Technical Bulletin 22

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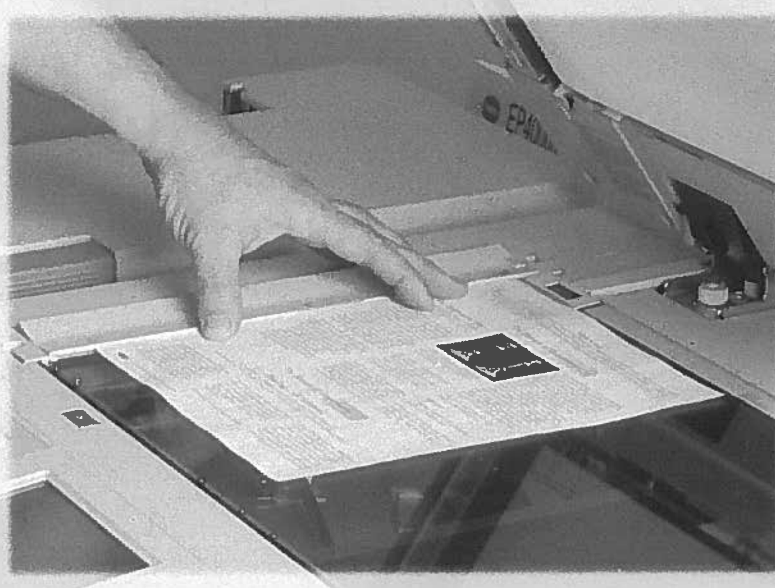
The Stability of Photocopied and Laser-printed Documents and Images: General Guidelines



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The Stability of Photocopied and Laser-printed Documents and Images: General Guidelines

by David Grattan

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Abstract

This bulletin reviews the technology of photocopiers and laser printers, and discusses the stability and preservation of copies. The conclusion is that black-and-white copies (i.e. those using carbon-based toner) on alkaline paper form very stable records, but colour photocopies do not. A full-sheet test for assessing the adhesion of toner to paper is described, and the results of testing papers according to the American Society for Testing and Materials (ASTM) standard for permanency of copy paper are given. The bulletin also includes a list of preservation concerns that will be useful to archivists responsible for the care of photocopied documents, and a number of current technical references that discuss the topic in more depth.

Author

David Grattan received a Ph.D. from the University of Keele in 1973, followed by work as a Research Fellow at the National Research Council of Canada where he combined his experience in polymers and photochemistry in a study of the stabilization of plastics against light. Since joining CCI in 1977, his research has included various topics such as waterlogged wood; treatment of fossils from the Fossil Forest, Canadian Arctic; parylene for museum and forensic use; stabilization of modern materials by use of anoxic conditions; degradation of polyethylene glycol, Polyox, and parylene; and the development of a light ageing apparatus for museum materials. David has been involved with numerous international organizations and has also authored many professional publications. For the last few years he has been leading CCI's research team in paper stability studies for the American Society for Testing and Materials and the Canadian General Standards Board standards for paper permanency.

This publication is printed on recycled paper.

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Introduction

There are a number of major concerns relating to the permanence of photocopied materials. These can be summarized as follows.

- *Preservation photocopying* is a technique used to preserve information when the source has little intrinsic value. The copy becomes the *preservation copy* and thus the primary source of information; therefore the photocopied record must have high permanence.
- Some records created by their sponsoring organizations should be produced on permanent media. Photocopiers and laser printers are universally used for this purpose, and guidelines are needed to ensure that these records have maximum permanency.
- Collections contain a wide variety of photocopied documents, and information is needed on how to care for this material and any possible problems.
- Colour photocopies are frequently used in exhibits because they are inexpensive, but they have very poor permanence.

The principal factors determining the stability of photocopied documents are the permanence of the paper and of the image. These issues are dealt with separately, followed by a list of practical recommendations.

Paper Permanence

If photocopies are to survive as permanent records, it is important that the copy paper does not become brittle or yellow. Industrial standards exist to ensure that copy papers are not only capable of being handled by photocopy machines, but also possess high permanency. Permanency standards specifically for copy paper have been set by the American Society for Testing Materials (ASTM). More general permanency standards have been set by many organizations such as the American National Standards Institute (ANSI), the National Information Standards Organization (NISO), and the International Standards Organization. A Canadian Standard is currently being developed by the Canadian General Standards Board (CGSB)

Copy Paper

Copy papers are usually modified bond grades made from chemical and wood pulps. The most common basis weight is 75 g/m^2 (20 lb.), but it may range from 60 g/m^2 (16 lb.) to 90 g/m^2 (24 lb.). Copy papers have a smooth finish, heat stability, non-curling qualities, and good aesthetic properties such as colour brightness and cleanliness.[1] Papers are often internally sized with rosin and surface sized. Up to 30% (by weight) of calcium carbonate may be present as a filler.

Permanent Copy Paper

Permanent copy paper is very similar to ordinary copy paper, except that a permanency standard has been established for it. ASTM D 3458-96[2] specifies criteria for "Copies from Office Copying Machines for Permanent Records." The most permanent paper described by the standard is coded "LE-1000" (or Type 1) and is expected to last several hundred years.[3]

Summary of the ASTM D 3458-96 Requirements for LE-1000 (Type 1—high permanency) Paper

The key permanence requirements are as follows:

- Papers should be made from cotton, linen, or fully bleached chemical fibre, and virgin or recycled fibre may be used in any proportion, "as agreed upon between buyer and seller at time of purchase."
- Papers should contain less than 0.7% lignin (i.e. Kappa number below 5).
- Papers should contain at least 2% calcium carbonate.
- The cold extract pH must be between 7.5 and 10.
- Papers must meet various strength requirements as defined in tear strength, tensile, and fold endurance testing. Two strength grades are defined: Grade 1 and Grade 2[4] (high referral papers that are stronger than Grade 1 papers). [It is extremely unusual for papers to meet the fold endurance required for Grade 2 status, so for most practical purposes only Grade 1 paper need be considered.]
- Papers must retain a high percentage of strength as determined in a prescribed ageing test.[5]
- Papers must meet certain requirements for opacity and brightness.

CCI Test Results for Commercially Available Papers

The Canadian Conservation Institute (CCI) conducted tests with four commercially available papers to see how well they performed against the ASTM D 3458-96 standard: Permalife (25% cotton, 50% recycled; Howard paper), Perma-dur bond (University Products Inc.), Repro Plus (Rolland Inc.), and Econosource (dual purpose Xerography - Unisource Inc.). The first three were high quality "permanent" papers, and the fourth was a typical economical office copy/laser-printer paper.

Physical tests
All papers except Repro Plus met the standard for high referral papers in internal tearing resistance, but not in fold endurance. All are thus Grade 1 papers. All had suitable brightness and opacity.

Ageing tests
All papers failed the ageing test for high referral (Grade 2) papers (based on retention of fold endurance), but performed reasonably well in the non-mandatory tests (based on retention of tear strength).[6]

Chemical tests
All papers passed the pH test, and the alkaline reserve requirement. Three papers met the standard for lignin content and fibre composition (Econosource contained too much lignin).[7]

In conclusion, these are all high quality papers with good permanence; however none passes the perhaps unrealistic ASTM fold endurance requirements for high referral, permanent copy paper. In most respects they can be considered as Grade 1, Type 1 papers. The Econosource performed very well in comparison with the more expensive papers marketed as permanent. All papers except Econosource, because of the presence of lignin, would pass the ANSI/NISO Z39.48 and ISO 9706 standards for paper permanency.

Creating the Image (Reprography)

Electrophotography or "reprography" (the technical term for photocopying or laser printing) is based on the principle that exposure to light changes the static electrical charge on surfaces. In photocopiers, the image of a document is projected on an electrostatically charged surface; for laser printing, a moving laser beam describes the image. The charged areas attract a powdery material, known as a toner, which is then transferred to paper. The toner is fused to the paper by heat, pressure, or solvent evaporation.

Modern processes were recently reviewed by Gregory[8] and by Scharfe, Pai, and Gruber.[9]

The following is a brief description of how reprography works.

Step 1. Charging
A photoconductive[10] drum or belt, also known as the photoreceptor, is given a uniform electrostatic charge of several hundred volts.

Step 2. Writing/exposure
In photocopying, the image to be copied is projected onto the charged surface. In the exposed areas, light causes current to flow, and hence the electrostatic charge is dissipated. This produces what is known as a "latent electrostatic image." The area exposed to light is the background.

In laser printing, a laser beam writes onto the surface and thus it is the exposed areas that contain the image. The result is an image that is the negative of photocopying.

Step 3. Developing
Toner in the form of a dry powder or a liquid suspension is brought into contact with the latent image. In photocopying and laser printing, the toner must have the opposite charge to the non-exposed areas in order to adhere to the latent image.

N.B. Toners for photocopying and laser printing are not interchangeable because they must have opposite charges.

Step 4. Transferring
The image (held by the toner particles) is transferred from the photoreceptor drum or belt onto a sheet of paper placed in contact. This is achieved by reversing the charge on the photoreceptor to repel toner particles.

Step 5. Fusing
Solid toners are fused to the paper surface by heat and/or pressure. Liquid toners are fixed simply by air-drying.

Step 6. Cleaning
In the final step, the drum is brushed to remove excess toner and exposed to light to wipe away any residual latent electrostatic image.

Image Permanency

The permanence of the image depends on the stability of the toner and its adhesion to paper. Information about the toner is available from toner cartridges, or from a Material Safety Data Sheet available from the manufacturer. This information can be useful in predicting permanency, as is discussed in the following section.

Developer Composition

There are two categories of dry developer: single-component and two-component. Dry two-component developers are, by far, the most common commercially.[11] Toner, the most important component of developers, becomes fused to the paper surface to create the image.

Toners are typically composed of 90% resin, 8% pigment (usually carbon black), and 2% charge control agent (CCA). The dry, two-component process involves coating fine toner particles (ca. 5 µm) onto oppositely charged much larger (ca. 60–200 µm) carrier particles. The function of the carrier particles is to carry the toner powder to the surface, usually by means of a "magnetic brush." Carrier particles are not intended to be incorporated into the image. The carrier is usually composed of silane- or Teflon-coated spherical beads of sand or glass or, more usually, a magnetic material such as iron or steel. In the single-component process the carrier bead is omitted, and the toner powder itself is made magnetic. Thus, single-component developers often (and two-component developers sometimes) contain magnetic iron oxides which are usually termed "ferrite." Each manufacturer alters the performance of copiers to accept only their particular toner mixture; therefore, for optimum performance, use only the manufacturer's sanctioned material.

Dry toner is fixed to the paper by pressure, by melting, or by a combination of heat and pressure. In the fused image, the degree of melting that takes place is limited. The toner melts sufficiently to adhere to the paper, but not so much that it becomes mobile and flows. Toner tends to form a layer above the paper in which the toner particles are still recognizable as discrete entities.

Resins must soften at rather low temperatures (ca. 60–70°C). However, once melted, their viscosity must be high enough that the liquid resin does not spread, but it must also be low enough to penetrate the paper web. Resins must be insulators so that they retain the electric charge. Polystyrene acrylates, such as copolymers of styrene and *n*-butyl methacrylate, are most commonly used. Gregory reported in 1994 that this latter resin was employed in about 80% of the toners in commercial use. The remaining 20% mainly use polyester resin, e.g. poly(ethylene terephthalate), although polyethylene and polypropylene resins are now of increasing importance. Currently, toners are tending to become more complex. Typically, they contain mixtures of several resins.

The polystyrene acrylate, polyethylene, and polypropylene resins used are all reasonably stable materials; they are not prone to oxidative breakdown or unduly sensitive to light. These resins, if present, should be listed in the manufacturer's literature or the Material Safety Data Sheet.

Liquid development systems have the toner particles held in suspension in an insulating organic solvent. The liquid developer also contains a resin which adheres the toner to the paper. Liquid toners may penetrate the paper web better than dry toners, and this may create an image that is more durable than those created by dry processes. Because of the time taken to evaporate solvent, liquid copiers tend to be slower than dry systems.

Pigment is usually a pigment-grade carbon black, although other inorganic pigments are increasingly being added. For effective dispersal in the resin, carbon blacks are usually acid treated.

Charge control agents (CCAs) are complex organic compounds that carry either an inherent negative charge or an inherent positive charge. Many are proprietary, and it is difficult to determine exactly what they are in any given toner.

Ferrite (iron oxides) may have a negative influence on the stability of paper. Given that iron oxides are unstable in damp conditions, there is also a possibility of staining. Though the risk of damage is thought to be minimal because of the fact that all toner particles are sealed in fused resin, it seems wise to avoid ferrite if possible.

Coloured toners are in many respects similar to black toners, except that the carbon black pigment is replaced by dye-containing pigments. All have light and heat fastness problems. According to Wilhelm,[12] Canon colour copies are much more stable than Ektacolor prints but not as good as Fujicolor SF A3 prints. In unfiltered fluorescent lights at 450 lx illumination, Canon colour copies survive for 7.8 years. [Ektacolor and Fujicolor prints are made by photographic processes.]

Image Adhesion

One of the main practical problems is adhesion of toner to paper, particularly with laser-printed images. The tape-peel test is a quick on-site method of measuring image adhesion (see Subt and Koloski[13]). The test has been modified at CCI for two reasons. Fuser failure can be very localized, and unless a whole sheet of paper is tested it is impossible to be certain that there are not defective areas. Instead of using a target, in which the image is rather artificial, a full sheet of printed text with the margins reduced to a minimum and containing both boldface and normal print is used in tests at CCI.

The full-sheet test method

Before making the test copy, allow the copier or printer to be used for 20–30 copies, until the fuser has reached operational temperature.

Place a freshly produced copy of a full sheet of printed text on a flat bench top. Making sure the paper is absolutely flat, tape the bottom and top edges to the bench.

Place parallel strips of fresh (less than 12 months old[14]) Scotch 230 C tape vertically so as to cover the whole paper sheet. [N.B. Leave a slight gap between adjacent strips.] Firmly press the ball of the thumb on the first strip and move it up and down the strip six times. Repeat for each strip. Mark the edges of the paper sheet on the tape with a ball-point pen and number the strips.

Place a sheet of Mylar or other transparent plastic sheet next to the paper and remove each strip by pulling it steadily parallel to the surface. The tape should be almost flat as it is pulled off. Stick each strip on the Mylar sheet so that the adhesive tape strips are reassembled exactly as they were arranged while on the paper. Trim the excess edges of the tape, flip the Mylar sheet, and place it on a white surface. Any areas of toner loss are immediately obvious. Very slight losses are normal. If transfer occurs to an extent such that the removed toner forms legible letters, then there is a problem with toner adhesion.

The single-strip test method
For regular testing, it may not be necessary to use entire sheets. A single strip applied diagonally from corner to corner on the sheet is probably sufficient. Application and peeling should be conducted exactly as described above, but attaching to the Mylar for examination is not really necessary with a single strip.

Problems with Toner

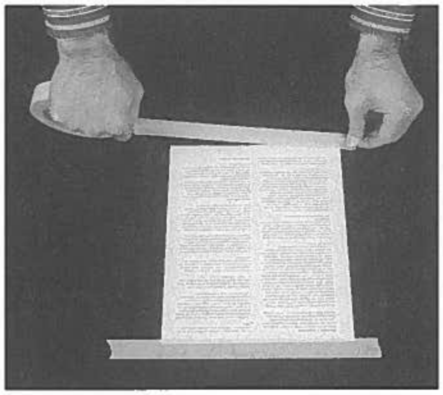
Failure of copied images seems to occur with heat and with pressure. Under these conditions toner can melt and migrate. In mass deacidification processes such as the Wei T'o system, where heat and pressure are used, photocopied papers tend to stick together. In the FMC-MG_3 (heptane solvent) and Wei T'o processes, coloured photocopy image layers are completely destroyed.

Images in contact with smooth plastic (especially PVC) surfaces tend to transfer. This is likely caused by plasticizer migrating into the toner from the plastic and softening it.

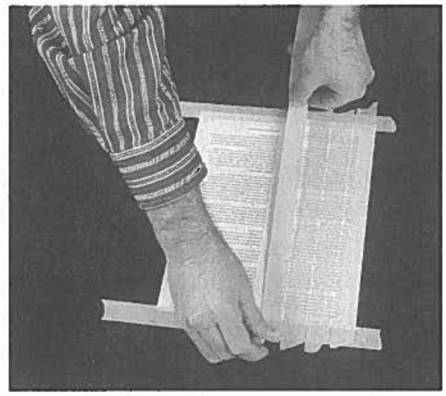
[N.B. PVC normally contains 25% phthalate plasticizer which is easily soluble in poly(*n*-butyl methacrylate).]

Practical Recommendations[15]

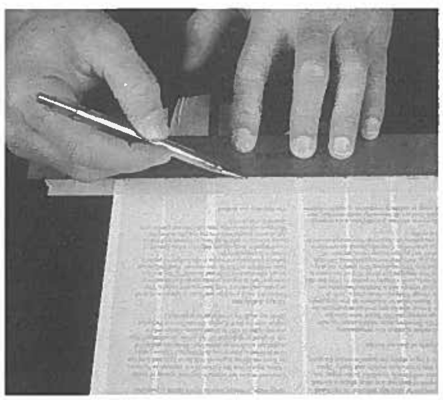
The following recommendations are based on the present level of knowledge and information. As more research is done, and our knowledge increases, these recommendations may change. It is advisable to keep abreast of current developments.



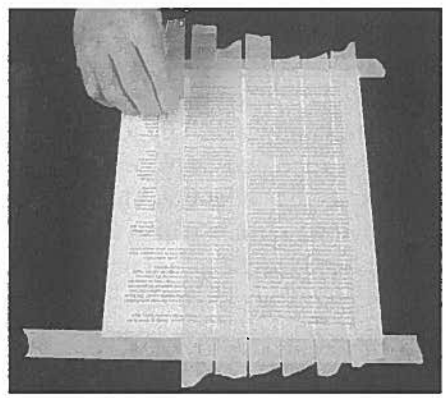
1. The top and bottom edges of the test sheet are taped to a flat surface.



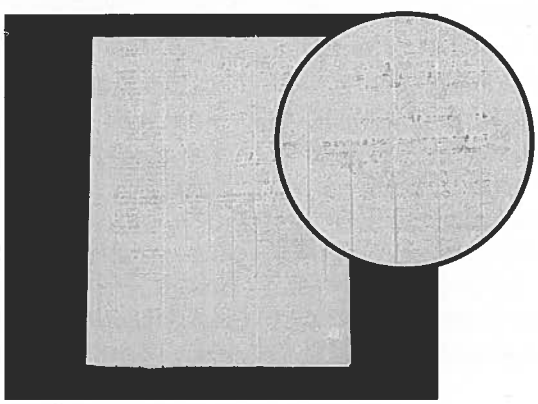
2. Parallel strips of tape are placed vertically on the sheet so as to cover the entire surface, leaving a slight gap between adjacent strips.



3. The edges of the paper sheet are marked on the tape strips with a ball-point pen, and each strip is numbered.



4. Each strip of tape is removed by steadily pulling it parallel to the surface of the paper (i.e. the tape is almost flat as it is pulled off).



5. The tape strips are reassembled on a Mylar sheet exactly as they were arranged on the paper. When the Mylar sheet is flipped over and placed on a white surface, any areas of toner loss are immediately visible (see inset).

Toner

- Consider toners composed of carbon black pigment and a stable resin to be permanent.
- Be aware of the composition of toner being used (composition is often described on the toner cartridges).
- Avoid single- or two-component developer systems that contain iron oxide ("ferrite").
- Replace the toner regularly or as soon as there is any indication that it is exhausted.
- Use only the toner produced by or sanctioned by the manufacturer for the specific model of copier.
- Do not use generic toners.

Paper

- Copy on paper that meets any one of the following standards: ASTM D 3458-96 LE 1000 specifications,[16, 17] the ANSI/NISO Z39.48 standard "Permanence of Paper for Printed Library Materials," or the ISO 9706 (03/94) standard "Information and Documentation—Paper for Documents—Requirements for Permanence."[17]
- If paper meeting the above standards is not available, use the list of papers prepared by McCrady[18] as a useful guide (it surveys papers that likely meet the ANSI/NISO Z39.48 standard). Although the papers are listed as alkaline, please note that the information is supplied by the manufacturers rather than based upon independent tests.

Maintenance

- Test a preservation photocopier before purchase to ensure that the copies it produces can pass an image adhesion test (therefore, if failure subsequently occurs, the problem must be caused by copier malfunction or poor toner). Image adhesion tests should then be conducted regularly: use a single-strip peel test once per day, and a full-sheet test once a month. Keep in mind that the tape-peel test is for freshly made copies only; it is not intended for testing the permanence of older copies.
- Ensure that staff responsible for making preservation copies have a basic knowledge of the operation and function of the copier being used, and of the particular process used by the photocopier.
- Have photocopiers properly and regularly maintained by qualified personnel. Ensure that the fuser is operating at the correct temperature, and run an adhesion test after maintenance.

Preservation Concerns

- Store photocopies and laser-printed copies according to the recommendations in "Guidelines for Humidity and Temperature in Canadian Archives and Libraries."[19] Most photocopied records (especially those prepared following these guidelines) would be classified as "High Stability." The storage guidelines are designed to give sensible and cost-effective advice, and consider temperature and relative humidity among a number of other factors that influence the usable lifespan of documents. Storage recommendations can be summarized by saying that while precise control of relative humidity and temperature is not necessary, Canadians can take advantage of the cool and dry conditions in winter but must avoid damp conditions and summer heat.
- Avoid stacking photocopies, especially at high temperatures, as they can stick together if placed under heat and pressure. Note that the softening temperature of toners may be as low as room temperature.
- Do not place copies in direct contact with PVC and similar plastics (polyester film is safer) as migrating plasticizer can make the toner sticky and capable of transferring to adjacent surfaces.
- Do not deacidify photocopies with solvent-based processes such as the FMC-MG_3 or Wei T'o methods.
- Avoid permanent or long-term storage of colour photocopied or colour laser-printed material.
- Do not fold or flex colour dry-toner copies, as the print layer is thicker and does not adhere to the paper as well as black toner copies.

Endnotes

1. *The Dictionary of Paper*, 4th ed. (New York: American Paper Institute, 1980).

2. It is important to use the most recent (1996) version of the ASTM standards, as earlier versions contain errors. Other closely related standards for permanency are ANSI/NISO Z39.48-1992, "American National Standard for Permanence of Paper for Publications and Documents in Libraries and Archives," and ISO 9706 (03/94), "Information and Documentation—Paper for Documents—Requirements for Permanence." In these, the requirements for lignin content, pH, and tear resistance harmonize very well with the ASTM standards except that neither demands an ageing test.

3. Though described in the standard, "high life expectancy, LE-100" or "medium life expectancy, LE-50" papers are not permanent.

4. Papers should have a fold endurance of 200.

5. In a non-mandatory specification, Type 1 papers must retain 90% of their internal tearing resistance or tensile energy absorption after 72 h of ageing at 105°C (or 90°C and 50% relative humidity). This is reduced to 80% retention for Type 2 papers. Humid ageing conditions as defined by ASTM D 4714 are recommended by CCI.

6. Permalife paper retained only about 87% of its tear resistance after ageing, thereby failing a non-mandatory requirement for a Type 1 paper. Perma-dur and Repro Plus failed to retain more than approximately 80% of their tensile energy absorption after ageing, and hence they both failed a non-mandatory requirement for a Type 1 paper. Econosource passed all the strength tests.

7. Analysis revealed that Econosource had 15% alkaline reserve and was composed of bleached hardwood and softwood with around 10% of BCTMP hardwood and softwood. [BCTMP is wood pulp that has been bleached for brightness and is produced by both mechanical and chemical pulping methods.] Repro Plus had 14.3% alkaline reserve, with bleached hardwood and softwood. Perma-dur had 4.4% alkaline reserve, with bleached hardwood and softwood. Finally, Permalife had 4.4% alkaline reserve, with bleached hardwood and softwood and also cotton.

8. P. Gregory, "Modern Reprographics," *The Review of Progress in Colouration* 24 (1994): 1–16.

9. M.E. Scharfe, D.M. Pai, and R.J. Gruber, "Electrophotography," ch. 5 in *Imaging Processes and Materials*, Neblette's 8th edn., ed. J. Sturge, V. Walworth, and Allan Shepp (New York: Van Nostrand Reinhold, 1989).

10. A photoconductive material is one that conducts electricity in the presence of light.

11. Manufacturers tend to prefer certain processes: Xerox, Mita, Panasonic, 3M, Sharp, Pitney Bowes, Konica, Ricoh, Toshiba, and Minolta often use two-component dry developers; Kodak and Canon use single-component dry developers; Savin copiers frequently employ liquid development.

12. Henry Wilhelm, *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures* (Grinnell, IA: Preservation Publishing Company, 1993), 137 pp.

13. Sylvia Subt and John Koloski, GPO Jacket No. 484-988, *Final Report Archival Xerographic Copying—Special Development Study for National Archives and Administration*, Quality Control and Technical Department U.S. Government Printing Office, August 25, 1987.

14. Twelve months is an estimate based on direct observations of tape behaviour at CCI.

15. This list is similar to one prepared recently for Australian Archives; see "Photocopying and Laser Printing Processes—Their Stability and Permanence," *Australian Archives* (Sept. 1993). Other important references are Sylvia Subt and John Koloski,[13] and Norvell M.M. Jones, *Archival Copies of Thermofax, Verifax and Other Unstable Records*, National Archives Technical Information Paper No. 5 (Washington, D.C.: National Archives and Records Administration, 1990).

16. With the additional requirement that the paper should contain at least 2% calcium carbonate.

17. Also specify that the paper passes the humid oven ageing test (ASTM D4714 at 50% relative humidity). Do not accept results from the dry-oven ageing test.

18. Ellen R. McCrady (ed.), *North American Permanent Papers—A Guide to Permanent Papers Available in the U.S. and Canada* (Austin, TX: Abbey Publications, 1995). See pp. 12 and 13 for a list of copy papers, then see p. 9 followed by p. 15 to identify sources. N.B. Within this document the separation of "copier," "laser print," and "xerographic" papers is largely artificial.

19. Stefan Michalski, *Guidelines for Humidity and Temperature in Canadian Archives and Libraries* (Ottawa: Canadian Conservation Institute), to be published.