20. Large-Scale, Humidity-Controlled Cold Storage Facilities for the Permanent Preservation of B&W and Color Films, Prints, and Motion Pictures

I kept seeing good color photographs, and I thought, "Well, we need to collect those, too." Attending the conference in Toronto [in 1978 at the Baldwin Street Gallery] was a fundamentally important step in realizing that the solution to keeping color was not difficult — you just freeze it. . . .

Now that we have the cold vault, we certainly do not have to look at a color photograph and say, "That is a great picture, but it will fade in 8 to 10 years and we will either have to show it constantly, or we will have to parade people in and out of the print study room just to get the use out of it [before it fades]." Now we can just say, "That's a great picture and it should be in the collection . . . and it will automatically be preserved. We can buy the most fragile color photographs, and they will be saved."

With the vault, we have a great advantage in collecting — several photographers have said they would make it very easy for us to acquire their work, because at least there would be one place where they know their work would survive. Some have even said they would give us prints at cost. If there were 20 museums with cold vaults, there would be no reason that *we* would have this offered to us. But I don't want to make photographers give us work for less than they want to sell it for. I want them to feel that their photographs are going to a place that actually cares that their work lives for future generations.[1]

David Travis
Curator of Photography
Art Institute of Chicago

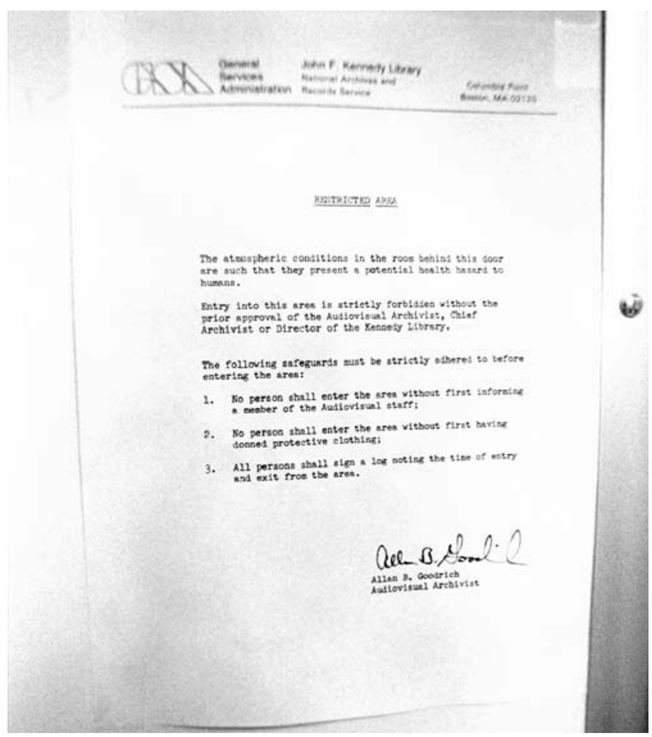
Since the middle 1970's, when the poor stability characteristics of most color photographic materials became widely known and discussed in the museum and archive field, there has been a gradual recognition of the fact that the only practical way to preserve color films and prints for long periods is to keep them in the dark in cold storage. Because of newspaper stories, magazine articles, and television programs dealing with color fading, the general public was alerted to the tragic consequences of the eventual loss of the bulk of color motion pictures, television footage, color prints, negatives, and slides of all types. This public concern has encouraged museum administrators to make funds available for construction of cold storage facilities. The preservation of color collections is increasingly viewed as a basic institutional responsibility by museum directors.

See page 697 for Recommendations

The fact that most color materials *require* cold storage for long-term survival is an unfortunate outcome of the adoption of the chromogenic system of color photography which began with Kodachrome film in 1935 and was followed by Kodacolor, Ektachrome, and Agfacolor in the late 1930's and early 1940's. Chromogenic materials came into almost universal use in the motion picture industry following the introduction of Eastman color negative and color print films in 1950.

Although Kodak, Fuji, Agfa-Gevaert, and Konica have improved the dark fading stability of many of their color materials during the last few years, most materials are still not stable enough to survive long-term storage at room temperature without objectionable fading and/or staining. Improving color stability was a low priority with manufacturers during most of the 1935–1982 period, and museum and archive personnel generally knew little about the stability problem. With their attention focused on black-and-white photography, many curators did not even consider

(continued on page 691)


General Services Administration
John F. Kennedy Library
National Archives and Records Service
Columbia Point
Boston, MA 02125

RESTRICTED AREA

The atmospheric conditions in the room behind this door are such that they present a potential health hazard to humans.

Entry into this area is strictly forbidden without the prior approval of the Audiovisual Archivist, Chief Archivist or Director of the Kennedy Library.

The following safeguards must be strictly adhered to before entering the area:

1. No person shall enter the area without first informing a member of the Audiovisual staff;
2. No person shall enter the area without first having donned protective clothing;
3. All persons shall sign a log noting the time of entry and exit from the area.

Allan B. Goodrich
Audiovisual Archivist

1981

A warning notice posted near the door to the 0°F (–18°C) cold storage vault at the John Fitzgerald Kennedy Library.

This document originated at <www.wilhelm-research.com> on June 6, 2003 under file name: <HW_Book_20_of_20_HiRes_v1.pdf>

1981

Allan B. Goodrich, audiovisual archivist at the John Fitzgerald Kennedy Library in Boston, Massachusetts, is shown inside the 0°F (–18°C), 30% RH cold storage vault, which preserves the large collection of color negatives, prints, transparencies, and motion pictures at the Library. According to data published by Eastman Kodak, storage at 0°F will, for a given amount of fading to occur, preserve color materials approximately 340 times longer than storage at 70°F (21°C) (e.g., the amount of fading that would occur in 10 years at room temperature is predicted not to take place until about 3,400 years have passed in a 0°F vault). The controlled-humidity environment in the vault eliminates the need for pre-conditioning and sealing films and prints in expensive vapor-proof containers before placing them in the vault.

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May 1979

The John Fitzgerald Kennedy Library, one of the presidential libraries, was built with private contributions and is now owned and operated by the National Archives and Records Administration. When this photograph was taken in 1979, exterior construction of the $12 million structure was nearly complete after 2 years of construction. The Library is located at Columbia Point, at the end of a peninsula in Boston Harbor.

May 1979

The prefabricated cold storage vault at the Kennedy Library is seen here during assembly. The vault was the world's first 0°F (–18°C) humidity-controlled (30% RH) storage facility for color photographic materials. When this book went to press in 1992, only five other such low-temperature vaults were in operation: three at NASA facilities in Houston, Texas and White Sands, New Mexico; one at The Historic New Orleans Collection; and one at the Jimmy Carter Library in Atlanta, Georgia.

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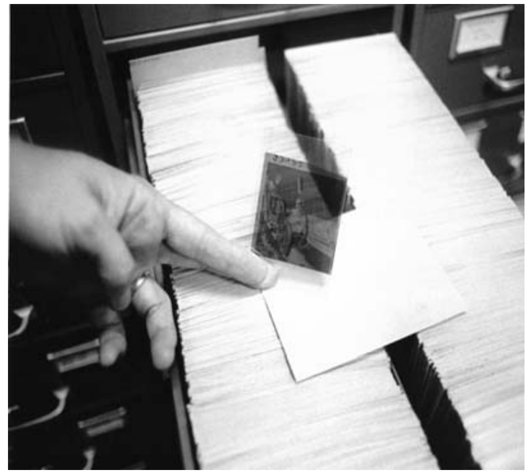
Allan B. Goodrich is seen here with the Kennedy White House negative file, which in this 1979 photograph was being stored in an air-conditioned government warehouse in Waltham, Massachusetts. Significant image fading occurred in the color negatives in the collection during the 20-year period from 1963 (when President Kennedy was assassinated) until the negatives were put in the cold vault after completion of the Kennedy Library.



John Kennedy was the first U.S. President to be photographed primarily in color; the White House negative file, which consists mostly of photographs taken by White House staff photographers, is the most important collection of photographs in the Library. The file contains about 35,000 photographs, of which more than 18,000 are color negatives (mostly Ektacolor Professional and Kodacolor-X films in the 120 roll film format).

May 1979

In storage at the warehouse, some framed portraits of Kennedy and his family were displayed on this wall together with other artifacts. The Kennedy Library, in common with most other historical collections, emphasizes the preservation of its negatives, motion pictures, and other original materials. Prints made from the negatives are to a certain extent considered to be expendable. This approach differs from fine art collections, which stress preservation of original prints, usually made by the photographer himself or herself. In most cases, fine art museums do not possess or otherwise have access to a photographer's negatives.

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Entering the cold storage vault, Goodrich carries a small roll of motion picture film and several boxes of color slides. The very cold, fan-circulated air in the vault requires that a jacket be worn, and visits are usually short.

1982

Linked to temperature and relative humidity controls, an automatic alarm system alerts security personnel if conditions inside the vault exceed preset limits.

color photography to be a serious medium. As was the case during the cellulose nitrate black-and-white era before color, the entertainment motion picture industry, with only a few exceptions, has continued to show little concern about the preservation of its movies. Museums are now trying to come to grips with the preservation of huge amounts of color film from the past five decades, a significant portion of which is already in a seriously faded condition. This is the unfortunate legacy of years of neglecting the importance of good color stability and proper storage conditions on the part of nearly everyone involved.

Museums and archives are faced with a simple choice: either they follow the examples of the John Fitzgerald Kennedy Library, the National Aeronautics and Space Administration (NASA), the Historic New Orleans Collection, the Peabody Museum of Archaeology and Ethnology at Harvard University, the Art Institute of Chicago, and a few other farsighted institutions, which have constructed large-scale, humidity-controlled cold storage facilities to halt further deterioration of their collections, or they can continue to store color materials at normal room temperatures as they have always done.

If cold storage is not provided, one can properly question the effort and expense of acquiring and administering color collections in the first place — since this is being done with the certain knowledge that most of the color films and still photographs in such collections will have severely deteriorated by the time they are seen by future generations. This do-nothing approach is particularly short-sighted because the cost of constructing and operating a cold storage facility is usually very small in relation to the cost of the collections placed in it.

In the past, some institutions — notably the American Film Institute and the Library of Congress — believed that some future technology, such as electronic digital storage or laser holographic separation techniques, would allow copies of color motion pictures to be stored permanently at room temperature with little or no quality loss and at a lower cost than cold storage. Such thinking has now been almost completely abandoned by knowledgeable people in the preservation field. As Lawrence Karr, former director of preservation for the American Film Institute and an early proponent of the "new technology" approach, observed in 1980: "This represents a fundamental shift in the attitude of the American archivists, in particular, since as late as 1971 they felt that future technology would provide the solution to the problem. Since this solution has failed to materialize in the past nine years, the consensus now is

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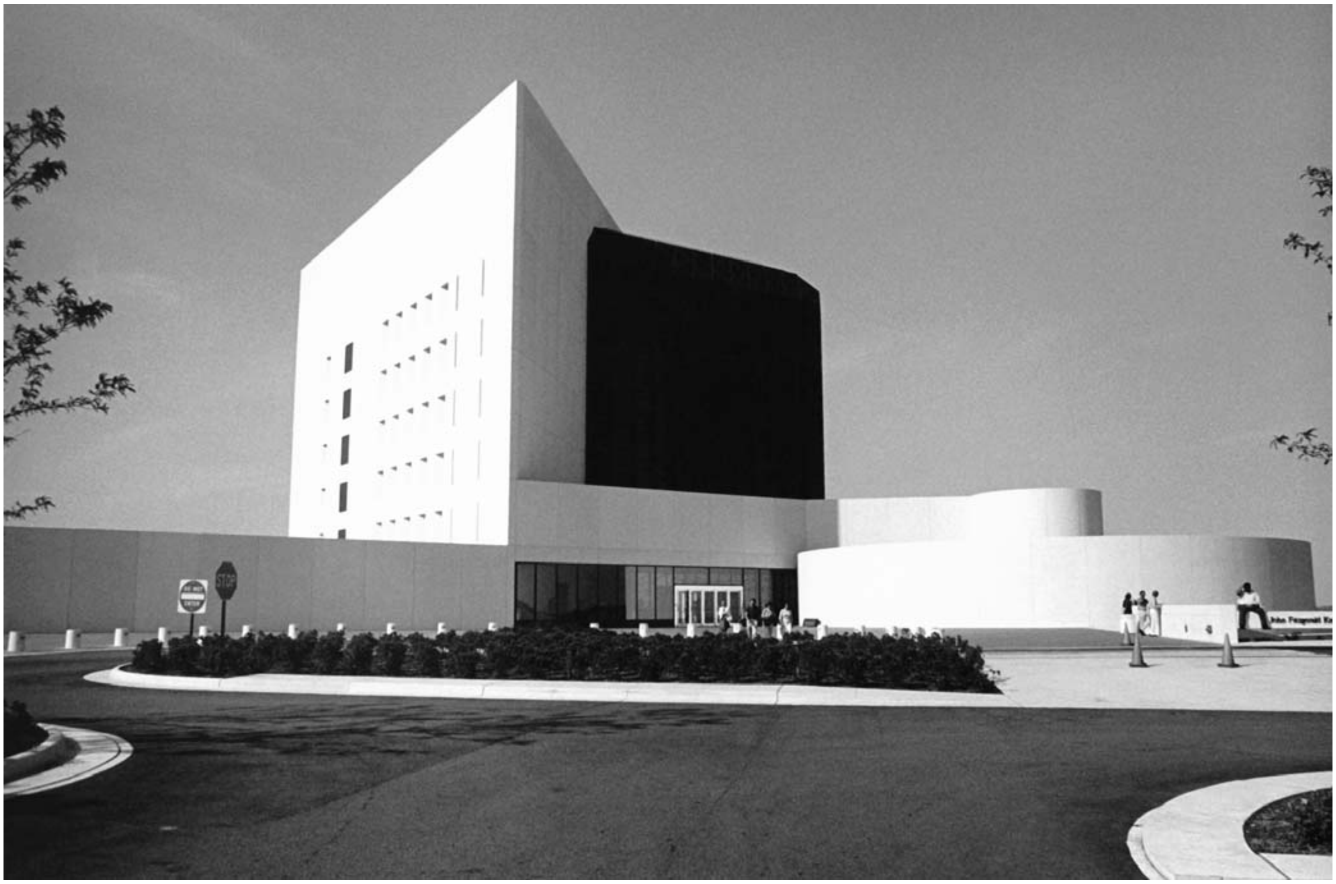

1982

The completed $12 million John Fitzgerald Kennedy Library is a modernistic glass and concrete structure. The Library, which has numerous exhibits highlighting Kennedy's life and a theater where a movie about Kennedy is shown, is visited by tens of thousands of people every year — far more than any of the other presidential libraries. The Library houses the papers and official files of Kennedy from his early years through his presidency. The collection includes nearly 150,000 still photographs and about 6,000 reels of motion picture film; in addition the Library has large numbers of videotapes, audiotapes, books, and a series of more than 1,000 oral history interviews.

that cold storage must be employed as soon as possible."[2]

In April 1980, the American Film Institute and the Library of Congress jointly sponsored the Conference on the Cold Storage of Motion Picture Films. Held in Washington, D.C., the meeting was attended by film archivists from all over the world; they discussed their experiences and problems with cold storage of films and encouraged construction of cold storage facilities by institutions that did not already have them. (Quite surprisingly, only three years later, the American Film Institute seemed to have forgotten the recommendations of the 1980 conference and said: "There is no practical solution for preserving [modern] color film."[3] The Film Institute quickly returned to its long-held notion that while some future technology may solve the problem of color preservation, there was currently little that could be done to save color films.)

Low-temperature, humidity-controlled cold storage is also practical for the permanent preservation of cellulose nitrate film, cellulose diacetate film (an early type of safety film), and cellulose triacetate film, all of which have inadequate stability when kept at normal room temperature and humidity. With large quantities of material, it is much less expensive to preserve the original films than to make duplicates; in addition, cold storage allows preservation of the original artifacts, and the subtle — or sometimes major — image-quality losses that *always* occur when making duplicates are avoided.

Estimates of the useful life of color photographs kept in cold storage greatly exceed the expected life for most black-and-white photographs stored at typical room temperature and humidity. By placing color photographic materials into a low-temperature vault, they will almost certainly last longer than most other objects in a museum collection. Ideally, all photographs in a museum — both color and black-and-white — should be kept in cold storage, or at least in an area with a controlled, moderate temperature and a relative humidity of 30–40%.

The Art Institute of Chicago has followed this approach and has a humidity-controlled room for black-and-white photographs with a temperature of 60°F (15.5°C) and 40% RH in addition to an adjacent vault for color materials, which currently is kept at 40°F (4.4°C), also at 40% RH. (The color vault was designed to maintain 0°F [–18°C], and although it currently is operated at a warmer temperature to afford more comfortable working conditions for the curatorial staff, the temperature will probably be reduced to

(continued on page 698)

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Table 20.1 Estimated Number of Years for “Just Noticeable” Fading to Occur in Various Kodak Color Materials Stored in the Dark at Room Temperature and Three Cold-Storage Temperatures (40% RH)

Time Required for the Least Stable Image Dye to Fade 10% from an Original Density of 1.0

Boldface Type indicates products that were being marketed when this book went to press in 1992; the other products listed had either been discontinued or replaced with newer materials. These estimates are for dye fading only and do not take into account the gradual formation of yellowish stain. With print materials in particular (e.g., Ektacolor papers), the level of stain may become objectionable before the least stable image dye has faded 10%.

Color Papers	Years of Storage at:* 75°F (24°C)	45°F (7.2°C)	35°F (1.7°C)	0°F (–18°C)
Ektacolor 37 RC Paper (Process EP-3) (“Kodacolor Print” when processed by Kodak)	10	95	200	3,400
Ektacolor 78 and 74 RC Papers (Process EP-2) (“Kodacolor Print” when processed by Kodak)	8	75	160	2,700
Ektacolor Plus Paper **Ektacolor Professional Paper** (Process EP-2) (“Kodacolor Print”) (“Kodalux Print”)	**37**	**350**	**750**	**12,500**
Ektacolor 2001 Paper **Ektacolor Edge Paper** **Ektacolor Royal II Paper** Ektacolor Portra Paper **Ektacolor Portra II Paper** **Ektacolor Supra Paper** **Ektacolor Ultra Paper** **Kodak Duraflex RA Print Material** (Process RA-4, water wash) (“Kodalux Print”)		**(not disclosed)** [A]		
Ektacolor 2001 Paper **Ektacolor Edge Paper** **Ektacolor Royal II Paper** Ektacolor Portra Paper **Ektacolor Portra II Paper** **Ektacolor Supra Paper** **Ektacolor Ultra Paper** **Kodak Duraflex RA Print Material** (Process RA-4NP, Stabilizer rinse) (“Kodalux Print”)		**(not disclosed)** [A]		
Ektachrome 2203 Paper (Process R-100)	7	65	140	2,400
Ektachrome 14 Paper (Process R-100)	10	95	200	3,400
Ektachrome Radiance Paper (Process R-3) (1991—)		**(not disclosed)**		
Ektachrome 22 Paper [improved] (Process R-3) (1991–92)		(not disclosed)		
Ektachrome Copy Paper (R-3) Ektachrome HC Copy Paper Ektachrome Overhead Material Ektachrome Prestige Paper Ektachrome 22 Paper (1984–90)	**8**	**75**	**160**	**2,700**

Color Negative Films	Years of Storage at:* 75°F (24°C)	45°F (7.2°C)	35°F (1.7°C)	0°F (–18°C)
Kodacolor II Film	6	55	120	2,000
Kodacolor VR 100, 200, 400 Films	**17**	**160**	**340**	**5,800**
Kodacolor VR-G 100 Film (“initial type”) (Kodacolor Gold 100 Film in Europe)	12	115	240	4,100
Kodacolor Gold 200 Film (1989–91) (formerly Kodacolor VR-G 200 Film) Kodak Gold 200 Film (new name: 1991–92)		(not disclosed) [B]		
Kodak Gold Plus 100 Film **Kodak Gold II 100 Film** (name in Europe) (1992—)		**(not disclosed)** [C]		
Kodak Gold Plus 200 Film **Kodak Gold II 200 Film** (name in Europe) (1992—)		**(not disclosed)** [D]		
Kodak Gold Plus 400 Film **Kodak Gold II 400 Film** (name in Europe) (1992—)		**(not disclosed)** [E]		
Kodacolor Gold 1600 Film (1989–91) **Kodak Gold 1600 Film** (new name: 1991—)		**(not disclosed)** [F]		
Ektar 25 Film (1988—)		**(not disclosed)** [G]		
Ektar 100 Film (1991—)		**(not disclosed)**		
Ektar 125 Film (1989—)		(not disclosed) [H]		
Ektar 1000 Film (1988—)		**(not disclosed)** [I]		
Ektapress Gold 100 Prof. Film (1988—)		**(not disclosed)** [J]		
Ektapress Gold 400 Prof. Film (1988—)		**(not disclosed)** [K]		
Ektapress Gold 1600 Prof. Film (1988—)		**(not disclosed)** [L]		
Vericolor II Prof. Film Type S	6	55	120	2,000
Vericolor II Prof. Film Type L	**3**	**28**	**60**	**1,000**
Vericolor II Commercial Film Type S	3	28	60	1,000
Vericolor III Prof. Film Type S **Ektacolor Gold 160 Prof. Film**	**23**	**220**	**460**	**7,800**
Vericolor 400 Prof. Film (1988—) **Ektacolor Gold 400 Professional Film**		**(not disclosed)** [M]		
Vericolor HC Professional Film		**(not disclosed)** [N]		
Vericolor Copy/ID Film		**(not disclosed)**		
Vericolor Internegative Film 6011	**5**	**48**	**100**	**1,700**

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Color Transparency Films	75˚F (24˚C)	45˚F (7.2˚C)	35˚F (1.7˚C)	0˚F (–18˚C)
	Years of Storage at:*			
Ektachrome Films (Process E-3) [O]	5	48	100	1,700
Ektachrome Films (Process E-4) [P]	15	140	300	5,100
Kodak Photomicrography Color Film 2483 (Process E-4)	**3**	**28**	**60**	**1,000**
Ektachrome Films (Process E-6) ["Group I" types since 1979]	**52**	**500**	**1,100**	**18,000**
Ektachrome Plus & "HC" Films [Q] **Ektachrome 64X, 100X, & 400X Films Ektachrome 64T and 320T Films** ["Group II" types since 1988] (Process E-6)	**110**	**1,000**	**2,200**	**37,000**
Kodachrome Films (Process K-14) [all types]	**95**	**900**	**1,900**	**32,000**

Motion Picture Color Negative Films

Eastman Color Negative II Film 5247 (1974)	6	57	120	2,000
Eastman Color Negative II Film 5247 (1976)	12	115	240	4,000
Eastman Color Negative II Film 5247 (1980)	28	270	550	9,500
Eastman Color Negative Film 5247 (1985 name change)	**28**	**270**	**550**	**9,500**
Eastman Color High Speed Negative Film 5293	(not disclosed) [R]			
Eastman Color High Speed Negative Film 5294	**(not disclosed)** [R]			
Eastman Color High Speed SA Negative Film 5295	**(not disclosed)** [R]			
Eastman Color High Speed Daylight Negative Film 5297	**(not disclosed)** [R]			
Eastman Color Negative II Film 7247 (1974–83)	6	57	120	2,000
Eastman Color Negative II Film 7291	**50**	**475**	**1,000**	**17,000**
Eastman Color High Speed Negative Film 7294	(not disclosed) [R]			
Eastman Color High Speed Negative Film 7292	**(not disclosed)** [R]			
Eastman Color High Speed Daylight Negative Film 7297	**(not disclosed)** [R]			
Eastman EXR Color Negative Film 5245 and 7245	**22**	**210**	**440**	**7,500**
Eastman EXR Color Negative Film 5248 and 7248	**30**	**285**	**600**	**10,000**
Eastman EXR High Speed Color Negative Film 5296 & 7296	**50**	**475**	**1,000**	**17,000**

Motion Picture Laboratory Intermediate Films	75˚F (24˚C)	45˚F (7.2˚C)	35˚F (1.7˚C)	0˚F (–18˚C)
	Years of Storage at:*			
Eastman Color Reversal Intermediate Film 5249 & 7249	**8**	**75**	**160**	**2,500**
Eastman Color Intermediate II Film 5243 and 7243	22	210	440	7,500
Eastman Color Intermediate Film 5243 and 7243 Improved	**(not disclosed)**			

Motion Picture Print Films

Eastman Color Print Film 5381 & 7381 [S]	[5	48	100	1,700]
Eastman Color SP Print Film 5383 & 7383	5	48	100	1,700
Eastman Color Print Film 5384 & 7384	**45**	**430**	**900**	**15,000**
Eastman Color LC Print Print Film 5380 & 7380	**45**	**430**	**900**	**15,000**

* Notes:

The estimates given here have been derived from data in **Evaluating Dye Stability of Kodak Color Products,** Kodak Publication No. CIS-50, January 1981, and subsequent CIS-50 series of dye-stability data sheets through 1985; **Kodak Ektacolor Plus and Professional Papers for the Professional Finisher,** Kodak Publication No. E-18, March 1986; **Dye Stability of Kodak and Eastman Motion Picture Films** (data sheets); Kodak Publications DS-100-1 through DS-100-9, May 29, 1981; **Image-Stability Data: Kodachrome Films,** Kodak Publication E-105 (1988); **Image-Stability Data: Ektachrome Films,** Kodak Publication E-106 (1988); and other published sources.

For many products, including Process E-6 Ektachrome films; Vericolor III, Vericolor 400, Kodacolor VR, Kodacolor Gold (formerly Kodacolor VR-G), Kodak Gold, and Kodak Gold Plus color negative films; and Eastman color motion picture films, storage at 60% RH will result in fading rates of the least stable dye (yellow) approximately twice as great as those given here for 40% RH; that is, the estimated storage time for reaching a 10% dye-density loss will be cut in half.

Furthermore, the dye stability data given here were based on Arrhenius tests conducted with free-hanging film samples exposed to circulating air. Research disclosed by Eastman Kodak in late 1992 showed that storing films in sealed or semi-sealed containers (e.g., vapor-proof bags and standard taped or untaped metal and plastic motion picture film cans) could substantially increase the rates of dye fading and film base deterioration. Therefore, the estimates given here for color motion picture films probably **considerably** overstate the actual stabilities of the films when they are stored in standard film cans under the listed temperature and humidity conditions. (See: A. Tulsi Ram, D. Kopperl, R. Sehlin, S. Masaryk-Morris, J. Vincent, and P. Miller [Eastman Kodak Company], "The Effects and Prevention of 'Vinegar Syndrome'," presented at the **1992 Annual Conference of the Association of Moving Image Archivists**, San Francisco, California, December 10, 1992.) See Chapter 9 for further discussion.

A) Kodak declined to release stability data for Ektacolor 2001 Paper introduced in 1986, or Ektacolor Edge Paper introduced in 1991 (processed with either the "washless" RA-4NP Stabilizer or with a water wash). However, according to a Kodak press release dated

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January 21, 1986, and titled "New Kodak Color Paper/Chemicals Offer Exceptionally Fast Processing," the stability of Ektacolor 2001 Paper (Processes RA-4 and RA-4NP) is "comparable to Ektacolor Plus Paper." This author's accelerated dark fading tests with 1988-type Ektacolor 2001 Paper (processed in a Kodak Minilab with Process RA-4NP "washless" chemicals) also indicate that the stability of the paper is generally similar to that of Ektacolor Plus Paper (processed in EP-2 chemicals with a water wash). Ektacolor 2001 Paper was introduced in mid-1986 for use in Kodak minilabs; this was the first Process RA-4 ("rapid access") color negative paper. Ektacolor Portra Paper, a lower-contrast "professional" version of Ektacolor 2001 Paper, was introduced in 1989. Ektacolor Supra, Ektacolor Ultra, and Ektacolor Royal papers were introduced in 1989. Kodak Duraflex RA Print Material (a high-gloss, polyester-base print material) was also introduced in 1989. Ektacolor Royal II Paper was introduced in 1991 and Ektacolor Portra II Paper was introduced in 1992.

B) Kodak declined to release specific stability data for Kodacolor Gold 200 Film, introduced in 1986 under the Kodacolor VR-G 200 name. This author's tests indicate that the stability of this film is similar to that of Kodacolor VR-G 100 Film (i.e., 12 years storage at 75°F [24°C] and 40% RH for a 10% loss of the yellow dye to occur).

C) Kodak declined to release stability data for Kodak Gold Plus 100 Film (called Kodak Gold II 100 Film in Europe) that was introduced in 1992 as a replacement for Kodak Gold 100 Film.

D) Kodak declined to release stability data for Kodak Gold Plus 200 Film (called Kodak Gold II 200 Film in Europe) that was introduced in 1992 as a replacement for Kodak Gold 200 Film.

E) Kodak declined to release stability data for Kodak Gold Plus 400 Film (called Kodak Gold II 400 Film in Europe) that was introduced in 1992 as a replacement for Kodak Gold 400 Film.

F) Kodak declined to release specific stability data for Kodak Gold 1600 Film, introduced under the Kodacolor Gold 1600 name in 1989. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 19 and 33 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

G) Kodak declined to release specific stability data for Kodak Ektar 25 Film, introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 8 and 14 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

H) Kodak declined to release specific stability data for Kodak Ektar 125 Film, introduced in 1989. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 8 and 14 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

I) Kodak declined to release specific stability data for Kodak Ektar 1000 Film, introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 19 and 33 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

J) Kodak declined to release specific stability data for Kodak Ektapress Gold 100 Professional Film, which was introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 8 and 14 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

K) Kodak declined to release specific stability data for Kodak Ektapress Gold 400 Professional Film, introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 19 and 33 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

L) Kodak declined to release specific stability data for Kodak Ektapress Gold 1600 Professional Film, introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 19 and 33 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

M) Kodak declined to release specific stability data for Kodak Vericolor 400 Professional Film, introduced in 1988. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 19 and 33 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

N) Kodak declined to release specific stability data for Kodak Vericolor HC Professional Film. Kodak has, however, provided data (Kodak Publication E-107, dated June 1990) which indicates that when this film is kept in the dark at 75°F and 40% RH, a storage life of between 8 and 14 years may be expected before a 10% loss of the least stable image dye (yellow in this case) occurs.

O) The estimate for Process E–3 Ektachrome films is from an article by Charleton Bard et al. (Eastman Kodak) entitled: "Predicting Long-Term Dark Storage Dye Stability Characteristics of Color Photographic Products from Short-Term Tests," **Journal of Applied Photographic Engineering,** Vol. 6, No. 2, April 1980, p. 44. The accelerated-test data given in the article were for Ektachrome Duplicating Film 6120 (Process E-3) and are assumed to apply to Process E-3 Ektachrome camera films; Kodak declined to release dye-stability data for these films.

P) From Kodak sources; Kodak has not officially released dark fading data for most Process E-4 Ektachrome films (e.g., Ektachrome-X and High Speed Ektachrome).

Q) Kodak declined to release stain-formation data for its high-saturation "Group II" Ektachrome 100 Plus Professional film and its amateur counterpart, Ektachrome 100 HC Film, both of which were introduced in 1988. Ektachrome 50 HC Film, Ektachrome 64X, 100X, 400X, 64T and 320T films, all of the "Group II" type, were introduced during 1989–1992. This author's accelerated tests with these new films indicate that when yellowish stain formation is considered, their dark storage stability is, overall, similar to that of Ektachrome 100 and other "Group I" Ektachrome films.

R) Kodak declined to release stability data on which to base estimates for low-temperature storage for these films; however, the company has implied that the films have stability characteristics similar to current Eastman Color Negative Film 5247 — which for 40% RH storage calculates to be about 270 years at 45°F (7.2°C), 550 years at 35°F (1.7°C), and 9,500 years at 0°F (–18°C).

S) Kodak declined to release stability data for Eastman Color Print Film 5381 and 7381; however, examination of films in collections indicates that the stability of these film is certainly no better and is quite possibly even worse than Eastman Color Print Film 5383 and 7383.

End of Notes for Table 20.1

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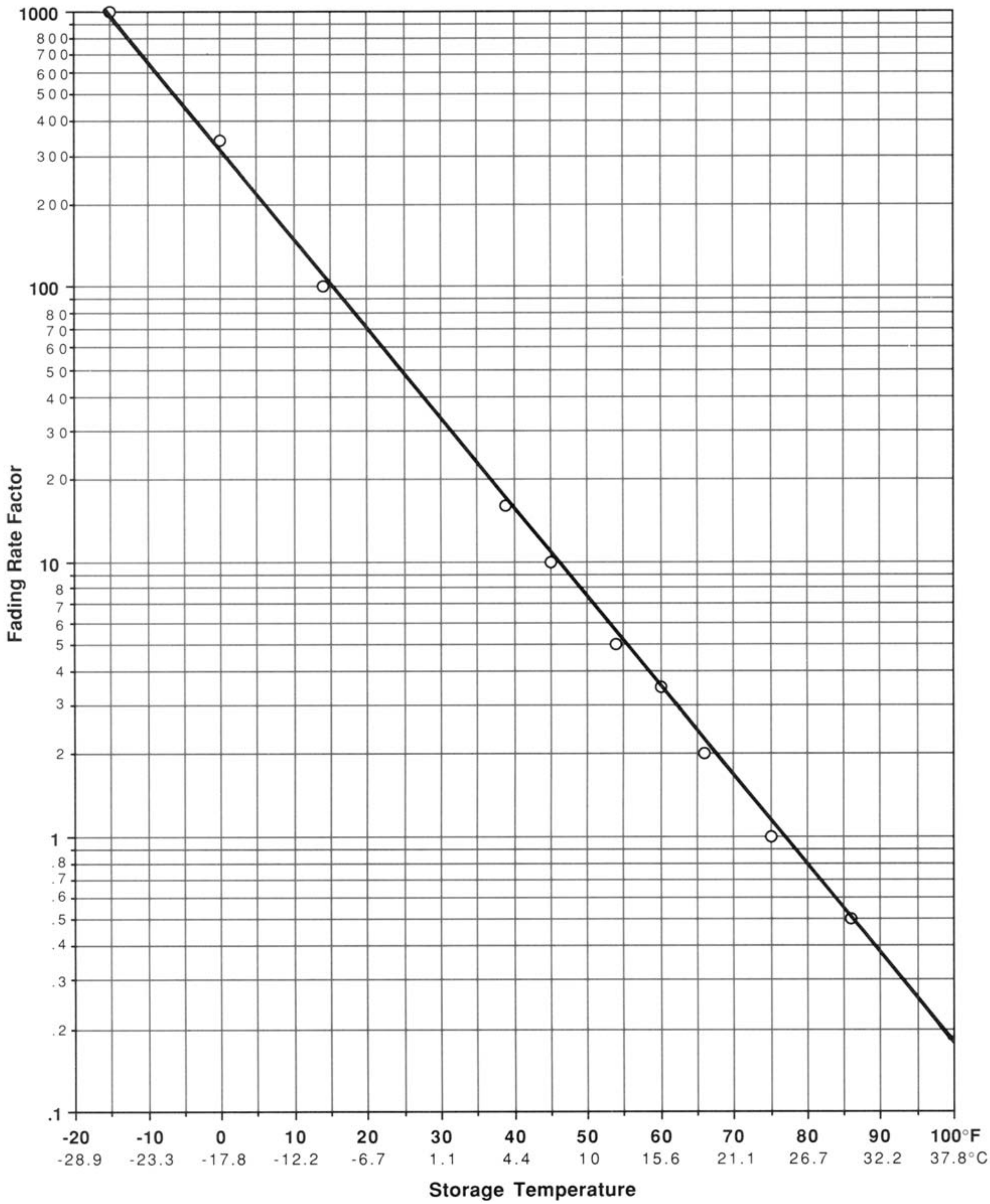

Figure 20.1 This graph, which illustrates color film and color print fading rates versus temperature at 40% RH, may be used to calculate the approximate fading rate for a color material in cold storage at any selected temperature when an Arrhenius estimate for that product is available (e.g., for storage at 24°C [75°F]). This graph is based on fading-rate temperature-dependence data published by Eastman Kodak Company in **Dye Stability of Kodak and Eastman Motion Picture Films** (Kodak Publication DS-100 [May 1981]) and **Conservation of Photographs** (Kodak Publication F-40 [March 1985]).

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Recommendations

Who Should Install Cold Storage Facilities?

- **Motion picture studios and film libraries:** Because of the immense commercial value, future earnings potential, and cultural importance of motion pictures and television productions, it is inexcusable not to preserve these films in humidity-controlled cold storage vaults. Cold storage affords simple and accessible long-term preservation of original negatives, intermediates, sound negatives, and magnetic tapes, and, perhaps of equal importance, enables unprojected release prints to be kept the way they looked the day they were made. The cost of suitable facilities is small, and savings in retiming and reprinting will quickly repay the initial investment. With films instantly available in their brilliant, original condition, there will be no delays in future releases, television broadcast, or conversion to high-definition television or other future formats while costly "restoration" efforts are made to salvage faded films. With cold storage available, there is no need to make black-and-white separations, which are not only extremely expensive but are a much inferior method of preserving film images, compared with cold storage of color originals. It is especially urgent that movies made on pre-1985 film stocks (e.g., Eastman Color Print Film 5383 and previous Eastman Color print films), which in general are far less stable than current materials, be refrigerated without further delay.

- **Museums and archives:** Cold storage is the only way to preserve color photographs in their original form for long periods of time. It is absolutely essential that institutions with valuable color photographs or motion pictures in their collections provide humidity-controlled cold storage. Neglecting to do so is shortsighted and irresponsible. Cold storage not only preserves color images but also preserves plastic film base, RC paper, and other support materials. Albumen prints and other unstable 19th-century prints — indeed, all black-and-white photographs as well as books, manuscripts, and works of art on paper — will last far longer if they are kept in cold storage. Restoration and conservation projects involving various works of art can be documented precisely on color film and be preserved unchanged for the benefit of future generations of conservators. Color photographic calibration standards for densitometric print monitoring can also be preserved unchanged to maintain the long-term accuracy of a monitoring program. It is highly unlikely that museums without cold storage facilities will in the future be offered photographers' archives or significant donations of color photographs. No photographer or benefactor wants to donate work to an institution that is unwilling to properly care for it.

- **Commercial picture collections:** Many of the world's most historically and culturally important photographs are found in newspaper and magazine picture collections and in the files of commercial picture agencies — the priceless collections at Time Warner Inc., the National Geographic Society, and the Magnum and Black Star picture agencies are prime examples. For many reasons, commercial picture collections should operate with duplicates and not send precious originals to clients, or otherwise handle them any more than absolutely necessary. Cold storage of inactive originals ensures that they will always be available in excellent condition. It is crucial that particularly unstable films, such as Process E-1, E-2, E-3, and E-4 Ektachrome films and all color negatives prior to around 1985, be refrigerated without delay to prevent further deterioration. Many commercial collections have large quantities of extremely unstable Process E-3 Ektachrome sheet and roll films (1959–1977) in their files. The cost of suitable cold storage facilities is very small in relation to the benefits.

- **Microfilm archives:** Because of the inherently poor stability of the fine-grain silver images of black-and-white microfilms, as well as increasing concern about the long-term stability of cellulose triacetate and earlier types of acetate film base in typical storage conditions, it is strongly recommended that microfilms be kept in humidity-controlled cold storage (e.g., at 40°F [4.4°C] and 30% RH). With microfilms, it is particularly important that the relative humidity in storage areas be kept at a low level — never above 40% RH.

- **Nitrate film storage:** Cellulose nitrate film still in good condition can be preserved almost indefinitely when stored at or below 0°F (–18°C), with the relative humidity in the range of 30 to 40%, in explosion-proof freezers (see Appendix 19.1 at the end of Chapter 19). When large quantities of nitrate film are involved, storage vaults should be constructed in isolated areas, away from other storage facilities. It is strongly recommended that original nitrate negatives and motion pictures be permanently preserved, with duplicate copies made as required for printing, projection, or other applications. It is particularly important to save all of the nitrate Technicolor imbibition prints — and the original nitrate camera separation negatives — that still survive (see Chapters 9 and 10).

Containers for Motion Picture Films in Humidity-Controlled Cold Storage Vaults

- **Packaging:** For long-term storage in humidity-controlled cold storage facilities, color and black-and-white motion picture films should be placed in "vented" plastic cans or vapor-permeable cardboard containers. Standard metal and plastic film cans (taped or untaped), vapor-proof bags, and other sealed containers are not recommended for the long-term storage of acetate-base motion picture films (see page 321 in Chapter 9 for an important discussion concerning the detrimental effects of sealed containers on dye stability and film base stability).

Storage Temperature and Relative Humidity

- **Temperature:** For museums, archives, and motion picture libraries — most of which have a variety of color materials in their collections — a temperature of 0°F (–18°C) or lower is recommended. This will afford essentially permanent preservation of even the most unstable types of color films and prints. Large collections may find it economical to segregate color materials in groups, according to their dark fading stability characteristics. The most unstable products should be stored at low temperatures and, for economy, the more stable materials can be kept in more moderate conditions. Although many factors can influence the choice of a specific storage temperature, some are difficult to quantify (e.g., how long a particular color print or motion picture should be preserved and how much fading can be tolerated); it is therefore always best to opt for the lowest temperature that funds permit.

- **Relative humidity:** In most situations, 30% RH is recommended. For older motion picture films, which may become excessively brittle at very low humidities, 40% RH is suggested. If materials will be subjected to higher relative humidities in work and study areas when they are withdrawn from a vault, it is preferable to

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avoid wide-range humidity cycling by selecting a higher relative humidity in the vault for storage. The reduction in image stability caused by the higher humidity can be compensated for by maintaining a lower storage temperature. Recent studies of emulsion stress and moisture relationships conducted by Mark McCormick-Goodhart of the Smithsonian Conservation Analytical Lab have underscored the dangers to prints and films posed by storage in cycling — or in very low — relative humidities. For reasons discussed in this chapter and in Chapter 9, the practice of pre-conditioning materials to a low moisture content, packaging them in vapor-proof containers, and then storing the packages in vaults with high, uncontrolled relative humidity generally is not recommended.

Design of Humidity-Controlled Cold Storage Facilities

- **Dehumidifiers:** Cargocaire automatic dry-desiccant dehumidifiers with HEPA filters in the air stream are recommended. Redundant systems should always be specified — in the event that one unit fails (which eventually it most certainly will), the second unit will automatically take over. In most instances, it is recommended that dehumidifier units be installed outside of the storage vault; this will simplify service and also eliminate a potential source of fire danger.

- **Refrigeration and air filtration equipment:** Vaults should be equipped with redundant, independent refrigeration systems. When one system fails, the other should automatically take over. The two systems should be designed so that one can be serviced and even disassembled without impairing the operation of the other. Air filtration systems to remove acetic acid vapors and oxidizing gases should be provided.

- **Alarms and automatic shutdown systems:** It is essential that all cold storage facilities for photographs or motion pictures be provided with fail-safe automatic shutdown systems that will cut off electrical power to all refrigeration and dehumidification equipment, vault door-frame heaters, interior lights, etc. if pre-set limits of temperature or relative humidity deviation are exceeded. At the same time, alarms should sound to alert personnel of the malfunction. Automatic shutdown systems should be tested periodically to be certain they are functioning properly. In the event of an equipment or power failure, the vault door should be kept closed until the interior of the vault reaches ambient temperature; this will prevent excessive humidity levels from developing in the vault and prevent moisture condensation on film cans, print boxes, and other containers within the vault. Storage vaults should be provided with continuous recorders for temperature and RH.

- **Recommended vault contractors:** The design and construction of a properly functioning humidity-controlled cold storage vault for photographic materials involve special expertise, and it is essential that an experienced contractor be selected. Bonner Systems, Inc. is recommended. Bruce Bonner, head of Bonner Systems, Inc., supervised the design and construction of the cold storage vaults at the John Fitzgerald Kennedy Library, the Peabody Museum of Archaeology and Ethnology at Harvard University, and the Art Institute of Chicago, among other institutions. For large installations, Turner Construction Company of New York City is recommended. Turner was the general contractor for the construction of the sophisticated archive buildings for the cold storage of motion picture film at the Warner Bros. and Paramount Pictures movie studios in California.

the zero-degree level in the future.)

Cold storage not only preserves the photographic image but also correspondingly lengthens the life of gelatin emulsions, paper supports, film bases, mount board, photograph albums, mounting adhesives, and so forth.

Increases in the Life of Color Materials Afforded by Cold Storage

The stability characteristics of color photographic materials have been discussed in detail in Section I of this book. Dark fading data for a representative group of Kodak color film and print materials are given for four different temperatures in **Table 20.1**; the estimated times are computed from the day the material was processed. The estimates given in **Table 20.1** are for a 10% loss, or "just noticeable fading," of the least stable image dye. Most of the dark fading data elsewhere in this book are given in terms of a 20% loss of the least stable image dye; however, this author believes that for critical museum and archive applications, a 20% dye loss is in most cases unacceptable, and that a 10% loss is a more meaningful basis on which to calculate storage times.

Kodak has not yet released estimates of minimum-density stain formation (almost always yellowish in color) during long-term dark storage. In critical museum and commercial applications, yellow stain is a more serious problem than dye fading with most products, especially color prints (e.g., Kodak Ektacolor prints and similar chromogenic materials made by other manufacturers). Rates of stain formation with most color materials are directly related to storage temperature and relative humidity, and cold storage at low humidity will probably reduce stain formation to a degree that approximates the reductions given in **Table 20.1** for dye fading.

Many Color Films and Prints Will Have Already Faded More Than 10% by the Time They Arrive in a Museum or Archive

In many instances, a color film or print will already have surpassed a 10% image dye loss and/or suffered excessive yellowish stain by the time it arrives at a museum, archive, or film library. If further deterioration is to be prevented, the color materials must immediately be placed in low-temperature storage. To obtain approximately the same life for a variety of products — which may have distinctly different fading rates — larger institutions may want to have two or more storage vaults which can be operated at different temperatures. For example, to reduce the rate of fading to approximately the same level, it is necessary to store motion picture negatives and prints that have inherently very poor image stability (e.g., most Eastman color film stocks in use prior to about 1985) at a lower temperature than is necessary with more recent Eastman and Fuji color negative and print films, nearly all of which have improved stability compared with the earlier products.

The greatly extended keeping times made possible by very-low-temperature storage (in the range of 0°F [–18°C]) are obvious from **Table 20.1**. In most cases the additional expenses of constructing and operating a very-low-temperature facility — instead of one that can maintain a

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more moderate temperature of 35°F (1.7°C) — are relatively small. However, for the same amount of dye fading, a given color photograph will last approximately 17 times longer at the lower temperature. An Ektacolor 74 RC print, which will show a noticeable loss of cyan dye in about 8 years when stored at room temperature, will last about 160 years at 35°F before the same amount of fading takes place. Even 160 years is not an adequate life in terms of a permanent museum collection. At 0°F, however, the print is calculated to last about 2,700 years before the same "just noticeable" amount of fading takes place. **Figure 20.1**, which is based on data published by Kodak, shows the approximate fading rate factor for any selected storage temperature.

In some cases — particularly for already-deteriorated materials that have poor inherent stability — temperatures below 0°F (–18°C) may be advised. The often-recommended 0°F temperature is a rather arbitrary figure that had its origin in the frozen food industry. Many food products have only a limited storage life if kept at temperatures just below the freezing point of water, but it was found that colder temperatures could meet most commercial storage requirements. As a result, much of the commercial equipment designed for food storage operates at approximately 0°F. Kodak has recommended storage temperatures as low as –15°F (–26°C) to maximize the life of color materials; at this extremely low temperature, Kodak estimates the life of color films and prints will be approximately 1,000 times greater than when stored at 75°F (24°C).[4]

The Moisture Content of Films and Prints as Influenced by Temperature and Ambient Relative Humidity

Films and prints normally contain significant amounts of moisture (as a percentage of weight) in the emulsion and support materials. With films, the gelatin emulsion accounts for most of the moisture uptake, but even solid plastic support materials absorb some moisture. Archivists have occasionally expressed fears about possible adverse effects of low-temperature storage on photographic materials, and a frequent concern is that the moisture content of films and prints will rise as the storage temperature drops (in a manner analogous to the way the relative humidity in a closed container of air rises as the temperature decreases — see the discussion of relative humidity in Chapter 16).

It is important to note, however, that the moisture content of paper, film base, gelatin emulsions, and many other solids is not affected by changes in *temperature alone*.[5] Even the actual moisture content, or *absolute* humidity, is not the critical factor. Instead, the moisture content of most photographic materials is determined by the *relative humidity* of the surrounding air. Therefore, film stored with the surrounding air at a temperature of 0°F (–18°C) and a relative humidity of 60% will have almost the same moisture content as film stored at 90°F (32°C) and a relative humidity of 60%. Although the relative humidity of the air is the same 60% at both temperatures, the warmer air would contain about 20 times the moisture content by weight as the colder air. Nonetheless, the moisture content of the films is nearly the same at both temperatures.

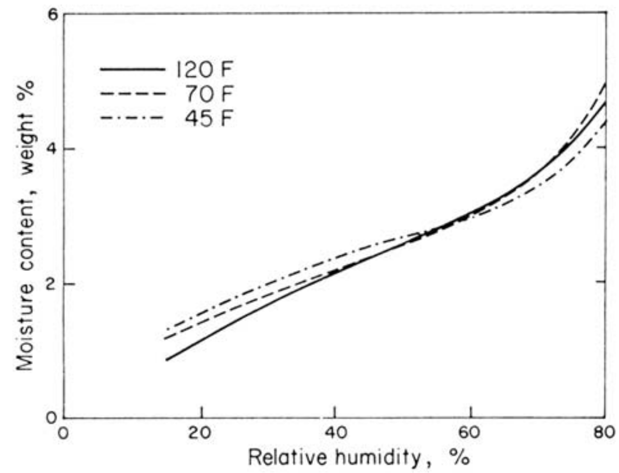

Figure 20.2 Effect of storage temperature on moisture content of typical motion picture color negative film on cellulose triacetate base. When stored at 60% RH, changes in storage temperature have very little effect; at lower humidities the effect is negligible. (From: Adelstein, Graham, and West, "Preservation of Motion-Picture Color Films Having Permanent Value," **Journal of the SMPTE**, Vol. 79, November 1970. With permission of SMPTE.)

Film sealed with little excess air in a vapor-proof can at room temperature and placed in a freezer at a temperature of 0°F (–18°C) will not experience any increase in moisture content. The moisture content of a typical motion picture film stored at three different temperatures and at various relative humidities is illustrated in **Figure 20.2**. The general relationship shown also applies at temperatures below freezing.

The reader may wonder what happens to the relative humidity of the air which is contained in a film can along with the film itself. The answer is that as long as the can does not leak air, the relative humidity of the air packed in the can with the film will remain essentially unchanged regardless of the storage temperature. This is because the moisture-holding capacity of the air is exceedingly small compared with that of the film, when equal *volumes* of air and film are compared.

For example, film in equilibrium with air at 50% RH might contain 3% moisture by *weight*.[6] Thus a reel of film weighing 1 kg (2.2 lb.) would contain about 30 grams of moisture. Assuming this reel of film occupies a volume of 1048 cc, the amount of air in the can might be about 174 cc, or one-seventh of the total volume of the can. If the can were sealed with the 174 cc of air at 70°F (21°C) and 50% RH, the volume of air in the can would contain only about 0.0015 gram of moisture. This is about 1/20,000 the quantity of moisture in the film.

When a can containing film and a comparatively small quantity of air is put in a refrigerator or cold storage vault, the relative humidity of the air starts to rise as the temperature drops. The film (principally the gelatin emulsion) then begins to absorb moisture from the air to re-establish equilibrium with the relative humidity of the air. Because of the large moisture-holding capacity of the film, virtually all the excess moisture in the air is quickly absorbed by the

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film, resulting in essentially no change in relative humidity of the air, or in the moisture content of the film by weight. The important point here is that the equilibrium moisture content of a roll of film in a sealed container is determined by the ambient relative humidity where the film was stored *before* being placed in the cold storage vault.

If, however, a single strip of film containing only a few frames were placed in a large and otherwise empty film can, and then put in a refrigerator and cooled, there would be a significant rise in both the relative humidity of the air and the actual moisture content of the small piece of film. This is because of the proportionately very small volume of film compared with the volume of air. The problem can be easily avoided by keeping free air space in packages to a minimum; if necessary, crumpled paper of good quality can fill excess space.

Can Moisture in Films Form Ice Crystals at Temperatures Below Freezing?

An often-voiced fear is that moisture contained within an emulsion might form ice crystals at temperatures below freezing (the way water in fruits and vegetables crystallizes when it freezes) and that such crystal formation could distort, blister, or otherwise damage films.

Unlike frozen food, which may contain 90% or more water by weight, a gelatin emulsion contains only about 15% moisture by weight when equilibrated with air at 80% RH. Even if stored in air with a relative humidity as high as 95%, there will not be enough moisture in a film or print to form ice crystals. John Calhoun of Eastman Kodak wrote in 1952 that:

> . . . ice crystals or damage from ice formation has never been found in photographic film stored at below freezing temperatures. The small amount of moisture normally found in photographic emulsions or dry gelatin is not present in the form of liquid droplets but is molecularly adsorbed within the colloid.
>
> In one experiment made by the Eastman Kodak Company in 1939 several types of film were stored for three weeks completely surrounded with dry ice (solid carbon dioxide) in an insulated container. Thermocouples indicated the film to be at a temperature below –100°F [–73°C]. After removal the film was subjected to microscopic examination and no change in the emulsion structure found. Exhaustive photographic tests, and physical tests made on the film before and after processing, showed no detrimental effect of any kind.
>
> . . . there has been considerable practical experience in the storage of film at low temperatures, in some cases for as long as three years at –10°F. Never has any detrimental effect been found, *provided that the film was protected from the penetration of moisture from outside the package*. It makes no difference whether the film is cooled slowly or is quickly frozen in dry ice, or how low a temperature is used.[7]

Physical Effects of Low-Temperature Storage on Films and Prints

Some film archivists have also expressed vague worries that storage of photographic materials at temperatures below freezing — especially if films and prints are *repeatedly* taken in and out of cold storage, producing temperature fluctuations over a wide range — could eventually cause the following: the emulsion to fall off of films; the base to become so brittle that (even after the film has warmed up to room temperature) the film would break; rolls of motion picture films to become deformed; or other types of physical damage.

There is no published evidence that any of these things have actually occurred as a consequence of cold storage, even though many people have an “intuitive feeling” that rapid fluctuations between 0°F (–18°C) and room temperature *must* put terrific physical stress on rolls of film, and that this stress will eventually cause damage. Such fears probably arise because *people themselves* feel uncomfortable, and can be harmed, as a result of exposure to very low temperatures, and therefore they think that cold storage must be harmful to film, also.

In 1981, in response to this author’s questions about possible adverse effects on motion picture film of repeatedly cycling storage temperatures over a wide range, Kodak said:

> Based on our lab data, no physical harm is predicted. We cycle these films repeatedly from deep freeze to room temperatures without detecting any problems. Of course, it’s important to protect the film from moisture condensation during the warm-up period.
>
> We have tested 35mm (but not 70mm) thousand-foot rolls of processed film, cycling repeatedly from deep freeze (as low as –61°F [–52°C]) and observing them physically, our main interest being roll integrity (spoking, for instance). . . . On shorter lengths (from several feet to several hundred feet), we have examined the film for all physical properties — image stability, emulsion adhesion, support stability, etc.
>
> There is no demonstrated advantage to lowering or raising the temperature of rolls of film in gradual stages.[8]

Kodak went on to say that in the company’s experience over many years, cold storage poses no problems if care is exercised to prevent condensation during warm-up. A great deal of processed and unprocessed film is shipped in the winter, and during transit the temperature of the film may occasionally drop below –30°F (–34.4°C); Kodak reports that it is unaware of any damage caused by this. Roll and motion picture films have also been extensively used in the Space Shuttle, manned trips to the Moon, and other space flight missions where at times films have been subjected to extremely low temperatures; again, Kodak indicates that no problems have been reported.

More recently, Kopperl and Bard of Eastman Kodak published results of a number of freeze/thaw cycling tests conducted by the company.[9] In one experiment, “samples

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of film and papers included in the Image Stability Technical Center's long-range sample collection were stored in heat-sealed foil bags in a freezer and removed, thawed, and measured approximately annually for 10 to 15 years. No adverse effects on image stability were seen." In another test:

> Samples of seven films and one color paper were pre-equilibrated at 24°C [75°F] and 45% RH, heat-sealed in foil envelopes, and stored in a freezer at –15 to –12°C [5 to 10°F] for 6 months. During each working day, the samples were removed from the freezer for 4 hours. This was sufficient time for the samples to be at room temperature for several hours during each cycle. They were then replaced in the freezer. Wedge brittleness, mushiness, and wet and dry cycle adhesion tests, similar to those in *ANSI PH1.41* [*ANSI IT9.1-1991*], as well as image stability tests, were performed after the 6 months of cycling. No adverse effects were seen as a result of the freeze/thaw cycling.

In other experiments, rolls of processed black-and-white (Type 5302) and color (Type 5384) motion picture films in taped cans, untaped cans (which afford little protection from moisture), and cans sealed in vapor-proof foil bags were cycled 100 times in and out of a freezer with high, uncontrolled relative humidity. After each 25 cycles, the films were projected and then machine-rewound to simulate actual customer use. "No projection problems or physical defects were observed upon projection of any of the test samples, regardless of the storage method." The films were tested for coefficient of friction, humidity curl, brittleness, and multimetric scratch properties. The slight differences observed between the cycled films and control samples were "not considered to be significant." Image stability tests on the cycled films were also reported, and "no significant changes in density were observed."

Does the Moisture Content Matter if Film Is Stored at Temperatures Below Freezing?

It has been suggested that at temperatures below freezing, the moisture content of film and the relative humidity of the storage environment may not matter. In fact, there could be serious problems. If a film were stored at 0°F (–18°C) with an ambient relative humidity of 95%, the film would eventually reach equilibrium with the 95% RH air. The moisture content of the film would then be essentially the same as if it were stored at room temperature at 95% RH. Upon removal from the freezer, the film would stick together, swell, and likely support fungus growth. This was dramatically illustrated a few years ago when a large quantity of cellulose nitrate motion picture film was found buried in permafrost in the Canadian Yukon. Much of the film was in good physical condition — even though saturated with frozen moisture — when the find was uncovered. However, once the film was dug up and allowed to thaw, some of it was ruined by the moisture it had absorbed during burial. Films and prints must always be protected from excessive humidity, regardless of the temperature.

Humidity-Controlled Storage versus Sealing Films and Prints in Vapor-Proof Packages for Storage in Uncontrolled Environments

For many years the standard cold storage facility for motion picture films was a vault with a temperature of about 55°F (13°C) and relative humidity in the range of 45–60%. Refrigeration equipment with cool-and-reheat systems provided marginal control of relative humidity. Films were generally placed in taped cans (which are not totally vapor-proof), and no attempt was made to pre-condition the films at a low relative humidity before placing them in the vault. This was — and still is — typical of "refrigerated" storage facilities in the motion picture industry in Hollywood and elsewhere. Actually, most of the color material produced by the entertainment film industry worldwide is not even stored in refrigerated vaults; instead it is kept in air-conditioned buildings at about 70°F (21°C), or even in totally uncontrolled warehouses. With only rare exceptions, still negatives and prints have not been stored in refrigerated environments.

The development of continuous high-volume dry-desiccant dehumidifiers has made it economically feasible to maintain constant and low relative humidity in a vault, regardless of the temperature — even if the temperature is well below 0°F (–18°C).

Given the total cost of building a cold storage vault, the additional expense of a desiccant humidity control system is not great — typically about 10% of the total vault cost for large-scale installations. Assuming that the walls, ceiling, and floor of the vault have low moisture permeability (as is the case with the low-cost steel- or aluminum-covered prefabricated-panel vaults in virtually all the cold storage facilities constructed in the U.S. in recent years), the added electrical energy required for dehumidification is comparatively small. Once the vault is in operation and the relative humidity is brought down to the desired level, the only additional moisture that must be removed is that which enters the vault when the door is opened, and the very small amount that diffuses through the seals joining the metal vault panels and that seeps in through small leaks. Little or no fan-forced air exchange is needed in most installations. High levels of air exchange with the outside (sometimes called "makeup air") will of course increase dehumidification and refrigeration costs.

Maintaining the relative humidity in a low-temperature storage facility at the recommended level of 30% offers a number of important advantages:

1. The need for vapor-proof storage containers is eliminated, saving time, labor, and, in large collections, considerable expense. Commonly used heat-sealable, laminated paper/aluminum-foil/polyethylene bags and envelopes are cumbersome, waste storage space inside a vault, and must be replaced each time a film or print is accessed. If one follows the recommendations of Kodak and this author, films and prints destined for low-temperature storage with uncontrolled humidity must first be heat-sealed inside one vapor-proof bag or envelope, and then that package must be heat-sealed inside a *second* vapor-proof container to minimize risk of a defective seal or puncture. This double-sealing proce-

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dure requires additional expense and labor. Also, sheet films, short strips of films, and prints can be damaged or destroyed should they accidentally slip into the heated area when an envelope is being sealed.

2. There is no danger of damage to films and prints, as could occur if a vapor-proof package failed in an uncontrolled, high-humidity storage vault, especially a vault operated at temperatures above freezing. A defective seal or puncture in a vapor-proof package stored in uncontrolled conditions could go unnoticed for years, allowing the contents to slowly absorb moisture until they have equilibrated at near 100% RH — which likely would result in the destruction of the materials. Storage in two individually sealed vapor-proof bags or envelopes (one inside the other) minimizes, but does not eliminate, this potentially catastrophic hazard.

3. Films and prints need not be pre-conditioned at a low relative humidity before placing them in a low-humidity vault. This not only saves time and labor (pre-conditioning a reel of 35mm motion picture film may require up to 4 weeks) but also greatly simplifies access to materials. The need for expensive pre-conditioning equipment or special conditioning rooms is eliminated. Films that have previously been stored in high relative humidity environments will slowly re-equilibrate to the lower relative humidity inside a low-humidity vault, even if the films are in taped metal film cans. Still photographs in the usual paper or plastic enclosures will generally re-equilibrate to the lower humidity in only a few days.

4. Steel film cans, cabinets, shelving, other equipment, and even the walls of the vault itself will not corrode over time in 30% RH. This eliminates the need for replacement of film cans and other equipment and keeps the storage area free of abrasive rust particles.

The two principal advantages of sealing films in vapor-proof packages are: **(1)** a humidity-control system in the storage vault is not needed, thereby reducing the initial cost and complexity of the vault and somewhat reducing the cost of operation, and **(2)** the films will be better protected from water damage which might result from burst pipes in the area, roof leaks, floods, and other disasters. Sealed films are also protected from airborne pollutants; depending on the storage conditions, this may be of value for black-and-white materials. With color films, however, especially when contained in motion picture cans, normally encountered levels of air pollutants are probably of negligible significance.

Vapor-proof bags, envelopes, or other containers for storing films and prints must be made of materials that have no adverse effects on image stability. Although accelerated test data have not been published, it is generally believed that vapor-proof bags made of a paper/aluminum-foil/polyethylene laminate are adequate for long-term storage of color materials.

Finally, it should be noted that some researchers have expressed concern that cellulose acetate safety-base films *may* be subject to increased rates of base decomposition if they are sealed in air-tight containers during long-term storage. This is based on the fact that some of the decomposition reactions are autocatalytic and if gaseous decomposition products are not allowed to escape, the rate of deterioration could accelerate (in a manner similar to that which has been documented with cellulose nitrate films). But compared with room-temperature storage — with films packaged in sealed containers or not — low-temperature storage will greatly slow the rate of film-base deterioration (and will also greatly slow the rate of image deterioration).

Pre-Conditioning Films or Prints Before Sealing in Vapor-Proof Bags or Envelopes

Although it has often been recommended that films and prints be pre-conditioned (or "pre-equilibrated") in a 30–40% RH environment before sealing in vapor-proof packages, it has never been demonstrated that in fact this is actually necessary.

At any given temperature, storage at 30% RH, instead of, for example, 60% RH, will slow color image fading and staining, discoloration and fading of black-and-white images, and film-base deterioration. However, with color materials in cold storage, it is the *low temperature* of storage that is primarily responsible for the slowing of deterioration. The increase in the life of the image afforded by pre-conditioning to a low relative humidity is small by comparison. Moreover, with the majority of older color materials, such as most pre-1983 Eastman Color print and negative films, the cyan dye is the least stable image dye, and the fading rates of the cyan dyes in these products are not greatly influenced by the level of relative humidity; pre-conditioning to a low moisture content will be of little benefit.

There also is concern that pre-conditioning fragile historical films and prints to a very low moisture content — and then periodically taking them out of cold storage and placing them into work areas or darkrooms with significantly higher relative humidity — could cause unwanted physical stress on the emulsions, increase the amount of curl of films and prints without gelatin anti-curl backings, and possibly cause other kinds of physical damage. The ANSI film-storage standards caution against widely cycling relative humidity. From a physical point of view it might indeed be safer to keep films in cold storage under approximately the same moisture conditions that (hopefully) are found in work areas and darkrooms in collecting institutions.

Whatever gain in storage life that might be afforded by pre-conditioning to a low relative humidity can more simply be achieved by lowering the temperature of the storage vault 5° or 10°F. Insofar as the fading rate of a particular color film or print material is concerned, the equilibrium moisture content and the temperature at which it is stored are two essentially unrelated subjects — and they should be thought of separately. The reader is referred to Chapters 2 and 5 for a more detailed discussion of the specific effects of temperature and relative humidity on color image stability.

In large collections in particular, omitting the pre-conditioning step will avoid a great deal of extra handling and

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National Archives of Canada – 1988

Constructed in 1987, the cold storage vault serving the Moving Image, Data and Audio Conservation Division of the National Archives of Canada in Ottawa is kept at 28°F (–2.2°C) and 28% RH. William O'Farrell, head of the Film Unit, wheels film into the vault. The National Archives is responsible for the preservation of films produced by the National Film Board of Canada, the Canadian Broadcasting Corporation, and other government agencies. Canadian feature films are also acquired for the collection. In late 1996 the unit will move to a large new National Archives installation in nearby Gatineau, Quebec. The motion picture vault in the new facility will operate at 0°F (–18°C) and 25% RH. An advanced air-filtration system will be employed to remove acetic acid vapors, nitrogen oxides, ozone, dust, and other airborne contaminants.

expense. Many films and prints have been stored for years in environments with uncontrolled relative humidity, and there is no compelling need to pre-condition them to a low moisture content simply because the decision has been made to place them in cold storage; in terms of the future life of the materials, the most important consideration is simply to put them in cold storage as soon as possible — and to keep the temperature as low as possible.

Furthermore, as discussed on page 321 in Chapter 9, recent research conducted by Eastman Kodak has shown that storing color films in sealed containers (e.g., ordinary taped or untaped metal and plastic film cans or vapor-proof laminated bags) can *markedly* increase rates of both color image dye fading and acetate film base deterioration!

A Study at the National Archives of Canada Indicates That Vapor-Proof Bags for a Collection Could Cost More Than an Entire Film Vault

In 1986, in the course of planning a new cold storage vault to house the rapidly growing collection of the Moving Image, Data and Audio Conservation Division at the National Archives of Canada in Ottawa, the staff of the Film Section examined the costs of pre-conditioning motion picture films and packaging them in vapor-proof bags versus the expense of adding humidity-control equipment to the vault — and thereby eliminating the need for the bags.

Capable of housing approximately 17,300 one-thousand-foot cans of 35mm motion picture film and maintaining a temperature of 28°F (–2.2°C) with a relative humidity of 28%, the new vault cost about $100,000. Of that amount, the Cargocaire HC-1125-EBA continuous dry-desiccant dehumidifier cost about $11,000. The high-quality, vapor-proof bags available from the Swedish Film Institute, on the other hand, cost $1.30 each (shipping from Sweden additional). For the 17,300 cans of film that eventually will be stored in the vault, the bags would cost $22,490. If one were to follow Eastman Kodak's recommendations for cold storage in non-humidity-controlled facilities, and use two bags for each roll of film (with the film sealed inside one bag and the resulting package sealed inside a second bag to minimize the chance that a tiny pinhole puncture or defective seal could ultimately lead to the destruction of the film), the bag expense would double to a total of $44,980.

Expenditures associated with the equipment and labor to pre-condition and package the films would increase the total cost of the vapor-proof bag method even more. In addition, each time a film is withdrawn from the vault, the bag is destroyed when it is opened and a new $1.30 bag is required when the film goes back to storage. The number of rolls of film than can be kept in a vault is also reduced because a roll of film sealed in a vapor-proof bag requires more space than a roll in a film can.

By controlling the humidity in the vault with an $11,000 dehumidifier, the Archives saved at least $11,500 in additional costs for vapor-proof bags (and that savings assumes only a single bag for each roll of film). If one adds to that figure the $72,600 cost of the Swedish FICA film-conditioning machine discussed later in this chapter, a total of $84,100 was saved. Labor costs associated with the film conditioning and bag sealing process would almost certainly push the actual savings to above $100,000 — enough for the National Archives to build a second humidity-controlled vault capable of storing an additional 17,300 rolls of film!

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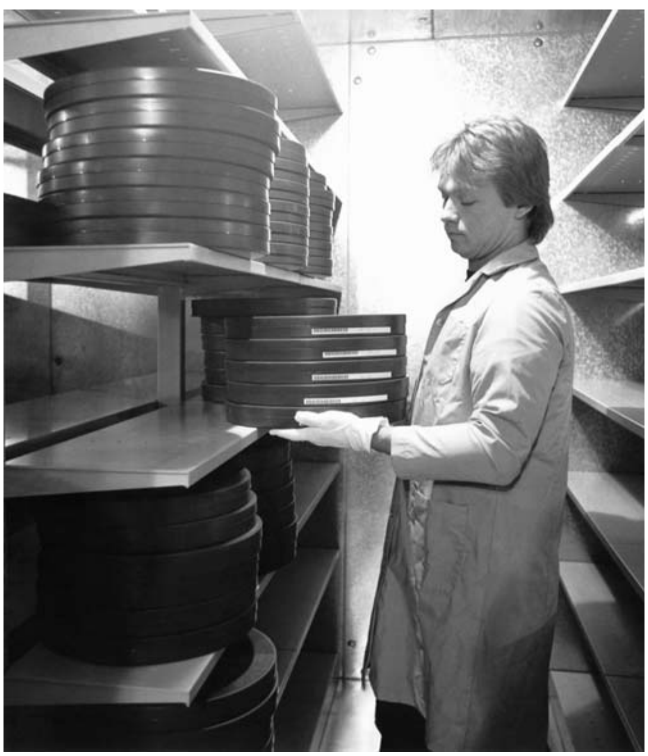
Four refrigeration compressors operating in a redundant mode cool the vault at the National Archives of Canada. Behind the compressors is a Cargocaire dry-desiccant dehumidifier that maintains 28% RH in the vault.

A computer-based catalog system tracks the films in the Archives. Operator Dennis Waugh inputs film titles and other data manually at a Hewlett-Packard computer terminal and uses a lightpen to read data from standardized preprinted bar codes. The bar-code labels are then affixed to the film cans.



Old metal film cans are replaced with new, color-coded plastic cans, which are stored horizontally on shelves within the vault. The vault can accommodate approximately 17,300 one-thousand-foot cans of 35mm film.

Sign on the vault door. A study conducted by the Film Section of the Moving Image, Data and Audio Conservation Division in Ottawa showed that it was far less expensive and much less labor-intensive to control the humidity in the vault than it would be to pre-condition and package films in vapor-proof bags for storage in a vault with uncontrolled humidity.

National Archives of Canada – 1988 (4)

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Other suppliers of vapor-proof bags have quoted prices for bags as low as $0.64 each when purchased in quantities of 50,000 or more at one time (made of less-expensive materials, these bags are less durable than the $1.30 Swedish Film Institute bags, which are heavy-duty bags made with a double layer of aluminum foil to minimize the chance of pinhole punctures). But even at $0.64 each, the cost of 17,300 bags comes to $11,072 — about the same as the price of the Cargocaire dehumidifier in the new Archives vault.

According to William O'Farrell of the Film Section, the comparison of the two storage methods made it clear that it was much simpler and far less expensive to incorporate a desiccation dehumidifier into the design of the vault.[10]

Headed by Roger Easton, the Moving Image, Data and Audio Conservation Division of the National Archives of Canada is the Canadian government's central repository for motion picture films and videotapes, with new material arriving weekly from the National Film Board of Canada, the Canadian Broadcasting Corporation, various government agencies, and even from private citizens. Prints from more than 1,000 Canadian feature films have also been purchased by the Archives and are now preserved in the cold storage vault (unlike the U.S. and some other countries, Canada does not have a mandatory copyright deposit law, and all films must be purchased from their producers). O'Farrell says there are over 200,000 cans of film in the collection, of which perhaps one-third are in color. "We are looking at another few years to identify exactly what additional color films in our collection warrant being placed in the cold storage vault."

The Moving Image, Data and Audio Conservation Division is replacing old metal film cans with new color-coded plastic cans, "as a visual identifier for different types of films and also acts as a deterrent to the deterioration of acetate film base," according to O'Farrell. "Everything is recanned because many of the original cans are rusted, dented, or otherwise in poor condition." To simplify record keeping as films are moved in and out of the vault, computer bar-code labels have been applied to the new cans.

November 1987

A Swedish FICA film-conditioning and vacuum-sealing machine at the Motion Picture, Broadcasting, and Recorded Sound Division of the Library of Congress in Washington, D.C. Film technician David Lee Reese prepares to vacuum-seal a vapor-proof bag containing a roll of film that has been equilibrated to a low moisture content in the machine. The system is no longer used by the Library.

Methods of Pre-Conditioning Films and Prints

If proper humidity-controlled cold storage is simply not available and it is necessary to pre-condition films or prints before sealing them in vapor-proof containers, there are several methods of accomplishing this. The most obvious way is to store the materials for a period of time in a room in which the desired relative humidity is maintained. Conditioning times may range from a few hours for individual films and prints that are open to the air, to a month or longer for 1,000- or 2,000-foot rolls of 35mm motion picture film. In most geographic locations, maintaining low relative humidity (e.g., 25% RH) on a year-round basis requires the use of a continuous dry-desiccant dehumidifier. If a more moderate level of relative humidity is acceptable, one or more home-type refrigeration dehumidifiers may be placed in a small, air-conditioned room; home dehumidifiers are much less expensive than desiccant units and are capable of reducing the relative humidity to about 45%.

In temperate climates, the simplest solution of all is to restrict the time that materials are sealed in vapor-proof containers to the cold months of the year. In non-humidified buildings during the winter, the indoor relative humidity is normally at a very low level; for example, as this was being written in Iowa in the winter of 1992, the relative humidity in this author's office was about 25% — the humidity generally remains below 30% for 5 months of the year. Films and prints may be pre-conditioned simply by laying them in the open for a period of a few weeks — they are then ready for sealing in vapor-proof containers. During warm months, when indoor relative humidity is higher, materials destined for cold storage can be accumulated until the next winter; the amount of fading that might occur during an additional few months of storage at room temperature is negligible.

A pre-conditioning method that has been suggested by Eastman Kodak requires placing film in a sealed container along with a measured amount of activated silica gel; the amount of silica gel required is computed from **(a)** the amount of film being conditioned, **(b)** the relative humidity in which the film has been stored in the past, and **(c)** the final humidity desired at equilibrium.[11] Particularly when large amounts of motion picture film are involved, this is a laborious and time-consuming procedure.

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November 1987

Because films sealed in vapor-proof bags are too bulky to fit in standard film cans, the Library had to purchase custom-made boxes and further added to the overall cost of the FICA procedure. After using the FICA system for several years, the Library was forced to give up the procedure because of insufficient staff. David Parker, a film curator at the Library of Congress, is shown here with color films packaged in the FICA vapor-proof bags (left) in the Library's large, 37°F (2.8°C) cold storage facility in Landover, Maryland, outside of Washington, D.C. Although the vault is controlled at 25% RH and sealing films in vapor-proof containers was not necessary to protect them from moisture, the Library staff felt that the FICA system was worthwhile because of the protection afforded to films by the waterproof bags in the event of a mishap during shipping, or of flooding caused by a burst water pipe near the vault. Films are now placed in the vault in standard metal or plastic film cans.

The Swedish Film Institute Film Conditioning Apparatus (FICA)

A more sophisticated pre-conditioning method, currently in operation at the Swedish Film Institute (Svenska Filminstitutet) in Stockholm, Sweden, involves a specially constructed temperature- and humidity-controlled conditioning cabinet to re-equilibrate rolls of motion picture film in 25% RH air before double-sealing the films in vapor-proof bags in a vacuum chamber.[12] Called the Film Conditioning Apparatus (FICA), the unit incorporates a continuous desiccant dehumidifier; a Purafil air filter to remove airborne contaminants; an air conditioner to remove heat produced by the dehumidifier and other mechanical equipment, and to maintain the temperature inside the cabinet at 68°F (20°C); a device to rewind film under controlled tension; and a vacuum-chamber and heat-sealing unit with which to double-seal rolls of film in vapor-proof bags.

Designed by Roland Gooes and Hans-Evert Bloman of the Swedish Film Institute, the FICA unit is available from the Institute for about $75,000 (with shipping from Sweden additional).[13] The time required to pre-condition (equilibrate) rolls of film to the desired 25% RH varies from 4 to 7 days, depending on the prior storage conditions of the film. The 80x30–inch cabinet can accommodate more than fifty 1,000–foot rolls of film at one time. For greater capacity, up to four satellite conditioning cabinets, which cost $20,200 each, can be attached to a central FICA unit.

The heavy-duty vapor-proof bags supplied by the Swedish Film Institute for the FICA unit cost $1.30 each (price applies to any quantity, with shipping additional). When a roll of film is first placed in the cabinet, it is rewound under controlled 10.5-ounce tension. After pre-conditioning and sealing in the vapor-proof bags, films may safely be stored in non-humidity-controlled, low-temperature vaults.

The Swedish Film Institute is attempting to preserve *all* Swedish motion picture films; the major funding for the Institute (which is also heavily involved in film production) comes from a 10% tax on all box office receipts and a set fee paid by the video industry for each videocassette sold to the public.[14] The Institute developed the FICA machine to pre-condition and seal camera negatives and printing

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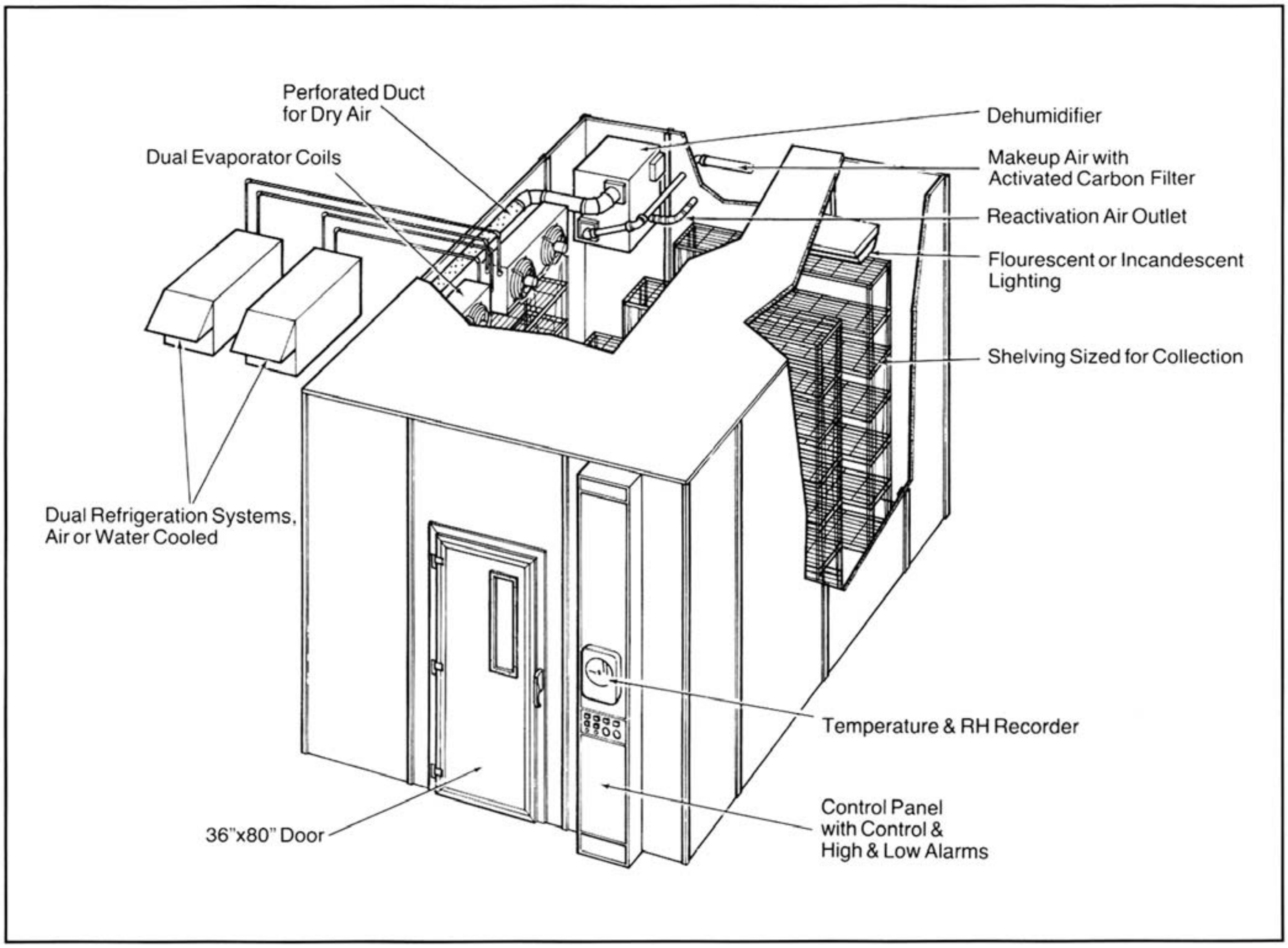

Figure 20.3 A schematic of a moderate-size humidity-controlled cold storage vault, similar to the installation at the Peabody Museum of Archaeology and Ethnology at Harvard University. Although this drawing shows a dry-desiccant dehumidifier inside the vault, the author recommends that dehumidifiers be located outside of a vault. (Courtesy Harris Environmental Systems, Inc.)

masters for storage in its preservation facility in Stockholm (the color film vaults are kept at 23°F (–5°C) and 40% RH).

In 1986 a FICA unit was purchased by the Library of Congress for pre-conditioning films prior to placing them in the Library's cold storage vaults in Landover, Maryland. Even though the Library of Congress storage vault for color film is maintained at 25% RH and vapor-proof containers are not necessary in such an environment, the Library felt that pre-conditioning color films in the FICA unit and then sealing the film in vapor-proof bags afforded added protection to the films. According to Paul Spehr, assistant chief of the Motion Picture, Broadcasting, and Recorded Sound Division of the Library, sealing films "is sort of a double insurance — it offers the film some protection against water and other types of damage that may happen."[15]

Citing a basement flood a few years ago at the Chicago Historical Society caused by a large water main outside the building that fractured during a construction project, Spehr said that the Library of Congress has had problems with malfunctioning fire sprinklers and burst pipes (although to date there has been no damage to films in the cold storage vaults). Spehr noted that one difficulty with films sealed in the bags is that they no longer fit in standard film cans or film boxes, so the Library had to purchase costly, specially made, oversize boxes. After using the FICA system for a few years, the Library was forced to abandon the procedure because of budget constraints.

Construction of Cold Storage Vaults

Most of the photographic cold storage vaults built in recent years have been constructed with prefabricated metal-clad panels with 4- or 5-inch-thick polyurethane foam insulating cores — similar in structure to the walk-in refrigerators found in food stores and restaurants. Indeed, one of the major suppliers of such refrigerated vaults, Bally Engineered Structures, Inc., sells most of its equipment to the food industry; Bally introduced its first urethane foam-core sectional prefabricated vault in 1962. The units are available in virtually any size, up to and including large drive-in buildings.

The aluminum, galvanized steel, or stainless steel cov-

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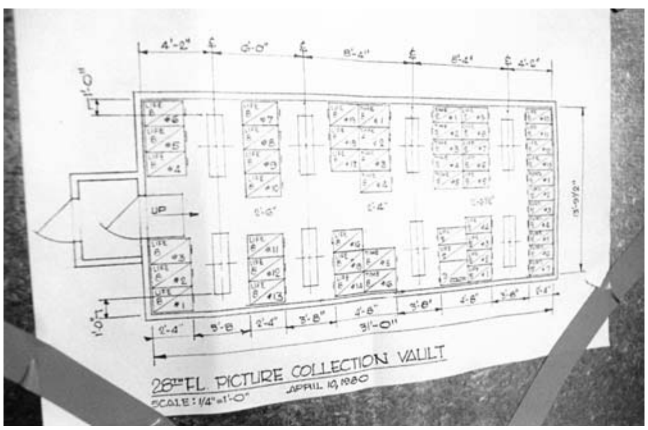
Picture collection staff member George Gonzalez in the interior of the cold storage vault at the Time Inc. Magazines Picture Collection; when this photograph was taken in 1981, the vault was in the final stages of construction.

A pressure-relief vent in the wall of the vault is provided to equalize air pressure differences that occur when warm, room-temperature air enters the vault and is cooled when the door to the vault is opened.



The floor plan for the vault shows locations of the file cabinets containing more than one million color transparencies that were moved into the vault after its completion and testing.

Henry Wilhelm – 1981

An exterior view of the vault. A vestibule and door in front of the vault door provide an air lock to minimize the influx of room-temperature air when the vault is entered. The vault is located in the Time Inc. Magazines Picture Collection in the Time & Life building in New York City.

ering on both sides of the vault walls not only provides a rigid surface and structural support but also serves as an effective moisture barrier to prevent outside water vapor from entering the vault, thus reducing the dehumidification requirements of the facility. In low-temperature installations, the floor as well as the walls must be insulated.

Vaults of this design can be readily constructed in almost any part of an already-existing building. When located on the ground floor or in the basement of a building, additional floor insulation may be required to prevent the earth beneath the floor from freezing and expanding, possibly causing structural damage to the building; the vault supplier can give advice on this point. The prefabricated vaults can be disassembled and moved to another location with relative ease, and sections can be added in order to expand the size of the vault. The load-bearing capacity of the building floor must be considered in deciding where to locate a vault — particularly when large quantities of motion picture film are to be stored on high-density movable shelving, the weight of the materials in a vault can be considerable.

Carol Brower – May 1983

The cold storage vault in operation (although built to maintain 0°F [–18°C] and 30% RH, the vault currently is operated at 60°F [15.6°C] and 35% RH).

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The roof of the vault should be waterproof to protect the contents from water dripping on the top as a result of burst pipes, leaking building roofs, fire-extinguishing water sprinkler systems, etc. There are several ways to waterproof the top of a vault: if the vault is not too large, covering it with a large sheet of plastic may suffice. The best approach is to install an "outdoor" roof on the vault; such roofs are available from most vault manufacturers. In general, photographic storage vaults should not be installed in basements because of the danger of flooding from natural causes (e.g., hurricanes), broken water mains, or backed-up sewers. Should a fire break out in the building, a basement may flood with tons of water released by automatic sprinkler systems or with water poured into the building by firefighters.

The design of a typical photographic storage vault is shown in **Figure 20.3**. Ideally, a vault should have a second door with a small air-lock section to reduce the air exchange each time the vault is entered. Doors should be large enough to accommodate shelves, file cabinets, or other equipment that must be moved in and out of the vault. Low-temperature vaults require a pressure-relief port to allow changes in air pressure (caused by sudden temperature changes when the door is opened) to equalize with the air pressure outside the vault.

For the lowest electrical requirements and operating costs, the urethane foam-insulated walls, ceiling, and floor of the vault should be as thick as possible — a minimum of 5 inches is recommended (5 inches is currently the thickest panel construction offered by Bally Case and Cooler, Inc. and most other suppliers).

Refrigeration and Dehumidification Equipment

The refrigeration equipment for photographic storage facilities is usually of fairly typical design and can be either air or water cooled. It is suggested that two — or even three — completely independent, redundant refrigeration and dehumidification systems be installed so that in the event of mechanical failure, one system will remain operating while the other is being repaired. In many facilities installed recently in the U.S., the equipment has been designed so that the dual refrigeration compressors alternate after each running period. If an upper temperature limit is reached, both compressors will switch on at the same time. Should one compressor fail, the other automatically takes over and will continue to cool the facility until the defective compressor can be returned to service.

Dehumidification equipment should also operate as a redundant system with two or more units. Because the photographs in storage will probably be kept for many hundreds of years — if not forever — many equipment failures will occur as the years pass, and this must be taken into account both in the design of the vault and in the maintenance procedures adopted for the equipment. As James Wallace, Curator/Director of the Smithsonian Institution's Department of Photographic Services in Washington, D.C., said about the design of a cold storage system:

> You have to remember that a cold storage room is a mechanical thing — like an automobile. It runs all the time and you either have to build in some redundancy or you can expect it to quit every once in a while. You simply cannot put in all of the refrigeration and dehumidification equipment, smoke and temperature alarms, air filters, and everything else and not expect some of this mechanical stuff to break down every now and then. The mistake is to have someone build a vault and present you with the key and then expect it to work absolutely perfectly forever. If we have a temperature where our Ektachrome slides will last 500 years — there isn't a piece of equipment made that will last even a fraction of that time.[16]

Wallace went on to say that the staff should understand the equipment and have both the knowledge and spare parts to do simple repairs. In addition, procedures for handling the collection in the vault during equipment failures should be worked out in advance.

Should all the equipment fail — or in the event of a prolonged power outage — no harm need be done. The temperature inside the vault will gradually rise to ambient conditions and the fading rates of the color materials inside will increase accordingly for as long as the vault is out of operation. A few months at room temperature during a hundred-year period will be of no great significance. If the vault door is kept closed until the inside of the vault has reached room temperature, the relative humidity in the vault will not rise to unacceptable levels during the warm-up period.

Allan Goodrich of the John Fitzgerald Kennedy Library reported that during a power outage, which lasted 2 days, the temperature inside the Library's 0°F (–18°C) cold storage vault rose to about 30°F (–1.1°C) before the electricity was restored; the relative humidity inside the vault remained low throughout the 2-day period.[17]

As discussed below, every vault should be equipped with temperature and relative humidity indicators that can be read from the outside as well as fail-safe automatic high- and low-level temperature electrical shutdown systems and alarms which will sound both at the vault and at a remote location to alert the maintenance staff immediately should conditions in the vault reach unacceptable levels.

High-Volume Dry-Desiccant Dehumidifiers for Humidity Control in Cold Storage Vaults

Ordinary refrigerated vaults and freezers do not have any system of humidity control, and relative humidities are often close to 100% — far too high for safe storage of unprotected photographs. Conventional refrigeration-type dehumidifiers do not function efficiently at low temperatures, and with most designs it is impossible to obtain relative humidities as low as 30%. In addition, refrigeration dehumidifiers with heated defrost cycles consume large amounts of electricity during operation.

Much more satisfactory are continuous high-volume dry-desiccant dehumidifiers, principally the lithium-chloride-impregnated wheel machines invented by Carl Munters in Sweden and manufactured in the U.S. by Cargocaire Engineering Corporation, Amesbury, Massachusetts (for a description of these machines, see Chapter 16). Cargocaire

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The Department of Photographic Services at the Smithsonian Institution in Washington, D.C. constructed this humidity-controlled cold storage vault in 1982 (40°F [4.4°C] and 27% RH). James H. Wallace, Jr., director and curator of Photographic Services, pulls negatives from an upper-level file cabinet in the vault. Color slides, large-format color transparencies, color negatives, black-and-white negatives, and safety-film duplicates of historical cellulose nitrate negatives are stored in the vault.

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October 1987

Constructed in 1982, the humidity-controlled cold storage vault at the Art Institute of Chicago was the first facility of this type in any fine art museum in the world. Shown here are Douglas Severson, conservator (left), and David Travis, curator of photography, looking at Kodak Ektacolor prints in the collection. Although now being operated at 40°F (4.4°C) and 40% RH for the convenience of the curatorial staff, the vault is capable of operating at 0°F (–18°C), and it is likely that in the future the temperature will be lowered to this level. A second, larger vault operating at the more moderate temperature of 60°F (15.6°C) and 40% RH contains all of the black-and-white photographs in the collection.

dehumidifiers have been installed in most of the photographic cold storage facilities built in the United States during the past 10 years.

A number of institutions, including the Art Institute of Chicago and the Peabody Museum of Archaeology and Ethnology at Harvard University (see below), have reported failures with the reactivation heaters in Cargocaire dehumidifiers. Reactivation heaters drive moisture off the rotating lithium-chloride-impregnated wheel in the Cargocaire units — when the heaters fail, the dehumidifiers cease to function. Humidity control in the vault will be lost and, unless backup dehumidifiers have been installed, the vault will have to be shut down until repairs are made.

Cargocaire acknowledged the problems with the reactivation heaters and introduced several redesigned models in 1989 which, according to the company, should prove to be far more reliable in cold storage applications (for further discussion, see Chapter 16).

Cold Storage Vaults Must Have a Fail-Safe Automatic Shutdown System

It is *essential* that cold storage facilities be equipped with a fail-safe shutdown system to cut off all electrical power to refrigeration equipment, dehumidifiers, air make-up fans, door-frame heaters, lights, and all other electrical equipment in a vault, should either the temperature or relative humidity exceed pre-set upper or lower limits. The shutdown limits should be set somewhat outside of the maximum temperature and humidity fluctuations observed in normal operation. The limits should be sufficiently wide so that the system does not unnecessarily shut down when, for example, the vault is frequently entered and exited during a short period.

The shutdown system should sound an alarm when activated and *must* operate independently and be separate from the controls that normally regulate vault temperature and relative humidity, or that are incorporated in dehumidifiers and other equipment. To make certain the shutdown system is functioning properly, it should be tested periodically by separately forcing temperature and relative humidity levels in the vault to exceed the pre-set upper and lower limits. With total system shutdown, failure of a dehumidifier, for example, will not result in the relative humidity inside the vault reaching dangerously high levels.

If a vault shuts down, the door should remain closed until the interior temperature rises to that of the ambient room temperature (during this period the materials stored

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in the vault are in no danger — as long as the doors are left shut during the warm-up period, the interior relative humidity will probably even drop somewhat as the air temperature rises to ambient conditions).

When a Dehumidifier Failed and the Relative Humidity Went Out of Control at Harvard's Peabody Museum

The importance of a total-shutdown system was dramatically illustrated to Daniel W. Jones, Jr., photographic archivist at Harvard University's Peabody Museum of Archaeology and Ethnology, when, during a hot and humid July weekend, the Cargocaire dehumidifier in the vault ceased to function (the vault normally operates at 35°F [1.7°C] and 25% RH). Improper wiring in the vault control circuitry caused a failure in the vault's supposed "fail-safe" shutdown system, and the refrigeration compressors continued to cool the vault. According to Jones, "The warm and humid makeup air kept coming in and the walls inside the vault became dripping wet. When I came in and saw the mess, I was mortified."[18]

Fortunately, the malfunction was detected before damage was done to the collection. Some of the motion picture film cans in the vault became rusted, but the films inside were not harmed. Color slides mounted in slide pages inside of cardboard boxes were also spared from damage.

The defects in the control system have since been corrected and Jones says that now, "If anything goes awry, the whole system shuts down."

Jones stressed the need to periodically test vault control systems in various failure modes, saying that with the Peabody vault, "Nobody had ever put it through its paces to see what would happen." He also advised that a *single* contractor be hired to perform all aspects of the vault installation, doing both the mechanical and electrical work. "When you get a lot of subcontractors involved, you greatly increase the chances of things going wrong."

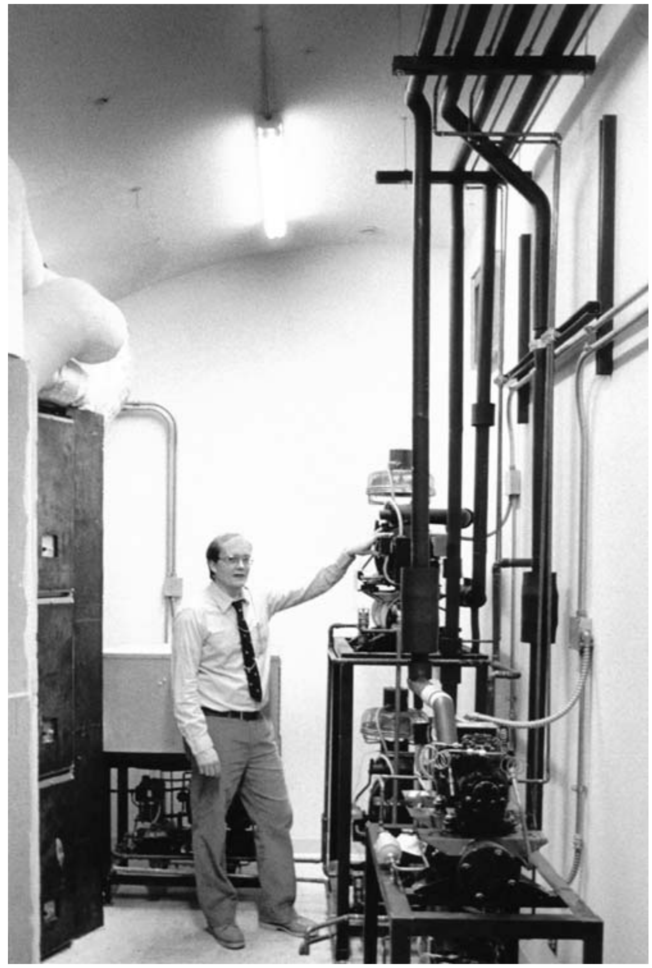
Cost of Complete Cold Storage Installations

Most of the museum and archive cold storage vaults constructed in the past few years have cost between $35,000 and $125,000. Harris Environmental Systems, Inc., which built the storage vaults at the John Fitzgerald Kennedy Library, the Art Institute of Chicago, the Peabody Museum, and a number of other institutions, gives the following price estimates for complete installed systems:[19]

- About $42,000 for a 12x12–foot vault with dual refrigeration equipment, and a single 150 CFM (cubic feet per minute) dehumidifier — capable of maintaining 38°F (3.3°C) and 30% RH. Operating costs are estimated at about $285 per month.

- About $55,000 for a 12x12–foot vault with dual refrigeration equipment, a higher-capacity dehumidifier, and a vault air lock — capable of maintaining 0°F (–18°C) and 30% RH. Operating costs are estimated at about $410 per month.

- About $125,000 for a 25x25–foot vault with dual refrigeration equipment, a 500 CFM dehumidifier, and a temperature- and humidity-controlled vestibule — capable of maintaining 0°F (–18°C) and 30% RH. Operating costs are estimated at about $1,250 per month.



February 1983

Cargocaire dry-desiccant dehumidifiers and refrigeration compressors for the Art Institute facility are located in a room adjacent to the vaults. Two compressors are used for each vault; the compressors operate in a redundant mode and if one of the units should fail, the other automatically takes over.

As can be seen by comparing the first two examples, the cost of building and operating a 0°F (–18°C) vault is not much greater than the cost of a 38°F (3.3°C) vault. The colder storage temperature, however, can add *thousands of years* to the useful life of color films and prints. From a cost-effectiveness point of view — given the cultural and monetary worth of most photographic collections — it would seem foolish to build the higher-temperature facility simply to save a little money.

Access to Materials in Cold Storage

Materials to be stored in a humidity-controlled low-temperature vault should be placed in boxes, portfolio cases, motion picture film cans, and other types of containers that are suitable for the long-term storage of photographs (see Chapter 15). Vapor-proof packing is not necessary,

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April 1988

Daniel W. Jones, Jr., photography curator at the Peabody Museum of Archaeology and Ethnology at Harvard University in Cambridge, Massachusetts, looking at a page of color slides in the Museum's cold storage vault (35°F [1.7°C] and 25% RH). Completed in 1979, this was the first example of a humidity-controlled cold storage vault for photographs to be built at an educational institution. For a description of the Peabody's innovative method for making compact color reference copies of the slides kept in the vault, see Chapter 18 (page 638).

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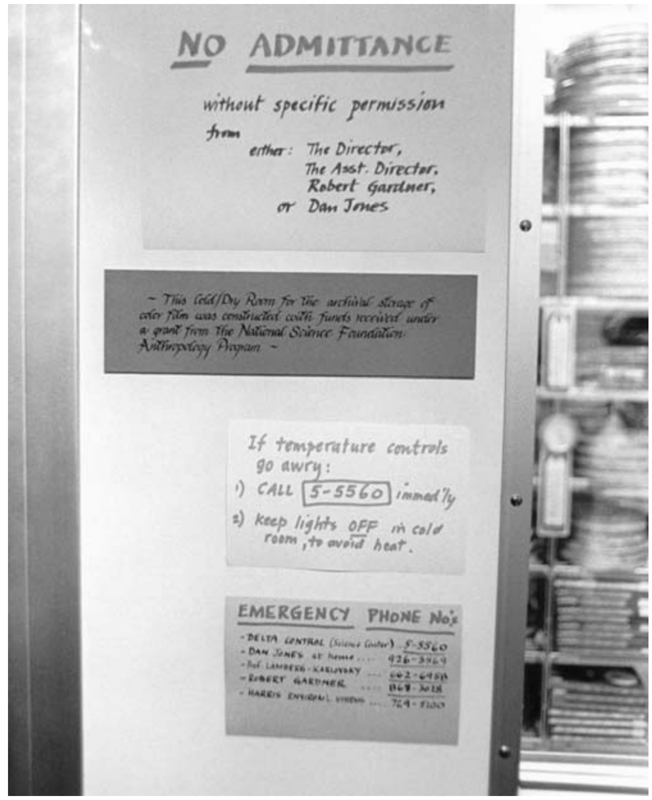
Jones changes the charts in the recorder for temperature and humidity in the control panel outside the vault door.



1981

Signs on the vault door. The vault was constructed with a grant from the National Science Foundation.

and under normal circumstances should not be used. Packages can be put in ordinary polyethylene bags if desired. Cans of motion picture films should be placed horizontally on shelves, with not more than ten cans in a stack.

When a package is removed from a vault, it must be protected from moisture condensation until it has warmed to room temperature — or at least until it has warmed above the dew point of the ambient air. Internal warm-up times from 0°F (–18°C) to room temperature for a number of different types of packages are given in **Table 20.2** on page 715. With a walk-in cold storage vault, a supply of polyethylene bags can be kept inside the vault for wrapping packages. Ziploc bags, which can be quickly sealed with the top-locking seam, are handy for this purpose.

A package or can of motion picture film should be placed in a polyethylene bag during warm-up even if the package itself is adequate for protecting its contents from moisture. Moisture condensation on a steel film can will produce rust in areas where the can has been scratched or abraded. Moisture can also harm package labels, cause ink to run or smear, and lead to other damage.

With proper planning, most institutions will find it practical to accumulate requests for material from the vault during each working day and then to remove all the material to the warm-up area at the end of the day. By the next morning, all except very large packages will have warmed to ambient conditions and can be opened. Smaller packages (e.g., a single print or 35mm slide in a plastic bag), which have very short warm-up times, can be available for use almost immediately upon removal from cold storage.

Zero-Degree F (–18°C), Humidity-Controlled Cold Storage Facilities for the Permanent Preservation of Color and B&W Motion Pictures and Still-Camera Photographs

At the time this book went to press in 1992, institutions in the United States and Canada with cold storage facilities that were operating (or planned) with the temperature and relative humidity conditions recommended by this author for the permanent preservation of color and black-and-white photographic materials included:

• **The John Fitzgerald Kennedy Library** in Boston, Massachusetts. This was the first collecting institution in the world to have a humidity-controlled, low-temperature storage facility. Opened in 1979, the Kennedy Library vault operates at 0°F (–18°C) and 30% RH (an outer vestibule is maintained at about 55°F [12.8°C] and 30% RH). The thirty-fifth President of the United States, John F. Kennedy was in office from 1961 until November 22, 1963, when he was assassinated in Dallas, Texas.

• **The National Aeronautics and Space Administration (NASA)** at the Lyndon B. Johnson Space Center in Houston, Texas. A color film storage vault maintained at 0°F (–18°C) and 20% RH was constructed in 1982, replacing a facility built in 1963 which was operated at 55°F (12.8°C) and 50% RH. In 1987, two new 0°F (–18°C) and 20% RH vaults were constructed — one located in a remote corner of the Johnson Space Center in Houston and the other at

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the NASA test facility in White Sands, New Mexico. These two vaults house duplicate sets of the more than 150,000 feet of spaceflight originals preserved in the primary NASA vault. These off-site duplicates serve as backups to insure that the color images of the first humans to set foot on the moon during the Apollo 11 mission in 1969, and other priceless still photographs and motion pictures from space, will not be lost in the event of fire, tornado, earthquake, war, sabotage, theft, or other disaster.

NASA has also made sets of polyester-base black-and-white separations from color films made during space missions that took place from 1961 until 1975 (see page 323); these separations are stored at 70°F (21°C) and 50% RH in a separate building located in NASA's Houston complex.

• **The Historic New Orleans Collection,** in New Orleans, Louisiana. Completed in 1987, one vault is used to store color photographs, early safety-base film, and cellulose nitrate negatives and is maintained at 0°F (–18°C) and 30% RH. A second, larger vault, kept at 30°F (–1.1°C) and 30% RH, is for storage of modern black-and-white prints and safety-base film.

• **The Jimmy Carter Library** at the Jimmy Carter Presidential Center, in Atlanta, Georgia. A vault maintained at 0°F (–18°C) and 30% RH is provided for color negatives, transparencies, and motion pictures; the vault was placed in operation in 1990. Another vault, which began operation in 1987, is kept at 55°F (13°C) and 30% RH and is used to store black-and-white materials and replaceable color films and prints. The thirty-ninth President of the United States, Jimmy Carter was in office from 1977 to 1981. The Jimmy Carter Library opened in 1986. (Carter and his wife Rosalynn are residents of Plains, Georgia.)

• **The National Archives of Canada – Moving Image, Data and Audio Conservation Division,** in Gatineau, Quebec. In late 1996 the National Archives of Canada will open a new Archives building in Gatineau, near Ottawa, that is to include what will probably be the world's best large-scale motion picture and color photography preservation facility. A large vault maintained at 0°F (–18°C) and 25% RH will be provided for the Archives' vast collection of color and black-and-white motion pictures; the vault will also be used for still photographic materials and to preserve selected paper documents.

Other temperature- and humidity-controlled vaults will be provided for storage of audio materials, videotapes, and computer tapes, disks, and other EDP records. A separate storage area maintained at 65.5°F (18°C) and 50% RH will be used to store oil paintings. In all, the new building will have eight separate controlled-environment zones, each of which will meet specific requirements for temperature and relative humidity. A sophisticated air-filtration system will keep airborne contaminants at low levels in all storage and laboratory areas.

The new National Archives of Canada facility, which will establish new standards for motion picture preservation in film libraries, archives, and museums worldwide, will replace the present 28°F (–2.2°C) and 28% RH color film storage vault located in Ottawa. The current National Archives of Canada motion picture film storage facility is discussed elsewhere in this chapter and in Chapter 9.

Table 20. 2 Approximate Warm-Up Times to Room Temperature for Various Types of Packages

Type of Package	From 0°F to 75°F (–18°C to 24°C)	From 35°F to 75°F (1.7°C to 24°C)
36-exp. box of slides in Kodak paper box	1 hour	45 min.
Single slide or negative strip in polyester or acetate sleeve	8 min.	5 min.
Envelope with 6 strips of 35mm film in polyester or acetate sleeves inside envelope	20 min.	15 min.
1,000-ft. reel of 35mm motion picture film in metal film can	5 hours	3 hours
1,000-ft. reel of 16mm motion picture film in metal film can	2 hours	1½ hours
10 paper prints in flat cardboard box	1½ hours	1 hour
100 paper prints in flat cardboard box	5 hours	3 hours

Approximate warm-up times are for single containers of the types listed, with the container wrapped in a single-layer polyethylene bag to prevent moisture condensation on the package during warm-up and placed on a table so air can freely circulate around the container. Do not stack containers during the warm-up period unless much longer warm-up times are provided. The listed times will allow the package to warm up to a temperature above the dew point of air at 75°F (24°C) and a relative humidity not above 60%; somewhat longer warm-up times may be needed if more humid conditions are present in the work or study area.

Medium-Temperature, 25° to 45°F (–3.9° to 7.2°C) Humidity-Controlled Cold Storage Facilities for the Long-Term Preservation of Color and B&W Motion Pictures and Still-Camera Photographs

Institutions in the U.S. and Canada with medium-temperature, humidity-controlled cold storage facilities include:

• **The Lyndon Baines Johnson Library** in Austin, Texas. The photographic storage vault for color films and prints in the Library's collections is maintained at 45°F (7.2°C) and 50% RH. Lyndon B. Johnson served as Vice-President under President John F. Kennedy. Johnson became the thirty-sixth President of the United States after Kennedy was assassinated on November 22, 1963; Johnson continued to serve as president until 1969. The Lyndon Baines Johnson Library, located on the campus of the University of Texas in Austin, opened in 1971. Johnson died in 1973.

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October 1987

NASA staff members Frank Zehentner (left) and Terry Slezak prepare to remove an aluminum case containing rolls of original color film from the primary NASA humidity-controlled cold storage vault built for the permanent preservation of spaceflight films. This is one of the two vaults maintained at 0°F (–18°C) and 20% RH located at the NASA facility in Houston, Texas; the other vault, situated in a remote corner of the NASA property, is used to store a complete duplicate set of the films, together with written documentation. A third NASA vault at the White Sands Missile Range in New Mexico, which also operates at 0°F (–18°C) and 20% RH, houses a second duplicate set of backup copies and documentation of the spaceflight films. See Chapter 9 for additional information on NASA's outstanding preservation program for color materials.

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1978

The cold storage vault at the National Anthropological Film Center at the Smithsonian Institution in Washington, D.C. Constructed in 1975 under the guidance of E. Richard Sorenson, at the time the director of the center, the vault operated at 39°F (3.4°C), and a dry-desiccant dehumidifier was used to keep the relative humidity at 50%. In 1985 the archive was moved to a different location in the Smithsonian and is now called the Human Studies Film Archive (35°F [1.7°C] and 25% RH). The original 1975 vault is pictured here. Most of the film in the vault is 16mm Eastman Color Negative Film 7247 which, when stored at room temperature, has very poor image stability. This vault, and the cold storage facility at the Cinematheque Quebecoise in Montreal, Quebec, also completed in 1975, are believed to have been the first humidity-controlled cold storage vaults for color film constructed anywhere in the world.

- **The Human Studies Film Archive**, Smithsonian Institution, in Washington, D.C. A storage vault built in 1975 and operated at 39°F (3.4°C) and 50% RH was replaced in 1985 by a new vault in a different building which is maintained at 35°F (1.7°C) and 25% RH. The Human Studies Film Archive was formerly known as the National Anthropological Film Center. The original 1975 vault, and the Cinematheque Quebecoise facility described below, also completed in 1975, are believed to have been the first humidity-controlled cold storage vaults for color film constructed anywhere in the world.

- **The Cinematheque Quebecoise** in Montreal, Quebec. In 1975 the Cinematheque began operation of a cold storage facility for motion picture film. A vault maintained at 35°F (1.7°C) and 35% RH is provided for color films, and other vaults operating at 50°F (10°C) and 50% RH are used for cellulose nitrate films and black-and-white safety films.

- **The Library of Congress** in Landover, Maryland. Located in Maryland just outside of Washington, D.C., this large facility was opened in 1978. The vault for color materials (mostly motion picture film) is operated at 37°F (2.8°C) and 25% RH. Three additional vaults capable of housing between 150,000 and 175,000 cans of 35mm motion picture film were constructed in 1986. These vaults are used to store black-and-white motion picture film and operate at 55°F (12.8°C) and 25% RH. The Library of Congress also operates a storage facility for cellulose nitrate motion picture film at Wright-Patterson Air Force Base near Dayton, Ohio (see **Appendix 19.1** at the end of Chapter 19).

- **The Peabody Museum of Archaeology and Ethnology at Harvard University** in Cambridge, Massachusetts. Constructed in 1979 with the aid of a grant from the National Science Foundation, the vault is used for storing color slides and color motion pictures and is maintained at 35°F (1.7°C) and 25% RH.

- **The Gerald R. Ford Library**, on the campus of the University of Michigan in Ann Arbor, Michigan. Opened in 1981, the cold storage vault is maintained at 40°F (4.4°C) and 40% RH; all films in the collection, including black-and-white negatives, color negatives, and color transparencies, are stored in the vault. Gerald Ford, the thirty-eighth President of the United States, had served as Vice-President

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The Records Center of Kansas City (a division of Underground Vaults & Storage, Inc. of Hutchinson, Kansas) operates a cold storage facility maintained at 38°F (3.3°C) and 40% RH in an inactive portion of a huge underground limestone mine on the outskirts of Kansas City, Missouri, and rents space at moderate cost. Among the collections stored in the high-security facility is the backup color film archive for the Los Angeles based Turner Entertainment Co. Film Library, which includes original color negatives, interpositives, and other pre-print elements for such films as **Gone With the Wind**, **2001: A Space Odyssey**, **The Wizard of Oz**, **The Maltese Falcon**, **Ben Hur**, and other classics (see Chapter 9). Black-and-white separations (YCM's), sound negatives, and other black-and-white film elements from the Turner Entertainment Co. Film Library are stored in the Underground Vaults & Storage, Inc. high-security underground facility in Hutchinson, Kansas.

under Richard M. Nixon. Ford became president upon the resignation of Nixon on August 9, 1974 because of the "Watergate" scandal; Ford served as president until 1977.

• **The Art Institute of Chicago** in Chicago, Illinois. The cold storage vault, constructed in 1982, was the first facility of its kind in an art museum. The vault was designed to maintain a temperature of 0°F (–18°C) and a relative humidity of 20 to 40%. However, at the time this book went to press in 1992, the unit was being operated at 40°F (4.4°C) and 40% RH to make access to the color prints stored in the vault more convenient for the curatorial staff. At some point in the future, however, the temperature of the vault probably will be lowered to 0°F (–18°C). Adjacent to the low-temperature vault is a larger vault housing all of the black-and-white collection; this vault is maintained at 60°F (15.6°C) and 40% RH.

• **The Smithsonian Institution, Photographic Services Department,** in Washington, D.C. Constructed in 1982 and operated at 40°F (4.4°C) and 27% RH, the cold storage vault houses the large collection of color transparencies and negatives produced by the staff of the Photographic Services Department. The vault is also used for storing modern black-and-white negatives as well as duplicate negatives made from cellulose-nitrate-base negatives (the nitrate originals were disposed of after duplication). The vault was expanded in 1992. (Note: The Photographic Services Department is not part of the Smithsonian's Division of Photographic History, which, at the time this book went to press in 1992, did not have a cold storage facility for its important collection of color photographs.)

• **Time Inc. Magazines Picture Collection**, Rockefeller Center, in New York City. Constructed in 1983 and designed to operate at 0°F (–18°C) and 30% RH, the vault provisionally is being operated at 60°F [15.6°C] and 35% RH to simplify access. The facility is used by the Picture Collection to store the more than one million 35mm slides and roll and sheet film color transparencies from *Time, Sports Illustrated, Life, People, Fortune,* and other Time Inc. magazines; some of the transparencies date back to the 1930's. (Time Inc. Magazines is a part of Time Warner Inc.)

• **The San Diego Historical Society** in San Diego, California. A cold storage vault for color materials, early safety

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November 1987

National Archives and Records Administration staff member Frank Stephens entering one of the three large humidity-controlled cold-storage vaults for motion pictures at the National Archives' temporary facility in Alexandria, Virginia, just across the Potomac River from Washington, D.C. Two of the vaults, for color motion pictures, are maintained at 35°F (1.7°C) and 30% RH; the third vault, for black-and-white films, is kept at 50°F (10°C) and 30% RH.

films, and cellulose nitrate negatives is maintained at 55°F (12.8°C) and 40% RH; the vault was constructed in 1983 under the direction of Larry and Jane Booth of the Historical Society.

• **Stokes Imaging Services** in Austin, Texas. With a cold storage facility operating at 45°F (7.2°C) and 35% RH, Stokes is believed to be the only commercial color processing lab in the world with a humidity-controlled cold storage vault for storage of processed color negatives, internegatives, and transparencies. The vault was constructed in 1983.

• **The National Archives and Records Administration** in Alexandria, Virginia (across the Potomac River from Washington, D.C.). This large storage facility constructed in 1985 consists of two vaults maintained at 35°F (1.7°C) and 30% RH, and one vault kept at 50°F (10°C) and 30% RH. In December 1993 the National Archives will open a large new facility (to be called Archives II) in nearby College Park, Maryland. Color motion pictures will be stored at 25°F (–3.9°C) and 30% RH in the new building. Color still photographs will be stored at 38°F (3.3°C) and 35% RH; general storage for black-and-white prints, negatives, and glass plate negatives will be maintained at 65°F (18.3°C) and 35% RH. After the move to College Park is completed, the Alexandria cold storage facility will be closed.

• **Records Center of Kansas City** (a division of Underground Vaults & Storage, Inc.)[20] in Kansas City, Missouri. Located in a high-security complex constructed 175 feet below ground in a worked-out section of a huge limestone mine on the outskirts of Kansas City, RCKC operates a large refrigerated vault, constructed in 1986, that maintains a temperature of 38°F (3.3°C) and 40% RH. For small amounts of film or other material, space in the Kansas City vault is rented for $5 per cubic foot per year; the cost is reduced to $3 per cubic foot per year when 2,500 cubic feet or more of space is rented. RCKC handles retrievals, shipping, and refiling of stored materials.

Among the materials stored in the Kansas City cold storage vault are original color negatives, interpositives, and other color pre-print elements for films in the Turner Entertainment Co. Film Library that was acquired when Turner Broadcasting System Inc. purchased MGM/UA in 1986 (retaining the film library, Turner subsequently sold most of the other assets acquired in the purchase; MGM Communications Inc. now operates as an independent company). The Turner Entertainment Co. Film Library, which is valued at more than *$1 billion*, now contains more than 3,300 feature films, including such motion picture classics as *Gone With the Wind, Casablanca, The Maltese Falcon, 2001: A Space Odyssey, Ben Hur*, and *The Wizard of Oz.*

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The three National Archives cold storage vaults were constructed in 1984 in a rented building. Film storage will be relocated to the new National Archives and Records Administration facility located 8 miles northeast of Washington D.C. in College Park, Maryland; it is scheduled to open in December 1993. The National Archives has been designated as the eventual repository for much of the motion picture film, still photographs, and videotapes produced by U.S. government agencies.

• **The National Archives of Canada – Moving Image, Data and Audio Conservation Division**, in Ottawa, Ontario. In 1986 the Conservation Division of the National Archives (at the time known as the Public Archives of Canada) constructed a color motion picture storage vault which maintains a temperature of 28°F (–2.2°C) and 28% RH. As discussed on page 715, in 1996 the National Archives will open a large new facility in nearby Gatineau, Quebec, that will provide 0°F (–18°C) and 25% RH storage for its vast collection of motion pictures and still-camera photographs.

• **The Arthur M. Sackler Gallery and the Freer Gallery of Art**, Smithsonian Institution, in Washington, D.C. Constructed in 1987, the cold storage vault was designed to maintain 40°F (4.4°C) and 30% RH. The vault serves both the Sackler Gallery and the Freer Gallery.

• **The National Museum of African Art**, Smithsonian Institution, in Washington, D.C. Constructed in 1987, the cold storage vault is maintained at 42°F (5.6°C) and 28% RH. Color and black-and-white motion pictures, 35mm color slides, black-and-white negatives, glass lantern slides, and videotapes are stored in the facility.

• **The National Gallery of Canada** in Ottawa, Ontario. For preservation of the National Gallery Photograph Collection, two temperature- and humidity-controlled vaults were provided in the new National Gallery building, completed in 1988. For storage of 19th-century prints and contemporary black-and-white photographs, one vault is maintained at 59°F (15°C) and 40% RH; for storing color materials, a smaller vault operates at 39°F (4°C) and 40% RH.

• **The Canadian Centre for Architecture** in Montreal, Quebec. With construction of its new building completed in 1988, the Centre has two temperature- and humidity-controlled vaults for its photographic collection. The larger vault, for black-and-white materials, is maintained at 55°F (12.8°C) and 40% RH. A smaller vault for storing chromogenic color prints is kept at 40°F (4.4°C) and 40% RH.

• **National Underground Storage, Inc.** in Boyers, Pennsylvania.[21] Located in an abandoned limestone mine 220 feet below the hills of western Pennsylvania 57 miles north of Pittsburgh, National Underground Storage provides commercial and governmental clients with high-security storage for vital records. Rental space for color and black-and-white motion picture films and other photographic materials is available in vaults maintained at 40°F (4.4°C) and 25% RH and 50°F (10°C) and 35% RH. Some private clients have their own film storage vaults in the underground facility, and at least one well-known movie director stores film here

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October 1992

The color film storage vault in the Paramount Pictures Film and Tape Archive, located on the Paramount Pictures studio lot on Melrose Avenue in Hollywood. The color film vault, one of nine vaults in the high-security building, is maintained at 40°F (4.4°C) and 25% RH. The Paramount archive building, which was Hollywood's first adequate preservation facility for color motion pictures, went into operation in June 1990. Shown here in a section of the color film vault, which is equipped with movable shelving to conserve space, is Robert McCracken, a supervisor in Archive Operations. McCracken and Bill Weber, Director of Operations Resources at Paramount, manage the operation of the multi-million dollar, 40,000-square-foot facility. See Chapter 9 for further discussion of the motion picture preservation program at Paramount Pictures.

in a vault kept at 0°F (–18°C). The Social Security Administration, the U.S. Patent Office, the National Archives, and other government agencies store vast quantities of microfilm and other types of records at National Underground Storage. It is also a high-security repository for black-and-white separations (YCM's) and other backup film elements for many of the major Hollywood movie studios.

• **Paramount Pictures** in Hollywood, California. In June 1990, Paramount Pictures began operating a new cold storage facility on its Melrose Avenue studio lot in Hollywood for the preservation of its vast film and videotape collection. Consisting of nine vaults, which operate at different temperature and humidity conditions depending upon the film or videotape elements stored in them and how long it is expected that the items will be retained, the facility currently houses over 270,000 reels of motion picture film, as well as a huge amount of videotape from television productions. The facility, which was built at the behest of former Paramount studio head Frank Mancuso, was designed with enough space to accommodate Paramount's expected film and videotape production for the next 20 years.

Color film intended for long-term keeping is stored at 40°F (4.4°C) and 25% RH. Black-and-white films are stored at either 50°F (10°C) and 40% RH for long-term keeping, or 60°F (15.5°C) and 50% RH for medium-term keeping. Paramount is continuing its policy of making a set of fully timed separations (YCM's) for all of its feature films.

Like most other Hollywood studios, Paramount has a strict policy of dividing the various preprint elements for a given film between two or more geographic locations. For example, an original camera negative is kept in Paramount's Hollywood cold storage vault, and the separations are stored in a high-security underground storage facility on the east coast. In recent years the Hollywood studios have become acutely aware of the potential for catastrophic loss of their irreplaceable collections because of fires, earthquakes, or other disasters. The Paramount Pictures cold storage facility is discussed in more detail in Chapter 9.

• **Ronald Reagan Library**, Simi Valley/Thousand Oaks, California. A vault maintained at 35°F (1.7°C) and 45% RH is used for storage of color negatives, black-and-white negatives, color transparencies, and color and black-and-white

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October 1992

One of the three film storage vaults in the new Warner Bros. high-security motion picture cold storage building on the Warner Bros. studio lot in Burbank, California. The color film vault, which is maintained at 35°F (1.7°C) and 25% RH, and the other vaults were operating and in the final phase of testing when this photograph was taken on October 8, 1992. Warner Bros. began moving its film collection into the vaults a few weeks later. Shown here in the larger black-and-white film vault, which, like the two other vaults in the building, is equipped with movable shelving that permits high-density film loading, are John Belknap, manager of Film Vaults/Assets, and Bill Hartman, manager of Asset Inventory Management and Research in Corporate Film Video Services at Warner Bros. The $9-million cold storage facility was designed under the direction of Peter R. Gardiner, vice president of Operations in Corporate Film Video Services at Warner Bros. (a division of Time Warner Inc.). See Chapter 9 for additional discussion of the film preservation program at Warner Bros.

motion picture films (some of which date back to the 1950's). Videotapes, audiotapes, replaceable motion picture prints, and black-and-white prints are kept in a second vault maintained at 60°F (15.6°C) and 45% RH. Manuscripts, books, magazines, newspapers, and other paper documents are stored at 70°F (21.1°C) and 45% RH. The Reagan Library collection includes 1,560,000 still photographs; 88,000 feet of motion picture film; 20,000 videotapes; 22,000 audiotapes; 47 million pages (23,500 linear feet) of manuscripts; 15,000 books; and 25,000 serial publications and other items. Ronald Reagan, who was the fortieth President of the United States, was in office from 1981 until 1989. The Reagan Library was opened in 1991.

• **Warner Bros.**, Burbank, California. The Warner Bros. motion picture studio opened a new high-security cold storage facility on its Burbank studio lot in October 1992 (Burbank is adjacent to Hollywood, just north of Los Angeles). The sophisticated Warner Bros. facility consists of three vaults, one of which is for color film and is maintained at 35°F (1.7°C) and 25% RH. A second vault is used for separations (YCM's) and other black-and-white materials and is maintained at 45°F (7.2°C) and 25% RH. The third vault is used to store less-critical duplicate film elements and circulating materials and is kept at 50°F (10°C) and 45% RH. An advanced air-filtration system is provided to remove any acetic acid or other gases resulting from film degradation, from Los Angeles air pollution, or from other sources.

Like Paramount Pictures, Warner Bros. has for a long time stored sets of black-and-white separations (YCM's) for each of its feature films in a high-security underground storage facility in Pennsylvania. Warner Bros. is a part of Time Warner Inc. which, with its Home Box Office (HBO) movie service for cable TV subscribers, a far-flung cable TV system, and extensive magazine publishing operations, is the world's largest entertainment company. The architect for the Warner Bros. film storage building was Archisystems International, of Santa Monica, California.[22] As was the case with the Paramount Film and Tape Archives building, the general contractor for the Warner Bros.

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facility was Turner Construction Company, which is based in New York City (see **Suppliers** list on page 726 at the end of this chapter). The Warner Bros. motion picture preservation facility is discussed in more detail in Chapter 9.

• **Eastman Kodak Company**, Hollywood, California. In May 1993, Eastman Kodak will open a new building adjacent to the company's Hollywood Marketing and Technology Center that will include three motion picture film storage vaults, totaling 12,000 square feet, in which space will be available on a rental basis.[23] Two of the vaults will be maintained at 45°F (7.2°C) and 25% RH; the third vault will operate at 32°F (0°C) and 25% RH. Operation of a film storage rental facility is a new type of business for Kodak. In announcing the new cold storage facility, Kodak said, "We expect to identify and develop products, practices, and services for asset protection of images and sound originated on motion picture film and magnetic media."

• **The Richard M. Nixon Presidential Materials Project**, under the auspices of the Office of Presidential Libraries of the National Archives and Records Administration in Washington, D.C. Richard M. Nixon, the thirty-seventh President of the United States, held office from 1969 until he resigned on August 9, 1974 because of the "Watergate" scandal. The controversy surrounding his administration and the legal proceedings that began while he was still president and continued after his resignation effectively prevented the establishment of a presidential library for Nixon along the lines of those built for Kennedy, Johnson, Ford, Carter, and Reagan.

Traditionally, the construction of a presidential library is financed with privately raised funds, and the project generally is completed within a few years after a president leaves office. The Ronald Reagan Library, for example, cost $40 million and was completed in less than 3 years after Reagan left office in 1989. Although construction is privately financed, after completion the presidential libraries are maintained and operated by the National Archives and Records Administration through its Office of Presidential Libraries.

At the time this book went to press in 1992, there were nine presidential libraries, the oldest being the Franklin D. Roosevelt Library, which is located in Hyde Park, New York, and was dedicated in 1941. Franklin Roosevelt was the thirty-second President of the United States and was in office from 1933 until 1945. Hyde Park was Roosevelt's birthplace. There is also a presidential library for Herbert Hoover, who was the thirty-first President of the United States. Hoover, who was in office from 1929 until 1933, died in 1964. Located at Hoover's birthplace in West Branch, Iowa, the Herbert Hoover Library was not dedicated until 1962, many years after the Roosevelt Library was established. Presidential libraries are usually located in the president's home state.

In the case of President Nixon, the photographs, motion pictures, audiotapes, videotapes, and manuscripts from the White House years were retained by the government and are handled by the Nixon Presidential Materials Staff in the Office of Presidential Libraries of the National Archives. The materials have been stored at 70°F (21°C) and 50% RH in a building in Alexandria, Virginia, across the Potomac River from Washington, D.C. All of the original color negatives, color transparencies, black-and-white negatives, audiotapes, and many of the videotapes have been duplicated for reference and study purposes. In 1993 the Nixon materials will be transferred to the new National Archives and Records Administration building in nearby College Park, Maryland. There, the color still photographs will be placed in a cold storage vault maintained at 38°F (3.3°C) and 35% RH. Color and black-and-white motion pictures will be stored at 25°F (–3.9°C) and 30% RH.

Many duplicate White House photographs have been supplied by private collections to the Richard Nixon Library & Birthplace, a privately constructed and administered museum and archive in Yorba Linda, California that opened in 1990. This library, which is not part of the federally administered presidential libraries program, also contains an extensive collection of photographs, manuscripts, and other materials that predate Nixon's presidency. Additional materials from the years following his resignation in 1974 continue to be added to the collection.

• **Future libraries for President George Bush and President Bill Clinton.** George Bush, the forty-first President of the United States and in office from 1989 until 1993, will have a library dedicated in his honor in Texas. Bill Clinton, who will be inaugurated as the forty-second President of the United States on January 20, 1993, is expected to have a library established in Arkansas after he leaves office. Both of these future presidential libraries are almost certain to include low-temperature, humidity-controlled cold storage facilities to preserve their collections of color and black-and-white still photographs, videotapes, audio tapes, and motion pictures.

• **The J. Paul Getty Museum**, Malibu, California. The Getty Museum is constructing a new museum complex in Brentwood (near Los Angeles), and tentative plans call for a 40°F (4.4°C) and 40% RH cold storage vault to be provided for the color photographs in its collection. The new building is scheduled for completion in 1996. At the time this book went to press in 1992, the museum's collection of mostly black-and-white photographs was being temporarily housed in an office building in Santa Monica, California; the temperature in the photograph storage area is maintained at 68°F (20°C) and 40% RH.

In keeping with the collecting philosophy of the Getty Museum, which is generally to refrain from acquiring contemporary art, the museum's Department of Photographs has purchased mostly 19th-century photographs and 20th-century photographs up until around 1950. Because color photography did not gain serious attention in the fine art world until the 1970's, the Getty collection, focused as it is on earlier black-and-white periods, presently contains comparatively few color photographs.

The Getty's modest collection of contemporary color photographs came into the museum as a result of the purchase of several major private collections in 1984, such as those of Chicago collector Arnold Crane and the late New York City collector Samuel Wagstaff. Weston J. Naef, Curator of the museum's Department of Photographs, acknowledges that contemporary photographs presently are not a high priority for his department in terms of new

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acquisitions, but he says that this emphasis could change in the future.[24] The Getty Museum, as a beneficiary of the J. Paul Getty Trust, is said to have the largest acquisitions and conservation budget of any art museum in the world. Also supported by the Getty Trust is the Getty Conservation Institute, a major center for conservation research located in Marina del Rey, California.

Cold Storage Facilities in Other Countries

Cold storage facilities for preserving color motion pictures and still photographs are also found in a number of other countries, including England, Germany, Japan, Norway, Russia, and Sweden. It is not possible to describe most of them here.

In 1970, the Swedish Film Institute in Stockholm, Sweden opened a large motion picture preservation facility which is maintained at 23°F (–5°C) and 40% RH.

In 1987, the National Museum of Modern Art in Tokyo, Japan, began operating a large cold storage facility for motion picture films. Part of the museum's Film Center-Archive in Fuchinobe, Japan, the two-story underground vault can accommodate 120,000 two-thousand-foot cans of 35mm film (approximately 22,000 feature films). One floor of the archive is used to store color film and is kept at 41°F (5°C) and 40% RH. The second floor is for black-and-white film and operates at 54°F (12°C) and 40% RH.

George Eastman House Sets Aside Plans for a Critically Needed Cold Storage Vault in Its New $7.4 Million Archives Building

In late 1988 the International Museum of Photography at George Eastman House in Rochester, New York, completed construction of a new $7.4 million archives building. The original plans for the building called for a cold storage vault for the museum's priceless collection of historical and fine art color photographs; the vault was also to be used to store cellulose nitrate still-camera negatives (including a large number of nitrate negatives made by George Eastman, the founder of Eastman Kodak Company). Tentative specifications for the vault were set at 35°F (1.7°C) and 25% RH.

When the new building opened, however, the cold storage vault was nowhere to be seen. Despite protests from the conservation staff, plans for the vault had been set aside; apparently, dropping the vault was seen as a convenient way to reduce construction costs.

As a consequence of years of neglect, many of the early color prints and transparencies in the Eastman House collection have already suffered substantial image deterioration. The image stability of many of these early materials is very poor and, with no cold storage provided, deterioration continues at a steady rate. At the time this book went to press in 1992, the Eastman House color motion picture and still photograph collections continued to be stored — and to deteriorate — without adequate cold storage. It is earnestly hoped that Eastman House will find a way to correct this very unfortunate situation.

Conclusion

The commitment to build and maintain a cold storage vault for preserving photographs has far-reaching implications. It tells the general public in no uncertain terms that the collections have lasting value — and that the institution will take whatever steps necessary to maintain them for generations far into the future.

Once a color photograph — or motion picture — has been placed in a low-temperature storage vault, it is very likely that it will be preserved forever. The longer the photograph is in a cold storage vault, the more significant it will become. Materials that have not been refrigerated will progressively fade until they become useless. Four or five hundred years from now, after most color photographs and motion pictures from this era have faded into oblivion, those relatively few refrigerated movies and photographs that remain in pristine condition will be so prized that their caretakers will see to it that they are refrigerated — at very low temperatures — forever.

Even if "perfect" electronic systems become available for recording and storing high-resolution photographs with no discernible loss of image quality, the original color photographs and motion picture films of the 20th century will continue to have great value as artifacts.

One can cite a number of important collections of color photographs that are now being preserved in humidity-controlled cold storage: Ektachrome transparencies photographed on the surface of the moon by astronauts Neil Armstrong and Edwin Aldrin on July 20, 1969, now securely stored in darkness at 0°F (–18°C) and 25% RH at the Lyndon B. Johnson Space Center in Houston, Texas (with backup sets of color duplicates stored under identical conditions at another site at the NASA facility in Houston, and at White Sands, New Mexico); and *Life* magazine's color photographs of Martin Luther King's nonviolent demonstrations in Selma, Alabama in 1965 (which led to the passage of the Voting Rights Act by Congress), now being preserved in the cold storage vault at the Time Inc. Magazines Picture Collection in New York City.

One can also cite the Ektachrome 35mm color slides photographed by the late Larry Burrows during the Vietnam War, preserved under refrigeration by the Larry Burrows Estate in New York City and by the Time Inc. Magazines Picture Collection; the Joel Meyerowitz and Stephen Shore Ektacolor 37 RC and 74 RC prints in cold storage at the Art Institute of Chicago; the Kennedy White House color negatives, preserved at 0°F (–18°C) and 30% RH at the John Fitzgerald Kennedy Library; the thousands of color movies in the Paramount Pictures, Warner Bros., and Turner Entertainment Co. film libraries; and the color motion pictures of the Stone Age Dani people of western New Guinea, filmed by Robert Gardner in 1961 and now preserved in cold storage at the Peabody Museum of Archaeology and Ethnology at Harvard University.

It is not wishful thinking to believe that these important color images from our time will be preserved, quite literally, forever.

Notes and References

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sponsored by the Baldwin Street Gallery of Photography, Toronto, Ontario. The Baldwin Street Gallery, one of Canada's first photography galleries, was founded in 1969 by American immigrants John Phillips and Laura Jones and continued in operation until 1979. An article by Gail Fisher-Taylor entitled "Colour – A Fading Memory?" and based on the presentations at the workshop was published in **Canadian Photography**, January 1979, pp. 10–11.

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13. The Film Conditioning Apparatus (FICA) machine is available from the Swedish Film Institute: Svenska Filminstitutet, Box 27126, 10252 Stockholm 27, Sweden. The FICA machine is manufactured for the Swedish Film Institute by AB Film-Teknik, P.O. Box 1328, S–17126, Solna, Sweden; telephone: 01-146-827-2820 (Stephen Lund, worldwide marketing director).
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20. Records Center of Kansas City (RCKC), a division of Underground Vaults & Storage, Inc., P.O. Box 1723, Hutchinson, Kansas 67504-1723; telephone: 316-662-6769 (toll-free: 800-873-0906). The refrigerated vault in the Kansas City facility replaced a refrigerated vault leased to the MGM Film Library for many years at the Underground Vaults & Storage, Inc. facility located 600 feet underground in an abandoned section of a working salt mine in Hutchinson, Kansas. The Records Center of Kansas City also has available a microfilm and magnetic media storage vault with a temperature of 66°F (19°C) and 40% RH.
21. National Underground Storage, Inc., P.O. Box 6, Boyers, Pennsylvania 16020; telephone: 412-794-8474 (Fax: 412-794-2838).
22. Archisystems International, 1106 Broadway, Santa Monica, California 90401; telephone: 310-395-7088.
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Suppliers

Equipment and General Contractors for Humidity-Controlled Cold Storage Facilities

Bonner Systems, Inc.
7 Doris Drive – Suite 2
N. Chelmsford, Massachusetts 01863
Telephone: 508-251-1199
(Bonner is recommended by this author as a designer and general contractor for humidity-controlled cold storage vaults.)

Turner Construction Company
375 Hudson Street
New York, New York 10014
Telephone: 212-229-6000
(Turner is recommended by this author as a general contractor for large, humidity-controlled cold storage installations and archive buildings.)

Archisystems International
1106 Broadway
Santa Monica, California 90401
Telephone: 310-395-7088
(Archisystems is recommended by this author as an architect for large, humidity-controlled cold storage buildings.)

Harris Environmental Systems, Inc.
11 Connector Road
Andover, Massachusetts 01810
Telephone: 508-475-0104

Cargocaire Engineering Corporation
79 Monroe Street
P.O. Box 640
Amesbury, Massachusetts 01913
Telephone: 508-388-0600
(Cargocaire is recommended by this author as a manufacturer of dry-desiccant dehumidifiers for humidity-controlled cold storage vaults and buildings.)

Bally Engineered Structures, Inc.
P.O. Box 98
Bally, Pennsylvania 19503
Telephone: 215-845-2311

Kester/Dominion Refrigeration Corporation
2929 Eskridge Road, Suite P-3
Fairfax, Virginia 22031
Telephone: 703-560-6644

Southeast Cooler Corporation
1520 Westfork Drive
Lithia Springs, Georgia 30057
Telephone: 404-941-6703
Toll-free: 800-241-9778 (outside Georgia)

North Brothers Company
P.O. Box 105557
Atlanta, Georgia 30348
Telephone: 404-622-4611

Vapor-Proof, Heat-Sealable Bags for Cold Storage

Conservation Resources International, Inc.
8000-H Forbes Place
Springfield, Virginia 22151
Telephone: 703-321-7730
Toll-free: 800-634-6923 (outside Virginia)
(large quantities only)

Light Impressions Corporation
439 Monroe Avenue
Rochester, New York 14607-3717
Telephone: 716-271-8960
Toll-free: 800-828-6216
(several sizes; available in small or large quantities)

Quality Packaging Supply Corporation
24 Seneca Avenue
Rochester, New York 14621
Telephone: 716-544-2500
(custom-made; flexible packaging)

Shield Pack, Inc.
411 Downing Pines Road
West Monroe, Louisiana 71292
Telephone: 318-387-4743
Toll-free: 800-551-5185 (outside Louisiana)
(custom-made; large quantities only)

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INDEX

This index was compiled by Rus Caughron for Carlisle Publishers Services, and was edited by John Wolf, Henry Wilhelm, and Carol Brower. Many of the color films, color papers, and other products appear in this book far too many times to be able to include all page references. The reader is referred to the Table of Contents (pages viii and ix) for additional guidance on where to find image stability data and other information for specific products.

Note especially the recommendations for the longest-lasting color films, color papers, and digital printing systems listed in Chapter 1 (pages 3–6). In addition, special recommendations sections can be found in most chapters (see Table of Contents for "Recommendations" page numbers). Also refer to the "Suppliers" lists located at the end of Chapters 4, 8, 12, 14, 15, 16, 18, and 20 for the names, addresses, and telephone numbers of manufacturers, distributors, and other sources of products.

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