19. Frost-Free Refrigerators for Storing Color and Black-and-White Films and Prints

An appropriate frost-free refrigerator is currently the only simple way to store color negatives, slides, prints, and motion pictures at low temperature and relative humidity. The photographs will be readily accessible, and there is no need to pre-condition them in a low-humidity environment or to package them in special hermetically sealed containers. The refrigerator section of a suitable combination refrigerator/freezer can maintain a temperature of about 35°F (1.7°C) and keep the relative humidity between 20 and 35% — the optimum level for most types of photographic materials[1] — regardless of ambient temperature and humidity conditions.

At the time of this writing, frost-free refrigerators were being used by a number of photographers, including Adam Bartos, Ellen Brooks, Mitch Epstein, Douglas Faulkner, David Hanson, Joel Meyerowitz, Leo Rubinfien, Stephen Scheer, and Victor Schrager, to store their color films and prints. Some serious collectors, such as Pepe Karmel of New York City, help preserve the quality and value of the color photographs they purchase by storing them in refrigerators.

After *Life* magazine photographer Larry Burrows was killed in Laos in 1971, his Ektachrome transparencies of the Vietnam War were stored in a frost-free refrigerator at the Time Inc. Magazines Picture Collection in New York City. In 1983, when Time completed construction of a large humidity-controlled cold storage vault, Burrows's Vietnam color slides were moved into the new facility along with the more than one million other color transparencies in the Picture Collection. (Time Inc. Magazines is part of Time Warner Inc.)

To preserve Burrows's color work that is not in the custody of Time Inc. Magazines or other publishing companies, Russell Burrows, Larry Burrows's son and caretaker of his father's estate, stores the transparencies in a frost-free refrigerator. Burrows is considered to have been the first photographer to comprehensively record war in color; his color photographs of the Vietnam war were made over a period of more than 8 years. An exhibition of his work, *Larry Burrows: Vietnam – The American Intervention 1962–1968*, was shown at the Laurence Miller Gallery in New York City in 1985. Color photographs from both the Larry Burrows estate and the Time Inc. Magazines Picture Collection were included. The 18 Kodak Dye Transfer prints in the exhibition were printed from the original transparencies; a limited-edition portfolio of some of the photographs in the exhibition was also made available by the Laurence Miller Gallery.

See page 658 for Recommendations

Notice: Although storage of photographic materials in appropriate frost-free refrigerators will effectively slow fading rates and greatly extend the life of color photographs, there is a possibility that mechanical malfunction of a refrigerator, improper handling of the photographs, or other factors could result in damage to the photographs. This author believes that if properly maintained refrigerators of a suitable type are used according to the suggestions included in this chapter, if refrigerators are replaced with new units after a maximum of ten years of service, if packages of photographs are *placed in polyethylene bags prior to storing them in the refrigerators,* and if the temperature and relative humidity inside the refrigerators are checked on a regular basis (at least once a week), there is very little likelihood of photographs being damaged. However, neither this author nor Preservation Publishing Company can take any responsibility for damage, regardless of the cause, that may occur as a result of placing photographs in a refrigerator or freezer. Cellulose nitrate film requires storage in special, explosion-proof freezers and should not be kept in an ordinary household refrigerator or freezer — see **Appendix 19.1** on page 675.

Refrigerated Ektacolor Prints at the Museum of Modern Art

The Museum of Modern Art in New York City obtained a Sears Roebuck Kenmore frost-free refrigerator in 1984 for storing the approximately 100 Ektacolor and other chromogenic color prints in its collection. (By 1992, the number of prints stored in the refrigerator had grown to more than 450.) Some of these photographs were included in the museum's 1984 exhibition *Color Photographs: Recent Acquisitions;* at the close of the exhibition, the prints were removed from their mats and returned to the refrigerator. Perceptible fading and staining of Ektacolor 37 RC and 74 RC prints will occur in less than 10 years in normal room-temperature dark storage, and the museum decided that if it wanted to continue collecting such unstable materials it had to provide refrigerated storage to preserve the prints. Stored at 35°F (1.7°C), Ektacolor 37 RC and 74 RC prints can be kept an estimated 200 years before image deteriora-

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February 1989

Russell Burrows, son of the late **Life** magazine photographer Larry Burrows, and Victoria Burrows, Larry Burrows's widow, are shown here with part of the collection of Larry Burrows's 35mm Ektachrome slides taken during the Vietnam war. Burrows, who arrived in South Vietnam in 1962 and spent more than 8 years covering the war, produced some of the most significant photographs from the Vietnam conflict. To preserve the images and to protect future income from the sale of reproduction rights, all of the transparencies have been duplicated; the originals are stored in a frost-free refrigerator in Russell Burrows's New York City apartment and in the cold-storage vault at Time Warner Inc. in New York City. Burrows was killed in 1971 at the age of 44 while covering the South Vietnamese incursion into neighboring Laos. Burrows was riding in a helicopter over the jungle near the border between the two countries when it was hit by antiaircraft fire; there were no survivors of the crash.

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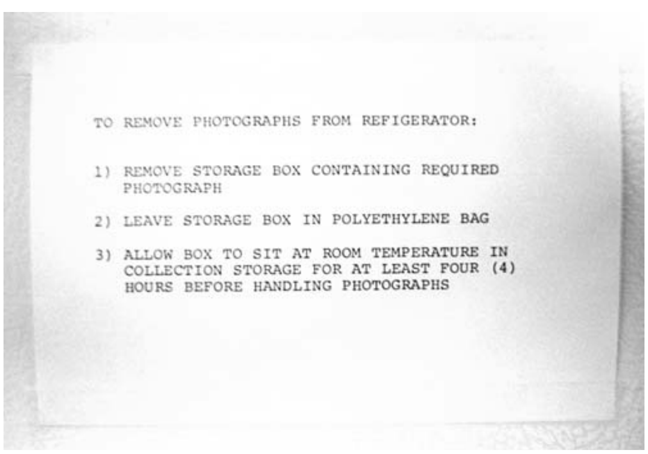
The Museum of Modern Art in New York City began storing Kodak Ektacolor and other chromogenic color prints in a Sears Roebuck Kenmore frost-free refrigerator in 1984. Peter Galassi, now the director of the Department of Photography, is shown here looking into the refrigerator. The Museum maintains that a large, walk-in cold storage unit cannot yet be justified, given the relatively small number of chromogenic prints now in its collection.



For ease of reference, the approximately 500 color prints in the refrigerator are cataloged in a separate card file (a small black-and-white image of the print is in the upper right corner of the card); the refrigerated prints are also cataloged in the general card index for the collection, using special, color-coded cards.

Included in the collection at the Museum of Modern Art are portfolios of Ektacolor prints by Stephen Shore *(Monet's House and Gardens, Giverny)* and William Eggleston *(Election Eve)*. The portfolios have been wrapped in transparent polyethylene for storage in the refrigerator. Since about 1984, the museum has been acquiring duplicates of most of the color prints it purchases; one set of prints is preserved in the refrigerator while the duplicate set is available for display and study purposes.

A large Ektacolor print by Cindy Sherman is being pulled out of a vertical storage shelf by Peter Galassi. Some prints like this are too big to fit in the refrigerator. At present, the Modern keeps such large chromogenic color prints with the rest of its collection (which, along with black-and-white prints, includes Ilford Cibachrome [Ilfochrome], Kodak Dye Transfer, Fresson Quadrichromie, and other types of color prints that have good dark storage stability) in an environmentally controlled room at 60°F (15.5°C) and 40% RH.

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Recommendations

- **Refrigerate photographic materials with poor stability.** It is particularly important to refrigerate color prints made from color negatives on papers that have poor stability (e.g., pre-1984 Ektacolor [Ektacolor 37 RC and 74 RC], as well as pre-1984 Fujicolor, Agfacolor, and Konica Color prints); all pre-1991 Kodak Ektachrome prints; current and past Ektachrome Prestige prints; color negative films with poor stability (e.g., Ektacolor, Vericolor II, Kodacolor-X, Kodacolor II, Fujicolor II, pre-1989 Agfacolor XR and XRS, and pre-1992 3M ScotchColor negative films); and relatively unstable types of color slides and larger transparencies (e.g., Process E-1, E-2, E-3, and E-4 Ektachrome films, Ansco and GAF films, pre-1989 Agfachrome, and some current and all past 3M Scotch color slide films).

- **Do not keep cellulose nitrate film in a refrigerator.** Because of the potential fire hazard associated with cellulose nitrate film, it should be stored only in special, explosion-proof freezers (see **Appendix 19.1** at the end of this chapter).

- **Recommendations for portrait photographers:** To assure customers that top-quality reprints will always be available, color negatives from all prints that have been sold should be refrigerated, especially negatives made with earlier films that have poor stability, such as Ektacolor, Vericolor (the original type), and Vericolor II (including current Vericolor II Type L).

- **Recommendations for fine art photographers:** All color negatives and transparencies, including those made with current films that have improved stability, should be refrigerated. This will assure that top-quality prints matching the original "vintage" prints can continue to be made during the photographer's lifetime and will preserve valuable negatives and transparencies so that upon the photographer's death they may be passed on to a museum in their original condition. Photographers should also preserve at least one copy of all important prints in a refrigerator in order to have a set of guide prints with which to make critical comparisons should new prints be made in the future. Although the dye stability of Kodak Ektacolor Plus, Ektacolor Professional, Ektacolor Edge, and Ektacolor Portra papers has been improved in relation to earlier Kodak papers such as Ektacolor 74 RC, the new Kodak papers still develop yellowish stain to an unacceptable degree. Storage in a frost-free refrigerator greatly slows the rate of yellowing.

- **Recommended frost-free refrigerators:** For reasons discussed in this chapter, Kenmore refrigerators sold by Sears Roebuck & Co. are recommended. Materials should be stored only in the refrigerator compartment (factory-packed, unprocessed film and paper can be stored in the freezer compartment if desired). For the reasons discussed in this chapter, a refrigerator should be purchased new, and should be replaced after 10 years of service. Large-capacity humidity-controlled refrigerators for museum and archive use are available from Bonner Systems, Inc., 7 Doris Drive, Suite 2, N. Chelmsford, Massachusetts 01863 (telephone: 508-251-1199).

- **Packaging for storage in a refrigerator:** Films and prints should be packaged in envelopes or boxes and placed in polyethylene bags or wrapped with polyethylene and the seams taped with freezer tape. Packaging in polyethylene eliminates the need for pre-conditioning and will prevent moisture condensation on the boxes or envelopes when the refrigerator door is opened or when packages are removed and warmed up to room temperature. Packaging in polyethylene also minimizes the possibility of damage to photographs in the unlikely event of refrigerator malfunction. (For maximum safety with valuable photographs, they should be conditioned in a low relative humidity and then sealed in vapor-proof envelopes before placing them in the refrigerator.)

- **A relative humidity gauge should be placed in the refrigerator:** A dial hygrometer, such as one of the units supplied by Abbeon-Cal, should be placed on an interior shelf and checked about once a week to be certain that the refrigerator is functioning properly. If the hygrometer does not have a self-contained thermometer, a separate thermometer should also be placed in the refrigerator compartment.

tion equals that expected after 10 years of storage at a room temperature of 75°F (24°C).

Speaking in 1987, John Szarkowski, at the time director of the Department of Photography at the Modern, said that he believed that the relatively small number of chromogenic color prints in the Modern's collection did not justify construction of a large-scale cold storage facility such as that at the Art Institute of Chicago. Szarkowski also expressed hope that in the not-too-distant future, the dark fading stability of negative-positive print materials would be improved to the point where refrigerated storage would not be required for acquisitions made on these new materials, just as refrigerated storage is not now required for the Ilford Cibachrome (Ilfochrome), Kodak Dye Transfer, and Fresson Quadrichromie prints in the collection. These prints, which have extremely good dark fading stability, are kept with the collection's black-and-white prints in a newly constructed print room in which the temperature is maintained at 60°F (15.5°C) and the relative humidity at 40%.

Peter Galassi, now the director of the department of photography at the Modern, says the museum tries to obtain two copies of each color print it purchases, offering to pay the artist's price for one and the "lab price," or actual cost of making the print, for the second copy.[2] In what will probably become a common practice with fine art musuems, one print is kept in permanent storage in the refrigerator while the other copy can be removed from the refrigerator as needed for study and exhibition. The two prints can be compared visually to determine if any fading or staining of the study/exhibition print has occurred.

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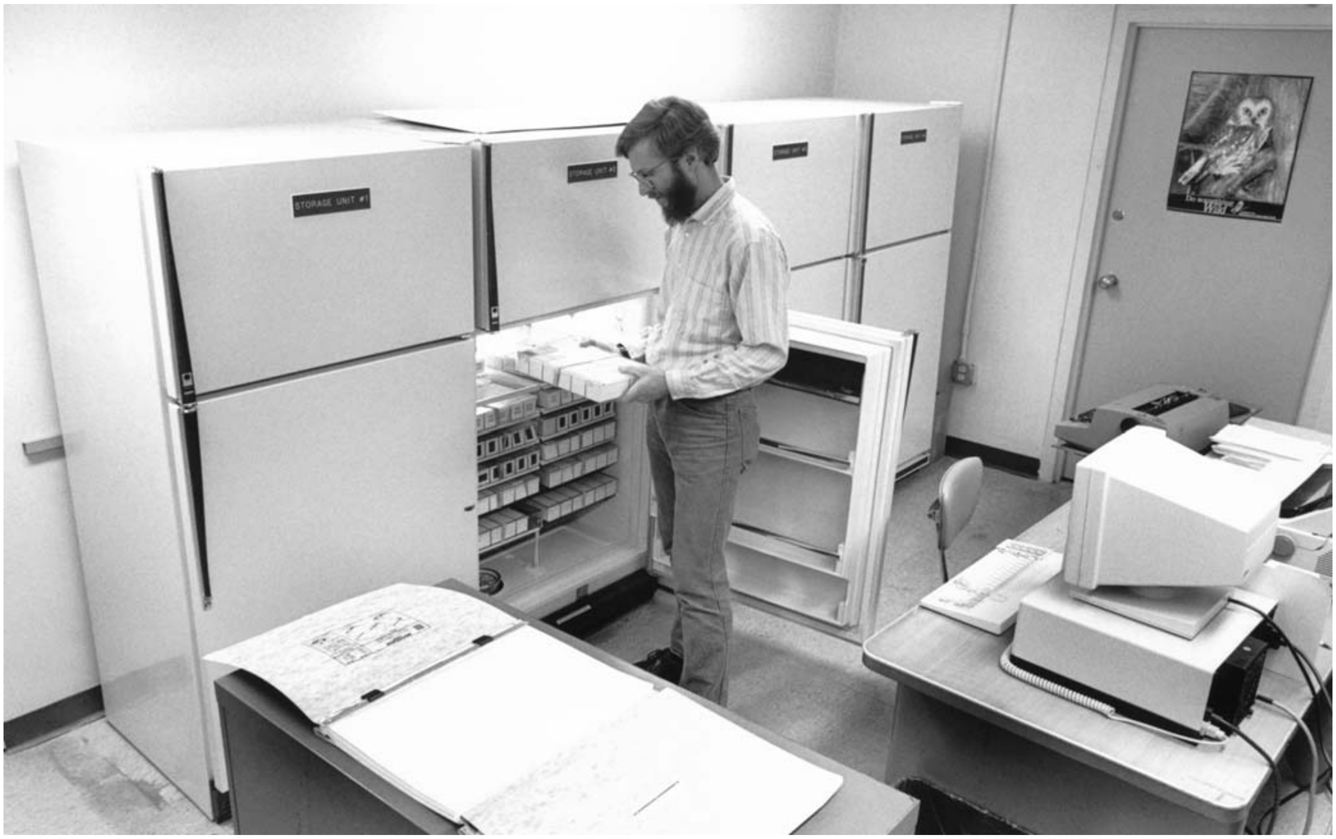

One of the largest installations of Sears Roebuck frost-free refrigerators for photographic storage is at Project VIREO (Visual Resources for Ornithology) at the Academy of Natural Sciences of Philadelphia. With more than 100,000 color slides preserved in its frost-free refrigerators, VIREO is the world's largest comprehensive collection of bird photographs.

VIREO is equipped with small- and large-volume slide duplicators. In-house duplication allows consistent quality-control, reduces costs, and, most importantly, avoids the possibility that originals will be damaged or lost if sent out for duplication.

Duplicate transparencies are examined on a light table.

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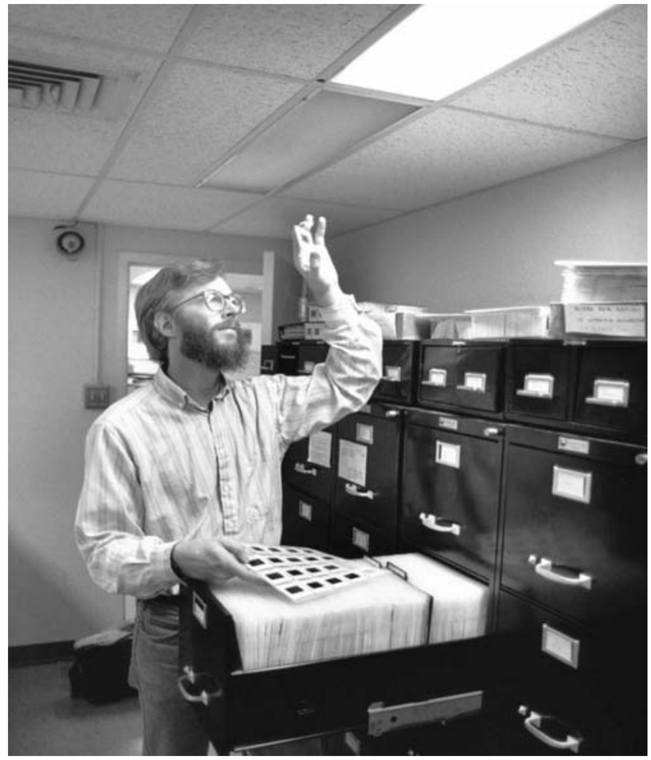
Project VIREO Director Douglas Wechsler, an active bird photographer specializing in Central and South American birds, supervises the collection. The slides, which have been numbered and entered in a microcomputer-based cataloging system, are stored in transparent plastic boxes in the refrigerators. Note the dial hygrometer on the bottom shelf of the refrigerator; the temperature and humidity levels in each refrigerator are checked frequently.



Duplicate transparencies have been made of all originals, and the duplicates form the work and study collection, stored in Saf-T-Stor rigid polypropylene slide pages housed in file cabinets. Original slides are kept refrigerated and are removed only to make additional duplicates (under certain circumstances, originals have been loaned to publishers for making laser-scanned color separations).

The Bird Photography Collection at Project VIREO

Another user of Sears Roebuck frost-free refrigerators is Project VIREO (Visual Resources for Ornithology), headquartered at the Academy of Natural Sciences of Philadelphia. In what is said to be the world's largest comprehensive collection of bird photographs, Project VIREO has gathered more than 100,000 color transparencies of birds and cataloged them in a computerized database; more than 140 photographers have contributed to the collection, including Crawford H. Greenewalt, Victor Hasselblad (in addition to the cameras bearing his name, Hasselblad was also well known for his photographs of birds), N. Philip Kahl, Roger Tory Peterson, and Eliot Porter.

In a long-term preservation procedure developed in 1982 by Project VIREO technical director Robert Cardillo,[3] two high-quality duplicates of each original transparency are made on Ektachrome Duplicating Film 5071 (Process E-6). One of the duplicates is sent to the contributing photographer and the other is added to the working collection. The original transparency is placed in one of VIREO's refrigerators for preservation and its physical location added to the computerized database; the original is not projected or otherwise accessed except for making additional duplicates when needed.

With a carefully organized file system in which the color slides are contained in flat plastic boxes — each of which can hold 960 slides — each refrigerator can accommodate about 26,000 35mm color slides. Photographs from the collection are available for commercial publication for a fee, as well as for educational and scholarly use. According to Cardillo, a principal impetus for establishing the VIREO collection was the realization that many early color photographs of birds, especially those made on Ektachrome films, had already seriously faded and "ultimately they lose all value."

To house the Crawford H. Greenewalt collection donated in 1985, VIREO obtained two additional Sears Roebuck frost-free refrigerators to supplement the two units already in operation; to accommodate future acquisitions, a fifth unit was purchased in 1988.

Among other institutions having frost-free refrigerators to preserve photographs are the Museum of Contemporary Photography at Columbia College, Chicago, Illinois; the Colorado Historical Society, Denver, Colorado; the U.S. Geological Survey Photo Library, Denver, Colorado; the Bernice P. Bishop Museum, Honolulu, Hawaii; the New Orleans Museum of Art, New Orleans, Louisiana; the University of Rochester Library, Rochester, New York; the Wisconsin Regional Primate Research Center at the University of Wisconsin, Madison, Wisconsin; and the State Historical Society of Wisconsin, Madison, Wisconsin.

(continued on page 664)

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Table 19.1 Estimated Number of Years for "Just Noticeable" Fading to Occur in Various Kodak Color Materials Stored in the Dark at Two Room Temperatures and Two Refrigerator 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:* 80°F (26.7°C)	75°F (24°C)	40°F (4.4°C)	35°F (1.7°C)
Ektacolor 37 RC Paper (Process EP-3) ("Kodacolor Print" when processed by Kodak)	7	10	140	200
Ektacolor 78 and 74 RC Papers (Process EP-2) ("Kodacolor Print" when processed by Kodak)	5	8	110	160
Ektacolor Plus Paper **Ektacolor Professional Paper** (Process EP-2) ("Kodacolor Print") ("Kodalux Print")	**25**	**37**	**520**	**750**
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)	5	7	100	140
Ektachrome 14 Paper (Process R-100)	7	10	140	200
Ektachrome Radiance Paper (Process R-3) (1991—)	**(not disclosed)**			
Ektachrome 22 Paper [improved] (Process R-3) (1991–92)	(not disclosed)			
Ektachrome Copy Paper (Process R-3) Ektachrome HC Copy Paper Ektachrome Overhead Material Ektachrome Prestige Paper Ektachrome 22 Paper (1984–90)	**5**	**8**	**110**	**160**

Color Negative Films	Years of Storage at:* 80°F (26.7°C)	75°F (24°C)	40°F (4.4°C)	35°F (1.7°C)
Kodacolor II Film	4	6	84	120
Kodacolor VR 100, 200, 400 Films	**12**	**17**	**240**	**340**
Kodacolor VR-G 100 Film ("initial type") (Kodacolor Gold 100 Film in Europe)	8	12	170	240
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 Professional Film Type S	4	6	85	120
Vericolor II Professional Film Type L	**2**	**3**	**40**	**60**
Vericolor II Commercial Film Type S	2	3	40	60
Vericolor III Professional Film Type S **Ektacolor Gold 160 Professional Film**	**16**	**23**	**320**	**460**
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	**3**	**5**	**70**	**100**

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Color Transparency Films	Years of Storage at:* 80˚F (26.7˚C)	75˚F (24˚C)	40˚F (4.4˚C)	35˚F (1.7˚C)
Ektachrome Films (Process E-3) [O]	3	5	70	100
Ektachrome Films (Process E-4) [P]	10	15	210	300
Kodak Photomicrography Color Film 2483 (Process E-4)	**2**	**3**	**40**	**60**
Ektachrome Films (Process E-6) ["Group I" types since 1979]	**35**	**52**	**730**	**1,100**
Ektachrome Plus and "HC" Films [Q] **Ektachrome 64X, 100X, & 400X Films Ektachrome 64T and 320T Films** ["Group II" types since 1988] (Process E-6)	**75**	**110**	**1,500**	**2,200**
Kodachrome Films (Process K-14) [all types]	**65**	**95**	**1,300**	**1,900**

Motion Picture Color Negative Films	80˚F	75˚F	40˚F	35˚F
Eastman Color Negative II Film 5247 (1974)	4	6	85	120
Eastman Color Negative II Film 5247 (1976)	8	12	170	240
Eastman Color Negative II Film 5247 (1980)	19	28	390	550
Eastman Color Negative Film 5247 (1985 name change)	**19**	**28**	**390**	**550**
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)	4	6	85	120
Eastman Color Negative II Film 7291	**34**	**50**	**700**	**1,000**
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	**15**	**22**	**310**	**440**
Eastman EXR Color Negative Film 5248 and 7248	**20**	**30**	**420**	**600**
Eastman EXR High Speed Color Negative Film 5296 & 7296	**35**	**50**	**700**	**1,000**

Motion Picture Laboratory Intermediate Films	Years of Storage at:* 80˚F (26.7˚C)	75˚F (24˚C)	40˚F (4.4˚C)	35˚F (1.7˚C)
Eastman Color Reversal Intermediate Film 5249 and 7249	**5**	**8**	**110**	**160**
Eastman Color Intermediate II Film 5243 and 7243	15	22	310	440
Eastman Color Intermediate Film 5243 and 7243 Improved	**(not disclosed)**			

Motion Picture Print Films	80˚F	75˚F	40˚F	35˚F
Eastman Color Print Film 5381 & 7381 [S]	[3	5	70	100]
Eastman Color SP Print Film 5383 & 7383	3	5	70	100
Eastman Color Print Film 5384 & 7384	**30**	**45**	**650**	**900**
Eastman Color LC Print Print Film 5380 & 7380	**30**	**45**	**650**	**900**

* 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 390 years at 40°F (4.4°C) and 550 years at 35°F (1.7°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 19.1

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Fading Characteristics of Color Materials Kept in a Refrigerator

As discussed in Chapter 5, most color materials will in time suffer objectionable fading, staining, and shifts in color balance if stored in the dark at normal room temperatures — even if the storage areas are air conditioned during warm and humid parts of the year. Estimates of the number of years required for a 10% density loss of the least stable dye for a number of Kodak color film and print materials stored at room temperature and in a refrigerator are given in **Table 19.1**. The Kodak data are based on a relative humidity of 40%. Process E-6 Ektachrome films, Vericolor III, Kodacolor Gold, Kodak Gold, Ektapress Gold, Ektar, Kodacolor VR-G, and Kodacolor VR color negative films, most of which have humidity-sensitive yellow dyes as the least stable dye, can fade approximately twice as fast as these figures indicate when stored at 60% RH. For many photographers, especially those living in tropical or near-tropical areas, it will not be possible to keep the average relative humidity as low as 40%, even in an air-conditioned room.

With most types of color prints stored in the dark, a 10% density loss will, when viewed by the average individual, produce a "just noticeable" color shift and/or loss of image contrast when a print is directly compared with an unfaded but otherwise identical print of the same scene. It is characteristic of most chromogenic color films and prints that one of the three image dyes — usually magenta — is much more stable in dark fading than is the least stable dye, and this differential in fading rates results in increasingly objectionable color shifts as fading progresses. By the time a 10% dye loss in dark fading is reached, Ektacolor and most other chromogenic prints also will have developed significant yellowish stain — this stain may in fact be more objectionable than is the dye fading itself. (At the time of this writing, Kodak had not released data on the dark-storage stain characteristics of any of its color products; however, information supplied to this author by Fuji Photo Film Co., Ltd. indicates that stain formation in chromogenic materials has a temperature dependence which, in a general way, is similar to that of image dye fading — thus low-humidity refrigerated storage should greatly slow the development of stain with these products.)

It is usually possible to make acceptable prints from color negatives that have suffered a 10% dye loss, although the exposure and filtration will be somewhat different from those needed to print an unfaded negative. A 10% density loss is *not* the end of the useful life of a color print or transparency in most applications. However, from a critical point of view, a 10% density loss is visually significant, and it is assumed that anyone going to the effort of storing color materials in a frost-free refrigerator has high standards for color photography and would like to preserve the color images in their original condition — with brilliant colors, sparkling highlights, and crisp image contrast — for as long as possible.

The number of years of storage for a 10% loss to occur is a meaningful measure for comparing the stability of one color material with another, and for evaluating the effects of different storage temperatures.

Seriously faded color negatives produce prints with objectionable — and uncorrectable — curve crossovers accompanied by reduced overall contrast. This results in prints with a "flat" appearance. In spite of efforts to adjust the filtration for an overall pleasing color balance, such prints will have distinctly different color balances in highlight and shadow regions of the image. Prints made from faded color negatives on Vericolor II, Kodacolor II, pre-1989 Agfacolor XR and XRS, Fujicolor II, Fujicolor HR (prior to the introduction of Fujicolor Super HR in 1986), and Konica Color SR (prior to the introduction of Konica Color SR-V and GX films in 1987), and color-balanced for optimum flesh tones, will have reddish midtones and shadow areas accompanied by greenish highlights. All of these negative films have poor-stability cyan dyes and relatively high-stability magenta dyes.

Fading-rate estimates published by Kodak indicate that, on average, color materials will last approximately 14 times longer at 40°F (4.4°C), and approximately 20 times longer at 35°F (1.7°C), than when stored at a typical room tem-


May 1981

Joel Meyerowitz, a New York City photographer well known for his fine art and commercial work, stores his color negatives in a frost-free refrigerator. Much of Meyerowitz's fine art photography has been done with Kodak Vericolor II Type L film in the 8x10-inch format. Estimated to lose 10% of its initial cyan dye density in as little as 3 years when stored at normal room temperature, Vericolor II Type L is the least stable of any of Kodak's current color negative films. When the negatives are kept in a refrigerator at 40°F (4.4°C), a 10% cyan density loss will not occur for an estimated 40 years.

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perature of 75°F (24°C). The Kodak data are based on a 40% RH; the relative humidity in a suitable refrigerator will normally be in the range of 20–35%, which will further extend the life of many of the products listed in **Table 19.1.** The data given in **Table 19.1** are *estimates* only; fading of a particular product may have a somewhat different temperature dependence and may not exactly follow the 14X and 20X factors for the listed refrigerated temperatures. Early versions of some of the products — notably Vericolor II Film Type S and the Process E-6 Ektachrome films — were less stable than the more recent types listed. Improper processing and washing can further reduce the stability of any product, sometimes drastically.

Storage in a *freezer* at 0° to –10°F (–18° to –23°C) will provide an extremely long life for color materials. However, photographs should not be stored in the freezer section of a frost-free unit or in a conventional freezer unless the films and prints are sealed in vapor-proof containers which are then placed in an insulated box (e.g., several thicknesses of cardboard). During the defrost cycle, the temperature of the freezer section rises rapidly from about 0°F (–18°C) to 70°F (21°C) or above. The relative humidity in the freezer section may reach nearly 100% during this period. Unexposed factory-packed film and paper can be stored in the freezer section without supplemental packaging, except for long-term storage when they should be placed in a double-wall cardboard box to prevent the abrupt temperature and humidity changes from affecting them.

Use of a suitable frost-free *refrigerator* for storage will prevent serious deterioration of even the most unstable types of color photographs during the photographer's lifetime, provided they are not mishandled when they are out of the refrigerator. Photographs will, of course, resume fading at the room-temperature rate when they are removed from the refrigerator for printing or duplication; those that are *frequently* withdrawn should be returned to the refrigerator as soon as possible. In most situations, however, photographs need be out of the refrigerator only for a small part of the total storage time. Except in adverse environmental conditions, there is usually no urgency to refrigerate photographic materials immediately after processing and printing. Many photographers will find it practical once a year to gather all *new* negatives and transparencies for which printing has been completed and place the whole group in the refrigerator at the same time.

What Should Be Preserved in a Refrigerator

A number of factors should be considered in deciding whether or not to refrigerate materials such as Kodachrome films and Process E-6 Fujichrome and Ektachrome transparency films that have relatively good dark fading stability under normal room-temperature conditions. Color negative films with relatively good stability include: Kodak Vericolor III, Vericolor 400, Kodacolor Gold, Kodak Gold, Kodak Gold Plus (Gold II in Europe), Ektapress Gold, and Kodak Ektar films; Fujicolor Super HG, Super G (introduced in 1992), and Fujicolor HG 400 Professional films; and Konica Color SR-V, GX, Super DD, and Super SR color negative films.

Important considerations include the expected keeping time of the photographs, how critical fading might be with the particular images, their perceived value, and the conditions of available room-temperature storage. Keep in mind that the value of a particular photograph often cannot be properly assessed until many years after it is taken.

It is particularly important to refrigerate valuable transparencies made on Process E-1, E-2, and E-3 Ektachrome films, as well as color negatives that were made on Kodacolor II, Vericolor II (including Vericolor II Type L), and older Ektacolor and Kodacolor films — all of which have very poor dark fading stability. Fujicolor II, Fujicolor HR, and pre-1986 Fujicolor Professional color negative films, Konica Color SR negative films, pre-1992 3M ScotchColor Print films, pre-1991 Polaroid OneFilm 35mm color negative films, as well as pre-1989 Agfacolor XR, XRS, XRG and earlier Agfa-Gevaert color negative films all have very poor dark fading stability and should be refrigerated if future printing is a possibility. Unlike Fujichrome and Ektachrome Process E-6 compatible transparency films, the E-6 compatible Agfachrome professional and amateur transparency films introduced in 1984 had very poor dark fading stability (Agfachrome films with improved stability began to appear on the market in late 1988).

Valuable color prints made on Ektacolor, Fujicolor, Konica Color, and Agfacolor papers — all of which had very poor cyan dark fading stability prior to the introduction of improved products in 1984 and 1985 — should also be refrigerated promptly. All types of pre-1991 Kodak Ektachrome papers, in addition to the Kodak Ektachrome Prestige and Ektachrome HC papers that were current at the time this book went to press in 1992, have poor dark fading stability, and valuable prints on these papers should be refrigerated.

Portrait photographers should consider the future sales possibilities of reprints from older Ektacolor and Vericolor II color negatives that have been stored in refrigerators. Fine art photographers working with color negative materials are advised to refrigerate *all* color negatives, since even the improved Kodak, Fuji, and Konica color negative films stored at room temperature will change perceptibly during the photographer's lifetime. For most fine art photographers, color and tone reproduction in prints are critical concerns.

If available room-temperature storage conditions are poor, a frost-free refrigerator is a simple way to properly store both color and black-and-white materials. Refrigerators are especially helpful in the tropics and other humid areas where fungus growths are a problem. Frost-free refrigerators can also be used to preserve chromogenic-dye-image black-and-white films such as Ilford XP-1 and XP-2, and the now-discontinued Agfa Vario-XL; negatives made with these films have poor stability compared with silver-gelatin films.

The Cost of Storing Photographs in a Refrigerator

The cost of a refrigerator is small in relation to the value of the films and prints stored in it. The cost of only 60 or 70 rolls of processed 35mm color film may equal the purchase price of a new refrigerator. Photographs of personal, artistic, or historical importance must be considered priceless, since once they are faded, damaged, or destroyed, they usually cannot be replaced.

Frost-free refrigerators consume more electrical energy than do the older types of manual-defrost refrigerators —

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three or four times as much on the average. Sears Roebuck estimates that the yearly operating cost of a typical Kenmore 18- to 20-cubic-foot frost-free refrigerator/freezer will be about $90 based on electricity costs of $0.09 per kilowatt hour (including tax), which was typical for much of the U.S. in 1988. Some areas have much higher electrical rates; for example, New York City in 1987 had an average residential cost of electricity of $0.14 per kilowatt hour (including tax), which would result in an average yearly operating cost of about $140 for the same Kenmore refrigerator.

Packaging Photographs for Refrigeration

Slides, negatives, and prints should be packaged in boxes or envelopes which are then placed in polyethylene bags such as Ziploc[4] bags commonly sold in food stores. Negatives and prints can be in sleeves or envelopes — whatever the photographer normally uses to file them (see Chapter 14). A sheet of paper or polyester should be placed on the top and bottom of a stack of prints (or on both sides of an individual print) to prevent direct contact with the polyethylene bag. Separating prints themselves with proper interleaves (such as Atlantis Silversafe Photostore Paper) is generally recommended. If prints are clean and free of rubber-stamp impressions and ink markings on both front and back, however, they can be safely packaged without interleaves, thus conserving limited space available in the refrigerator.

To further conserve space, packaging should be as compact as possible; for example, if prints are matted, it is usually best to remove them from their mats and refrigerate only the prints. Slides can be placed in suitable non-PVC slide pages, left in the original boxes received from the processor, or filed in larger compartmented slide boxes. Low-cost boxes particularly recommended for slides are the Slide-File box available from Light Impressions Corporation, and the Lig-free Type II Archival Slide Storage box supplied by Conservation Resources International, Inc.; these two-piece cardboard boxes come with movable cardboard dividers to form compartments.[5] Rolls of motion picture films should be placed in taped cans, and the cans enclosed in tightly wrapped polyethylene bags.

Although polyethylene bags are not vapor-proof over prolonged periods, they do provide short-term protection from moisture condensation when the cold packages are warming up after removal from the refrigerator. To avoid danger of condensation on the photographs themselves, the packages must not be opened until the photographs inside have reached room temperature — see **Table 19.2** for typical warm-up times. The bags will also protect photographs from possible water damage in the unlikely event that certain parts of the refrigerator's internal defrost system malfunction. Because polyethylene slowly transmits water vapor, photographs need not be conditioned in a low-humidity environment before placing them in the refrigerator; over time, excess water vapor will diffuse through the bag, and the photographs will equilibrate with the low-humidity conditions in the refrigerator.

The refrigerator should not be packed too tightly — space should be left for air to circulate freely between the refrigerator shelves, and in the area between the front of the shelves and the door. It is permissible, however, to tightly pack the refrigerator vegetable and fruit storage drawers with photographs. (Photographs should never be placed directly on the bottom of the refrigerator compartment, and the bottom drawers should not be removed in an effort to increase the available space.)

Even though packaging photographs for storage, monitoring refrigerator temperature and humidity, and performing scheduled refrigerator maintenance may appear complex, use of the refrigerators is actually quite easy once the proper procedures are established. The detailed instructions and precautions given here are simply to make sure that the possibility of damaging irreplaceable photographs is reduced to an absolute minimum.

Recommended Refrigerators

Research for this book was, to this author's knowledge, the first investigation into the suitability of low-cost, frost-free refrigerators for storing color photographs without the need for vapor-proof packaging.[6] This author has been using a Kenmore frost-free refrigerator/freezer sold by Sears Roebuck and Company for storing color materials since 1975. Sears Roebuck started selling frost-free refrigerators in 1960, although it was several years later before they came into wide use. Frost-free refrigerators eliminate the messy and troublesome manual defrosting that was periodically necessary with earlier refrigerator/freezer designs. Most of the refrigerators sold in the U.S. are now of a frost-free design.

This author's refrigerator/freezer has a 10.6-cubic-foot capacity refrigerator section, which can accommodate about 20,000 35mm color slides in standard cardboard mounts; this figure is based on the slides being packed in standard Kodak 36-exposure cardboard slide boxes, enclosed in tightly wrapped polyethylene bags, with a reasonable amount of care in orderly packing. The 20,000-slide capacity leaves sufficient space between groups of boxes so that air can circulate freely throughout the refrigerator section. At the time of this writing, however, there were only a few thousand slides stored in this author's refrigerator — the remainder of the space was occupied by color negatives, color prints, and unprocessed color film and paper.

Basic design features of suitable refrigerators are given in **Table 19.3**. A type of refrigerator often confused with the true "frost-free" design is known as the "cycle-defrost" refrigerator, generally advertised as having a frost-free refrigerator section but a manual-defrost freezer section. This type of refrigerator functions by having separate cooling coils attached to thin aluminum plates in the refrigerator section. When the unit operates, the coils and plates form a small amount of frost. Between running cycles, the plates rapidly warm up to the temperature of the refrigerator section, which is above freezing, and water from the melted frost is drained off. These units require much less electricity than a true frost-free unit and are often advertised as being "energy saving." ***Cycle-defrost refrigerators are not suitable for storing unprotected photographs*** because they have very high levels of relative humidity. An older design based on a similar principle had cooling coils located behind the walls of the refrigerator section that were so arranged that they never reached a temperature below freezing. The interior walls of such a refrigerator

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Slide pages can be packaged in a polyethylene garbage bag and flip-top museum box. To be able to find a specific slide or negative stored in a refrigerator, it is essential that the materials be cataloged and filed in an orderly manner. All boxes and other packages should be clearly marked as to their contents.

Carol Brower – 1983

Kodalux (Kodak) 24- and 36-exposure yellow cardboard slide boxes are packaged in an ordinary polyethylene garbage bag, which in turn is placed in a flip-top museum box for storage in the refrigerator.

are usually wet with condensed moisture, and the relative humidity level is normally near 100%.

None of the older manual-defrost refrigerators should be used for storing unprotected photographs, since they normally have relative humidity levels of between 90 and 100%.

Because this author has not had the opportunity to examine all of the many brands of frost-free refrigerators on the market, this discussion will be limited to general observations about the various types of refrigerators now being sold; in addition, specific information is given for the Kenmore frost-free refrigerator/freezers sold by Sears Roebuck and Company.[7] An important reason for using Sears Roebuck refrigerators is that the company includes a complete parts list with each refrigerator, and replacement parts and service are readily available from any of the Sears outlets in North America.

With the frost-free units recommended here, only the refrigerator section is acceptable for unprotected storage; although the freezer section is also "frost-free," it has much higher levels of relative humidity than the refrigerator section and is not suitable for storing photographs unless they are sealed in vapor-proof containers. The freezer section is safe for storing unprocessed materials that are still sealed in their original vapor-resistant factory packages. By the same token, "frost-free" freezers, which have no refrigerator sections, cannot be used for storing unprotected photographs.

Large-Capacity "Photoarchive" Refrigerators

In 1992, Bonner Systems, Inc., a supplier of cold storage vaults (see Chapter 20), introduced the Photoarchive line of humidity-controlled refrigerators for museums and archives. Equipped with temperature and humidity recorders, the units are priced from $11,000 and are available in sizes up to 11 feet long x 6 feet high x 3 feet deep. Contact: Bonner Systems, Inc., 7 Doris Drive, Suite 2, N. Chelmsford, Massachusetts 01863; telephone: 508-251-1199.

Table 19.2 Approximate Warm-Up Times for Various Types of Packages Before They Should Be Opened

Type of Package	From 35°F to 75°F (1.7°C to 24°C) [40°F (22°C) Temperature Rise]
36-exposure box of slides in Kodalux (Kodak) paper box	45 minutes
Envelope with 6 strips, 6 frames each, 35mm film in polyester or acetate sleeves	15 minutes
35mm reel of movie film in metal film can	3 hours
16mm reel of movie film in metal film can	1½ hours
10 RC or fiber-base paper prints in flat cardboard box	1 hour
100 RC or fiber-base paper prints in flat cardboard box	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 and placed on a table so air can freely circulate around the container. Do not stack containers together during the warm-up period unless warm-up times are greatly increased. These warm-up times were determined using packages of refrigerated photographs in which an externally monitored electronic temperature sensor had been placed in the center of the package.

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Slide boxes can also be packaged two or three at a time in small, transparent Ziploc polyethylene bags for safe and accessible storage in the refrigerator.

Carol Brower – 1983

Prints and negatives (shown here in their original processing envelopes) can be packaged in large, gallon-size Ziploc bags.

How a Frost-Free Refrigerator Maintains Low Relative Humidity

Top-freezer models of suitable frost-free refrigerators have the cooling coils located behind a metal wall in the freezer section; side-by-side models are constructed in a similar manner with the cooling coils in the back of the freezer section. A fan located in the front of the cooling coils circulates cold air from the coils into the refrigerator and freezer sections; the fan operates only when the unit's compressor is running, during which the cooling coils are about –20°F (–29°C). Excess moisture in the air is condensed on the coils in the form of ice crystals (frost) as the air passes over the coils. When the compressor is not running, the temperature of the coils rises to about that of the freezer section (0°F or –18°C), and some of the ice on the cooling coils sublimes directly to water vapor — without passing through a liquid state — gradually raising the relative humidity in the freezer section to as high as 80 or 90%. As the moist but very cold air from the freezer section enters the refrigerator section, it warms to about 35°F (1.7°C). In doing so, the capacity of the air to retain moisture greatly increases, thereby dropping the relative humidity of the air to between 20 and 35% (see **Figure 19.1**). The exact level of relative humidity will vary somewhat with the particular type of refrigerator, as well as with the temperature at which the refrigerator section is operated, but it is not significantly affected by external humidity conditions except when the door is opened and for a short period after it is closed.

Very low relative humidity in a refrigerator dehydrates food left open to the air; this is one of the "problems" of a frost-free refrigerator, according to one manufacturer. However, what is a problem for food storage is an advantage for photographs. As the cooling coils condense moisture from the air, they become covered with frost, which must be removed from time to time or the coils will become clogged with ice and the fan-forced air will not pass through the coils. To remove the ice, most frost-free refrigerators have a timer-controlled "defrost cycle," during which the compressor is shut off and a radiant electric heater located under the coils melts the ice. The heater is switched on at the beginning of the defrost cycle and continues to operate until it is switched off by a "bimetal" thermostatic cut-off located on the cooling coils (the temperature of the coils rises above freezing after the accumulated ice melts), or until the approximately 20-minute defrost cycle is completed. Most current models go through a defrost cycle after each 6 to 8 hours of compressor run time; earlier models had defrost times about twice each day and were not dependent on compressor run time. The water formed

Table 19.3 Design Features of Frost-Free Refrigerators Suitable for Storing Photographic Materials

1. Unit must have separate refrigerator and freezer sections. Sections must have separate doors which may be side-by-side or one above the other.

2. Cooling coils are located *ONLY* in the freezer section.

3. Cooling coils are located in an isolated compartment in the freezer section and cannot be seen without disassembling the unit. No part of the freezer or refrigerator which condenses moisture or forms ice crystals should be visible.

4. Air is forced over the cooling coils and into the freezer section by an internal fan. The fan will make noise when running and a current of cold air can be felt coming out of one or more ducts in the freezer and refrigerator sections.

5. This is the most important design feature: ALL cooling in the refrigerator section comes from cold air blown in from the freezer section by an internal fan.

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Table 19.4 Cautions When Using a Frost-Free Refrigerator for Storing Photographs

1. Be absolutely certain that you have the proper type of frost-free combination refrigerator/freezer unit.. Place an accurate hygrometer and thermometer inside, and keep it there at all times. Before putting any photographs or films in the refrigerator, monitor the unit's relative humidity (under operating conditions) daily for at least 2 weeks. Thereafter, check relative humidity and temperature levels at least once a week.

2. Temperature in the refrigerator section should be adjusted to an average of 35–40°F (1.7–4.4°C); the temperature should never drop below freezing (32°F or 0°C). Prolonged temperatures below freezing could result in a blocked condensate drain tube and cause water to leak inside the refrigerator section.

3. Use only the refrigerator section (not the freezer section) for storing processed photographs.

4. Photographs should be put inside envelopes or cardboard boxes which are then placed in polyethylene bags (or wrapped with polyethylene sheets and the seams taped with freezer tape) to protect the photographs from humidity peaks which occur when the refrigerator door is opened, after defrost cycles, or when boxes are removed and allowed to warm up. Heavy Duty Ziploc freezer bags, available from grocery stores, are particularly well suited for this application. Slides may be kept in original cardboard or plastic slide boxes as supplied by the processor, with the boxes placed in polyethylene bags. Packaging the photographs in polyethylene bags will also provide protection from water damage in the unlikely event an interior water leak occurs.

5. The refrigerator should not be too tightly packed with photographs. Space should be provided so that air can freely circulate between the shelves and in the area between the front of the shelves and the door. Particular care should be taken not to block the vent for fan-forced cold air, which is usually located just below the top of the refrigerator section. The air flow in the freezer section should also not be obstructed.

6. Avoid opening the refrigerator door more often than necessary.

7. Food and drinks should never be kept in a refrigerator or freezer used to store photographs.

8. In the event of a power failure of up to 48 hours (2 days) duration, do not open refrigerator door.

9. In the event of a power failure of longer than 48 hours, the unit should be unplugged and the door left open until power is restored.

10. Due to possible fire hazards associated with certain types of refrigerator malfunctions, cellulose nitrate film should not be stored in a frost-free refrigerator or freezer unless special precautions are taken.

during this process is collected in a drain pan under the cooling coils and runs through a plastic tube to an “evaporator” pan located near the compressor in the bottom of the refrigerator.

The temperature and relative humidity levels in the refrigerator section remain fairly constant during the defrost period, though there will be a humidity rise for about 15 minutes after the cooling compressor and fan resume operation. When materials are placed in a polyethylene bag (or wrapped with polyethylene sheets or freezer paper, with the seams taped with freezer tape) as suggested, the short rises in relative humidity will have no effect inside the packages. This author’s tests indicate that this short humidity peak in the refrigerator section is of such short duration that even a single thickness of paper wrapped around a box of slides will prevent more than a couple of percentage points of humidity rise inside the container. The temperature of the refrigerator rises somewhat immediately after the defrost cycle, but the interior temperature of the packages of photographs changes very little during this period.

One recently introduced type of Sears Roebuck frost-free side-by-side refrigerator/freezer (Sears Catalog No. 46 R 53781N) has an “adaptive” defrost system which is equipped with sensors that cause the unit to defrost only when an excessive amount of frost has accumulated on the freezer coils; this saves energy if the doors are opened infrequently or if the ambient relative humidity is low, and also results in more stable refrigerator and freezer temperatures. This model, which sold for $1,850 in 1993, is also equipped with electronic temperature indicators for the refrigerator and freezer compartments. The unit has indicator lights and audible alarms that signal if a door has been left open longer than 3 minutes, if the power fails, if the unit is not functioning properly, if the interior temperature rises above a certain limit, and if the temperature has been above a certain level for more than 4 hours. Although expensive, this refrigerator is this author’s primary recommendation for photographic storage applications.

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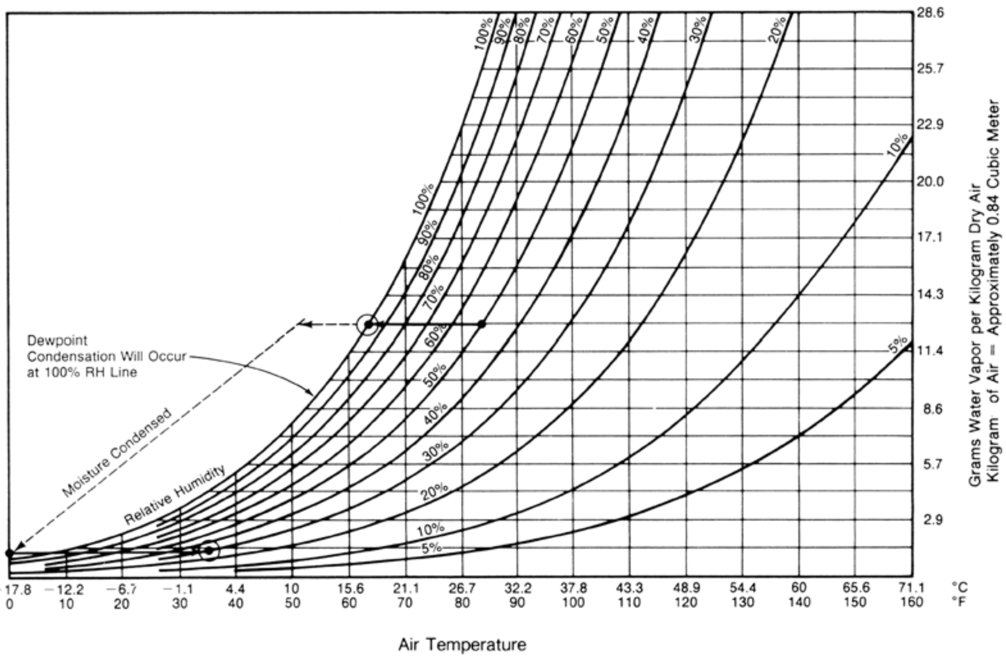
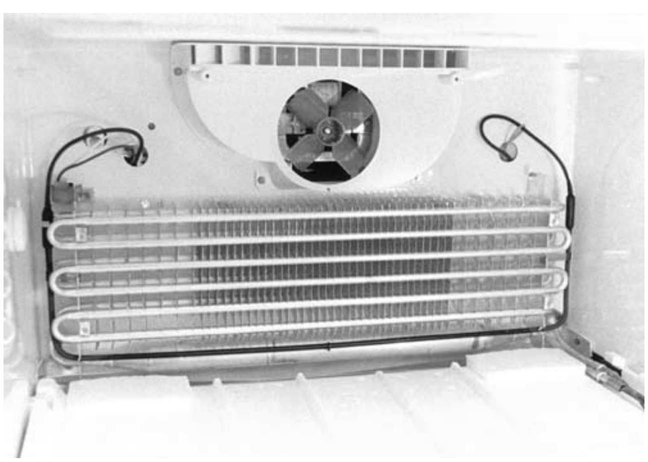


Figure 19.1 A psychrometric chart illustrates how a frost-free refrigerator maintains low relative humidity in the refrigerator compartment. Room-temperature air (e.g., 84°F at 60% RH) is chilled to below 0°F (–18°C) by cooling coils behind the back wall of the freezer compartment. Moisture condenses on the cold coils, and as the air warms up to about 35°F (1.7°C) in the refrigerator compartment, the relative humidity drops to around 30%.

Recommended Refrigerator Temperature

Sears frost-free refrigerators have a temperature control (usually called the "Cold Control") inside the refrigerator section which should initially be set to the middle position; the precise setting should be determined by placing a thermometer in the refrigerator and adjusting the control until a temperature of 35–40°F (1.7–4.4°C) is obtained. A second control found in most frost-free refrigerators regulates the temperature balance between the freezer section and the refrigerator section; it is usually called the "Usage Control." This control should normally be set in the middle, or "B," position. Frost-free refrigerators have only one thermostat, located in the refrigerator section, and the temperature in the refrigerator section determines the on/off periods of the refrigerator compressor. If the freezer temperature is not cold enough after the refrigerator-section temperature has been properly set, the "Usage Control" should be moved toward the "Heavier Freezer Usage," or "A," position. Changes in the setting of the "Usage Control" will not significantly alter the temperature of the refrigerator section, which is determined solely by the position of the "Cold Control."



1978

Cooling coils in the freezer compartment of a Sears Roebuck frost-free refrigerator (the back panel of the freezer section has been removed to show the cooling coils). The electric fan above the coils circulates air past the cold coils, through the freezer section, into the refrigerator compartment, and back to the cooling coils.

The refrigerator should be checked periodically over a period of several days to be sure the temperature setting is correct. To minimize the chance of water freezing inside the condensate drain tube and fittings (which would block the tube and eventually result in water dripping down the back *inside* wall of the refrigerator section during a defrost cycle and collecting in a pool at the bottom of the compartment), the temperature of the refrigerator section should be adjusted so that it remains *at or above* 35°F (1.7°C) at all times.

Cautions

Some basic points to keep in mind when storing photographs in a frost-free refrigerator are given in **Table 19.4**. Under no circumstances should food items be kept in a refrigerator in which photographs are stored. It is especially important that no foods such as ice cream be stored in the freezer section; in the event of a power failure, the ice cream would melt and might drip down through the contents of the refrigerator. Stored foods can give off a variety of chemicals which are potentially harmful to photographs; in addition, there is the very real danger of getting food, oils, etc. directly on storage boxes or photographs as they are removed from the polyethylene bags.

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Refrigerators and freezers should be operated in a well-ventilated room — never in a closet or other small enclosed room. Refrigerators, especially frost-free models, give off considerable heat from the compressor motor, the defrosting heater, and the anti-condensation heating wires built into the refrigerator walls near the door openings. Basements are generally not advised because of the possibility of flooding caused by rain, backed-up sewer lines, or broken water pipes. In addition, refrigerators should be in an area that is reasonably free of dust.

Storage of cellulose nitrate films in frost-free refrigerators is *not* recommended because, in the event of certain types of mechanical malfunctions, there is a potential fire hazard with this very flammable type of film. For discussion of long-term storage of cellulose nitrate film in explosion-proof freezers, see **Appendix 19.1** at the end of this chapter.

Testing the Refrigerator Is Necessary

The operating characteristics of any refrigerator destined for storing photographs must be known before photographs are placed in it. *This prior testing is absolutely necessary.* Designs of refrigerators are constantly changing, and frost-free refrigerators with the characteristics described here may not be available in the future. Also, a person may inadvertently purchase the wrong type of refrigerator. It is especially important that the levels of relative humidity in a refrigerator be checked from time to time during the summer months to be certain that excessive humidity levels do not develop. For instance, a manual-defrost refrigerator with no food in it may, for a time, have an acceptable level of relative humidity during the winter months in temperate climates because of the very low indoor humidity in most buildings when outdoor temperatures are low. But the relative humidity in this type of unit will rapidly rise to near 100% when warmer weather arrives, thus damaging or even destroying any photographs stored within.

At all times, an accurate hygrometer (humidity gauge) and thermometer[8] should be kept inside the refrigerator section and checked whenever the door is opened, keeping in mind that there will be a short period of high relative humidity after each defrost cycle. When purchasing a refrigerator, make certain it is a true frost-free model, with *both* the refrigerator and freezer sections guaranteed frost-free. Then check the hygrometer daily over a period of 2 or 3 weeks to make certain the unit continues to operate within satisfactory limits of relative humidity. The temperature control in the refrigerator section should be adjusted so that the temperature is in the range of 35–40°F (1.7–4.4°C) and does not drop below freezing.

Refrigerator Mechanical Failure

While this author believes that photographs packed as described above and stored in a refrigerator of the recommended type are subject to very little risk, there is always a possibility that an unnoticed equipment failure or some other circumstance could cause damage to photographs. With reasonable care, there is little chance of trouble. Storing especially unstable materials — such as Kodak Ektacolor 37 RC and 74 RC prints, Process E-3 Ektachrome transparencies, or Kodacolor II, Vericolor II, Fujicolor HR, pre-1986 Fujicolor Professional, Konica Color SR, and pre-1989 Agfacolor XR and XRS color negative films — at room temperature will assure that they will fade to an objectionable degree in a relatively short time; this certainty must be considered when assessing the remote dangers of proper refrigerated storage.

A conventional refrigerator or freezer is less prone to mechanical failure than a frost-free unit. This advantage, however, must be balanced against the possibility of improper sealing or puncture of the vapor-proof packaging which is required when storing photographs in a conventional refrigerator. The inconvenience of pre-conditioning photographs to a low relative humidity and then heat-sealing them in a vapor-proof envelope will discourage most people from even attempting to store photographs in a conventional, non-frost-free refrigerator or freezer.

In addition to compressor or thermostat failure, refrigerant leaks, and other cooling system problems, there are a number of other ways a frost-free refrigerator can malfunction. For example, the plastic drain tube for defrost water on some earlier models came with a rubber grommet on the end, apparently intended to prevent insects from crawling in and clogging the hose; however, it is possible for the grommet itself to clog and cause water to back up and leak inside the refrigerator (the water will slowly drip down the inside back wall of the refrigerator section and accumulate on the bottom under the vegetable drawers). The rubber drain grommet is usually accessible from the front of the refrigerator — it is located just above the removable evaporator pan at the bottom of the refrigerator. The grommet can be removed and cleaned once a year to minimize the chance of its becoming clogged. Sears Roebuck refrigerators apparently no longer have grommets on the drain tubes. As previously discussed, the water drain tube could freeze and become blocked if the temperature in the refrigerator section remains below freezing for a prolonged period. Enclosing packages of photographs in plastic bags will minimize danger in the unlikely event that a water leak does occur.

The defrost system can fail if the defrost cycle timer, interior fan, or defrost heater malfunction. The bimetal defrost thermostatic cut-off can also stick in the open position. Any of these failures can result in the cooling coils accumulating so much frost that the fan can no longer force air through them, and the refrigerator will start to warm up even though the compressor runs constantly.[9] A thermometer which can be read from outside the refrigerator will alert the user should this type of failure occur; a thermostat with an electronic alarm is best as it will immediately sound if the temperature rises above pre-set limits.[10] If the bimetal defrost cut-off sticks in the closed position, the freezer section may become warm during each defrost cycle (this is another reason why processed films and prints should not be stored in the freezer section), and, for a short time after the defrost cycle is completed, the refrigerator section will also become quite warm.

Refrigerators should be checked about once a week to make certain they are operating correctly. A hygrometer and thermometer placed inside will indicate at a glance whether the refrigerator is functioning properly.

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Refrigerators Should be Replaced With New Units After 10 Years

To minimize chances of mechanical difficulty, a new refrigerator should be purchased at the outset; used units should be avoided. While refrigerators can be expected to last many years before mechanical problems with the compressor and cooling system are likely to be encountered,[11] this author strongly recommends that refrigerators in which photographs are stored be replaced after 10 years of use (be sure to write the purchase date on the refrigerator with a felt-tip pen in some easily noticed location, such as on an inside wall near the door opening).

For maximum protection of very valuable photographs, they should be conditioned in a low relative humidity (about 25–40%) and carefully sealed in vapor-proof envelopes before placing them in the refrigerator.

Humidity-Protected Storage

Old-style refrigerators, which have to be manually defrosted from time to time, do of course maintain a low temperature, but the relative humidity in these units is generally between 90 and 100%. At this high relative humidity, films and prints will stick together, fungus will grow on the photograph emulsions and cardboard slide mounts, and there will be moisture-caused deterioration (hydrolysis) of the color image dyes.

Photographs stored unprotected in a high-humidity refrigerator will be destroyed in a short time.

If it is necessary to store photographs in a freezer or high-humidity manual-defrost or cycle-defrost refrigerator, the photographs must be sealed in a true vapor-proof container, such as a properly capped glass bottle or an aluminum-foil/plastic laminated envelope that can be heat sealed. Virtually all types of plastics will absorb and transmit water vapor over time and are thus *not suitable* for moisture protection of photographs in high-humidity cold storage.[12]

Although not strictly necessary, it is best to pre-condition films or prints in a low relative humidity environment (i.e., 25–40% RH) for several days prior to sealing them in a vapor-proof container. Rolls of motion picture film should be pre-conditioned for about 2 weeks.

The Museum of Fine Arts, Museum of New Mexico, located in Santa Fe, New Mexico, has installed a large upright Sears Roebuck Kenmore freezer for storage of Ektacolor prints. The freezer operates at about 0°F (–18°C) and because the relative humidity is uncontrolled, the prints are pre-conditioned to a low relative humidity and then packaged in vapor-proof envelopes before placing them in the freezer. Under the direction of Steve Yates, curator of photography, the Museum obtained the freezer in 1984, initially to house approximately 100 Ektacolor prints from the New Mexico Survey Project commissioned by the Museum. Yates says that providing cold storage is "doing something for the arts and for the artists — instead of hitting them over the head with the stability problems of Ektacolor prints."[13] The museum also has Cibachrome (Ilfochrome), Dye Transfer, and Polacolor prints in its collection; these are stored at room temperature along with black-and-white prints.

Vapor-proof envelopes made of an aluminum-foil/polyethylene laminate that can be sealed with a commercial heat-sealing unit or a household electric iron at a temperature between 250–300°F (120–150°C) are available from Light Impressions Corporation, Conservation Resources International, Inc., and several other suppliers.[14] These envelopes are similar to those in which sheet films are packed at the factory.

For a number of years Kodak supplied vapor-proof Storage Envelopes for Processed Film in 4x5- and 8x10-inch sizes; apparently because of lack of demand, Kodak discontinued the envelopes in 1987.

To minimize the chance of damage caused by an improper seal or puncture of vapor-proof envelopes, the films and prints should be sealed in an envelope and the edges of this envelope folded in so that it can be placed in a second envelope which is then sealed (for further discussion of vapor-proof envelopes and the pros and cons of pre-conditioning photographs to a low relative humidity, see Chapter 20).

In general, this author advises against using any high-humidity cold storage unit for storing valuable photographs, even if they are hermetically sealed in vapor-proof containers. There is the constant risk of improper seals, punctures, or the containers' failing for other reasons. Envelopes may be punctured in handling, causing small tears or pinholes which are not readily visible.

Even if metal cans containing motion pictures are taped shut, adhesive tapes generally give poor long-term protection against vapor transmission. With film cans there is the risk that a particular can may not be properly taped, or that the can will rust during long-term storage.

Any system that requires vapor-proof containers will reduce accessibility to the photographs, increase costs, and probably require trained personnel to pre-condition and properly seal the film containers. There will always be the possibility that a container will fail because of a manufacturing fault, improper sealing, or damage in handling, thus destroying photographs which can never be replaced.

A final objection to refrigerated storage with uncontrolled humidity is that the containers may — depending on the design of the particular refrigerator or freezer — actually become wet with condensed moisture or covered with ice if the temperature is below freezing. This can create a very messy situation and make identification of the containers difficult. At temperatures above freezing, mold and slime may form on the containers in non-frost-free refrigerators.

Conclusion

Most photographers and conservators will find that storing color photographic materials in a frost-free refrigerator offers the only simple and low-cost method of safely preventing fading and staining of valuable color photographs. The procedures outlined in this chapter will virtually eliminate chances of accidental damage to the photographs.

Without refrigerated storage at low relative humidities, most color photographs will gradually fade and/or stain. Depending on the particular type of color film or print, image deterioration may become objectionable after only a few years of storage under normal conditions.

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Notes and References

1. See, for example: **ANSI IT9.11-1991, American National Standard for Imaging Media – Processed Safety Photographic Film – Storage**, American National Standards Institute, Inc., 11 West 42nd Street, New York, New York 10036; telephone: 212-642-4900.
2. Peter Galassi, Museum of Modern Art, New York City, telephone discussions with this author, March 9 and August 20, 1984. See also: Gene Thornton, "The Modern Still Favors the Documentary," **The New York Times**, August 19, 1984.
3. John P. Myers, Robert F. Cardillo, and Martine A. Culbertson, "VIREO – Visual Resources for Ornithology," **American Birds**, Vol. 38, No. 3, May–June 1984, pp. 267–277. See also: John P. Myers, Robert F. Cardillo, and Martine A. Culbertson, **Visual Resources for Ornithology – VIREO – Annual Report 1983**, (1984), Academy of Natural Sciences of Philadelphia, Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103; telephone: 215-299-1069; R. W. Norris and E. S. Preisendanz, **Color Transparency Archival Storage**, report prepared by the Engineering Service Division, E. I. du Pont de Nemours & Company, Inc., Engineering Department, Wilmington, Delaware, May 7, 1982; and Norman Schrieber, "Pop Photo Snapshots," section entitled "Bird Tracks," **Popular Photography**, Vol. 19, No. 2, February 1984, pp. 35–36.
4. Ziploc polyethylene bags are made by Dow Brands, Inc., P.O. Box 68511, Indianapolis, Indiana 46268; telephone: 317-873-7000. Ziploc Heavy Duty freezer bags, made of 2.7 mil polyethylene and available in one-quart, one-gallon, and larger sizes, are better suited for storing photographs than the lighter-weight general-use Ziploc bags. Ziploc bags have a waterproof seal along the top edge which is closed by squeezing the bag between the thumb and forefinger as the fingers are run across the top. The bags can be opened and closed repeatedly without losing the integrity of the seal. Larger bags of similar design (Lock-Top Media Bags) can be purchased from: The Highsmith Company, Inc., P.O. Box 800, Highway 106 East, Ft. Atkinson, Wisconsin 53538; telephone; 414-563-9571; toll-free: 800-558-2110. Bags of similar design (Easy-Zip Bags) in a wide variety of sizes up to 14x24 inches, and custom-made bags in any size, are available from Chiswick Trading, Inc., 33 Union Avenue, P.O. Box G, Sudbury, Massachusetts 01776-0907; telephone: 508-443-9592; toll-free in Massachusetts: 800-322-7222; toll-free outside Massachusetts: 800-225-8708. Chiswick requires a minimum order of 1,000 bags in small sizes and 500 bags in larger sizes. Bags of this type (Resealable Polyethylene Bags) are also available from Conservation Materials, Ltd., 1165 Marietta Way, Box 2884, Sparks, Nevada 89431; telephone: 702-331-0582.
5. The Light Impressions Slide-File Box (Code No. 5015)is 2⅜"Hx 2⅛"W x11"D and is made of lignin-free, alkaline-buffered cardboard with metal corners ($3.05 singly or $2.45 each in quantities of 10 or more). Each box can accommodate about 200 cardboard-mounted slides and is excellent for high-density packaging of slides for refrigerator storage or for general, non-refrigerated storage. The boxes are supplied by Light Impressions Corporation, 439 Monroe Avenue, P.O. Box 940, Rochester, New York 14607-0940; telephone: 716-271-8960 (toll-free: 800-828-6216).

   Six of the Slide-File boxes will fit inside a Light Impressions Corporation Drop-Front Box, 1½"Hx11"Wx14"D, Code No. 5012 ($6.85 singly or $5.50 each in quantities of 10 or more). The Light Impressions Code No. 5012 box, a shallow drop-front box, is only barely high enough to accommodate the slide boxes; however, the "standard" Light Impressions 11x14-inch Drop-Front Box (Code No. 2021) is too tall and wastes valuable refrigerator space. Also available from Light Impressions Corporation is the Slide Stack Box (Code No. 3211). Made of yellow polypropylene with a tight-fitting lid, and 2⅝x2⅛x2⅛" in size, each box accommodates up to 50 slides; a package of 6 boxes costs $6.95.

   Another cardboard box that is suitable for storing slides in a refrigerator is the Lig-free Type II Archival Slide Storage Box (#35ST) available from Conservation Resources International, Inc., 8000-H Forbes Place, Springfield, Virginia 22151; telephone: 703-321-7730 (toll-free: 800-634-6932). The boxes cost about $5 each in quantities of 5, or $4 each in quantities of 10 or more (shipping additional). Each box has a capacity of 360 slides and is 18x2⅝x2⅝" in size. Also available is a large Master Unit consisting of six #35ST slide boxes inside a drop-front cardboard box 17x19x2¾" in size; a Master Unit (#35MU) has a capacity of about 2,190 slides and costs $34.50. Boxes of similar design are also available for mounted 120 roll film transparencies. The interior of these boxes is made of nonbuffered, lignin-free cardboard. Each box (or Master Unit) should be sealed in a polyethylene bag — or wrapped with a sheet of polyethylene and the seams taped with masking tape or freezer tape — before placing in a frost-free refrigerator. Upon removal from the refrigerator, the box should be allowed to warm up for about 3 hours before taking it out of the bag. These boxes are, of course, also suitable for storing slides in normal room-temperature conditions.

   Very good low-cost polypropylene plastic boxes suitable for slide storage are manufactured by Flambeau Products Corporation, 15981 Valplast Road, P.O. Box 97, Middlefield, Ohio 44062; telephone: 216-632-1631. Box No. M-812, recommended for slides, has 12 interior compartments, each holding about 65 slides (about 800 in total). The box, which has a hinged lid and is made of yellow polypropylene, is 2½"x13"x9" in size. Flambeau requires a minimum purchase of $200 when ordering directly from the company; No. M-812 boxes cost only $3.24 each (5 boxes to a carton) when purchased direct. These boxes also should be sealed in a polyethylene bag prior to placing them in a frost-free refrigerator.
6. Henry Wilhelm, "Storing Color Materials – Frost-Free Refrigerators Offer a Low-Cost Solution," **Industrial Photography**, Vol. 27, No. 10, October 1978, pp. 32ff. The article was based on a presentation by the author on the use of frost-free refrigerators for storing color photographs given at **The Permanence of Color – Technology's Challenge, The Photographer's and Collector's Dilemma**, a conference held at the International Center of Photography, New York City, May 7, 1978.

   The author first became aware of the low-humidity operating characteristics of frost-free refrigerators when — during a visit to his mother's home in Leesburg, Virginia in 1975 — he observed that an uncovered cake kept in a Kenmore frost-free refrigerator had become partially dehydrated after less than 2 days of storage (this was contrary to all of the author's previous experience with household refrigerators).

   In **Conservation of Photographs**, Kodak Publication No. F-40, Eastman Kodak Company, Rochester, New York, March 1985, use of frost-free refrigerators is recommended. The discussion of frost-free refrigerators for storing photographs (p. 103) is in part taken from this author's 1978 **Industrial Photography** article. Kodak concluded this section by noting that, "The details of unit design and of storage of photographic materials are quite extensive and important. Further information can be obtained from literature on the subject. The custodian should be familiar with these procedures before purchasing or using a frost-free refrigerator or freezer." No literature citations were given, however.
7. Suitable frost-free refrigerators, parts, and service are available from Sears Roebuck and Company, P.O. Box 1530, Downers Grove, Illinois 60515-5721, and the more than 3,000 Sears retail stores throughout North America; telephone: 316-652-7584 (toll-free: 800-366-3000). The following Sears Kenmore low-humidity frost-free refrigerators, suitable for the storage of photographs, were among those listed in the Sears 1993 Annual catalog, which can be ordered from until January 31, 1994 (for advice on suitable models after that date, consult Preservation Publishing Company, P.O. Box 567, Grinnell, Iowa 50112-0567; telephone: 515-236-5575; Fax: 515-236-7052). Prices listed below remain in effect until January 31, 1994:

   – No. 46 R 63041N (7.5-cu.-ft. refrigerator section
   – size: 59"Hx24"Wx28"D). . . . .$470.

   – No. 46 R 63421N (10.6-cu.-ft. refrigerator section
   – size: 61"Hx28"Wx30"D). . . . .$530.

   – No. 46 R 63831N (13.3-cu.-ft. refrigerator section
   – size: 67"Hx30"Wx31"D). . . . . $580.

   – No. 46 R 63651N (11.7-cu.-ft. refrigerator section
   – size: 64"Hx28"Wx30"D). . . . . $600.

   – No. 46 R 63851N (13.1-cu.-ft. refrigerator section
   – size: 64"Hx30"Wx32"D). . . . . $630.

   – No. 46 R 63861N (13.3-cu.-ft. refrigerator section
   – size: 67"Hx30"Wx31"D). . . . . $670.

   – No. 46 R 63031N (14.4-cu.-ft. refrigerator section
   – size: 67"Hx33"Wx31"D). . . . . $680.

   – No. 46 R 63061N (14.4-cu.-ft. refrigerator section
   – size: 67"Hx33"Wx31"D). . . . . $730.

   – No. 46 R 63171N (14.3-cu.-ft. refrigerator section
   – size: 67"Hx32"Wx32"D). . . . . $780.

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– No. 46 R 63471N (16.4-cu.-ft. refrigerator section
– size: 67"Hx35"Wx32"D). . . . .$900.
(The above unit is the best buy, in this author's opinion.)

– No. 46 R 63271N (15.0-cu.-ft. refrigerator section
– size: 67"Hx32"Wx33"D). . . . .$930.

– No. 46 R 63571N (17.1-cu.-ft. refrigerator section
– size: 67"Hx35"Wx33"D). . . . .$1,050.

The best (and most expensive) Sears Kenmore side-by-side refrigerator is:
– No. 46 R 53781N (16.6-cu.-ft. refrigerator section
– size: 69"Hx36"Wx34"D). . . . .$1,850.

This unique refrigerator is equipped with external temperature indicators for the refrigerator and freezer compartments. The unit has indicator lights and audible alarms which signal when the door has been left open for longer than 3 minutes; when the interior temperature has risen above acceptable levels; if the unit has been above an acceptable temperature for longer than 4 hours; or if there has been an interruption in electrical power.

Other acceptable Sears Kenmore side-by-side models include:
– No. 46 R 43021N (13.3-cu.-ft. refrigerator section
– size: 66"Hx33"Wx31"D). . . . . $780.

– No. 46 R 43041N (13.3-cu.-ft. refrigerator section
– size: 66"Hx33"Wx32"D). . . . . $830.

– No. 46 R 53071N (12.8-cu.-ft. refrigerator section
– size: 67"Hx32"Wx33"D). . . . . $1,100.

– No. 46 R 53281N (14.5-cu.-ft. refrigerator section
– size: 66"Hx33"Wx34"D). . . . . $1,200.

– No. 46 R 53271N (14.9-cu.-ft. refrigerator section
– size: 67"Hx34"Wx33"D). . . . . $1,300.

– No. 46 R 53471N (14.9-cu.-ft. refrigerator section
– size: 67"Hx36"Wx33"D). . . . . $1,400.

– No. 46 R 53771N (16.6-cu.-ft. refrigerator section
– size: 69"Hx36"Wx34"D). . . . . $1,600.

Most Kenmore refrigerators are equipped with a "Power Miser" switch for shutting off wall heaters located inside the refrigerator walls near the door openings during periods of the year when the ambient relative humidity is low; the heaters prevent moisture from condensing on the somewhat cooled exterior surfaces near the doors of the refrigerator during periods of high relative humidity. The heaters are not necessary in temperate climates during the winter when the indoor relative humidity is generally low. The "Power Miser" switch has no influence on conditions inside the refrigerator.

Most of the refrigerators sold by Sears Roebuck during recent years have been manufactured by the Whirlpool Corporation of Benton Harbor, Michigan. Whirlpool also sells refrigerators under its own name; with the exception of interior and exterior trim, most are essentially identical to the refrigerators sold by Sears Roebuck. Reportedly, Whirlpool sells far more refrigerators to Sears than it markets under its own name (in the 5-year period from 1981 to 1986, Sears Roebuck sold more than 5 million refrigerators).

8. Suitable dial hygrometers (relative humidity gauges) are available from Abbeon Cal, Inc., 123 Gray Avenue, Santa Barbara, California 93101; telephone: 805-966-0810; toll-free: 800-922-0977. Model No. HTAB-176 (with built-in thermometer), $131.64 including shipping; and No. AB-167 (similar to HTAB-169, but without built-in thermometer), $113.87 including shipping. In spite of the manufacturer's claims about the accuracy of these and other hygrometers, they should be carefully calibrated by the user, especially before they are put into service for the first time following purchase — see Chapter 16 for instructions on how to calibrate a hygrometer.
9. Sears Roebuck and Company, Sears Coldspot and Kenmore Refrigerators Service Manual, Sears Roebuck and Company, Chicago, Illinois, 1977.
10. A suitable electronic temperature indicator, with two remote sensors, digital readouts and alarm functions, is the Computemp5, available from Rodco Products Company, Inc., 2565 16th Avenue, P.O. Box 944, Columbus, Nebraska 68601; telephone: 402-563-3596. Price for the unit is approximately $90. The Computemp5 is also available from Abbeon Cal, Inc. (see Note No. 8). Other electronic temperature indicators and alarms available from Abbeon Cal, Inc. include: the Protecto Freeze battery-powered temperature alarm which sounds if the temperature should exceed 25°F (–3.9°C), $36.95; Adjustable Temperature Alarm and Display, Model Q, $158; Adjustable Freezer/Cooler Alarm, Model 200, $87; Model 210, with 100-hour timer to show how long a refrigerator has been off, $100. The sensors of these units can be placed in a small cardboard box (to prevent them from responding during the temporary temperature elevations which occur during each defrost cycle) in the freezer section of a frost-free refrigerator to indicate defrost system or other mechanical malfunction which will lead to overheating inside the refrigerator. Also useful is a product called Flood Alert, available for $20.95 from Abbeon Cal, Inc., which sounds an alarm if water should come into contact with the sensor.
11. Roger B. Yepsen, Jr., **The Durability Factor**, Rodale Press, Emmaus, Pennsylvania, 1982.
12. **Modern Plastics Encyclopedia**, 1984/1985, Vol. 61, No. 10A, McGraw-Hill Company, New York, New York, 1984. See also: **The 1984 Packaging Encyclopedia**, Vol. 29, No. 4, Cahners Publishing Company, Boston, Massachusetts, 1984.
13. Steve Yates, Museum of Fine Arts, Museum of New Mexico, telephone discussion with this author, September 12, 1984.
14. Heat-sealable vapor-proof envelopes called Light Impressions Heat Seal Envelopes are available from Light Impressions Corporation, 439 Monroe Avenue, P.O. Box 940, Rochester, New York 14607-0940; telephone: 716-271-8960 (toll-free: 800-828-6216). Two standard sizes are supplied: Code No. 3920 (4¾x6½-inches; $6.30 for a package of 25) and Code No. 3921 (12x15-inches; $13.25 for a package of 25).

Similar envelopes called Containers for Freezing Photographic Material are available in the 10x12-inch size (minimum order of 500 envelopes) and larger custom-made sizes from Conservation Resources International, Inc., 8000-H Forbes Place, Springfield, Virginia 22151; telephone: 703-321-7730 (toll-free: 800-634-6932). These envelopes are true vapor-proof, heat-sealable, aluminum-foil/polyethylene laminated containers that can provide added security in a frost-free refrigerator, or be used in a double-layer package in a non-humidity-controlled refrigerator or freezer.

Custom-made heavy-duty, heat-sealable vapor-proof envelopes in any size or configuration are available under the XT-08 name (large-quantity orders only) from Quality Packaging Supply Corporation, 24 Seneca Avenue, Rochester, New York 14621; telephone: 716-544-2500 (California office: 3028 East 11th Street, Los Angeles, California; telephone: 213-264-1102).

Custom-made heat-sealable vapor-proof envelopes for films and prints in any size are also available (large-quantity orders only) from Shield Pack, Inc., 2301 Downing Pines Road, West Monroe, Louisiana 71291; telephone: 318-387-4743 (toll-free: 800-551-5185).

Eastman Kodak has given two sources for laminated aluminum-foil/polyethylene material suitable to make vapor-proof storage envelopes: Crown Zellerbach, Flexible Packaging Division, Park 80 Plaza – West I, Saddlebrook, New Jersey 07662; and Northern Packaging Corp., 777 Driving Park Avenue, Rochester, New York 14613. This laminated material can be used to make custom-size envelopes for storage, or for wrapping boxes of films or prints before placing them in a refrigerator. Packages should be wrapped with overlapping seams and taped to completely cover the seams with, for example, 3M Scotch No. 600 Transparent Tape, available at most office supply stores.

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Appendix 19.1 – Freezer Storage for Permanent Preservation of Cellulose Nitrate Still-Camera Negatives and Motion Pictures

Because cellulose nitrate film is highly flammable, it should not be stored in a conventional refrigerator or freezer. It is conceivable that an electrical or mechanical malfunction could, under certain circumstances, cause the film to ignite — with potentially catastrophic results not only to the stored film but also to other, nearby photographs and to the building in which the refrigerator or freezer is located. Frost-free refrigerators are, however, suitable for storage of cellulose diacetate black-and-white negatives as well as other types of early and modern "safety" film. For a comprehensive study of the deterioration of early cellulose acetate safety film — some of which in storage has proven to be less stable than cellulose nitrate film — refer to the 1987 publication, *The Acetate Negative Survey: Final Report*, by David G. Horvath.[1]

There is no doubt that storage of cellulose nitrate film at low temperatures will greatly prolong its life, and special "explosion-proof" freezers, in which nitrate film can be kept safely, are being manufactured.

If cold storage facilities are not available, the film should be kept as cool and in as low relative humidity as possible. Nitrate film should be segregated from safety film and kept in separate files — or better yet, in a separate room — as decomposition products from the film can over time seriously harm safety film images, gelatin, and acetate supports.[2]

Even if it appears to be in good condition, nitrate film should not ordinarily be re-washed or otherwise moistened with water because the emulsion may become soft or actually dissolve because of the effects of base decomposition.

Nitrate still-camera negatives should be stored in alkaline-buffered paper envelopes (it is believed that the alkaline buffering will, for a time at least, retard the action of evolved gases from the film on the envelope paper); in room-temperature storage, plastic envelopes and sleeves should be avoided since they restrict the escape of fumes which slowly evolve from the film.

Low-temperature storage in explosion-proof freezers will be discussed later, but first it will be helpful to provide some background on the history and problems of cellulose nitrate films.

Cellulose Nitrate Film Base

Cellulose nitrate was the support material for the first commercial transparent roll film; it was perfected by George Eastman and his research chemist Henry M. Reichenbach and was first marketed in 1889. Cellulose nitrate roll film was first invented by the Rev. Hannibal Goodwin, who applied for a patent on the film in 1887; however, Goodwin's patent was not granted until 1898. Reichenbach applied for a patent in 1889 and received it shortly thereafter. Goodwin sold his patent to Anthony and Scovill (which later became Ansco, and later still was known as GAF). After a long patent-infringement suit, Goodwin's patent was upheld in 1914, and Eastman paid Ansco 5 million dollars in settlement. Although 5 million dollars was a great deal of money in the early 1900's, the final outcome was nevertheless very much to Kodak's advantage because by the time the matter was settled, Eastman Kodak dominated the worldwide market for flexible roll film and motion picture film.

Flexible film base made possible the development of Thomas Edison's motion picture camera and projector in 1891, and the first commercial cellulose nitrate motion picture film became available in 1895.

In the U.S., most roll films (e.g., 620 and 616 films) and film packs were made of cellulose nitrate until about 1950; professional 35mm motion picture films in the U.S. continued to use this support until 1951 (manufacture of cellulose nitrate still negative and motion picture films continued in some countries until the mid-1950's). Some photographers made 35mm still-camera pictures on spooled motion picture films, and examples of 35mm still-camera negatives made as late as the mid-1950's on cellulose nitrate film base can be found occasionally.

Cellulose nitrate, also known as nitrocellulose, is a pyroxylin plastic. It is made by treating cotton or wood fiber cellulose with a mixture of nitric and sulfuric acid; it is then further processed by adding solvents, camphor as a plasticizer, and other compounds, forming a viscous solution which is then "solvent-casted" on a polished metal drum or other smooth surface. A thin sheet of cellulose nitrate film base remains after the solvents evaporate.

Cellulose nitrate is highly flammable and it was long believed that nitrate films had intrinsically poor long-term storage stability compared with cellulose ester "safety-base" films (e.g., cellulose diacetate, cellulose acetate butyrate, cellulose acetate propionate, and cellulose triacetate). In spite of the poor reputation nitrate film has had insofar as its keeping properties are concerned, there are large quantities of nitrate film that are still in excellent condition after more than 50 years of storage, and many nitrate still-camera negatives remain in better condition than cellulose diacetate and other types of safety-base films from the same period. In fact, under normal storage conditions, nitrate film is considerably more stable than the dye images of many types of color films that have been manufactured during the last 30 years.

When new, nitrate film has good strength and handling characteristics; and this, combined with the difficulty of producing a slow-burning "safety" film equal to nitrate film in physical characteristics, kept nitrate film in use long after the fire hazards of this film base had been clearly recognized.

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Burr Lewis – © 1978 Times-Union

Stored without air conditioning, humidity control, or an alarm system in an abandoned incinerator building on the grounds of the International Museum of Photography at George Eastman House in Rochester, New York, this large store of cellulose nitrate motion picture films ignited on a hot day in May 1978. Original negatives from 329 motion pictures, some of them classics from the early days of the Hollywood motion picture industry, were destroyed in the fire.

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Identification of Cellulose Nitrate Film

Until recently, Kodak acetate and polyester safety-base black-and-white films had almost always been edge-printed with the word "Safety," although a particular negative cut from a roll may not include the marking. Non-nitrate films made by other manufacturers may or may not include "Safety" in the edge markings. "Safety" means that the film is not highly combustible; that is, under typical conditions it burns no more readily than ordinary paper when ignited. Nitrate film from the 1930's through the 1950's was generally edge-printed with the word "Nitrate"; early nitrate film usually was not identified as to its composition. The dates of last manufacture of Kodak nitrate films in various formats are given in **Table 19.5**.

If an older film has neither "Nitrate" nor "Safety" markings, it should be assumed to be nitrate until proven otherwise. In recent years, however, the word "Safety" has been dropped from many color films; it no longer appears on most Kodak color negative films. The "Kodak Safety Film" imprint on all Kodak color transparency and color negative films was changed to "Kodak" beginning in September 1982. "Safety Film" also is not included in the edge markings of some current black-and-white films.

A simple test to distinguish nitrate film from safety film is to place a small fragment (a piece about ⅛ inch in diameter can be cut from the film with an ordinary paper punch) in a test tube containing trichloroethylene and shake the tube to thoroughly wet the sample. If the sample sinks, it is cellulose nitrate. If it floats, it is an acetate or polyester safety film.[3] Tests also are available to indicate whether the film is nearing the end of its useful life.[4]

Since some photographers keep film and paper in storage even years after purchase, nitrate film continued to have limited use for some time after production of the material ceased. Throughout the 1940's and 1950's, it was a common practice for photographers to load 35mm film cassettes with low-cost nitrate motion picture film; so even though Kodak discontinued sale of packaged 35mm nitrate roll films in 1938, some nitrate film continued to be used for 35mm still-camera negatives until the early 1950's. Also, the manufacture of nitrate film in Europe and Asia continued for some years after Kodak ended nitrate production in the U.S.

Table 19.5 Dates of Last Cellulose Nitrate Films Manufactured by Eastman Kodak Company in the United States

Type of Film	Date
X-ray film	1933
35mm roll film for still camera	1938
Portrait and commercial sheet film	1939
Aerial film	1942
Film pack	1949
Roll film in sizes 616, 620, 828, etc.	1950
35mm motion picture film	1951

Source: John M. Calhoun, "Storage of Nitrate Amateur Still-Camera Film Negatives," **Journal of the Biological Photographic Association**, Vol. 21, No. 3, August 1953, p. 2.

Fire Hazards of Nitrate Film

With reasonable precautions, storage of relatively small quantities of cellulose nitrate still-camera negatives packaged in individual paper envelopes does not present a significant fire hazard. The reputation of nitrate film as being extremely dangerous — even explosive — came about because of a series of major fires involving motion picture film and dating back to near the beginning of the motion picture business. The one major fire involving sheet film of which this author is aware occurred in May 1929, when between 6 and 8 thousand pounds of cellulose nitrate X-ray film stored in the basement of the Cleveland Clinic in Cleveland, Ohio caught fire; the heat and toxic fumes produced by the blaze resulted in the deaths of 124 people. Following the disaster, safety requirements for storing nitrate film were made much more strict, and, 4 years after the fire, Kodak converted its manufacture of X-ray film to safety-base materials.

New nitrate film ignites at a temperature of about 266°F (130°C); it contains its own oxidant, so once large quantities of film start to burn, it is difficult to extinguish. As the film begins to decompose with age, the ignition temperature lowers. In the later stages, the decomposition of the film is an exothermic reaction, and if large quantities of the film are present in one location — as might be the case with tightly packed reels of motion picture film — the generated heat will speed decomposition, thus producing even more heat. Under these conditions, it is possible for nitrate film to spontaneously ignite when storage temperatures are greater than about 100°F (38°C) for a prolonged period of time.[5] With proper temperature- and humidity-controlled storage, spontaneous combustion cannot occur.

In the last 15 years, major losses of nitrate motion pictures have occurred from fires in the United States, France, and Mexico. A nitrate motion picture film fire, believed to have started as a result of spontaneous combustion, occurred at the International Museum of Photography at George Eastman House in Rochester, New York on May 29, 1978. Original negatives from 329 motion pictures, including such classics as *Strike Up the Band* starring Mickey Rooney and Judy Garland, were destroyed in the blaze. The film was stored under totally inadequate conditions on the Eastman House grounds in — ironically — an abandoned incinerator which was without air-conditioning or dehumidification equipment and which had no alarms or sprinkler system. The fire started on a hot afternoon after a series of very warm days in Rochester. Losses were estimated to be in excess of one million dollars.[6] In December 1978 there was a large nitrate fire at the U.S. National Archives storage facility outside of Washington, D.C. in Suitland, Maryland in which an estimated 15 million feet of mostly irreplaceable motion picture film was destroyed. This fire started from undetermined causes; it is not believed that spontaneous combustion was a factor.

Persons responsible for keeping large quantities of nitrate film should read the available literature on storage of this material.[7] Particularly useful are *Nitrate Film Testing for the National Archives*, a report prepared by the National Archives and the Naval Ordnance Station of the Department of the Navy following the 1978 Suitland fire,[8] and *Storage and Preservation of Motion Picture Film*, published in 1957 by Eastman Kodak Company.[9]

Aging Behavior of Nitrate Film

Because of factors not fully understood but likely involving certain aspects of how the film was originally manufactured, some nitrate film appears to have a significantly longer useful life than other nitrate film stored under the same conditions. The temperature and humidity conditions to which any nitrate film has been subjected during its storage history are very important factors in determining its life. Film that has remained in good condition for a great many years in normal storage conditions may in the course of only a year's time suffer significant deterioration. Nitrate collections should be inspected on a regular basis to identify and remove any films that are beginning to visibly deteriorate. John M. Calhoun of Eastman Kodak has described five distinct stages in the decomposition of cellulose nitrate films:[10]

1. Amber discoloration of the film occurs with fading of the picture image.
2. The emulsion becomes adhesive and the films tend to stick together.
3. The film contains gas bubbles and emits a noxious odor.
4. The film becomes soft, welded to adjacent film and frequently covered with a viscous froth.
5. The film mass degenerates partially or entirely into a brownish acrid powder.

Nitrate film that has reached the second or third stage of decomposition is usually very brittle and must be handled with care. According to Calhoun:

> This type of film brittleness is permanent and severe in contrast to the temporary de-

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> crease in flexibility which occurs when film is kept at very low relative humidities. The odor mentioned under the third stage is very characteristic of decomposing cellulose nitrate or nitric acid and once known is easily recognized. It is less pronounced but still noticeable in the second stage of decomposition.

Nitrate negatives in the first or second stage — and even many in the third stage — of deterioration can be photographically duplicated.[11] Using a rather time-consuming process, it is possible to remove the emulsion from a deteriorating cellulose nitrate (or acetate) negative and transfer it to a new, stable support; a workable method has been described by Vilia Reed of Eastman Kodak.[12] A negative should be duplicated before any attempt is made to transfer the emulsion. Emulsion transfer is particularly desirable for deteriorating negatives that have significant artifact value (e.g., negatives made by well-known photographers or negatives of historical importance).

As nitrate film decomposes, nitrogen oxides are produced; nitrogen dioxide, together with nitric acid produced by the combination of nitrogen dioxide with moisture from the air, attacks the silver image, gelatin, and film base. Nitrate still-camera negatives should be stored so that there is reasonable air circulation between sheets to slow deterioration; that is, the film should not be stored in sealed containers. As explained by Calhoun:

> The decomposition of cellulose nitrate is autocatalytic, the evolved gases acting as catalysts to accelerate further decomposition. This means that as the decomposition proceeds the reaction goes faster and faster unless these gases are allowed to escape. This is a very important factor in film storage because it means that the life of nitrate negatives depends on the ready escape of these fumes. This is one of the reasons why the thicker sheet film negatives are more likely to decompose than roll film or film pack negatives. It also explains why a quantity of film in close contact with itself, as in a roll of motion picture film or a stack of non-interleaved negatives, is more apt to decompose than individual films stored in envelopes where the nitrogen oxides have a better chance to escape to the air.[13]

New Research Shows That Nitrate Film Is More Stable, and Modern Cellulose Triacetate Film Is Less Stable, Than Previously Believed

Because in the past most people believed that cellulose nitrate film was inherently unstable and had only a short life — and because of worry about the fire hazards associated with the film — it has often been advised that all nitrate films be duplicated and the originals disposed of. The recommendation was based on two assumptions, the first being that nothing could be done to significantly extend the life of nitrate film, and the second being that modern triacetate safety film was essentially permanent. Research published in 1991 and 1992 by Peter Z. Adelstein, James M. Reilly, Douglas W. Nishimura, and C. J. Erbland at the Image Permanence Institute (IPI) at the Rochester Institute of Technology has shown than neither of these assumptions is necessarily valid:[14]

> The chemical stability of different cellulose ester base films is generally quite similar.
>
> . . . there is no evidence to suggest that diacetate, triacetate or mixed esters have *inherently* different stabilities because of their chemical differences. The often-repeated statement that the obsolete diacetate films are less stable than more recent films is not supported by this study.
>
> . . . it has been established that cellulose nitrate film in storage will not necessarily degrade faster than other cellulose ester base films.
>
> The superior chemical stability of polyester base films supports the conclusions of earlier studies.[15]

In a finding of major importance, Adelstein, Reilly, Nishimura, and Erbland's film base aging studies led them to conclude that under *common* storage conditions, the life of modern cellulose triacetate base film can be significantly shorter than previously thought.

The Profound Influence of Storage Temperature on the Life of Nitrate Film

Based on data from Arrhenius accelerated aging studies with a large number of cellulose triacetate and cellulose nitrate film samples, Adelstein and his co-workers reported that every 10°F decrease in storage temperature will increase film life by a factor of approximately two. This research marked the first major application of the multi-temperature Arrhenius test method to cellulose nitrate film. In the past, most testing of nitrate film was done at a single, very high temperature (commonly 212°F [100°C]) under either dry conditions or at 50% RH. When subjected to this type of harsh, short-term incubation test, nitrate film does indeed appear to be less stable than cellulose acetate film.

Adelstein and his co-workers also showed that the rate of film base decomposition is influenced by moisture content, and lowering the ambient relative humidity from 60% to 40% RH should more than double the life of the film. The benefits of low-temperature and low-humidity storage were found to be additive. For long-term storage of all types of film, 20–30% RH is recommended.

In 1991, as a result of these studies, the American National Standards Institute, Inc. (ANSI) standards pertaining to photography adopted a maximum life expectancy rating (LE rating) of 100 years for cellulose triacetate film. For polyester-base films, a maximum LE rating of 500 years was adopted. (The long-standing "archival" designation for acetate and polyester-base films is being phased out of ANSI photographic standards in favor of specific LE ratings for different types of film, and for processing and storage conditions.)

The findings of Adelstein and his co-workers are in striking agreement with estimates of temperature dependence of

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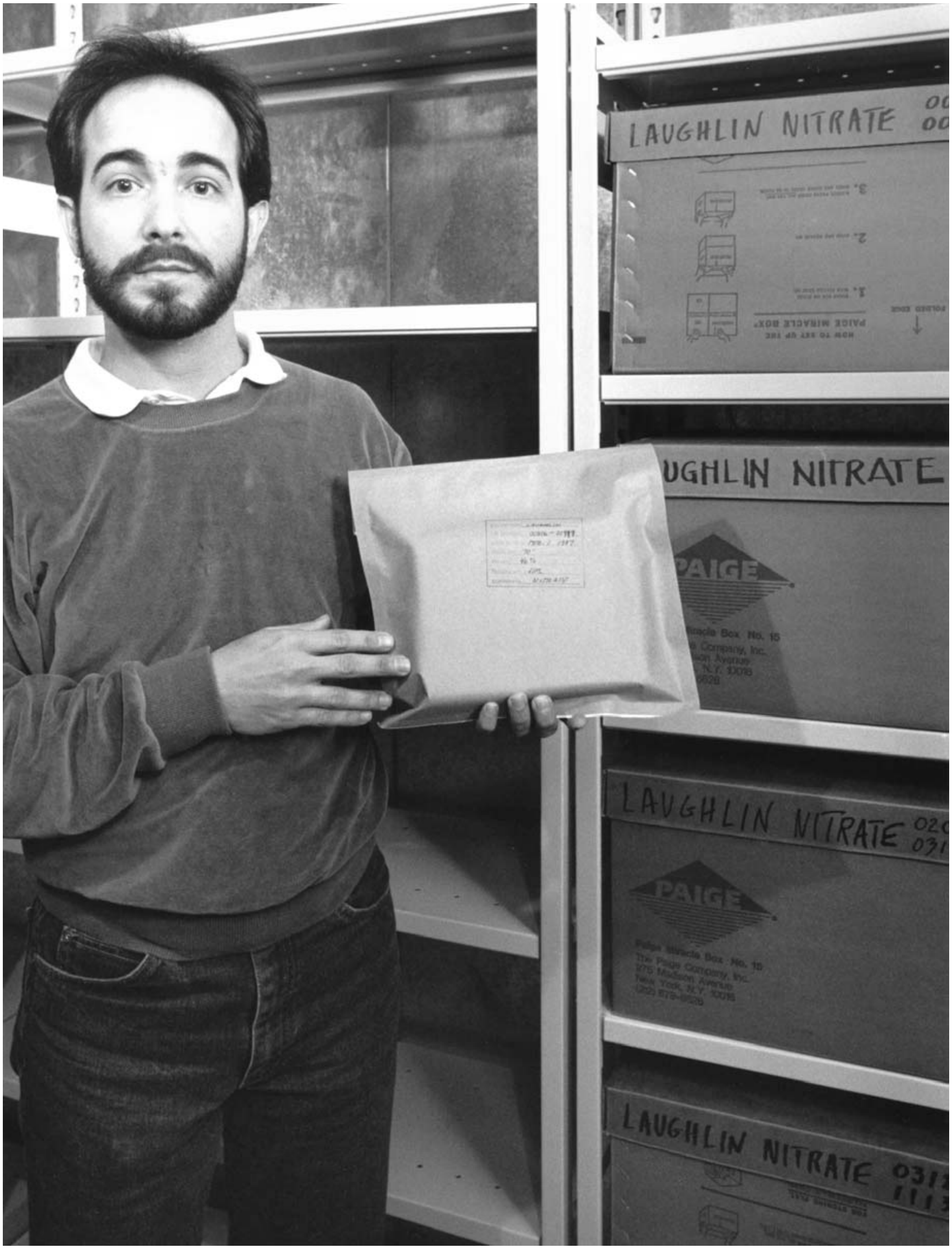

Alan B. Newman – February 1987

To preserve the original cellulose nitrate negatives made by Clarence John Laughlin (1905–1985), the Historic New Orleans Collection stores the negatives at 0°F (–18°C) and 30% RH. The negatives have been preconditioned and sealed in vapor-proof envelopes to avoid any possibility of damage to other materials in the vault by gases that are slowly evolved from the nitrate negatives. Holding a package of negatives in the vault is curator John Lawrence. Recent studies conducted with the Arrhenius test method have produced convincing evidence that nitrate film still in good condition when placed in storage at 0°F (–18°C) will last more than 1,000 years before the film deteriorates to the point where the negatives no longer can be printed.

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Alan B. Newman – February 1987

The 0°F vault for nitrate film storage is located inside the larger 32°F vault. The control panel on the right monitors temperature and humidity levels in both vaults.

nitrate-base film decomposition in a 1953 technical article by John M. Calhoun of Eastman Kodak:

> The rate of decomposition of cellulose nitrate is also very dependent on temperature and moisture content. The temperature coefficient of the reaction is about 4 per 10°C or 2 per 10°F which means that the rate of decomposition approximately doubles for every 10°F increase in storage temperature. Moisture absorbed from the air, the amount of which is determined by the relative humidity, also accelerates the decomposition reaction.[16]

Permanent Preservation of Nitrate Film in Cold Storage

The Arrhenius predictions given by Adelstein and his co-workers for the life of nitrate film stored at various temperatures, which correlate well with the earlier estimates given by Calhoun, indicate that nitrate film should last more than 50 times longer when stored at 25°F (–4°C) — and at least *200 times longer* when stored at 0°F (–18°C) — than when the film is kept at 75°F (24°C). When stored at 85°F (29.5°C), nitrate film is estimated to last only about one-half as long as it will at 75°F (24°C).[17] These figures are only estimates — ongoing research should provide more precise predictions — but they do illustrate the dramatic increase in the life of nitrate films afforded by low-temperature, humidity-controlled storage.

The work by Adelstein and his co-workers is particularly important because it shows clearly that the common belief that nitrate film "cannot be preserved" is simply not correct. A roll of nitrate motion picture film that today is still in good enough condition to last another 6 years at room temperature is predicted to remain in good condition for at least a 1,000 years when stored at 0°F (–18°C) and 30% RH. (The temperature coefficient of cellulose nitrate decomposition appears to be not unlike that of the fading of color photographs: both types of materials benefit greatly from low-temperature storage.)

Duplication of Nitrate Motion Picture Films Should Stop and a National Cold Storage Program Be Established Immediately

A thorough discussion of the storage and handling of large quantities of cellulose nitrate motion picture film is beyond the scope of this book. It is this author's strong belief, however, that the current practice of piecemeal duplication of nitrate motion pictures by assorted government and private collecting institutions has been a slow and wasteful process.[18] Furthermore, image-quality losses are unavoidable in the duplication process and it is always best to go back to the original (or as close to the original as possible) when making copies. With the availability of improved, electronic defect-suppression and image-enhancement techniques, access to original materials for making film copies, videotapes, and videodiscs will become even more crucial in the future.

Instead of duplication, a far more effective and less expensive method of preserving large quantities of nitrate film is to store it in a well-designed, humidity-controlled cold storage facility with a temperature of 0°F (–18°C) or lower and a relative humidity of about 30%. Working copies or videotapes of the films can be made as needed — and as funding becomes available. Film vaults can be constructed in a manner that minimizes the possibility of a fire starting in a storage area and, in the very unlikely event that a fire should occur, that prevents it from harming more than a small quantity of film.

It is particularly important that the many valuable color motion pictures printed by Technicolor and other firms on cellulose nitrate base be preserved in their original form; color positive films cannot be duplicated without significant losses in image quality. All of the Technicolor prints made from 1932 until about 1951 were made on cellulose nitrate film; these include such classics as *Gone With the Wind*, *Phantom of the Opera*, and *Joan of Arc*, as well as the early Walt Disney animated films such as *Snow White and the Seven Dwarfs*, *Pinocchio*, *Bambi*, *Dumbo*, and *Cinderella*.

A large, centralized, low-temperature film preservation facility with duplication and video transfer capabilities would be a far more efficient use of the millions of dollars that will otherwise be consumed on nitrate duplication during the coming decades. It would require a huge expenditure — money which simply is not available — to immediately duplicate all of the hundreds of millions of feet of nitrate motion pictures still remaining in film archives and private collections around the world. According to Susan Dalton, director of preservation and archival projects for the National Center for Film and Video Preservation at the American Film Institute, as of mid-1989 the film archives held approximately 150 million feet of uncopied nitrate motion picture film awaiting duplication, and the laboratory costs to duplicate the film will amount to at least $300 million.[19]

Furthermore, as research on film base stability by Adelstein and his co-workers has shown, cold storage is also required to preserve the many millions of feet of cellulose-triacetate-base duplicates that have already been made. Even duplicates made with polyester-base film should be kept in cold storage to insure permanent preservation of the gelatin emulsion and delicate silver images.

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September 1982

The Time Inc. Magazines Picture Collection stores its extremely valuable collection of between 3 and 4 million cellulose nitrate negatives at 50°F (10°C) and about 50% RH. Pulling negatives from the files for printing are Joseph Schilling (left) and George Gonzalez (right) of the Picture Collection staff. Time Inc. Magazines is part of Time Warner Inc.

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The specially constructed nitrate film storage vault for the Time Inc. Magazines Picture Collection is located in rented space in The Film Center, a commercial motion picture storage facility in New York City. The downtown building is equipped with blow-out panels, fireproof doors and walls, and other fire-safety features.

September 1982

Unless cold storage is provided for existing duplicates and for the vast amount of nitrate film that has not yet been duplicated, ever increasing numbers of motion picture films will deteriorate to the point where they can no longer be used and satisfactory copies can no longer be made. Only a relatively modest amount of money would be required to build a low-temperature storage facility that would prevent this ongoing and tragic loss.

Institutions Preserving Nitrate Still-Camera Negatives in Cold Storage

When large numbers of negatives are involved, there are many benefits to preserving the originals in cold storage. An important advantage is that constructing and operating a cold storage facility can be far less expensive than duplicating a large quantity of negatives.

Every attempt should be made to preserve original nitrate negatives with important artifact value. An example is the collection of 5,000 nitrate negatives documenting early Peary-MacMillan expeditions in the Arctic and to the North Pole: the negatives, which actually traveled with Peary to the North Pole and on other expeditions, are currently housed at the Peary-MacMillan Arctic Museum at Bowdoin College in Brunswick, Maine.

There are now a number of institutions in the United States that store nitrate still-camera negatives at low temperatures. The most sophisticated nitrate storage facility is at The Historic New Orleans Collection in New Orleans, Louisiana. The two-room, humidity-controlled cold storage facility, which began operation in 1987, has a special area maintained at 0°F (–18°C) and 30% RH for storage of the approximately 12,000 nitrate negatives and color materials in its collections. In spite of the fact that the vault is humidity-controlled, the nitrate negatives were sealed in vapor-proof laminated aluminum-foil bags before being placed in the vault. This was done to protect other materials in

1988

Recommended for safe storage of cellulose nitrate film is the Lab-Line Explosion-Proof Freezer Model 3552, available from Lab-Line Instruments, Inc.

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June 16, 1989

The Library of Congress Film Conservation Center at Wright-Patterson Air Force Base near Dayton, Ohio is the repository of over 120,000 reels of valuable original cellulose nitrate black-and-white motion picture camera negatives, duplicate negatives, release prints, Technicolor camera separation negatives, and full-color Technicolor imbibition prints. To reduce fire hazard, the films are segregated in 96 separate fire-proof vaults, all of which are maintained at 50°F (10°C) and 30% RH.

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the vault from damage that conceivably could be caused by fumes released from the nitrate films over time, to simplify access and prevent condensation on the negatives during warm-up, and to protect the negatives from damage should a water leak or other accident occur.

John Lawrence, curator of the collection, says that despite the heat and humidity of the New Orleans area, many of the nitrate negatives are still in very good condition, although some are not. Duplicate "working" negatives have been made of the more frequently printed nitrate negatives so that the originals will not have to be repeatedly withdrawn from the storage vault. According to Lawrence, cellulose nitrate negatives in good condition are always retained after duplication. The collection contains many nitrate negatives made by the late Clarence John Laughlin, a well-known photographer who lived and worked in the New Orleans area. Lawrence says, "We are preserving the nitrate originals as artifacts."[20]

A sizable collection of Edward Weston's nitrate sheet-film negatives (together with nitrate negatives taken by W. Eugene Smith and a number of other photographers) is stored in 0°F (–18°C) freezers at the Center for Creative Photography, which is associated with the University of Arizona in Tucson, Arizona. The negatives are sealed in vapor-proof envelopes for protection against moisture in the non-humidity-controlled freezers. Although the Center has duplicated the nitrate negatives in its collection, it intends to preserve the nitrate negatives themselves "for as long as we possibly can" because they are the actual negatives made by the photographer, according to curator Terence Pitts. The Center houses the archives of Edward Weston, Ansel Adams, W. Eugene Smith, Harry Callahan, Louise Dahl-Wolfe, Aaron Siskind, and a number of other well-known photographers.

About 8,000 nitrate negatives taken by Joseph Dixon of American Indians during the period 1908–1921 are preserved in a 0°F (–18°C) freezer at the W. H. Mathers Museum at Indiana University in Bloomington, Indiana..

Other institutions with 0°F (–18°C) freezer storage for cellulose nitrate films include the University Museum at the University of Pennsylvania[21] and the Humanities Research Center at the University of Texas at Austin.[22]

The Time Inc. Magazines Picture Collection keeps its priceless collection of between 3 and 4 million cellulose nitrate negatives in a New York City commercial film-storage facility at 50°F (10°C) and about 50% RH; the negatives are inspected periodically and any found to be obviously deteriorating are removed and duplicated. The San Diego Historical Society in San Diego, California stores its collection of nitrate still negatives at 55°F (13°C) and 40% RH.

George Eastman House Drops Plans to Build a Cold Storage Vault in Its New Archives Building

When architects for the International Museum of Photography at George Eastman House in Rochester, New

Evan Nesbitt, a vault collection attendant, returns reels of nitrate film that had been withdrawn for duplication on modern safety base film. In addition to its own films, the Library of Congress facility also stores nitrate film for Eastman House and the American Film Institute. The original Technicolor camera separations negatives from **Gone With the Wind** were stored here for some years before they were returned to Eastman House in 1990.

York drew up plans for the museum's new $7.4 million archives building, which was completed in 1988, the design included a humidity-controlled cold storage vault (35°F [1.7°C] and 25% RH) for the museum's priceless collection of contemporary and historical color photographs. The vault was also to be used to preserve the thousands of original cellulose nitrate still-camera negatives in the Eastman House collection. Among these negatives are photographs made by Alvin Langdon Coburn (1882–1936), Nickolas Muray (1892–1965), Lewis Hine (1874–1940), and other historically important photographers. The collection also has a sizable number of original nitrate negatives produced by George Eastman (1854–1932), the founder of Eastman Kodak.

In spite of the fact that the stated purpose of the new archives building was ". . .to better preserve the vast collections of historical photographs, films, technology and library owned by the Museum," the vault was not constructed, apparently in an effort to cut costs.

In 1988, concerned about the inadequate storage conditions provided in the new building, Michael Hager, the negative archivist at the museum, asked the museum to purchase an explosion-proof freezer to preserve the George Eastman negatives. The freezer was not acquired, and Hager is no longer on the Eastman House staff. At the time this book went to press in October 1992, the George Eastman negatives and the other nitrate still negatives in the museum's collections continued to be stored at room temperature, without special protection. It is hoped that Eastman House will soon find a way to provide proper, refrigerated storage for its nitrate negative collection.

Jim Harwood, a vault collection attendant, holds a roll of the original nitrate Technicolor camera separation negatives from a color sequence in the 1939 MGM movie **The Wizard of Oz**, which starred Judy Garland.

June 16, 1989

Film vault manager Sam Tyler regularly checks the fire alarm control panel. Sensors in each of the 96 vaults will trigger an alarm if there is a mechanical failure in the cooling equipment or if smoke or fire is detected. Smoking is absolutely forbidden in the vault area.

Special Explosion-Proof Freezers for Safe Storage of Cellulose Nitrate Films

There are a number of suppliers of explosion-proof refrigerators and freezers that are safe for storing nitrate films. Freezer units are recommended because their very low operating temperatures will preserve nitrate films far longer than will refrigerators.

A recommended freezer is the Lab-Line Explosion-Proof Freezer Model 3552, available from Lab-Line Instruments, Inc. of Melrose Park, Illinois.[23] The upright unit, which cost $2,775 at the time this book went to press in 1992, is

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available in 110-volt (60 Hz) and 220-volt (50 Hz) models and has 21 cubic feet of storage space with 18.8 square feet of shelf space provided on four shelves; it is equipped with a key-locked door.

The freezer has no internal electrical components that could trigger a fire, and for maximum safety, all external components are sealed so that it is safe to operate in an environment where explosive vapors (e.g., natural gas fumes) may be present; it meets National Fire Protection Association Standards as specified in Articles 500–501. The freezer temperature can be set between 23° and –10°F (–5° and –23°C); for storing of nitrate film, it is suggested that the thermostat be set at the lowest possible temperature.

In the event of power outage or equipment failure, the internal temperature of the freezer will gradually rise to that of ambient conditions; in an air-conditioned building, this should present no hazard. However, if the indoor temperature should rise above 95°F (35°C), and the freezer is not functioning, all nitrate film should be removed from the freezer and taken from the building to a safe location.

Packaging Films for Freezer Storage

Because these freezers operate with a high internal relative humidity, films must be sealed in vapor-proof packages. Vapor-proof storage envelopes made of a paper/aluminum-foil/polyethylene laminate are available in 4¾x 6½-inch and 12x15-inch sizes from Light Impressions Corporation,[24] and in 10x12-inch and custom-made larger sizes from Conservation Resources International, Inc.,[25] Quality Packaging Supply Corporation,[26] and Shield Pack, Inc.[27] To minimize the danger of gradual moisture penetration through pinholes or other punctures in a vapor-proof envelope, films should always be *double-sealed:* that is, they should be placed in an envelope and sealed, and the resulting package inserted into a second envelope and sealed. Films should be interleaved with a high-quality, alkaline-buffered paper such as Howard Paper Company Permalife.

Where possible, films should be pre-conditioned to a low relative humidity prior to sealing them in the envelopes; in cold months in temperate areas, when indoor relative humidities are generally low, conditioning can be easily accomplished by spreading the films out on a table for a day or two (open rolls of motion picture film should be pre-conditioned for about 2 weeks). With still negatives, a relative humidity of 30–40% is recommended. If a low-humidity environment is not available, a closed room with a home dehumidifier and small air conditioner should be able to provide a 45 or 50% RH atmosphere. While preferable, it is by no means essential that nitrate films be pre-conditioned before sealing them in vapor-proof envelopes; if a low humidity environment is simply not available, then the films should be sealed and placed in the freezer in whatever condition they are in.

If paper interleaves are placed between sheets of film and excess air is squeezed from the packages (or drawn out with a hose connected to a vacuum pump) prior to heat-sealing, there is no danger of moisture condensation inside the packages when they are placed in the freezer. (Even if paper interleaves are not used and excess air is not withdrawn from the package prior to sealing, moisture condensation could not occur unless there was only a small piece of film in the package and a large amount of air was sealed inside with the film.)

Upon removal from the freezer, packages must be permitted to warm up to room temperature before they are opened in order to avoid moisture condensation on the cold films.

It has been stated frequently that nitrate films should never be stored in a sealed container because accumulations of gases resulting from decomposition of the film can further accelerate the deterioration. However, storage at 0°F (–18°C) or below virtually halts the decomposition process, and this author believes that sealing films stored at such a low temperature will have little detrimental effect on their life. Certainly, nitrate films will last *far* longer when they are sealed and stored at 0°F (–18°C) than they will when kept unsealed at normal room temperatures.

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9. Eastman Kodak Company, **Storage and Preservation of Motion Picture Film**, Eastman Kodak Company, Rochester, New York, March 1957. (This is an excellent general reference for both nitrate motion picture films and still-camera negatives; although out of print, it may be available in libraries, or contact Eastman Kodak Company in Rochester, New York.)
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22. Siegfried Rempel, "A Conservation Priority for HRC's Photography Collection," **Perspectives on Photography** (Dave Oliphant and Thomas Zigal, editors), Humanities Research Center, University of Texas at Austin, Austin, Texas, 1982, pp. 167–178.
23. Lab-Line Instruments, Inc., 15th and Bloomingdale Avenues, Melrose Park, Illinois 60160-1491; telephone: 708-450-2600; Fax: 708-450-0943. At somewhat lower cost, a Flammable Materials Storage (FMS) version of the freezer (Model 3552-10) is also available from Lab-Line; this unit, which cost $2,360 in 1992, has no interior electrical components but is not certified as safe for operation in explosive environments. For maximum safety, this author recommends the Explosion-Proof units.
24. Heat-sealable, vapor-proof envelopes called Light Impressions Heat Seal Envelopes are available from Light Impressions Corporation, 439 Monroe Avenue, Rochester, New York 14607-3717; telephone: 716-271-8960 (toll-free outside New York: 800-828-6216; toll-free inside New York: 800-828-9629). Two standard sizes are supplied: Code No. 3920 (**4¾x6½** inches; $6.30 for a package of 25) and Code No. 3921 (12x15 inches; $13.25 for a package of 25). These envelopes are true vapor-proof, heat-sealable, aluminum-foil/polyethylene laminated containers that can provide added security in a frost-free refrigerator, or be used in a double-layer package in a non-humidity-controlled refrigerator or freezer.
25. Vapor-proof envelopes called Containers for Freezing Photographic Material, supplied in the 10x12-inch size (minimum order of 500 envelopes), and custom-made in almost any size, can be obtained from Conservation Resources International, Inc., 8000-H Forbes Place, Springfield, Virginia 22151; telephone: 703-321-7730 (toll-free telephone: 800-634-6932). Conservation Resources has sales offices in Ottawa, Ontario; Oxon, England; and Brisbane, Australia.

    Kodak has given two sources for laminated paper/aluminum-foil/polyethylene material suitable for making vapor-proof photographic storage envelopes: Crown Zellerbach, Flexible Packaging Division, Park 80 Plaza – West I, Saddlebrook, New Jersey 07662; and Northern Packaging Corp., 777 Driving Park Avenue, Rochester, New York 14613. This material can be used to make custom-size storage envelopes.
26. Custom-made heat-sealable, vapor-proof envelopes for films and prints in any size or configuration are available under the XT-08 name (large-quantity orders only) from Quality Packaging Supply Corporation, 24 Seneca Avenue, Rochester, New York 14621; telephone: 716-544-2500 (California office: 3028 East 11th Street, Los Angeles, California 90023; telephone: 213-264-1102). The puncture-resistant XT-08 envelopes are made of a laminate consisting of Tyvek on the outside, a heavy aluminum-foil vapor barrier, and a heat-sealable polyethylene layer on the inside. Quality Packaging has supplied XT-08 envelopes to Lorimar Telepictures Corporation and MGM for packaging of motion picture films and videotapes. The packages are used for protection during routine shipping as well as for room-temperature and refrigerated storage.
27. Custom-made heat-sealable, vapor-proof envelopes for films and prints in any size or configuration are also available (large-quantity orders only) from Shield Pack, Inc., 2301 Downing Pines Road, West Monroe, Louisiana 71291; telephone: 318-387-4743 (800-551-5185).

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