

## ASTM Paper Aging Research Program

### ABSTRACT

The American Society for Testing and Materials (ASTM) has administered a five-year research effort into the aging of printing and writing papers. The purpose of the research was to develop accelerated aging test methods that can be used to predict the life expectancy/stability of such papers for various intended end uses. In order to meet a key goal of the program, it was necessary to show that the chemistry and physics produced by proposed accelerated aging test methods were essentially the same as occurs in natural aging.

Five laboratories have been at work since 1995. They pursued three test methods. The means to accelerate aging included elevated temperature, elevated light flux, and elevated concentration of common atmospheric pollutant gases. Thirty-three organizations have sponsored this four million dollar program.

This paper reviews the program and the likely test methods that will be presented to ASTM for ballot in 2001.

### PROGRAM BACKGROUND

Within the Paper and Paper Products Committee of ASTM, a discussion arose in 1992 at a meeting of the Permanent Paper Subcommittee. It dealt with the then current means to assure paper permanence. At that time, permanent paper standards required that papers have alkaline pH, have an alkaline reserve like calcium carbonate to react with any pollutants that might turn the paper acid, and that they contain less than one percent lignin content. Such papers were known to be likely to have long life expectancy. This was based on experience with handmade papers from as long ago as five hundred years that have held up well over the centuries.

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At the same time producers, end-users, and others interested in paper longevity all agreed that it would be far better to base paper specifications on performance capabilities rather than on narrow composition limits. This was because of the great variety of components that are included in modern papers, many of which are unknown as to their effect on paper longevity. To move to performance-based standards, it was agreed that reliable means to accelerate the aging of any paper would be required in order to evaluate its stability to aging.

Out of this initial discussion a working group was established. Their work showed there was substantial energy within various constituencies to undertake research toward development of the needed accelerated aging test methods.

A workshop was sponsored by nineteen organizations in July 1994. Some one hundred ten people attended from twelve countries. They included people from pulp and paper manufacturing companies, libraries, archives, government groups, academia, and environmental groups. The purpose of the workshop was twofold. First, a series of scientific papers was presented so that all participants could understand the then current state of knowledge regarding the aging of paper. This was so that all participants could begin a dialog from a common base of understanding. Sixteen papers were presented by some of the leading scientists from around the world who had been engaged in paper aging research efforts.

The second intent was to have a true dialogue between the participants in an effort to gain consensus on the scope and details of the needed research. A goal was to define research that would likely lead to new test methods that could be shown to be scientifically sound. Happily consensus was reached on a purpose statement and specific research objectives for the program.

At the workshop a statement of program purpose was crafted. It identified the purpose to be "to develop scientifically sound accelerated aging test methods by which to

reliably predict the life expectancy of printing and writing papers regardless of paper composition.”

The details of the research called for studies in which the aging would be accelerated by three different means. They included the use of elevated temperature wherein moisture content within the paper was held at the same level as would normally occur at room temperature. A second method was to utilize elevated light flux while maintaining the temperature and moisture content in the paper at normal room levels. The third method was to use increased concentration of common atmospheric pollutant gases to see how potential acidification of papers would affect aging.

With a clear purpose and a series of specific research thrusts defined, a fund-raising effort was launched. At the same time a request for research proposals was sent to twenty-five scientific organizations around the world. Fifteen proposals were received. A small group developed criteria for selecting those to be funded, and from the list of fifteen, six were chosen. Ultimately only five could be funded, but it was agreed that they promised delivery of the new information needed.

Three categories of financial support to the program were developed. Leading the list were for-profit organizations that pledged at least U.S. \$75,000 to the effort and not-for-profit organizations that pledged at least U.S. \$15,000. This top group then became the committee that managed the program and made the business and technical decisions to move it properly forward. In total, thirty-three organizations contributed to the research effort. Together with in-kind contributions of materials and research effort, a total of four million U.S. dollars was raised to complete the program.

#### PROGRAM PREPARATION

The sponsors wanted the research to be comprehensive and thorough. They wanted the paper to be evaluated to behave in a way that would mirror the behavior of commercial papers, but to be specially made under conditions of thorough documentation of materials and methods of manufacture. A total of fifteen paper compositions were defined that covered a wide spectrum of paper characteristics. They ranged from pure cotton papers to those containing all of the lignin from within the wood from which the paper fibers were derived. A mix of both acid and alkaline papers was included in the array.

Thirteen of the papers were made on a small paper machine at the Herty Foundation in Savannah, Georgia. Herty is a highly respected organization that has four small “pilot” paper machines for the manufacture of experimental and small quantity commercial grades of paper. They have an excellent laboratory in which the paper can be tested for a wide variety of performance factors.

Originally it had been hoped that the Herty Foundation could make all fifteen papers. However, it was found that they could not effectively process the long-staple textile grade cotton fiber specified by the sponsors. Very generously Crane & Co., Inc., the makers of U.S. currency, donated all materials, labor, and manufacturing time on one of their commercial paper machines in Dalton, Massachusetts. It was from that source that the two cotton papers were obtained. The full list of papers evaluated in the research program is shown in table 1.

None of the papers was printed or coated because of the confounding effects those additional treatments would have created in the attempt to understand the causes and effects in the aging process. Neither was recycled fiber included in the composition because there is no single mix of wastepaper that is a standard recipe for making recycled paper.

In making the papers there was extra effort made to thoroughly document all ingredients and papermaking variables. They were then very thoroughly tested for a variety of performance factors when freshly made.

There was a large quantity of paper made during each paper machine run. Large rolls of each of the fifteen paper types were produced. These large rolls were then cut to individual sheets at full paper machine width. They were then cut again into sheets of standard office cut size, namely, 8-1/2 inches by 11 inches. When these steps had been completed, approximately 30,000 sheets of paper of each type were available for research study.

To ensure that each laboratory that would study the papers had the same paper source, a rigorous, statistically accurate procedure was used to randomize or shuffle the papers. When this was completed, every 500-sheet ream of paper sent to the labs contained some of all portions of the specific paper from the individual production run associated with that paper type.

To as fully as possible prevent the paper from aging during storage, each ream was wrapped in polyethylene plastic film, and placed in an acid-free carton; multiple cartons were packed in sealed corrugated containers. It was felt that the film and acid-free cartons provided a sufficient barrier to prevent any chemical interaction between the corrugated containers and the paper samples. The containers were kept in cold storage at temperatures just above the freezing mark. Thus the paper was stored cold and in the dark until used.

#### ACCELERATED AGING RESEARCH PROGRAM

Five laboratories were awarded contracts to undertake the research. They were as follows:

Temperature Aging Studies:

- Canadian Conservation Institute (CCI) in Ottawa, Canada, under the direction of Dr. David Grattan, Mr. Paul Bégin, and Ms. Elzbieta Kaminska;

Sample Number	Pulp Type Number 1	Pulp Type Number 2	pH	pH Control Chemical	CaCO <sub>3</sub>	Starch	AKD or Rosin Size
1	100% BNSWK	None	5	Alum	None	None	2#/T Rosin
2	100% BNSWK	None	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
3	100% SW-BCTMP	None	5	Alum	None	None	None
4	100% SW-BCTMP	None	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
5	100% COTTON	None	5	Alum	None	None	2#/T Rosin
6	100% COTTON	None	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
7	20% BNSWK	80% SLUSH-SGW	5	Alum	None	None	None
8	20% BNSWK	80% SLUSH-SGW	7	SMI Process	5% PCC	None	None
9	20% BNSWK	80% HW-BCTMP	8.1	Na <sub>2</sub> CO <sub>3</sub>	None	None	None
10	20% BNSWK	80% ITW-BCTMP	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
11	50% BNSWK	50% BNHWK	8.1	Na <sub>2</sub> CO <sub>3</sub>	None	None	None
12	50% BNSWK	50% BNHWK	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
13	50% BNSWK	50% ITW-BCTMP	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	None	None
14	50% BNSWK	50% HW-BCTMP	5	Alum	None	None	2#/T Rosin
15	50% BNSWK	50% BNHWK	8.1	Na <sub>2</sub> CO <sub>3</sub>	5% PCC	Purified Gum	4#/T AKD

In the table above, the following are definitions of the terms used:

AKD = Alkyl Ketone Dimer, an alkaline sizing material

Alum = Aluminum sulfate, Al<sub>2</sub>SO<sub>4</sub>, a chemical used to cause pine tree resin to stick to the paper fibers

BNHWK = Bleached Northern Hardwood Kraft (a type of hardwood chemical pulp that has high cellulose content)

BNSWK = Bleached Northern Softwood Kraft (a type of softwood chemical pulp that has high cellulose content)

CaCO<sub>3</sub> = Calcium carbonate, a chemical that reacts more readily with acids that find their way into paper than the paper fibers themselves. It is known as an "alkaline reserve" to protect the alkalinity of the paper.

COTTON = Long-staple textile grade cotton

ITW-BCTMP = Hardwood Bleached ChemiThermoMechanical Pulp (a type of hardwood pulp with high lignin content)

Na<sub>2</sub>CO<sub>3</sub> = Sodium carbonate, a chemical used to make the paper alkaline

PCC = Precipitated Calcium Carbonate, a type of alkaline reserve

Purified Gum = A type of commercial starch used to size paper to make it partially waterproof so ink will stay on its surface when applied

pH = a measure of paper acidity. 7 is neutral. Less than 7 is acid. Greater than 7 is alkaline

Rosin = Pitch from pine trees used to size paper. When used with alum, it creates a fairly strong level of acidity in paper.

SLUSH-SGW = Never-dried pulp of Stone GroundWood (a mechanical process in which the debarked tree is ground into fiber, thus containing all the lignin originally occurring in the tree)

SMI Process = A patented process of Specialty Minerals Inc. for treating mechanical groundwood papers to permit the use of calcium carbonate fillers without darkening of the paper

SW-BCTMP = Softwood Bleached ChemiThermoMechanical Pulp (a type of softwood pulp with high lignin content)

Table 1. Paper sample composition

- U.S. Library of Congress (LOC) Preservation Research & Testing Division in Washington, D.C., under the direction of Dr. Chandru Shahani.

#### Light Aging Studies:

- USDA Forest Products Laboratory (FPL) in Madison, Wisconsin, under the direction of Dr. Rajai Atalla, Dr. James Bond, and Mr. Chris Hunt;
- Oy Keskuslaboratorio Centrallaboratorium Ab (KCL) in Espoo, Finland, under the direction of Dr. Ingegerd Forsskåhl.

#### Pollutant Aging Studies:

- Image Permanence Institute (IPI) at Rochester Institute of Technology in Rochester, New York, under the direction of Mr. James Reilly, Dr. Peter Adelstein, and Mr. Edward Zinn.

#### Temperature Aging Study Procedures

In the temperature aging studies, three configurations were used to accelerate the paper aging process. In one, individual free-hung sheets were suspended in an oven in which both temperature and relative humidity could be controlled. The second method utilized the same oven, but the sheets of paper were placed in a stack between plates of glass to simulate the condition of a closed book in a bookshelf. The final technique made use of high quality glass tubes that could be hermetically sealed. In this case, the aging was done in a dry oven, as the moisture contained in the paper could not escape from the sealed tube.

It was necessary in all three accelerated aging situations to manage the process so as to hold paper moisture content constant. Thus the two paper configurations aged in the humid oven required that relative humidity be raised to prevent moisture from evaporating from the paper. Holding moisture constant was important to ensure that similar chemical reactions could occur within the paper as do at normal room conditions.

Aging of the papers was done at four temperatures and five aging times. For a given temperature, plots of the change in physical strength and optical properties through time were developed. The intent was to look for straight lines through the various points. If such lines were present, that suggested that the reactions followed Arrhenius relationships and could be extrapolated back to room conditions. Because the accelerated process was done in only a matter of a few days at the elevated temperature, it was important to develop the straight lines. To create the same degree of aging at normal room conditions would have required a period of years. The intent of the accelerated process being to gain reasonable predictions of aging behavior of various papers, it was important to be able to project life expectancies under normal aging conditions.

The physical properties of strong papers show no to very little change in the early stages of their aging, even though chemical changes have already taken place within

the structure of the fibers. Therefore an important element of the studies was to look at changes in the length of the cellulose molecules, which make up the greatest amount of paper sheet strength. Very careful studies of this nature were undertaken at the Canadian Conservation Institute and provided a means to track chemical changes over the entire period of aging.

It was important in this work to show that the changes in the physics and chemistry of the individual papers were essentially the same in the accelerated work as occur in natural aging. Sophisticated studies at the Library of Congress permitted evaluation of the chemical products produced by aging. These studies involved use of ion chromatography, gel permeation chromatography, high performance liquid chromatography, and other precise chemical analytic tools. Using such information it was possible to compare chemical products that were evolved in the papers aged by the elevated temperature method with those contained in papers of similar composition that had been resident at the Library for one hundred years or more.

#### Light Aging Study Procedures

Two separate elements of study were undertaken at the labs that were engaged in the light aging work. In the first, very long-term natural aging was conducted. In the second, two different methods for accelerating aging were undertaken.

At the Forest Products Laboratory, three special chambers were prepared for the natural aging study. In one, a standard gypsum wall was constructed opposite a nearly floor-to-ceiling window that faced north. All fifteen of the ASTM papers were hung on that wall and exposed continuously to natural daylight for over four years. Such a period of exposure is equivalent to centuries of such exposure for the vast majority of paper uses. In normal handling practice they would see such light exposures for only brief, interrupted periods. In the same large room, two additional, completely isolated chambers were also constructed. In one, fluorescent light illuminated the papers. In the other, halogen light was used. In both cases the level of illumination to which the papers were exposed was equivalent to that which is found at desktop in a well-lit office space. The light bulbs in these chambers were changed well before their normal life expectancy to assure a very constant level of exposure. These chambers were illuminated around the clock every day of the year. They too were exposed for over four years of continuous illumination.

At KCL, which is at sixty degrees north latitude, the natural aging studies were conducted in a southeast-facing window for two summers. Because that location is so near the Arctic Circle, there is a very extended period of daylight in the summer months.

In the accelerated aging studies, both xenon arc and ultraviolet-only light sources were used to provide the high light flux needed to promote rapid aging. Xenon arc light was used because it very closely simulates natural daylight that has passed through window glass. The ultraviolet light was of interest because it is at those wavelengths that the greatest optical damage is done to papers.

In both the natural and accelerated aging studies, a series of evaluations were made to understand how the photochemistry was impacting both physical strength and optical properties.

#### Pollutant Aging Study Procedures

At the Image Permanence Institute, two carefully designed chambers are available for aging materials in gas polluted environments. The chambers were originally created for study of photographic film aging.

In the ASTM study, the papers were hung separately from rods inside the chambers. Then various levels of gas concentration were applied to the papers for a range of aging times. The gases studied were sulfur dioxide, oxides of nitrogen, and ozone. These are the most common pollutant gases found in our industrialized world. They are emitted from automotive vehicles and industrial operations. The gases were studied individually and in combinations. They were applied at levels that were ten, one hundred, and one thousand times greater than would be found in an average office space in a polluted urban area. The temperature in the aging chambers was held at normal room level. At various times during exposure sheets of paper were removed to be tested for physical strength and optical properties. It is clear that this study of the effect of pollutant gases on the aging of paper was by far the most comprehensive such scientific work ever attempted to this date.

#### LONG-TERM NATURAL AGING STUDY

During the literature search preceding this program, it was recognized that there was an almost total lack of information on the natural aging of paper that had been done on well-documented papers under tightly controlled conditions. Therefore the sponsors agreed to launch a century-long study of such scope using the fifteen special papers made for the ASTM program.

Ten libraries in the U.S.A. and Canada agreed to participate in the program. They are located in both urban and small city locations. Some have state-of-the-art control of their storage spaces while others have only moderate control of the library environment. A complete list of the libraries is included in appendix 1.

A very comprehensive set of instructions and program background information has been placed along with the

collections of the fifteen books of ASTM papers at each library. By virtue of required monthly monitoring and reporting of environmental conditions (i.e., temperature and humidity) in the various storage spaces, there is reasonable assurance that the program will be continued even though the personnel involved change many times over the one hundred years of the study.

Four of the five labs that have conducted the accelerated aging research have agreed to accept papers from the libraries for at least the next thirty to forty years. They will conduct routine testing of the papers as received. Graphs of the changes in paper performance properties (strength, optical, chemical, etc.) will be created and an excellent database for use by future producers and users of printing and writing paper will thus be created. It is expected that it will serve as an outstanding set of data on which to base prediction of life expectancy of newly made paper in future years. The first test began in June 2000 and the next is scheduled for June 2003.

#### LIFE EXPECTANCY PREDICTIONS

In order to make reasonable predictions of paper life expectancy, it was necessary that relevant data be developed to compare papers that had been aged naturally with those of this program that had been aged rapidly. To ensure an "apples-to-apples" comparison, it was necessary that the composition of the old and new papers be quite similar. The program developed three means to make these comparisons.

In the light aging studies the very long, continuous periods of exposure to light gave excellent information by which to compare natural and accelerated aging of identical papers. In that case, since the same papers were involved in both aging experiences, a one-to-one comparison could be made.

Old papers were found at the Library of Congress that had composition very similar to papers of the ASTM program. By looking at the chemical products of degradation of those old papers, direct comparisons could be made with the similar chemical products from the freshly aged papers of this program.

Finally it was discovered that the Forest Products Laboratory had saved samples of every run of experimental paper made on its pilot paper machine for the last sixty years. In addition, they had preserved the machine settings information and initial paper properties information from the time the paper was first produced. It was found that a number of the paper samples had composition very similar to a number of the fifteen papers of the ASTM program. That provided a means to track paper degradation over a series of decades of natural aging and to allow comparison with the new papers that had been aged quickly.

## PRELIMINARY FINDINGS

### Temperature Aging Studies

Paper ages more rapidly in stacks than in single sheets. This appears to be caused by the buildup of acids that are products of decomposition within the stack. These products cannot easily diffuse from the stack, whereas some of them are sufficiently volatile in the free sheets that they can evaporate away from the paper. It is well demonstrated that acid hydrolysis (shortening) of the cellulose fibers is the major cause of paper degradation. Thus the more acidic the paper becomes, the more rapid is its degradation.

Chromatography techniques were used to track chemicals that evolve during paper degradation. They defined "marker" chemicals that behaved in the same ways under both natural and accelerated aging and show that the mechanisms of the two processes are essentially the same. That finding shows that the chemistry and physics of the accelerated aging technique mirror that which occurs in a natural aging experience. This provides powerful evidence that the proposed test method will be shown to be scientifically sound.

Because of the simplicity associated with aging inside sealed glass tubes, it is likely that the test method recommendation will specify this means. To do so would permit aging to take place in a dry oven. The other two methods require very precise control of relative humidity in the aging oven. This makes the ovens expensive and much less broadly available than simple dry ovens.

### Light Aging Studies

In natural aging daylight is more damaging than artificial light in the early stages of aging. Additionally in natural aging, all papers reach a limit beyond which loss of optical properties ceases. The papers remain optically stable thereafter.

In a minor way color and brightness properties of the paper are affected by humidity change. In the chambers at the Forest Products Laboratory, temperature was held quite constant. However at the forty-seven degrees north latitude of Madison, Wisconsin, the amount of moisture that can be held in the outside air is much lower in the cold of winter than in the warmth of summer. Thus when the cold outside air is brought into the building for ventilation purposes in the winter and is heated, it yields a very low indoor relative humidity. When this winter air was circulated about the aging papers, the optical properties became slightly brighter than when the more humid air of summer was in the room.

The rates of change of optical properties differ considerably depending on the particular paper composition. For example, the cotton papers and those of pure chemical wood pulp lost optical properties only very slowly. Those containing lignin experienced rapid loss of optical proper-

ties. This was as expected because of the known photoreactivity of lignin.

From the extensive work at both FPL and KCL, it is clear that interested parties will be unable to predict the life span of a paper to an intermediate level of brightness or color. That is to say that if a paper had ISO brightness of ninety percent when freshly made, and for a given user it would no longer serve the user's needs below an ISO brightness of eighty-five percent, it will not be possible to predict the time to pass the eighty-five percent mark. However, users will be able to predict the relative amount of time for all papers to reach steady state optical properties. That is to say that the point at which a given paper reaches relative stability of optical properties will be a predictable condition. Those that will be stable for long periods of time will be able to be separated from those that will be unstable with regard to preservation of optical properties. Another way to say this is that the relative rates at which different papers will lose optical properties will be defined by the proposed test method.

An unexpected finding of the light aging work was that all papers (including those of pure cotton) suffered measurable strength loss over the extended time of natural aging. Almost certainly this was primarily caused by the photochemistry created by incidence of light on the paper surfaces. This finding has significance to libraries and archives that are entrusted with the keeping of valuable documents over very long periods of time. It provides additional emphasis to the need to prevent such papers from exposure to bright light for extended periods.

### Pollutant Aging Studies

Even after exposure to the highest concentration of pollutant gases (one thousand times the amount found in an office space in a polluted urban environment), there was only very small loss of paper strength. The most sensitive strength test, fold endurance, was the only parameter which showed this loss of strength.

Color change was another matter. When lignin-containing papers were exposed to oxides of nitrogen, they darkened and turned very yellow. The buffering effect of calcium carbonate contained in about half of the papers had only minor beneficial effect in reducing yellowing behavior.

It had been hoped that exposure to elevated temperature following the pollutant aging would spread the differences between papers more greatly than the data from just pollution exposure. If this had been the case, a better understanding of relative life expectancies of different papers could have been had. The spread of information was conjectured to happen on the basis that a substantial quantity of acidic chemical would have been taken up by the paper during the pollution exposure. Unfortunately the post aging with elevated temperature did not provide fur-

ther distinction between the papers. Those that were stable during pollution exposure remained stable when further exposed to elevated temperature. Those that were unstable were still unstable. None that were initially stable became only moderately stable.

#### LIMITATIONS

The expected test methods will provide approximations of relatively stable versus unstable papers. It will not be possible to specify a particular number of years for the life expectancy of the particular papers. Indeed, for the requirements of different users, the same paper may have very different period of usefulness. This is because, for example, one user may require high strength while another requires only moderate strength. Say the paper started with strength of 200 units. If, for the first user, the paper was no longer useful when strength dropped below 180 units, but for the second, the paper continued to be useful until strength dropped below 100 units, it is clear it would have much greater period of usefulness for the second user.

Storage and handling conditions will affect life expectancy. A paper that is seldom used, is stored under ideal conditions of moderate temperature, low relative humidity, constant conditions, and little exposure to light, and is kept in a space that has excellent filtration systems to keep out pollutant gases, has good probability of reasonable life, even if the paper is somewhat unstable to aging. On the other hand, if the paper is frequently used and is kept in conditions that are hot, humid, and variable, it will have less life expectancy.

From the research of this program, it is clear that stable papers will be readily discriminated from those that are unstable to aging effects. Beyond that capability, much will depend on the needs and handling practice of the end users.

#### TIMETABLE

At the writing of this paper, all research had been completed, with the exception of fairly extensive tests to confirm the validity of the proposed temperature aging test method. That work will be complete at the end of October 2000.

A group of ten different distinguished individuals has agreed to provide peer review of the three separate studies. They are either scientists or paper conservators who have distinguished themselves in the area of the particular science associated with the test method they will review. Trusted people from the library and archive communities who understand the issues associated with paper longevity but do not have a strong background in paper science have also been included in the panels. In addition, a high-

ly recognized scientist has been retained to serve as editor/referee of the peer review process. All of these persons are third parties with no tie to the research effort. This has been done to insure the highest possible level of integrity for the peer review process. The final research reports will be issued only after all valid issues raised in the peer review have been answered by the particular lab to the satisfaction of the editor.

Upon the publication of the final reports early in 2001, ASTM Committee D6 on Paper and Paper Products will develop standard ASTM test methods for each of the three protocols. These will be balloted and it will be only after consensus agreement has been reached on their wording and validity that the test methods will move into publication and availability for use by all interested parties.

#### PRELIMINARY CONCLUSIONS

There is high probability that the science will be sufficient to lead to sound test methods for the prediction of printing and writing paper life expectancy. Rather than specific year periods, the standards will identify stability rankings. Three classes of stability are expected to be included in the new test methods. They will define those papers that will be stable for long periods of time, those that will be only moderately stable, and those that will be unstable to aging effects. If all parties agree that the science permits those ratings to be soundly made, it will be possible to move to performance-based standards for printing and writing papers.

The proposed temperature aging test method will likely call for aging in sealed glass tubes in a dry oven. The proposed light aging method will likely call for use of a xenon arc lamp with filters to simulate natural daylight that has passed through window glass. The proposed pollutant aging method will likely call for use of just one gas, as nitrogen dioxide exposures produced the strongest and most useful paper changes. The pollutant and light aging tests will be conducted at room temperature. Specific aging times will be proposed for each of these tests.

#### ASTM STANDARDS MAKING PROCESS

If at the time of reading of this paper it can be determined that the ASTM process for adopting these new test methods is still in progress, all interested parties are encouraged to join ASTM. In the year 2000, the annual membership fee is just U.S. \$65.00. All active members are able to participate in the debate over the wording and scientific sufficiency of the proposed standard test methods. The widest possible audience is sought in the debate to ensure that the issues and concerns of all parties have been considered and resolved prior to issuance of the test methods.

## ACKNOWLEDGMENTS

Thirty-three organizations participated in funding this research. Included in the list were:

- Sixteen pulp and paper companies,
- Five federal libraries, archives, and museums,
- Four non-government organizations (NGOs),
- Four government agencies with broad charters,
- Four suppliers to the pulp and paper companies.

A full list of the individual organizations is included in appendix 2.

R. BRUCE ARNOLD

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APPENDIX 1: LONG-TERM NATURAL AGING  
STUDY: LIBRARY LOCATIONS

Arizona State University  
Canadian Conservation Institute  
Columbia University  
National Archives and Records Administration  
National Library of Medicine  
University of British Columbia  
University of California at Berkeley  
University of Florida  
University of Texas at Austin  
Washington University (St. Louis, MO)

APPENDIX 2: FINANCIAL AND IN-KIND  
CONTRIBUTORS TO THE RESEARCH PROGRAM

*Sixteen pulp and paper companies:*

Abitibi-Consolidated Inc.  
Appleton Papers Inc.  
Boise Cascade Corp.  
Bowater Pulp & Paper Canada Inc.  
Crane & Co., Inc.  
Domtar, Inc.  
Donohue, Inc.  
Fibreco Pulp Inc.  
FICAB  
Fletcher Challenge Canada Ltd.  
Fraser Paper Inc.  
Millar Western Forest Products Ltd.  
Simpson Paper Co.  
Stone Container (Canada)  
Tembec Inc.

West Fraser Pulp Sales

*Five Federal Libraries, Archives and Museums*

Australian Archives

National Archives and Records Administration (USA)

National Gallery of Art (USA)

National Library of Medicine (USA)

U.S. Library of Congress

*Four Non-Government Organizations*

Canadian Cooperative Heritage

FACTS Institute

National Information Standards Organization

Heritage Preservation

*Four Government Agencies*

Alberta Economic Development and Tourism

Industry Canada

National Institute for Standards and Technology (USA)

USDA Forest Products Laboratory

*Four Suppliers to the Pulp and Paper Industry*

Andritz Sprout-Bauer

Ciba Specialty Chemicals Corp.

Degussa Canada Inc.

Specialty Minerals Inc