday Magazine* have been favorably impressed by Fuji, and *USA Today* has gone so far as to recommend Fujichrome as the "film of choice" for staff and freelance photographers. "When we assign a photographer," explains Bob Deutsch, *USA Today* staff shooter based in New York, "we talk about Fuji as a film which is superior enough to Kodak to make it our choice. Fuji emphasizes the warm tones, and it's very good with blues outdoors. We prefer the 50-speed film, although I often use the 100-speed film for the extra bit of speed."

The 1988 introduction of Ektachrome 100 Plus Professional Film, and its Ektachrome 100 HC Film amateur counterpart, brought Kodak closer to Fujichrome in terms of color saturation. The "warm-balance" Ektachrome 64X, 64T, 100X, 320T, and 400X professional films introduced during 1990–92 were designed to compete directly with the high-saturation, somewhat "warm" color rendition of the Fujichrome professional films. While the color and tone-scale reproduction gap between Fujichrome and Ektachrome films has narrowed, and some photographers feel that the skin tone reproduction of Ektachrome 64X and 100X films is superior to that of Fujichrome films, the projector-fading stability of the new Ektachrome films has not been improved, and in this respect they remain markedly inferior to Fujichrome films. Where extensive projection might occur, and it is impractical to make expendable duplicates from originals for projection, Fujichrome films are the obvious choice.

In 1993 Kodak will introduce a new series of Ektachrome films that the company claims will have the best speed/grain ratio of any color transparency films in the world (presumably including Kodachrome and Fujichrome Velvia). It is of course possible that the new Ektachrome films also will have improved projector-fading characteristics when compared with that of current Ektachrome films, but no image stability data on the new films were available at the time this book went to press in 1992.

With the exception of a 120 roll-film version of Kodachrome 64 Professional Film, marketed in early 1987, Kodachrome films are currently available only in 35mm, with ISO speeds restricted to 25, 40 (tungsten balance), 64, and 200, and the complicated processing procedure can be carried out only by Kodalux labs and a very small number of commercial labs. Kodachrome 25, 40, and 64 films have very fine grain and excellent image sharpness, and Kodachrome films also have by far the best dark fading stability of any chromogenic color film — transparency or negative. But one must be very careful to restrict the projection of Kodachrome originals; duplicates, preferably on Fujichrome Duplicating Film, should be made when significant projection is a possibility.

With an Improved Magenta Dye, Kodachrome Could Have the Best Projector-Fading Stability of Any Color Slide Film

Kodachrome is unique among the world's chromogenic color films in that the dye-forming color couplers are in the developer solutions, and are not placed in the film itself during manufacture (see Chapter 1 for a description of the complex Kodachrome processing procedure). It should not be difficult for Kodak to design a new magenta coupler that would produce a magenta dye with better projector-fading stability. Given the good stability of the present cyan and yellow dyes, a sufficiently improved magenta would make Kodachrome the most stable of all color slide films when projected — and Kodachrome is already the most stable color film in the world when kept in the dark.

Apparently believing that Kodachrome was primarily an amateur product that was destined for eventual oblivion, Kodak has made no significant improvements in the Kodachrome K-14 process since it was introduced in 1974 — and this research and development neglect has taken its toll. No other color film in the world has gone for so long without significant improvement. In both color reproduction and projector-fading stability, Kodachrome has fallen behind Fujichrome, Ektachrome, and other E-6 films.

Short versus Long Projection Times

One important conclusion of this author's research is that — at least for Ektachrome, Kodachrome, Agfachrome, and PolaChrome films — much *more* fading is caused by projecting slides for short, intermittent periods than by long, continuous projections of an equivalent total projection time (as will be discussed later, fading of Fujichrome films is less variable under different projection conditions). Recognition of this slide projection "reciprocity failure" is crucial in developing meaningful projector-fading tests. This topic is discussed in more detail later.

Kodak and other film manufacturers have frequently advised that slides not be projected for "longer than one minute." This advice is apparently given in an attempt to restrict total projection time, but it has often been interpreted by photographers and other users of slides to mean that disproportionate damage is done by long projections. The most frequent explanation for this belief given to this author is that heat which "builds up" in the slide during long projection causes premature dye fading.

Glass Mounts versus Open-Frame Mounts

Kodak Ektachrome 50 Tungsten and Kodachrome 25 films were tested in conventional open-frame plastic mounts and in a modern type of plastic-framed glass mount.[12] After 6 hours of intermittent 30-second projections, both types of film appeared to have faded slightly more in the glass mounts (see **Figure 6.2**). The differences in fading between the glass and open-frame mounts were so small as to be within the range of experimental error and are an insignificant factor in deciding which type of mount to use. What was clear, however, was that glass mounts did not *increase* the life of the color image, as has sometimes been suggested. Other types of films possibly may respond differently to projection if they are in glass mounts, and films stored in either a higher or lower relative humidity than the 60% chosen for these tests may also show dissimilar results. The length of each projection and the time interval between projections are probably significant variables. Polyester-tape-sealed glass mounts of the type advocated by Christine L. Sundt of the University of Oregon at Eugene were not included in this study because of the lengthy test periods required to accurately evaluate this type of semi-sealed slide mount.[13]

Visual Characteristics of Projector-Faded Color Slide Images

When a color slide image fades in a projector, it loses density; undergoes a shift in color balance because of unequal fading rates of the cyan, magenta, and yellow image dyes; and in some cases develops objectionable yellow stains which are most apparent in the highlight areas of the image. In contrast to dark fading, which is characterized by a more or less equal percentage loss of density throughout the density range, the visual effects of light fading are very much concentrated in the lower-density portions of the image. The percentage losses of green density (represented mostly by magenta dye) throughout the density range of a Kodachrome 64 slide after 1 and 6 hours of intermittent projection are illustrated in **Table 6.3**. The disproportionate loss of image dyes in low densities is a characteristic of light fading (and of projector-fading of transparencies) that is recognized in the new *ANSI IT9.9-1990, American National Standard for Imaging Media – Stability of Color Photographic Images – Methods for Measuring.*[14] The topic is discussed in Annex A of the Standard.

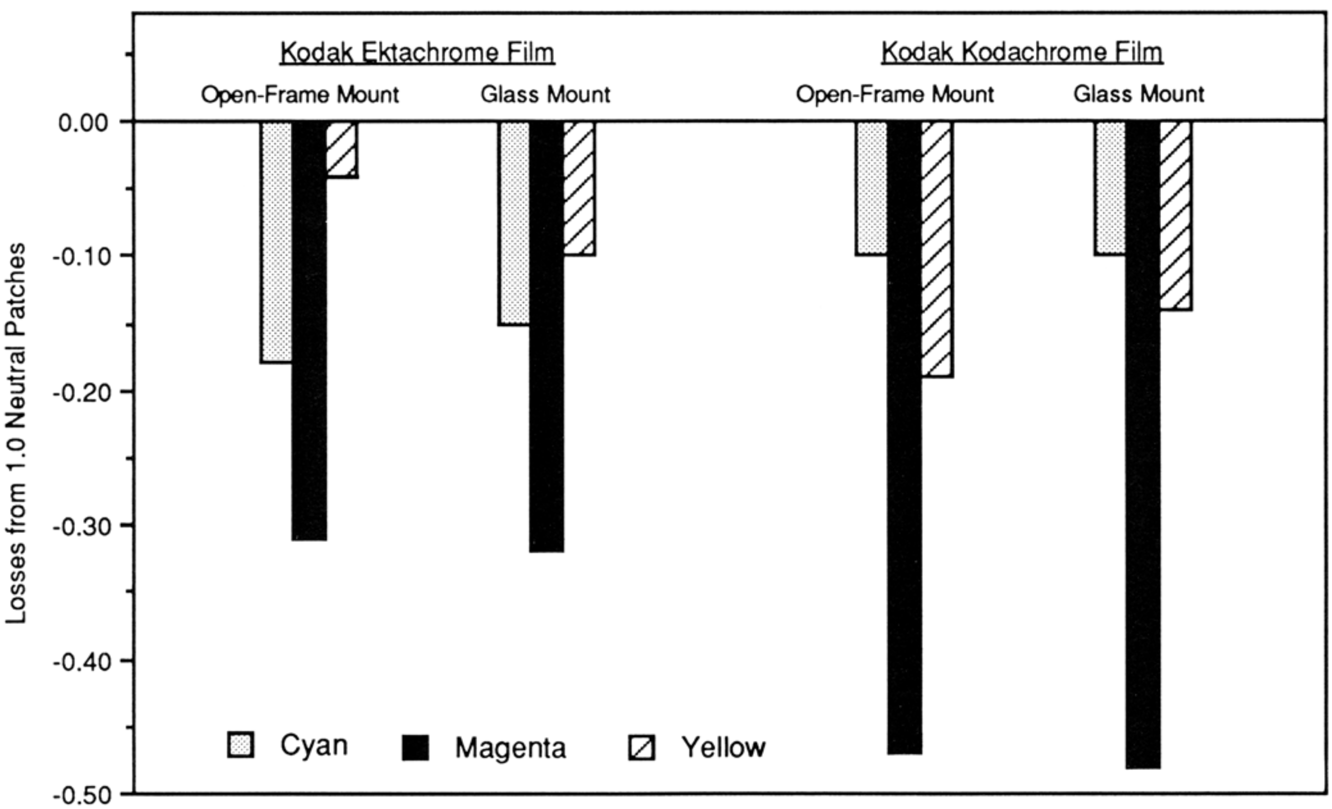

Figure 6.2 Comparison of fading of Ektachrome and Kodachrome slides in glass mounts and open-frame mounts during intermittent projection. With both films, slightly greater fading took place in the glass-mounted slides.

Table 6.3 Percentage Losses of Green Density (Magenta Dye) in Kodachrome 64 Film as a Result of Fading in a Kodak Ektagraphic III Projector – GE Type EXR Lamp

Six 30-Second Projections Per Day — Slide Kept in Dark at 75°F (24°C) and 60% RH Between Projections
Neutral-Gray Patches (Base + Fog Density = 0.18)

Density at Start	Loss After 1 Hour	% Loss	% Loss Minus Base + Fog	Density at Start	Loss After 6 Hours	% Loss	% Loss Minus Base + Fog
0.25	–0.08	–32%	–100%	0.25	–0.16	–64%	–100%
0.35	–0.11	–31%	–65%	0.35	–0.23	–66%	–100%
0.45	–0.11	–24%	–41%	0.45	–0.29	–64%	–100%
0.6	–0.11	–18%	–26%	0.60	–0.37	–62%	–88%
1.0	–0.10	–10%	–12%	1.00	–0.47	–47%	–57%
1.5	–0.09	–6%	–7%	1.50	–0.56	–36%	–42%
2.0	–0.07	–4%	–4%	2.00	–0.54	–27%	–30%
2.5	–0.06	–2%	–3%	2.50	–0.53	–21%	–23%
3.0	–0.06	–2%	–2%	3.00	–0.53	–18%	–19%

Note: These integral green-density values were computer-interpolated based on data from a 10-step gray scale with a minimum density of 0.21 and a maximum of 3.30. Measurements were made with a Macbeth TR924 densitometer equipped with Status A filters.

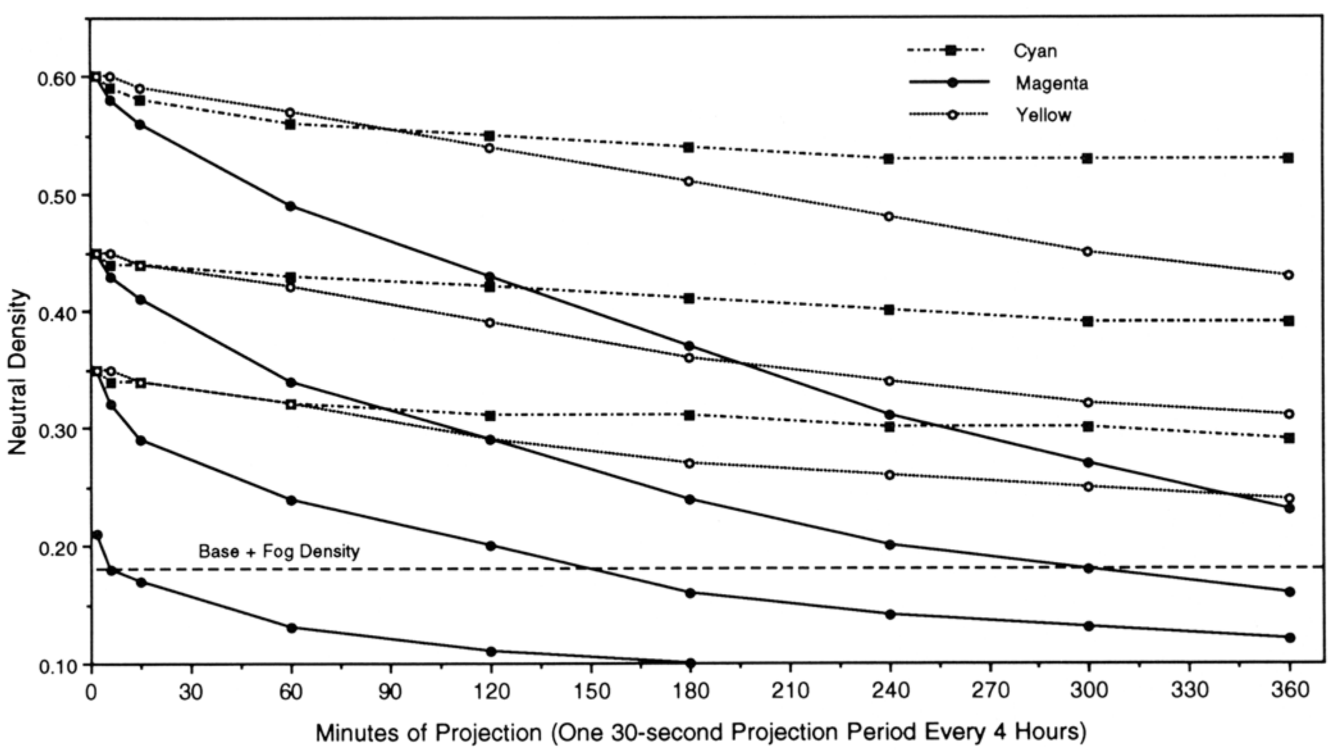

Figure 6.3 Fading of the magenta dye at selected lower densities in a projected Kodachrome slide. For clarity, the yellow and cyan curves in this graph have been omitted at the lowest density. The disproportionate fading of the magenta dye causes a marked color shift toward green. In the low, highlight, and near-highlight densities, even a relatively short projection time can result in a **total** loss of the magenta image.

In projector-caused fading of Kodachrome films, the magenta dye is significantly less stable than either the cyan or yellow dyes. As fading of the image progresses, ever more serious color-balance shifts toward green, coupled with a loss of detail, occur in low-density and highlight regions of the color image; the color shifts cannot be corrected by means of filter adjustments during printing without causing undesirable color changes in higher-density parts of the image.

Figure 6.3 shows the progression of fading of Kodachrome 64 starting at an original neutral density of 0.6 and three lower densities. As can be seen, the lower green densities fade very quickly to the base + fog level of about 0.18 (at which point the image detail contained in the magenta dye layer is entirely lost). The base + fog density of most color images consists of the optical density of the film base (typically about 0.05) with the remainder composed of a dye "fog," perhaps with a small of amount of residual sensitizer dye or other stain. The base + fog density of a particular product is considered to be the d-min (minimum density). The dye present in the d-min is of course subject to light fading just like the image itself, and this is why projector-caused fading often results in a density that is less than the original d-min.

At an original density of 0.35, a little over 2 hours of projection is required for the green density of a Kodachrome slide to reach the base + fog level; most slides have important parts of the image with a density of 0.35 or less. At 0.25, in the highlight region, only about 45 minutes of projection is required to reach the base + fog level! The extreme color-balance shifts toward green that occur in the lower densities as Kodachrome progressively fades are readily apparent from the curves in **Figure 6.3**.

How visually obvious these defects are depends not only on how much fading has taken place in all three image dyes but also to a very significant degree on the nature of the image. Scenes with large low-density areas show this effect much more than high-contrast scenes which consist mostly of medium- and high-density areas. A beach scene with large areas of light sand and a gray, overcast sky along with darker areas of muted colors would be particularly sensitive to projector-caused fading. A portrait of a person with light brown or blonde hair may show a shift in color in the lighter portions of the hair, which can be very obvious when compared with the hair in darker areas. Because of the poor stability of the magenta dye versus the cyan dye, Kodachrome films are particularly susceptible to this type of fading.

When slides are viewed in a dark surround, the eye can adapt to shifts in color balance much more readily than is the case when color prints are viewed in a normally lighted room. With many types of scenes, fairly substantial fading and color shifts can take place in a projected slide without the viewer thinking anything is wrong with the image — unless an unfaded image is projected next to or immediately after the faded one. A slightly pink sky in a Kodachrome slide can very quickly shift to a neutral sky — and later to a slightly green sky — as a result of projector-caused fading. If the viewer did not know what the sky looked like in the original slide, this major change in the appearance of the image would probably not be noticed. Multi-image slide shows, in which two or more projectors are operated simultaneously so that images are projected next to each other, or even in edge-to-edge contact, can clearly reveal even slight shifts in color balance in similar scenes.

Low-density color shifts due to moderate projector-caused fading can be partially corrected in the course of duplication or printing by filtration. The appearance of a duplicate made from a faded Kodachrome slide can almost always be improved in this manner, but the image will still suffer from loss of highlight detail. If the best correction is selected for lower mid-tone portions of the image, both lighter and darker portions of the image will continue to have color imbalances — the highlights will be shifted to magenta and the higher-density image areas will have a greenish cast. Once lost through projector-caused fading, highlight detail cannot be restored. Because of this, corrective duplication using contrast-adjusting masks for the faded dyes, such as the procedures suggested by Edwin Wiitala of Eastman Kodak for dark-faded transparencies,[15] has only limited effectiveness with light-faded images.

In the hands of a skilled operator, better success might be had with electronic digital image-processing equipment such as Apple Macintosh computers running Adobe Photoshop, the Kodak Premier Image Enhancement System, or the Agfa Digital Slide Printer. In general, however, restoration of transparencies that suffer from serious light fading is much more problematic than restoration of dark faded transparencies. The general impression one gets from projector-faded images of most slide films is a highlight and mid-tone color shift — with most current films the shift is toward green because the magenta dye fades more rapidly than either the cyan or yellow dyes. With some exceptions, the magenta dyes in chromogenic films and prints have historically had inferior light fading stability compared with cyan and yellow dyes; however, magenta dyes in most products have much better dark fading stability than the other two dyes.

But progress is being made. The second-generation Fujichrome E-6 compatible films introduced in 1983, and improved in 1988, show better retention of neutral color balance in critical lower densities during the course of projector-caused fading compared with any of the Kodak camera slide films on the market at the time this book went to press in 1992. The Process E-6 compatible Agfachrome films introduced in 1984–85, and improved in 1988 and 1992, have greatly improved projector-fading characteristics compared with previous Agfachrome films; nevertheless, they are still not as stable as Fujichrome and Ektachrome films when projected. Correctly exposed or slightly overexposed slides show the effects of fading more readily than darker (underexposed) slides; the overexposed slide has a greater portion of the image contained in the low-density portions of the curve. For best photographic results, of course, slides should be correctly exposed — this is especially important if prints are to be made.

Criteria for Color Balance Shift and Loss of Density

Two sets of image-deterioration criteria were used in this study.[16] One set allows a fairly large degree of fading and color balance shift to occur before the limits are reached and is intended for general use where it is not normal practice to make prints from slides. The other set of criteria specifies much less density loss and smaller deviations in color balance; it is intended for critical commercial and museum applications.

General Commercial and Amateur Use

For general commercial and amateur applications, projected color slides will be considered to have faded an objectionable amount when the *first* limit (end point) has been reached in any of the following image-life criteria, as determined from changes measured in gray-scale densities of 0.6 and 1.0:

Loss of cyan dye (red density) 25%

Loss of magenta dye (green density) 20%

Loss of yellow dye (blue density) 35%

Color imbalance between cyan dye (red density)
and [minus] magenta dye (green density) 12%

Color imbalance between magenta dye (green density)
and [minus] cyan dye (red density) 15%

Color imbalance between cyan dye (red density)
and [plus or minus] yellow dye (blue density) 18%

Color imbalance between magenta dye (green density)
and [plus or minus] yellow dye (blue density) 18%

Critical Commercial and Museum Use

For critical commercial and museum applications, projected color slides will be considered to have faded an objectionable amount when the *first* limit (end point) has been reached in any of the following image-life criteria, as determined from changes measured in gray-scale densities of 0.45 and 1.0:

Loss of cyan dye (red density) 15%

Loss of magenta dye (green density) 12%

Loss of yellow dye (blue density) 20%

Color imbalance between cyan dye (red density)
and [minus] magenta dye (green density) 8%

Color imbalance between magenta dye (green density)
and [minus] cyan dye (red density) 10%

Color imbalance between cyan dye (red density)
and [plus or minus] yellow dye (blue density) 15%

Color imbalance between magenta dye (green density)
and [plus or minus] yellow dye (blue density) 15%

Since 0.45 density was selected as the primary measurement point in the "Critical" set of criteria, the difference between the "General" and "Critical" sets of criteria is greater than might be supposed. Because 0.45 is further down the density scale than 0.6, the effect of any given density loss or color imbalance is — percentage-wise — magnified. The data in **Table 6.1** indicate that while the relationship of the fading times with the two sets of criteria varies among the various films, the "General" criteria typically allow projection two to three times longer than the "Critical" criteria.

Although changes in near-minimum-density areas (the lowest density, or "clear" gray-scale patch) were measured, with most of these film samples the areas were not true minimum densities and thus could not be used for "stain-correction" of the fading data for determining absolute density loss, such as was done with the analysis of light-faded color prints in Chapter 3 and with the accelerated dark fading of films and prints in Chapter 5. In the case of the slide films tested here, stain-correction of the data would probably have made little if any difference in the results. None of the films was yellow-dye-limited (it is with yellow-dye fading that stain formation usually has the most effect), and in any event it is this author's practice *not* to stain-correct data used for color-balance analysis.

A further complication with the stain-correction of data from projected slides is that whatever stain that does take place frequently will be obscured by fading of the relatively high d-min fog levels characteristic of most reversal films. It was also apparent that stain growth in higher-density image areas of Ektachrome and a number of other films was not correctly reflected by d-min changes.

Pure cyan, magenta, and yellow color patches were also measured, but changes in these areas were not included in the criteria limits because this author felt that much more study of a variety of faded pictorial scenes — with slides made on a variety of films — was needed to assign meaningful limits to each of the three image dyes. In most cases, separate magenta and yellow areas faded faster in projection than did the three dyes when combined to form a neutral gray; this is because of the protective effect of one layer on another.

With most films, the cyan layer is coated on the bottom next to the film base, and in projection the cyan dye to a certain extent shields the magenta and yellow dye layers from the light of projection. From looking at many projector-faded slides, it is apparent that the significance of the more rapid fading of the dyes that can take place when they are in separate color patches is *very* dependent on the scene.

This author believes that the sets of criteria given here, which concern only changes in neutral density, are a good reflection of the overall visual changes that take place when slides with typical scenes are projected. Had pure cyan, magenta, and yellow color patches been included in the analysis, the indicated projection times before the first limit was reached would probably have been shortened for some of the films, but in most cases the stability rankings of the various films would have been the same. For example, no realistic method of analysis could rank Ektachrome as being more stable than Fujichrome in projector-caused fading.

Study by this author of many faded slides and color prints clearly demonstrated that the eye is most sensitive to changes in color balance along the magenta/green axis

— this is especially true in near-neutral colors and in the colors of human flesh-tone reproduction. Changes in cyan/red are somewhat less critical in most scenes, and most people are quite tolerant of color shifts along the yellow/blue axis, especially if the direction of change is toward yellow. Yellow dye principally influences the yellow/blue hue of the image and contributes very little to the rendition of image detail and the impression of image contrast — or the sense of light and dark in a scene. Another reason for the acceptance of an excess of yellow, especially in low-density image areas, is that paper, oil paintings, wood, and many other materials gradually yellow with age. Yellowing is thus a key characteristic of what is often referred to as "the patina of age." North American Caucasians often express a preference for a decided excess of yellow — and, to a lesser extent, excess magenta — in the color balance of their portraits. This is the "healthy tanned look."

Both sets of fading criteria give different, weighted values to the cyan, magenta, and yellow image dyes to reflect typical visual responses. The criteria chosen here for slides are this author's attempt to take into account the observed disproportionately rapid low-density and highlight-detail fading due to projection. Various individuals have distinctly different responses to the effects of color fading; in addition, the perception of fading is also highly dependent on the pictorial content of a particular photograph. Much more study needs to be done concerning visual responses to faded slides — both projected in a dark surround and used to make reflection prints.

Since photographers, museum curators, and other visually oriented people are the most likely to be concerned with color stability, the studies should focus on these groups of slide users. Casual observation indicates that the general public usually has a less rigorous notion of what good photographic quality is. However, it has been this author's experience that the average person can be quite discriminating when comparing an even slightly faded print with the same picture in its original state. The fact that a person may accept as adequate a significantly faded picture if no comparison is available may be more an indication of limited familiarity with carefully printed color photographs than it is an indication of lack of visual discrimination. Presented with a selection of color prints of varying quality, the average person's opinions about which prints look the best are usually similar to the views expressed by experienced photographers.

Some people may feel that the criteria given here are too strict and that for general purposes — where the information content of a slide is usually more important than aesthetics and precise color and tone reproduction — significantly more fading can be tolerated. On the other hand, some photographers — especially those who are more concerned with how prints or published reproductions look than they are with the appearance of projected slides — may feel that in at least some respects even the set of criteria intended for critical commercial and museum use is not strict enough.

Indeed, a slide with important areas of the image in the 0.20 to 0.35 density range may exhibit obvious changes in the color balance and density of these low-density areas before it has been projected long enough to reach one or more of the limits specified in this author's "Critical" set of criteria. In the fine art field and other areas of photography that have very high standards for print color and tone reproduction — and where a slide may be printed repeatedly over the years — it would be wise to adopt a policy of *never* projecting originals, especially Kodachrome slides.

Because of the vagaries of a particular emulsion batch of film, exposure conditions, and/or processing of the film, a transparency may be only barely acceptable even in an unfaded condition. If projector-caused fading results in accentuating these defects, only a very short projection time may be needed to push the image past acceptable limits. For example, some of the "amateur" Kodachrome film used by this author in preparing samples for these tests had distinctly low magenta-dye-layer contrast after it was processed by Kodak, resulting in a pronounced green color balance. Projector-caused fading only accentuated the problem. In fact, one could argue that the greater the film/processing/exposure variations experienced with a particular type of slide film, the more strict the fading criteria should be in order to avoid ending up with unacceptable color images.

Unless projector-caused fading of a slide becomes severe, the overall impression of its *brightness* on the screen changes very little. Based on the "General" criteria given here, the increase in projected brightness of a faded slide that has reached the specified limits would typically be equivalent to less than a one *f*-stop increase in camera exposure. A slide that has reached the stricter commercial and museum limits would typically be equivalent to less than a one-half *f*-stop increase in exposure. The fact that the faded image as a whole does not appear to have lost much density can easily obscure the much more significant changes that have taken place in low-density and highlight areas of the image.

While this author's two sets of criteria were arrived at after study of many slides and prints with known amounts of fading and are offered in good faith without bias for or against any particular product, other individuals may have different opinions about the relative values assigned to each dye, the permissible color-balance deviations, and the overall amount of fading that can be tolerated. Whether or not a print is to be made from a slide — or if it is to be reproduced in a magazine or other publication — is an important consideration in any discussion of slide fading. As stated previously, slides that will be used only for projection generally can tolerate much more fading than those that will be reproduced in print form.

Despite the subjective nature of any determination of "acceptable limits of fading," a well-thought-out set of criteria can be effectively employed to *compare* the stability of the various slide films marketed now and in the past. The criteria given here, and the computer programs with which the data were analyzed, are to a significant extent unaffected by inherent color and contrast imbalances within the range found in the films that were tested. This author was indeed surprised by the great irregularities in sensitometric characteristics of most of the films (and in manufacturers' processing); as might be expected, the professional films were much better in terms of consistency and neutral color balance than amateur films. The computer programs and methods of data analysis are discussed in Chapter 2.

Table 6.4 Projector-Fading and Dark Fading Stability Data Supplied by Eastman Kodak to the Dunlap Society in Washington, D.C. in 1975

Kind of Film	If Kept in the Dark the Color Should Be Stable for. . . .	If Projected for 15 Seconds with a Tungsten-Halogen Bulb, the Color Should Not Change Until Projected. . . .
Kodachrome Film [Process K-14]	50+ years	250–500 times [1 hr 2 min to 2 hr 5 min]
Ektachrome Slide Duplicating Film 5071 [Process E-6]	at least 10–20 years perhaps 20–50 years	300–500 times [1 hr 15 min to 3 hr 8 min]
Ektachrome-X Film [Process E-4]	10–20 years	375–1000 times [1 hr 34 min to 4 hr 10 min]
Kodacolor Slide Print Film 5028 [Process C-41]	5–10 years	500–1000 times [2 hr 5 min to 4 hr 10 min]
Ektachrome Slide Duplicating Film 5038 [Process E-4]	5–10 years	300–750 times [1 hr 15 min to 3 hr 8 min]
Eastman Color Motion Picture Print Film 5381 [Process ECP-1]	5 years	400–800 times [1 hr 40 min to 3 hr 20 min]

Eastman Kodak's Recommendations for Slide Projection

Kodak has published relatively little on the projection life of color slides. Part of the reason for this is that most amateurs do not project their slides enough to cause objectionable fading, and the company has probably received few complaints about projector-caused fading. In recent years the popularity of slides among amateurs has sharply declined, with most people now showing a strong preference for color prints made from color negatives. However, during the last decade, slide use has grown considerably in the audiovisual area, where slide presentations are frequently employed for education and training purposes and to accompany talks at meetings and conferences. Slides have been consistently preferred in the photojournalism, commercial, and advertising fields — where they are often subjected to repeated and prolonged projection.

The March 1973 edition of Kodak publication E-30, *Storage and Care of Kodak Color Films,* stated:

> The projection life of a color slide depends on the amount of light and heat from the projection lamp falling on the slide and upon the total projection time. Prolonged projection with high-wattage lamps or arc lamps will shorten the life of, and may even distort, the transparencies. Avoid projection times longer than one minute. If long projection times are unavoidable, make duplicate slides of the original and use them for projection purposes.[17]

In common with other Kodak publications of the period, no specific information about the projector-fading or dark fading stability of the company's various films was given.

In the January 1976 edition of *Storage and Care of Kodak Color Films,* Kodak's policy was changed somewhat and this information was offered:

> The dye images most stable to light are those in slides made on Kodak Ektacolor Slide Film 5028, Kodak Ektachrome Duplicating Film 5038, and Kodak Ektachrome Films. Slides made on Kodachrome Film are somewhat less stable, but may be expected to withstand 250 to 500 15-second projections (one projection per minute) in non-arc slide projectors before significant dye fading results.[18]

The Kodak figures of 250 to 500 15-second projections amount to 1 hour 2 minutes to 2 hours 5 minutes total projection time.

In 1975, a researcher in color stability at Kodak supplied the Dunlap Society, an archive and producer of American art and architecture slides and microfiche, with the dark fading and projector-fading characteristics of certain Kodak films the Society was considering for production of slide sets (see **Table 6.4**). This information included the same figures given above for projection life of Kodachrome film, and "300 to 750 15-second projections" (1 hour 15 minutes to 3 hours 8 minutes) for the then-new Process E-6 Ektachrome Slide Duplicating Film 5071. This latter estimate was not contained in any regular Kodak publication,

Table 6.5 Variations in Projector Lamp Intensity

Intensities of various lamps measured with a Minolta Illuminance Meter, 10 feet from front of lens (Kodak Ektanar C Lens, 127mm, f2.8) of Kodak Ektagraphic III AT projector. Open-frame slide mount (without film) in projector film gate; measurements made in center of frame. Equipment was not available to measure lamp intensities directly in projector film gate. Lamps allowed to stabilize about 20 seconds before measurements were made.

General Electric EXR Lamps	
1) 2,560 lux	
2) 2,690 lux	Average: 2,678 lux
3) 2,640 lux	Difference between brightest lamp and average: 8.3%
4) 2,700 lux	
5) 2,560 lux	Difference between dimmest and brightest lamps: 12.3%
6) 2,920 lux	
Sylvania EXR Lamps	
1) 2,410 lux	Average: 2,425 lux
2) 2,440 lux	
General Electric EXW Lamp	
1) 3,080 lux	
General Electric EXY Lamp	
1) 1,740 lux	

however, and was seen by few people outside of the specialized art and architecture slide library field.

Extracting this information from Kodak was a major breakthrough on the part of the Dunlap Society. According to the Society's Isabel Lowery, who obtained the data from Kodak, "We didn't want to repeat the Sandak fiasco and have all our slides turn pink."[19] Lowery was referring to the millions of slides, printed on Eastman Color Print Film (a motion picture print film), that suffered catastrophic cyan and yellow dye loss only a few years after they had been sold by Sandak, Inc. to art slide libraries and other collections all over the world.

Lowery said that when she called Kodak with questions about the stability of various films, she received only vague and generalized cautions about color fading. But the customer service representative she talked to "let slip" the name of a man at the company who worked in research and who "knew about color fading." She called him directly and he supplied her with the information given in **Table 6.4**. Based on this, the Dunlap Society selected Ektachrome Slide Duplicating Film 5071 for making distribution copies of the original slides in its archive. At the time, the Society was about to embark on a major slide-production program funded by the National Endowment for the Humanities; this was one of the initial activities of the Society's Visual Documentation Program.

In the 1977 and 1984 editions of *The Sourcebook – Kodak Ektagraphic Slide Projectors,* Kodak said:

> For most viewing purposes, pictorial slides made on properly processed Kodak Color Films will be acceptable through 3 to 4 hours of total projection time. This is true when the slides are used in an Ektagraphic or Carousel Slide Projector that is equipped with a tungsten-filament lamp and has unrestricted air circulation, even if the projector is operating with the selector switch set at HIGH.[20,21]

Surprisingly, in this publication Kodak did not distinguish between Kodachrome and Ektachrome slides in terms of projector-caused fading.

More recently Kodak has stopped publishing specific recommendations for "acceptable" projection times. Beginning in early 1982, in answer to individual requests to the company, Kodak started releasing data in the form of graphs showing density loss as a function of projection time for the common slide and print films for still cameras.[22] At first these sheets were accompanied with color prints showing the visual effects of projector-fading and accelerated dark fading tests. About a year later, these prints were discontinued. The graphs are based on one 15-second projection in a Kodak Carousel Projector every 20 minutes; data for up to 720 projections (3 hours total exposure time) are given.

A Kodak spokesman has indicated that the company receives very few requests for this information. This perhaps is not surprising in view of the fact that the company has, to this author's knowledge, never announced the availability of the stability data sheets in any Kodak publication, and they are not listed in the Kodak publications catalog. Very few photographers and archivists were aware that the sheets existed.

In 1988 Kodak quietly published new image-stability data sheets for Ektachrome (not including Ektachrome Plus, HC or X films)[23] and Kodachrome,[24] but as was the case with the data sheets published in 1982, these new publications were not announced and they saw little circulation.

Kodak has apparently decided to publicly minimize the rather large differences between Kodachrome and Ektachrome films in terms of projector-fading stability; and the recommendation on the permissible projection time for Kodachrome film given in the 1976 edition of Kodak Publication E-30, *Storage and Care of Kodak Color Films,* has been dropped in recent editions of E-30 (now entitled *Storage and Care of Kodak Color Materials,* because of the addition of some information on the care of color prints). In the December 1980 edition of E-30, Kodak stated only that "Ektachrome Films . . . withstand the effects of light better than Kodachrome Films." In the May 1982 edition of the same publication, Kodak watered this down a bit further and changed the sentence to read: "Ektachrome Films . . . withstand the effects of light somewhat better than Kodachrome Films."

In 1984, Kodak took the matter of the comparative projector-fading rates of different types of slide films such as

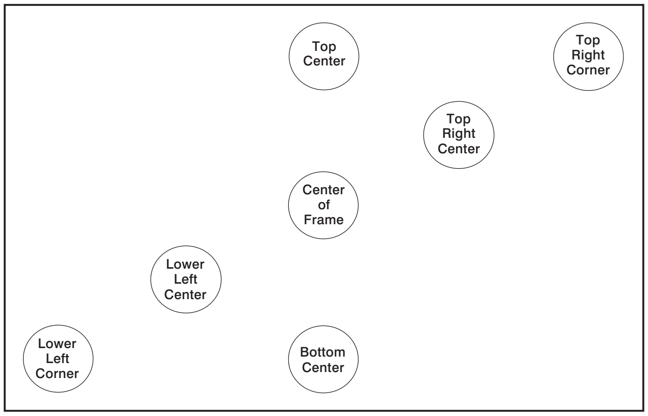

Figure 6.4 Light intensity at a projector film gate tends to be higher in the center of a slide than at the corners, and this results in correspondingly greater fading in the center area. For the data reported in Figure 6.5, density readings were taken at the film-gate locations shown here.

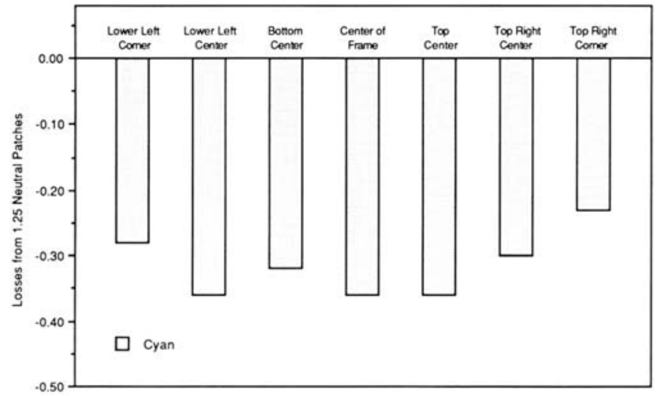

Figure 6.5 After 5 hours of continuous projection of a slide with a uniform neutral density of about 1.25 and made with now-obsolete Agfachrome 64 film, density readings were taken at the film-gate locations shown in Figure 6.4. Note the reduced fading that occurred at the corners of the image due to the fall-off in illumination intensity.

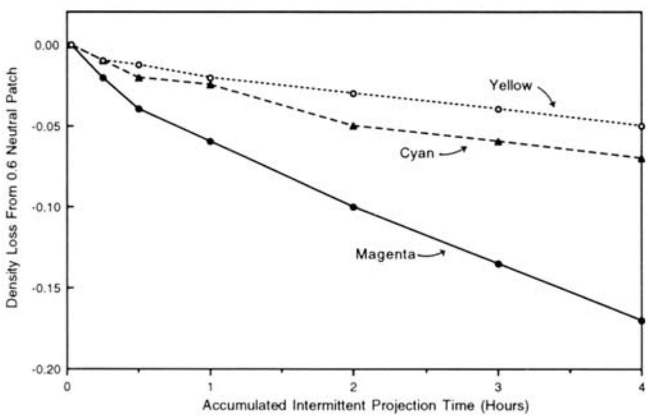

Figure 6.6 After some fairly abrupt initial changes, projector fading of Ektachrome film and most other slide films proceeds in a fairly linear fashion as a function of projection time.

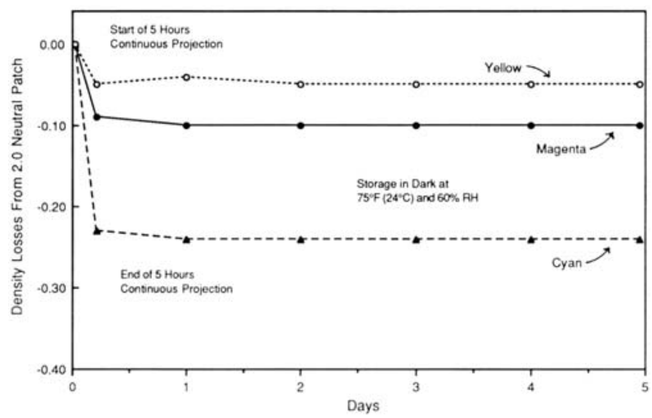

Figure 6.7 In this example involving Ektachrome film, image fading occurred essentially simultaneously with exposure to light in a projector; negligible change occurred after the end of the projection period. Because of massive reciprocity failure during the continuous 5-hour projection period of this particular test, the cyan dye faded more than the magenta (the opposite occurs during normal, intermittent projection).

Kodachrome and Ektachrome one step further and, in a rather astonishing statement, said: "... the film type, if it is a photographic film with dye images, does *not* make a significant difference, assuming proper processing and the projector operating at relatively normal room temperatures."[25]

In the 1986 edition of *Kodak Color Films and Papers for Professionals* (Kodak Publication No. E-77), Kodak said: "Color slides are usually projected on a screen by a bright light for several seconds and then returned to storage. Therefore, the preservation techniques for these materials is much the same as for color negatives." While cautioning against "prolonged or repeated projections such as might occur in a commercial display," Kodak concluded the discussion by saying, "Kodak transparency film is very stable. All Kodak slide films are made to be projected, and it is usually not projection that causes image deterioration if reasonable care is taken . . . ."[26] The previous, 1980 edition of E-77 contained a section that briefly discussed the projector-fading and dark storage stability differences between Ektachrome and Kodachrome films.[27] In what appears to signal a major change in Kodak's stance regarding the relative merits of Ektachrome vis-a-vis Kodachrome, this entire section was deleted from the new edition of E-77.

Why Kodak would change its position on such an important matter is open to speculation. One possibility is that with the introduction of Kodachrome Professional films, and Kodak's renewed emphasis on Kodachrome in the professional market, the company does not wish in any way to disparage Kodachrome in the minds of photographers. It is also conceivable that, fearing the inevitable unfavorable comparison of the projector-fading stability of *both* Kodachrome and Ektachrome with Fujichrome, Kodak wants to discourage this line of thinking altogether. Fujichrome is the principal competition for Ektachrome and Kodachrome in the professional market.

Projector-Fading Test Procedures

For the tests conducted by this author and reported here, each slide was subjected to six 30-second projections each day, with approximately 4 hours between each projection. The tests were carried out over a 140-day period, resulting in a total projection time of 7 hours for each slide (for the less stable films, such as Kodachrome, the tests were ended after 120 days — a total of 6 hours projection for each slide). During the tests the projector was located in a darkened room at a temperature of 75°F (24°C) and a relative humidity of 60%; fans in the room maintained indirect air currents over the projector and slide tray, cooling both fairly quickly after each projection period.

A Kodak Ektagraphic III AT projector, equipped with the standard ANSI Code EXR 82-volt, 300-watt quartz-halogen tungsten lamp (made by General Electric), was used in the tests.[28] Ektagraphic projectors are heavy-duty versions of the popular Kodak Carousel projectors introduced in 1961; in the United States, Carousel and Ektagraphic projectors have achieved practically total domination in educational and commercial markets. The Ektagraphic III projectors were introduced in 1981. The microprocessor-controlled Ektapro projectors introduced by Kodak in 1992 are expected to produce rates of slide fading that are generally similar to that of Ektagraphic III projectors. This author had used a Carousel 750H projector with an ANSI Code ELH quartz-halogen lamp in previous experimental work; an initial study was done in 1979 with a Sawyer rotary projector.

A precise electronic repeat-cycle timer designed by this author was set at 31 seconds to control the Ektagraphic slide-change mechanism; the additional 1 second[29] allowed for the slide-change mechanism to function, giving an actual projection time of 30 seconds. The primary sequence timer controlled a secondary timer set at 0.1 second to provide a short but sustained electrical contact closure to cause the projector to move to the next slide (this simulated a momentary depression of the change button on the hand control). These timers and the projector itself were controlled by a third timer which turned the entire system off after all of the slides had been projected once.

The slide tray was manually returned to the starting position and the bulb checked at the start of each projection sequence to make certain it had not burned out. Experience showed that it was unnecessary to monitor the projection lamp during the course of each sequence; when lamps burned out, they did so without exception within a fraction of a second of a new sequence being started. At the end of a lamp's life, the filaments fail suddenly, apparently due to the initial current surge. Given the relatively short projection time of 20 or 30 minutes for each sequence, the lamps would remain operational throughout this period if they had survived the initial current surge.

To determine the evenness of illumination at the film gate, a full-frame, neutral-density Agfachrome 64 slide was projected for a period of 6 hours. Various locations on the slide (see **Figure 6.4**) were measured with a densitometer; the fading that took place at each of the locations is given in **Figure 6.5**.

A Macbeth ColorChecker was photographed onto the

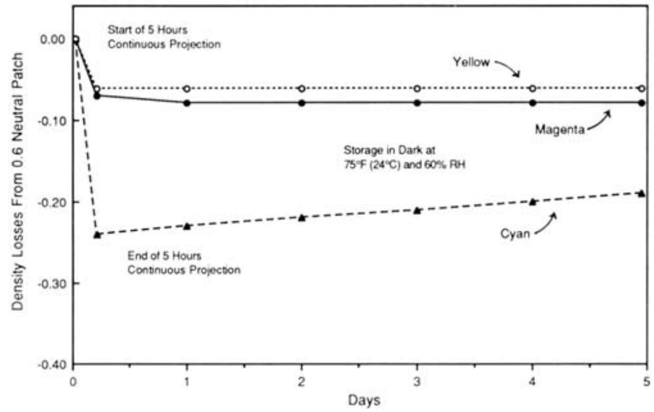

Figure 6.8 In now-obsolete Agfachrome 64 film, some "regeneration" was noted in the cyan dye during dark storage after a 5-hour period of continuous projection. The yellow and magenta dyes were not similarly affected.

various slide films included in the tests. The critical densities of the gray-scale image were contained in the density steps in the center of the scale, and even though they were on the bottom of the image, they received essentially the same amount of light as the center of the frame. Slides with ten-step gray scales centered in the middle of the frame were included with some of the films.

The projector was operated at the recommended 120 volts (measured with the projector turned on and the lamp on "High"). Kodak states that Ektagraphic projectors will operate satisfactorily in the range of 110 to 125 volts; however, the lamp light intensity — and hence the fading rate — varies considerably with the operating voltage. According to Kodak figures, the ELH quartz-halogen lamp produces 15% more light at 125 volts than it does at 120 volts.[30] At 115 volts, the light level is reduced 12% from that at 120 volts, and at 110 volts, the light level is reduced 25%.

Variations from one lamp to another can also be expected at any given voltage. Robert Beeler of Kodak explained:

> . . . there is a good bit of variation in the total illumination and in the evenness of illumination from different lamps. It appears that the lamp manufacturers can make the filaments fairly consistent, but the dichroic [infrared-transmitting] coatings on the reflectors are something else. The total variation usually falls within perhaps ± 10 percent, but sometimes is more. In addition, the coatings are often not perfectly even on the reflector, and this may affect the evenness of illumination at the projector gate. Putting the lamps on an illuminator (preferably with a tungsten light source) will show up differences in the light transmitted by the reflectors, and it is often considerable.[31]

Variations in the intensity of a number of the projector lamps used in this author's study are listed in **Table 6.5**. By the conclusion of the initial phase of this study, when the majority of the films were tested as a group, a large quantity of lamps had been consumed, and it is assumed that differences in intensity and evenness of illumination were largely averaged out in the course of the tests. For subsequent tests of more recently introduced films, the lamps were individually tested and only those which measured very close to the average intensity of the initial set were included. Only General Electric Type EXR lamps were used in these tests (this was the type of lamp originally supplied by Kodak with the Ektagraphic III projector when it was purchased and is considered to be the "standard" lamp for this projector as well as Kodak's new Ektapro projectors, introduced in 1992).

Measurement of Density Changes

Many films exhibit relatively rapid losses in density of one or more dyes during the first 5 or 10 minutes of projection; **Figure 6.6** illustrates the changes that took place in a low-density, neutral-gray area of an Ektachrome 50 Tungsten slide. The cause of these initial rapid density losses is not known. It is possible that residual sensitizer dyes remain in the film after processing and that these fade comparatively quickly on exposure to light; however, low-level stains from other sources may be the cause. To a certain extent, fading slows after early projection periods as a consequence of the reciprocity failures in light fading which are discussed in more detail later. To observe these early changes, density measurements were made after 6 minutes of projection time; these were followed with additional measurements after 15 minutes, 30 minutes, and 1 hour. For the remainder of the test, measurements were made after each hour.

Density measurements were taken with a Macbeth TR924 Densitometer equipped with Kodak Status A filters. The densitometer was connected directly to a Hewlett-Packard HP-125 microcomputer which, running the programs described in Chapter 2, processed the data, interpolated preselected gray-scale step values, provided a hardcopy printout, and set up data files on computer disks for storage and later analysis with the sets of fading criteria.

Judging from the instances in which two or more samples of films of the same type were included in the tests, the repeatability of the procedure — including the computations of the criteria analysis program — was reasonably good. As an example, samples of Kodachrome 25 and Kodachrome 64 were tested, with each sample having a distinctly different color balance. The "Critical" museum criteria program predicted 19.5 minutes for the Kodachrome 25 sample to reach the cyan/magenta color imbalance limit, and 19.8 minutes for the Kodachrome 64 sample to reach the same limit. The potential experimental error for samples analyzed with the "General" set of criteria is estimated to be about ± 10%; the potential error is larger for the "Critical" set of criteria.

ANSI IT9.9-1990, American National Standard for Imaging Media – Stability of Color Photographic Images – Methods for Measuring[32] specifies correction of densitometric data for changes in d-min densities when measuring density losses in the individual cyan, magenta, and yellow dyes, but not when determining changes in color balance. For the purposes of this study, however, this author felt it was more meaningful in a visual sense to use uncorrected data for *both* density losses and color balance changes. Unlike the blue-density increases (caused by gradual yellowish stain formation) that take place over time with most types of color photographs in dark storage, projection usually causes a *reduction* in d-min densities. Projection of a slide generally does not result in yellowish stain that can be measured in d-min areas and, therefore, this author feels that the usual rationale for making d-min corrections does not apply to projector-fading of color slides.

For most films, projector-caused fading appears to take place virtually simultaneously with exposure to the intense projector light. **Figure 6.7** shows the changes that took place in a neutral-gray, moderately high-density (2.0) area of an Ektachrome 50 Tungsten slide during a period of 5 days in the dark (75°F [24°C], 60% RH) after 5 hours of continuous projection. An initial density reading was made within 15 seconds of the end of the 5-hour projection. No further detectable loss in image density took place during 5 days in dark storage.

However, with an Agfachrome 64 transparency (an obsolete film developed with Agfa Process 41), with an initial density of 0.6, (see **Figure 6.8**), there was a gradual increase in red density during dark storage following the 5-hour projection period, suggesting a "regeneration" of some of the faded cyan dye. An apparent partial regeneration of cyan dye has also been noted with some types of color prints after (or during) exposure to intense light.

Two years after completion of the initial 6- or 7-hour intermittent projection tests (3 minutes projection per day for 120 or 140 days), densities of Fujichrome 100D, Kodachrome 64, Ektachrome 50 Tungsten, and PolaChrome color slides were measured again; none of the films showed significant further density changes. During the 2-year storage period, the slides had been kept in the dark at 75°F (24°C) and 60% RH.

Reciprocity Failures in Projector-Caused Fading

Accelerated light fading tests for color prints employ high-intensity illumination in an attempt to simulate in a short time the fading and staining that the prints will experience in actual long-term, low-intensity display conditions. For example, exposing an Ektacolor print to fluorescent light with an intensity of 20 klux for 1 month should result in the same amount of fading as if the print were exposed to fluorescent illumination with an intensity of 1 klux for 20 months — in both cases the prints would receive 14,400 klux-hours of illumination. Stated simply, exposure to a bright light for a short period should produce the same amount of fading as exposure to a less intense light for a proportionally longer time.

Unfortunately, as discussed in Chapter 2, most types of color prints fade faster and stain more under long-term, low-intensity illumination than they do when exposed to an equivalent amount of light in short-term, high-intensity accelerated tests.[33] This deviation is known as *reciprocity failure*. There are very few examples of color prints or films that exhibit the opposite relationship — that is, fade

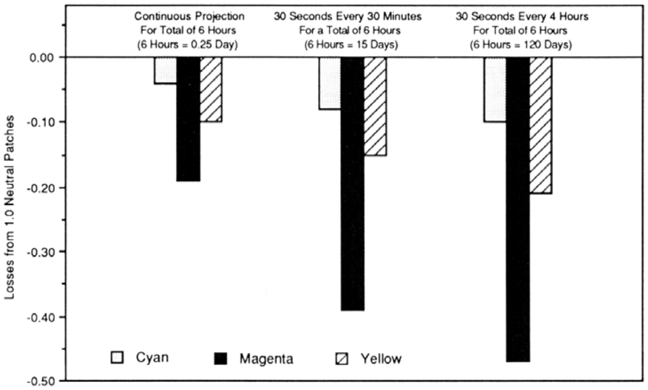

Figure 6.9 Reciprocity failure in projector fading of Kodachrome film. For a 6-hour total projection time, intermittent projection of 30 seconds every 4 hours produced more than twice the magenta dye loss than that which occurred with continuous projection. In normal, intermittent projection, which is usually spread over a period of many years, it is likely that even greater fading would take place after 6 hours of accumulated projection.

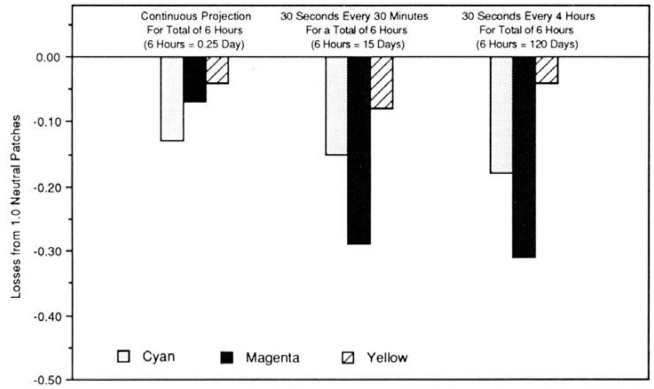

Figure 6.10 With Kodak Ektachrome films (including the newer "Plus," "X," and "HC" type films, and 64T and 320T films), the magenta dye faded far more in intermittent projection than with continuous projection; the cyan dye was not greatly affected. Note that in continuous projection, the cyan dye faded the most and caused a red color shift. In normal, intermittent projection, the magenta dye fades the most, causing an obvious green color shift.

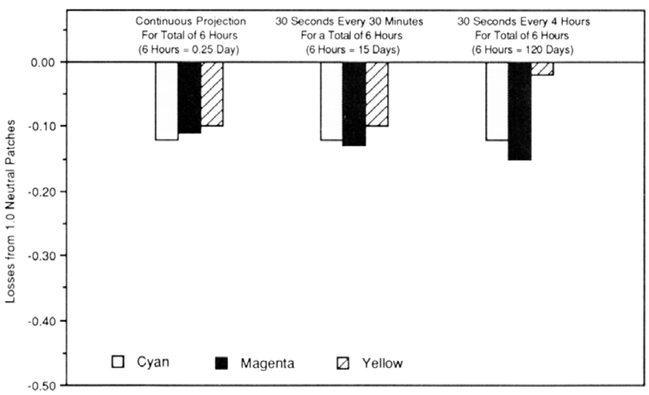

Figure 6.11 Fujichrome showed very little reciprocity failure (the reduced yellow loss measured during intermittent projection of 30 seconds every 4 hours probably resulted from a compensating stain increase that was not reflected at d-min). These tests show that continuous projection can produce highly misleading comparisons of slide films. With continuous tests, one would erroneously conclude that the stability of Ektachrome was similar to that of Fujichrome.

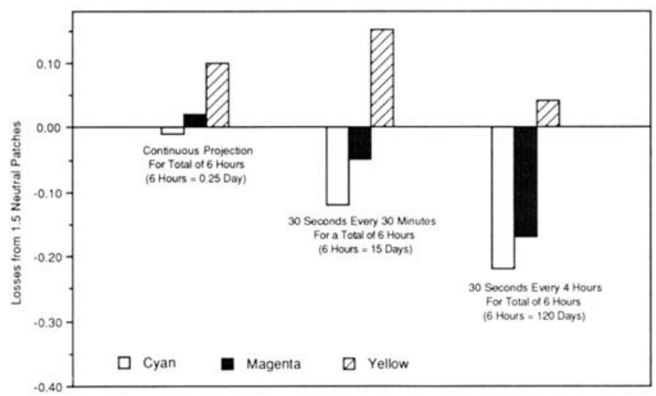

Figure 6.12 Polaroid PolaChrome instant color slide film also suffered from reciprocity failure in continuous projection. The stability problems of PolaChrome relate more to the discoloration and fading of the silver image layer than with dye stability per se; for this reason, the data presented in this graph produce an incomplete depiction of the stability behavior of the film.

more in high-intensity tests than in low-intensity tests. There are, however, a number of print materials with one or more dyes which, in this author's tests, showed almost identical fading behavior in high- and low-intensity tests; the magenta dyes in Konica Color Paper Type SR, Ektacolor Plus, and Ektacolor Professional papers are examples.

With some types of color prints — Polaroid Polacolor ER, Ilford Ilfochrome (Cibachrome), and the now-obsolete Agfacolor PE Paper Type 589 are examples — reciprocity failures can be quite large. Thus, in normal display conditions, one or more of the image dyes in such prints can fade significantly faster than predicted by high-intensity accelerated tests. These prints can be said to have a large *reciprocity failure,* or *RF Factor.* An RF Factor can be expressed numerically; for example, if the yellow dye of a certain type of print fades twice as much in a low-intensity test as it does under the same total light exposure in a high-intensity test, the RF Factor of the yellow dye is 2.0 (for those two test conditions). If the yellow dye fades the same amount in both test conditions, the RF Factor is said to be 1.0.

To further complicate matters, the cyan, magenta, and yellow dyes that make up the color image usually have *different* RF Factors, which means not only that the print may fade faster overall under long-term, low-intensity illumination but also that the color shift may be different as well. When evaluating prints with a set of criteria such as those used here, the relationship between the criterion which fails first in a low-intensity test and that which fails first in a high-intensity test can be expressed as an

RF Factor — the print material as a whole can then be said to have a certain RF Factor, under the two given test conditions.

The significance of the RF Factor is that meaningful estimates of fading behavior in long-term use under normal conditions cannot be obtained from high-intensity tests if a print material has a large RF Factor. Stain behavior frequently is also subject to reciprocity failures in high-intensity tests. It is of course possible for a print material to have a large RF Factor and still be relatively stable — Ilfochrome is an example. Likewise, a print material with a small RF Factor may nevertheless have poor light fading stability.

Experimental work by this author in 1980 indicated that projected slides were subject to reciprocity failures in fading that were somewhat similar to the reciprocity failures observed previously in the fading of color prints. In the case of slides, where the light intensity in the projector is essentially a constant, however, the important variables were the length of time of each individual projection and, more significant in terms of the usual short projections for color slides, the length of time between projections. The relative humidity of the air surrounding the slides *between* projections is probably also an important factor, especially when the intervals between projections are short.

To investigate reciprocity failures in projector-caused fading, a number of films were projected under the following three conditions:

1) Continuous projection for a total of 6 hours.

2) Intermittent projection for 30 seconds every 30 minutes, for a total of 6 hours projection over a period of 15 days. Between projections, the slides were quickly re-equilibrated with ambient conditions of 75°F (24°C) and 60% RH.

3) Intermittent projection for 30 seconds every 4 hours, for a total of 6 hours projection over 120 days. Between projections, the slides were re-equilibrated with ambient conditions of 75°F (24°C) and 60% RH.

In every case, projection for intermittent 30-second periods caused greater losses in dye density than did a single continuous projection of 6 hours. The degree of reciprocity failure varied considerably with the type of film. Among conventional color films, the magenta dye of Kodachrome had an RF Factor of 2.5 (**Figure 6.9**), the Ektachrome magenta dye had a very large RF Factor of 4.4 (**Figure 6.10**), and the Fujichrome magenta dye exhibited an RF Factor of only 1.4 (**Figure 6.11**). In the case of these three films, the RF Factors were computed from density losses from an initial 1.0 neutral density; losses measured from "pure" cyan, magenta, and yellow areas generally had even higher RF Factors under these test conditions. For example, based on losses measured from a "pure" magenta with an initial density of 1.0, Ektachrome film had an RF Factor of 6.6 (versus an RF Factor of 4.4 when magenta losses were measured from a 1.0 neutral density). In other words, the "pure" magenta in Ektachrome film faded *6.6 times more* in the intermittent test than it did in the continuous-projection test!

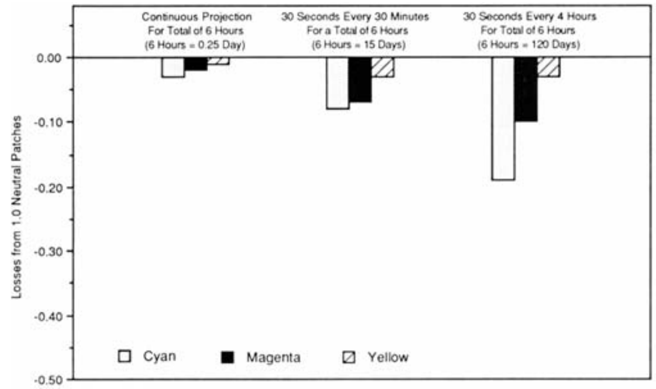

Figure 6.13 Ilford Ilfochrome (Cibachrome) Micrographic color film suffered large reciprocity failures in continuous projection compared with more normal, intermittent projection. When projected 30 seconds every 4 hours, the special-purpose Ilfochrome film proved to be somewhat more stable than Fujichrome when evaluated according to this author's image-fading criteria.

The apparently reduced fading of yellow dye in Fujichrome film in the 4-hour intermittent condition was caused by low-level yellow stain formation; Ektachrome exhibited similar low-level stain formation in intermittent projection. The stain formation was not observed in either type of film in low-density (e.g., 0.6) or d-min areas. Density measurements detected the stain only in higher-density portions of the images; the stain had little effect on the visual impression of color balance and is considered by this author not to be a significant problem. Further study of this would require the use of a spectrophotometer, which this author did not have available at the time of this research. Neither Ektachrome nor Fujichrome developed significant stain at any density during continuous projection (at least stain was not evident at the lowest density available in the test slides in this study); Kodachrome appeared to be free of stain formation under all projection conditions.

PolaChrome instant color slides (**Figure 6.12**) also showed marked deviations in fading depending on the projection condition, although the total amount of fading, relatively speaking, was not great compared with Ektachrome and Kodachrome. Because PolaChrome slides have an extremely high base density (d-min) of about 0.7, they were measured at a neutral density of 1.5, instead of the 1.0 selected for the conventional films. The *increase* in blue density observed with PolaChrome film was the result of significant yellow stain formation; that the apparent stain was less in the 4-hour intermittent condition can probably be attributed to a complementary fading of the red, green, and blue additive-screen elements in the film.

In intermittent projection, Ilford Ilfochrome (Cibachrome) Micrographic film (**Figure 6.13**) also showed a significant increase in fading rate compared with continuous projection. The now obsolete Agfachrome 64 and 100 films had only a moderate RF Factor under the three projection conditions in this author's tests.

Of particular note was the excellent test performance of Fujichrome film. Either by intention or as a fortunate occurrence related to other aspects of the film's design, Fuji has managed to mitigate those factors that cause other films to exhibit significant RF Factors. This also underscores the importance of the test method in evaluating projector-caused fading of slide films. Under *continuous projection,* Fujichrome fades at a rate similar to that of Ektachrome film, and the obvious superiority of Fujichrome in normal, intermittent-projection conditions might go unappreciated. In continuous-projection tests, the image stabilities of all the films — with the singular exception of Fujichrome — are greatly overrated compared with what would actually be experienced in normal use.

A possible explanation of the observed reciprocity failures in projector-caused fading is that oxygen plays a role in the light fading of certain dyes. During high-intensity light fading, oxygen is depleted at the sites of the dye molecules, resulting in a slowing of the photochemical reactions. Oxygen availability may be further hindered by low humidity, which lowers the permeability of gelatin to oxygen. This dependence of light fading of magenta and yellow chromogenic dyes on oxygen availability was suggested by Tuite of Kodak in 1979[34] and further discussed by Seoka *et al.*[35] and Aono *et al.* of Fuji in 1982.[36] It is also possible that water vapor plays a direct role in the fading of image dyes.

By allowing a significant length of time between projections, the emulsion can equilibrate with ambient atmospheric conditions, and both the moisture and oxygen content of the emulsion can normalize before the next projection, thus increasing the rate of fading.

Even the Intermittent Tests Reported Here Probably Overestimate the Stability of Slides in Normal Use

Normal use of a slide, of course, does not imply projection for 30 seconds every 4 hours. In actual practice, slides may be projected for 10, 15, or 30 seconds at a time, but in nearly every case, there will be a great deal more time than 4 hours between projections. Days, weeks, months, or even years between showings are more common. Judging from the slope of the fading rates of Kodachrome film, under the three projection conditions in this author's tests, for example, there is no reason to assume that the fading rate would not be even *greater* with shorter projections and/or longer periods between projections. Therefore, the estimates of useful life given by this author in **Tables 6.1** and **6.2** almost certainly *overestimate* the actual stability of the slides under normal use. The magnitude of the error will depend on the particular film; because of the small RF Factors for Fujichrome films, the estimates of stability under normal use for them are probably more meaningful than for the other films.

The undesirable "greasy" surface residue noted on 3M Scotch 640T Color Slide Film (see note in **Table 6.1**) and Eastman Color Print Film 5384 (see **Table 6.2**) after 6 hours of intermittent projection was not found when identical slides were subjected to 6 hours of continuous projection.

The relationships between length of individual projections, the interval between projections, and the influence of relative humidity are probably different for every product, and for each type of dye of a given product. In order to more accurately predict the long-term stability of slide films under typical intermittent-projection conditions, study of all of these factors is continuing, and this author hopes in the future to publish results from tests with much longer periods between projections.

Projector-Fading Curves of Slide Films

Projector-fading curves for some of the films included in this study are given in **Figures 6.14** to **6.22**. A starting neutral-gray density of 0.6 was used for all the films. Each slide was subjected to six 30-second projections each day, with approximately 4 hours between each projection. The tests were carried out over a 120-day period, resulting in a total projection time of 6 hours for each slide. The ambient temperature in the test room was 75°F (24°C) and the relative humidity was 60%.

Eastman Kodak's Test Methods

Reciprocity failures as a consequence of the test method may account for the differences between this author's tests with Ektachrome films and the data reported by Kodak in CIS No. 50–45, August 1982, *Evaluating Dye Stability of Kodak Color Products – Transparencies on These Kodak Ektachrome Films,* and in Kodak Publication E-106 (1988), *Reference Information from Kodak – Image Stability Data: Kodak Ektachrome Films (Process E-6).*[37] Both of these publications indicate that during projector-caused fading of a neutral patch with an initial density of 1.0, the cyan dye (red density) and magenta dye (green density) faded at a similar rate over a 3-hour projection period, while the yellow dye (blue density) faded almost not at all.[38] In this author's tests, the magenta dye in a neutral patch faded significantly faster than the cyan dye, as illustrated in **Figure 6.18**. Continuous projection of Ektachrome film caused the magenta to fade *less* rapidly than the cyan; the magenta dye appears to have a larger RF Factor in projector-caused fading than either the cyan or yellow dye.

Kodak indicated that it used one 15-second projection every 20 minutes (720 projections in a 10-day test period) in a Carousel projector, which is in keeping with the procedure for testing slide-projector fading described in the now-obsolete *ANSI PH1.42-1969, American National Standard Method for Comparing the Color Stabilities of Photographs.*[39] Such a projection sequence can easily be achieved by placing slides in an 80-slide Carousel tray and setting a projector timer for 16 seconds (which allows 1 second for slide changing). As the tray continues to rotate, each slide will be projected once every 20 minutes and will have achieved 720 projections in approximately 240 hours (10 days) of continuous operation.

In a projection situation such as this, where the projector operates continuously, heat from the projector keeps the entire tray of slides warm. This in turn reduces the relative humidity of the air in the vicinity of the slides and maintains the moisture content of the film emulsion at a low level throughout the duration of the test.

Whether Kodak actually applied this method of projecting the slides has not been revealed. In any event, the Kodak test method (one 15-second projection every 20 minutes) did not allow as much time to elapse between projections as in this author's tests; in addition, the Kodak tests apparently did not allow the film emulsions to regain much moisture between projections, probably contributing to a reduction in fading rates. The resulting reciprocity failures likely account for the differences in results. This author's longer-term tests, with full moisture equilibration at 60% RH between projections, produced more rapid fading of the magenta dye, leading to a significant shift in color balance toward green, while Kodak's tests produced a less noticeable shift toward yellow. In **Figure 6.11,** it can be seen that a projection condition somewhere between continuous projection and the intermittent projection periods employed in this author's tests would produce slower magenta dye fading, resulting in similar fading rates for the magenta and cyan dyes.

The new *ANSI IT9.9-1990, American National Standard for Imaging Media – Stability of Color Photographic Images – Methods for Measuring* specifies a 15-second projection period each hour (a total of 6 minutes of illumination each 24 hours), with the surrounding air having a temperature of 75°F (24°C) and 50% RH. This test cycle falls in between the old *ANSI PH1.42-1969* specification of a 15-second projection every 20 minutes, with an air temperature of 75°F (24°C) and no RH specified (this is the test cycle used by Kodak in the past), and this author's test cycle of a 30-second projection every 4 hours, with an air temperature of 75°F (24°C) and 60% RH.

In 1983 Patrick Young, staff photographer in the Department of History of Art, University of Michigan, reported a projector-fading experiment done with Kodachrome and Ektachrome films (and a now obsolete Agfachrome film) in which slide copies of a Claude Monet painting were projected for periods of 2 minutes (with 2 minutes between projections) for totals of 50 minutes, 100 minutes, and 200 minutes.[40] Significant change was noted in the Kodachrome slide at the end of 200 minutes, but no visually detectable

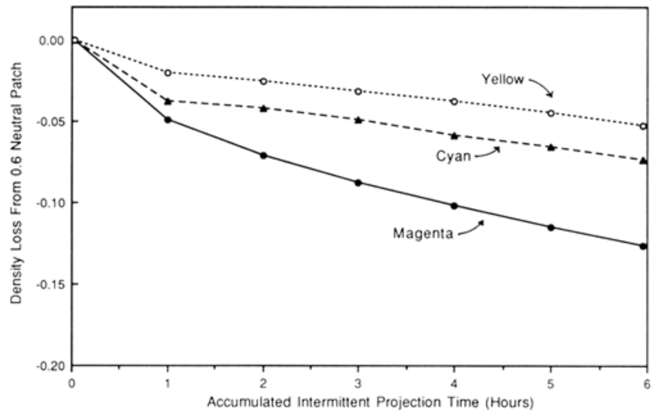

Figure 6.14 Fujichrome films (except Velvia).

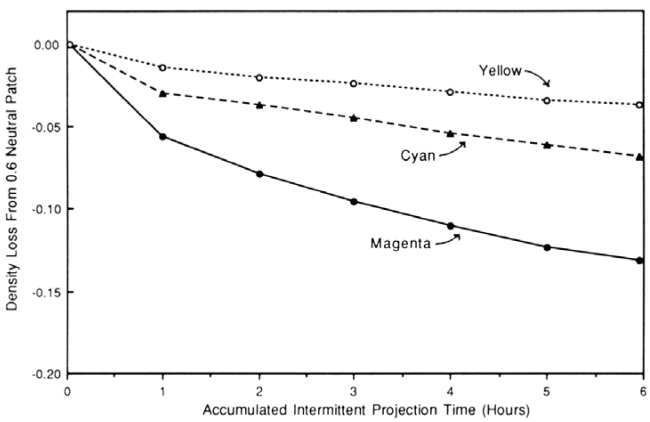

Figure 6.15 Fujichrome Velvia film (ISO 50).

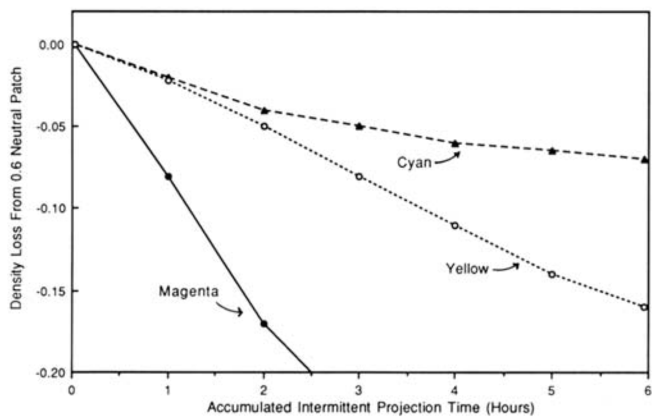

Figure 6.16 Kodachrome films (all current K-14 types).

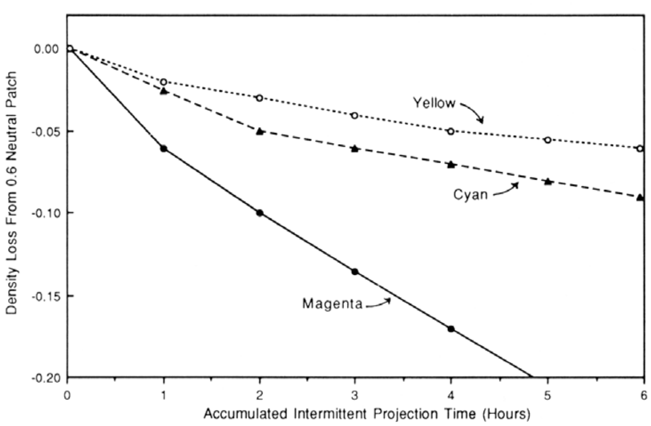

Figure 6.17 Ektachrome films (current E-6 types, except for Ektachrome Plus, "HC," "X," 64T, and 320T films).

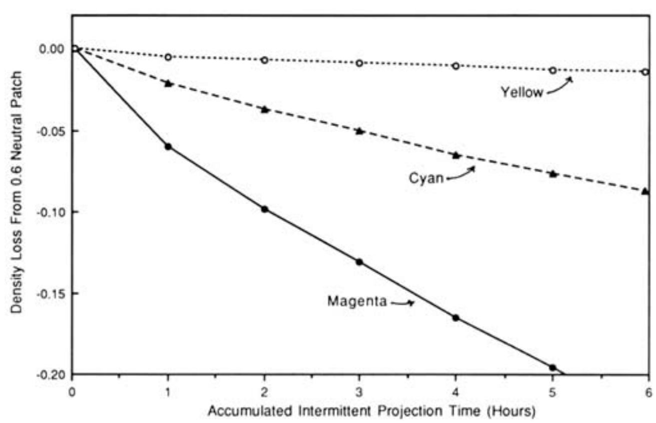

Figure 6.18 Ektachrome Plus, "HC," "X," 64T, and 320T films (E-6 films introduced by Kodak beginning in 1988).

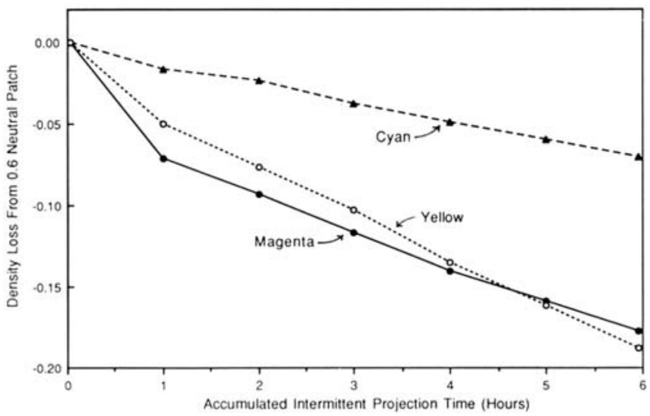

Figure 6.19 Agfachrome RS film and CT films (E-6 types).

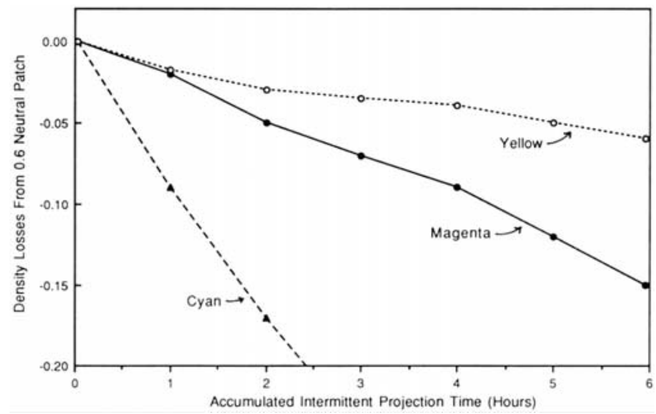

Figure 6.20 Agfachrome 64 and 100 films (obsolete).

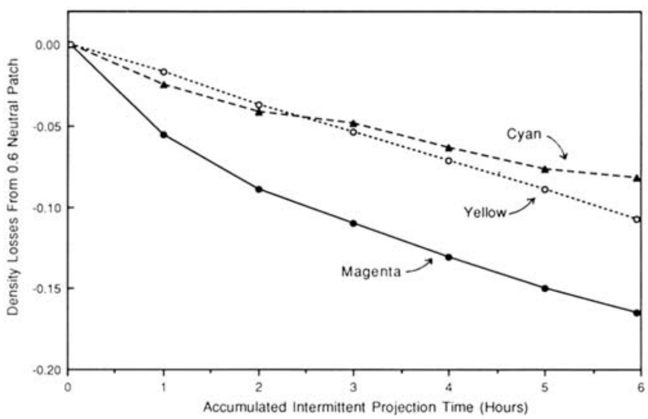

Figure 6.21 Kodachrome II and Kodachrome-X films (obsolete K-12 types).

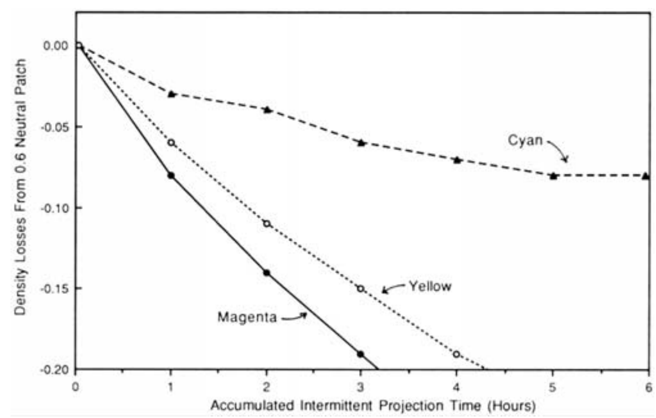

Figure 6.22 3M ScotchChrome 100 Film (E-6 type).

color shift was observed in the Ektachrome slide at the end of this time. Favorable reciprocity effects afforded by these test conditions were probably a significant factor in the degree of stability attributed to the Ektachrome slide.

Problems with Polaroid PolaChrome Instant Color Slides

Introduced in 1983, Polaroid PolaChrome instant color slide film is used in conventional 35mm cameras (a related film, High Contrast PolaChrome, was marketed in 1987 for making high-contrast slides of graphs, charts, etc.). PolaChrome film is developed in about a minute in a separate Polaroid Autoprocess tabletop processor; the slides can be mounted and ready for projection in as little as 5 minutes after exposure. PolaChrome is a modern reincarnation of the additive-screen Autochrome plates and similar color processes popular in the early part of the 1900's. Because of problems inherent in any additive color system, these processes were abandoned soon after Kodachrome and other continuous-tone subtractive color films became available.

PolaChrome utilizes the same imaging technology as the ill-conceived — and quickly abandoned — Polavision instant movie system introduced in 1978. In PolaChrome, the color image is formed by a positive silver image layer which controls light transmission through an extremely fine series of dyed red, green, and blue lines imprinted on the film base. Deterioration of a PolaChrome image is a complex matter and can involve either the silver layer and the dyed screen elements separately, or *both* at the same time. Being an additive system, the d-min of PolaChrome is very high (about 0.70), and correctly exposed slides have a very dense appearance. When projected, PolaChrome images appear much darker on the screen than conventional slides.

During the course of the 120-day intermittent projection tests, all of the PolaChrome slides developed serious, irregular yellow stains — this was in addition to a more uniform, overall yellow staining. **Figure 6.24** illustrates the changes that occurred in a light skin-tone patch from a Macbeth ColorChecker (the area of the light skin-tone patch developed an especially high stain level on this particular PolaChrome slide). The red and green densities dropped in a fairly orderly fashion, but after a short drop at the very beginning of the test, the blue density increased rapidly, reflecting the formation of yellow stain; the color balance of the skin-tone patch shifted markedly toward yellow.

The stain formation is probably accompanied by some fading of the blue dye; integral densitometry, such as that employed in these tests, cannot distinguish between these two causes of density change. Unlike subtractive films which have relatively clear d-min areas, PolaChrome is an

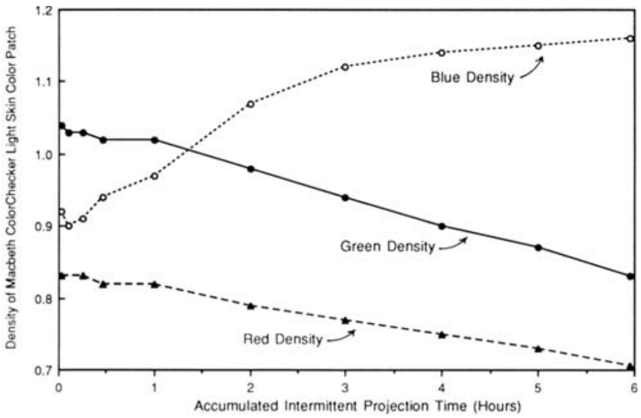

Figure 6.23 During intermittent projection, PolaChrome instant color slide film developed high levels of yellowish stain — generally in visually objectionable, irregular patterns. The example shown here occurred in the light skin-tone patch of an image of a Macbeth ColorChecker.

additive film with full-density red, green, and blue strips in all areas of the film, making analysis of changes more problematic. Direct comparisons between the fading characteristics of PolaChrome and other films are difficult because of the high base density, compressed density-scale, and other unusual aspects of PolaChrome images.

Because of the *irregular* nature of the yellow stains that occurred in the course of projection, and because PolaChrome images had essentially disappeared by the end of this author's 90-day, high-humidity (144°F [62°C], 75% RH) accelerated dark fading tests, PolaChrome film cannot be recommended for any application requiring more than short-term stability. Irregular stains of this type are virtually impossible to correct in duplication or printing and are one of the most serious flaws that a photographic material can have.

Using continuous-projection tests, Polaroid concluded that PolaChrome slides have very high resistance to projector-caused fading (to this author's knowledge, Polaroid has not published data from intermittent-projection tests):

> All color slides subjected to long periods of projection will eventually fade. Tests under typical projection conditions indicate that PolaChrome slides can be projected two to five times longer than conventional (chromogenic) slide films before exhibiting a similar degree of fading.
>
> A PolaChrome slide projected continuously for 10 hours in a 300-watt projector showed a subtle visual change in some colors. After 20 hours the change was still small enough to be unnoticed unless directly compared to an identical, unprojected slide.
>
> Because of this resistance to fading, PolaChrome film is particularly recommended for slide shows . . . .[41]

Because of its poor image quality, lack of a continuous-tone image, extremely high base density, large grain structure, compressed density range (which reduces the brilliance of projected images), slow speed of ISO 40, color-fringing with certain types of scenes, difficulty of making color separations for photomechanical reproduction, poor stability under commonly encountered projection and storage conditions, and other drawbacks, the *only* reason anyone would want to use PolaChrome film is that it can be processed and ready for projection in slightly less than 5 minutes — the only current "instant" 35mm color slide film.

Polaroid has suggested that PolaChrome slides be treated with gold chloride toners to protect the delicate silver image if better stability is desired, especially under less-than-ideal storage conditions.[42] However, it is highly unlikely that many photographers would be willing to get involved in toning and washing the films prior to projection or storage in an effort to improve the stability of the product.

Notes and References

1. Eastman Kodak Company, **The Source Book – Kodak Ektagraphic Slide Projectors**, Kodak Publication No. S-74, October 1984, p. 153, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000. The light intensity at the film plane of an Ektagraphic III projector equipped with an EXR lamp is given as 95,000 footcandles [1,022,200 lux]. See also: Eastman Kodak Company, **Evaluating Dye Stability of Kodak Color Products, Transparencies and Movies on Kodachrome [Films]**, Kodak Current Information Summary CIS No. 50–41, Eastman Kodak Company, June 1982. This publication gives a film-plane intensity of 925 klux (86,000 fc) for a Kodak Carousel projector with a quartz-halogen lamp. The **1982–1983 Kodak Photographic Products Reference Guide**, Kodak Publication No. R-50, states that the then-new Ektagraphic III projectors had "Increased illumination (25% more than Ektagraphic Slide Projector Models E-2 through AF-2)" (p. 70). The coated condensers in Ektagraphic projectors result in about an 8% increase in light intensity at the film plane over Kodak Carousel projectors, which are equipped with lower-cost, uncoated condenser lenses. Kodak Ektapro 7000 and 9000 slide projectors, introduced in 1992, employ the same EXR lamps that are used in Ektagraphic III projectors. According to James Parker, Coordinator of Presentation Technology for Kodak's Professional Imaging Division (telephone discussion with this author, February 19, 1992), an improved mirror design in the Ektapro projectors gives about a 10% increase in film plane illumination intensity compared to that in Ektagraphic III projectors. This author did not have the necessary equipment to be able to directly measure the projector-gate light intensities.
2. The estimated light intensity at the film plane of typical xenon-arc projectors was based on discussions with three makers of such projectors. None had actual data on film-plane light intensity, but expressed the light intensity of their projectors in terms of the percentage increase in screen illumination compared with an Ektagraphic III projector, using the same lens and projection distance. Reciprocity failures at the extreme illumination levels of xenon-arc projectors have not been investigated.
3. This author delivered a talk entitled "Projector-Caused Fading of 35mm Color Slides" at the annual conference of the Society of Photographic Scientists and Engineers, held in Minneapolis, Minnesota, May 5, 1980. This presentation included some data on reciprocity failures in projector-caused fading. Additional research was reported at the **Advanced Studies in Visual Resources Seminar, Production and Preservation of Color Slides and Transparencies**, sponsored by the Department of Art, School of Architecture, and Humanities Research Center at the University of Texas at Austin, Texas, March 27–28, 1981. The proceedings of this landmark seminar were reported by Bob Schwalberg in "Color Preservation Update," **Popular Photography**, Vol. 89, No. 1, January 1982, pp. 81–85, 131. In February 1990, further research was reported in a presentation by this author entitled "The Stability and Preservation of Color Slides: Duplicates for Use, and Cold Storage of Originals Provide the Only Answer," ARLIS–VRA Joint Session, **Conservation and Preservation Issues Beyond the Book: Slides, Microforms, Videodiscs and Magnetic Media**, at the ARLIS (Art Libraries Society of North America) 18th Annual Conference, New York City, February 14, 1990. Comparative projector-fading and dark fading stability data for color slide films were included in: Bob Schwalberg, with

Henry Wilhelm and Carol Brower, "Going! Going!! Gone!!! – Which Color Films and Papers Last Longest? How Do the Ones You Use Stack Up?," **Popular Photography**, Vol. 97, No. 6, June 1990, pp. 37–49, 61. The stability data in the article were condensed from this book.
4. Peter Moore, "The Great Carousel Go-Around," **Modern Photography,** Vol. 45, No. 10, October 1981, pp. 128–133, 172, 176.
5. David C. Hubbell, Robert G. McKinney, and Lloyd West, "Methods for Testing Image Stability of Color Photographic Products," **Photographic Science and Engineering,** Vol. 11, No. 5, September–October 1967, p. 297. This article was the basis for **ANSI PH1.42-1969, American National Standard Method for Comparing the Color Stabilities of Photographs,** American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018; telephone: 212-354-3300. In 1990 **ANSI PH1.42-1969** was replaced by **ANSI IT9.9-1990** (see Note No. 14).
6. Eastman Kodak Company, see Note No. 1.
7. In practice, however, cyan absorbs some green light and contributes to green density; magenta absorbs some red and some blue light in addition to green. Readings taken with a normal densitometer are known as "integral density" measurements and usually equate fairly well with the visual perception of an image. A loss in green density of a gray scale patch is caused mostly by the fading of magenta dye, but losses in the cyan dye may also contribute to the measured losses because of the secondary absorption of the cyan in the green region. Strictly speaking, one cannot say that losses in green density are losses of magenta dye. This is the principal reason that graphs and other data are often expressed in terms of changes in red, green, and blue densities. If yellow stains are present, they will have considerable influence on the blue density readings.
8. A somewhat simplified version of the criteria given here was first proposed by this author in 1978 as part of a presentation entitled "Light Fading Characteristics of Reflection Color Print Materials" at the 31st Annual Conference of the Society of Photographic Scientists and Engineers, May 1, 1978, in Washington, D.C. Preliminary data on reciprocity effects in the light fading of color prints, with specific reference to the light fading characteristics of Polacolor 2 prints, were also discussed during the presentation. Further research by this author was described in a presentation entitled "Reciprocity Effects in the Light Fading of Reflection Color Prints" at the 33rd Annual Conference of the Society of Photographic Scientists and Engineers, held in Minneapolis, Minnesota, May 5, 1980. See also: 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.
9. Stokes Imaging Services, Inc., 7000 Cameron Road, P.O. Box 14277, Austin, Texas 78761-4277; telephone: 512-458-2201.
10. Microcolor International, Inc., 85 Godwin Avenue, Midland Park, New Jersey 07432; telephone: 201-445-3450.
11. Thom O'Connor, "Pros Winners of Film Wars," **Photo District News,** Vol. VII, Issue II, February 1987, pp. 1, 14, 16, 18.
12. Gepe Double Glass Slide-Binders were used for the glass-mounted slides in the tests reported here. The mounts have plastic frames which snap together, thin aluminum masks that also serve to position the film in the mount, and "anti-Newton's rings" glass on both sides of the mount. Gepe mounts, which are popular in the U.S. and many other countries, are made in Sweden by BiWex. The mounts are distributed in the U.S. by Gepe, Inc., 16 Chapin Road, Pine Brook, New Jersey 07058; telephone: 201-808-9010.
13. Christine L. Sundt, "Mounting Slide Film Between Glass – For Preservation or Destruction?" **Visual Resources**, Vol. II, Nos. 1–2–3, Fall/Winter 1981/Spring 1982, pp. 37–62. See also: Christine L. Sundt, "How to Keep Slide Mounts Clean," **International Bulletin for Photographic Documentation of the Visual Arts**, Vol. 13, No. 2, Summer 1986, pp. 14–15; and: Christine L. Sundt, "Conservation Practices for Slide and Photograph Collections," **VRA Special Bulletin No. 3**, Visual Resources Association, 1989. Sundt, who is continuing the research reported in these articles, currently is curator of the slide collection of architecture and applied arts at the University of Oregon at Eugene.
14. American National Standards Institute, **ANSI IT9.9-1990, American National Standard for Imaging Media – Stability of Color Photographic Images – Methods for Measuring**, American National Standards Institute, Inc., 11 West 42nd Street, New York, New York 10036; telephone: 212-642-4900; Fax: 212-302-1286. This author has served as a member of the ANSI subcommittee that wrote this standard since the group was founded in 1978; in recent years this author has been secretary of the subcommittee. This Standard replaced **ANSI PH1.42-1969** in 1990 (see Note No. 5).
15. Eastman Kodak Company, **Restoring Faded Color Transparencies by Duplication (White-Light Printing Methods)**, CIS No. 22, Current Information Summary, July 1979, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
16. Henry Wilhelm, see Note No. 8. The criteria proposed in 1978 were for reflection prints and did not assign weighted values to changes in red, green, and blue densities; in other respects the concept of specified limits for density loss, color imbalances, and stain formation was similar to that discussed here.
17. Eastman Kodak Company, **Storage and Care of Kodak Color Films,** Kodak Publication No. E-30, March 1973, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
18. Eastman Kodak Company, **Storage and Care of Kodak Color Films**, Kodak Publication No. E-30, January 1976, p. 5. The quoted statement was slightly reworded in **Conservation of Photographs** (George T. Eaton, editor), Kodak Publication No. F-40, March 1985, p. 69, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
19. Isabel Lowery, the Dunlap Society, telephone discussion with this author, February 15, 1984.
20. Eastman Kodak Company, **The Sourcebook – Kodak Ektagraphic Projectors,** Kodak Publication No. S-74, 1977, p. 59, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
21. Eastman Kodak Company, **The Sourcebook – Kodak Ektagraphic Projectors,** Kodak Publication No. S-74, October 1984, p. 154. Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
22. Eastman Kodak Company, **Evaluating Dye Stability of Kodak Color Products (**Current Information Summary), Kodak Publication No. CIS No. 50 (1981–1985), Customer Technical Service, Eastman Kodak Company, Rochester, New York 14650. CIS No. 50–41 gives data on Kodachrome films; CIS No. 50–45 gives data on Ektachrome films. Inquiry should be made to Eastman Kodak Company to obtain current image stability data sheets for the particular Kodak products of interest (see Notes No. 23 and 24). The data sheets are usually reissued (and possibly updated) each year. The data sheets for Ektachrome and Kodachrome films referenced by this author were dated 1982. See updated Kodak publication: **Evaluating Image Stability of Kodak Color Photographic Products** (Current Information Summary), Kodak Publication No. CIS-130 (March 1991), Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
23. Eastman Kodak Company, **Reference Information From Kodak – Image Stability Data: Kodak Ektachrome Films (Process E-6),** Kodak Publication No. E-106 (May 1988), Eastman Kodak Company, 343 State Street, Rochester, New York 14650.
24. Eastman Kodak Company, **Reference Information From Kodak – Image Stability Data: Kodachrome Films,** Kodak Publication No. E-105 (March 1988), Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.
25. Eastman Kodak Company, see Note No. 21, p. 153.
26. Eastman Kodak Company, **Kodak Color Films and Papers for Professionals**, Kodak Publication No. E-77, March 1986, p. 58. Eastman Kodak Company, 343 State Street, Rochester, New York 14650.
27. Eastman Kodak Company, **Kodak Color Films**, Kodak Publication No. E-77, September 1980, pp. 34–35. Eastman Kodak Company, 343 State Street, Rochester, New York 14650.
28. Because the original Kodak patents for the Carousel projector and tray have expired, anyone can make a projector based on the Carousel design; Telex Communications [formerly Singer] (Caramate Projectors), Elmo (Omnigraphic Projectors), Leitz (Pradolux Projectors), and a number of other companies market projectors of this type that accept the standard Kodak "Carousel" 80- or 140-slide-capacity trays. From a conservation point of view, a noteworthy feature of all of these projectors is that when the rotating tray moves a slide into position for projection, the slide drops by gravity into the projection gate. If the mount is warped or if something else causes the slide to jam, in most cases it either remains in the tray slot or drops part way into the gate and is then usually, but not always, ejected without physical damage. Many other projector designs force a slide into the projection gate, and the slide can be seriously damaged if it should jam on the way in or out of the gate.
29. Eastman Kodak Company, see Note No. 20. For the Kodak Ektagraphic Projectors E-2 through AF-2, the total time required for the slide-change mechanism to function was given as 950 milliseconds, with the projector gate shutter closed 830 milliseconds of that period (p. 39). This author allowed 1 second for changing each slide in the tests described here.
30. Eastman Kodak Company, **Kodak Slide Projector Lamp Data and**

Light Output Modification, Publication No. S-80-2, March 1979, Eastman Kodak Company, 343 State Street, Rochester, New York 14650; telephone: 716-724-4000.

31. Robert S. Beeler, Motion Picture and Audiovisual Markets Division, Eastman Kodak Company, letter to this author, February 28, 1980.
32. American National Standards Institute, Inc., see Note No. 14.
33. Henry Wilhelm, "Reciprocity Failures in Accelerated Light Fading and Light-Induced Staining of Color Prints," presentation at the **Third International Symposium on Image Conservation**, sponsored by the Society for Imaging Science and Technology (SPSE) and held at the International Museum of Photography at George Eastman House, Rochester, New York, June 17–20, 1990.
34. Robert Tuite, "Image Stability in Color Photography," **Journal of Applied Photographic Engineering**, Vol. 5, No. 4, Fall 1979, pp. 200–207.
35. Yoshio Seoka, Seiiti Kubodera, Toshiaki Aono, and Masato Hirano, "Some Problems in the Evaluation of Color Image Stability," **Journal of Applied Photographic Engineering**, Vol. 8, No. 2, April 1982, pp. 79–82. This article was based on a presentation given at the **1980 International Conference on Photographic Papers**, William E. Lee, chairman, sponsored by the Society of Photographic Scientists and Engineers (SPSE), Hot Springs, Virginia, August 11, 1980.
36. Toshiaki Aono, Kotaro Nakamura, and Nobuo Furutachi, "The Effect of Oxygen Insulation on the Stability of Image Dyes of a Color Photographic Print and the Behavior of Alkylhydroquinones as Antioxidants," **Journal of Applied Photographic Engineering**, Vol. 8, No. 5, October 1982, pp. 227–231.
37. Eastman Kodak Company, see Notes No. 23 and No. 24.
38. Eastman Kodak Company, **Evaluating the Dye Stability of Kodak Color Products – Transparencies on These Kodak Ektachrome Films** (Current Information Summary), Kodak Publication No. CIS 50–45 (August 1982), Customer Technical Service, Eastman Kodak Company, 343 State Street, Rochester, New York 14650.
39. American National Standards Institute, Inc., see Note No. 5, p. 11, Sec. 3.4, Intermittent Type Slide Projector (50,000 fc) specifies the following test: "A 35 mm slide projector with continuously repeated intermittent exposure of the test specimens is specified. An automatic slide projector with a cylindrical magazine and a 500-watt tungsten lamp is a convenient type of test unit . . . . Each slide is projected for 10 to 20-second intervals. The projector is operated in room conditions, 75°F ± 5°F, which will allow the blower to circulate air around the slide and maintain a slide film temperature of less than 160°F. . . ." The Standard, including the slide-fading test, is largely based on a 1967 article by Hubbell, McKinney, and West of Eastman Kodak (see Note No. 5). This now-obsolete Standard did not specify the length of time between each projection, other than saying the projections are "intermittent," and the possibility of reciprocity failures is not mentioned; the relative humidity of the test area is not specified.
40. Patrick Young, "A Comparison of Color Films Used to Photograph Works of Art," **International Bulletin for Photographic Documentation of the Visual Arts**, Vol. 10, No. 2, June 1983, pp. 7–11.
41. Polaroid Corporation, **Polaroid 35mm Instant Slide System,** A Polaroid Book by Lester Lefkowitz, Polaroid Corporation, Cambridge, Massachusetts, and Focal Press, Boston, Massachusetts and London, England, 1985, p. 57.
42. Polaroid Corporation, see Note No. 41, p. 99. Illustrated is an example of a PolaChrome instant color slide stored for 1 year at 68–74°F (20–23°C) and 40–50% RH, and an identical slide stored for 1 year in a "tropical" environment with an average temperature of 80°F (28°C) and an average relative humidity of about 75%. The film stored in the warm and humid environment lost considerable density, with changes taking place in an apparently irregular pattern. Polaroid concluded: "High heat and humidity adversely affect image stability of processed [PolaChrome] film." Especially under less-than-ideal storage conditions, gold chloride toning was recommended to increase the image stability of PolaChrome slides. Gold-toning instructions are available from Polaroid: Technical Assistance, Polaroid Corporation, 784 Memorial Drive, Cambridge, Massachusetts 02139; toll-free telephone: 800-354-3535.

Additional References

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Henry Wilhelm, "Color Photographs and Color Motion Pictures in the Library: For Preservation or Destruction?", chapter in **Conserving and Preserving Materials in Nonbook Formats**, (Kathryn Luther Henderson and William T. Henderson, editors), pp. 105–111, 1991. The book contains the papers presented at the **Allerton Park Institute** (No. 30), sponsored by the University of Illinois Graduate School of Library and Information Science, held November 6–9, 1988 at the Chancellor Hotel and Convention Center, Champaign, Illinois. Published by the University of Illinois Graduate School of Library and Information Science, Urbana-Champaign, Illinois.