Introduction

PURPOSE OF THIS STUDY

Millions of books at the Library of Congress and other libraries around the world are deteriorating. Many books published since the mid- 1800s are currently, or will soon become, too fragile to handle. The paper these books are written on becomes brittle over time and crumbles. The primary cause of this deterioration is acid. Chemicals used in the manufacture of paper from wood pulp, which stay in the paper, convert to a variety of acids and slowly destroy the strength of the paper's fibers over time. Other factors such as oxidation, varying or extreme temperature and humidity, exposure to light, air pollutants in storage areas, and the amount of use also contribute to the destruction of the books.

The Library of Congress has been working to solve the problem of acid paper in books since the early 1970s, developing a mass deacidification process that would inhibit the deterioration of book paper. About 25 percent of the 14 million books at the Library of Congress are too brittle for normal use. The main purpose of the Library of Congress program is to preserve and extend the life of paper materials before they reach this brittle, unusable condition. This would involve deacidification of new materials coming into their collection as well as existing materials not yet damaged beyond use.

Other libraries and researchers have also worked on this problem and small-scale processes are in use. The purpose of this assessment is to evaluate the appropriateness of the system under development by the Library of Congress and compare it to other available or potential processes. Although this report focuses mainly on the Library of Congress, it will hopefully assist the library community, in general, with decisions on how to cope with the acid book problem. Another recent report on this subject is titled "Mass Deacidification for Libraries' by George M. Cunha, published in Library Technology *Reports* of the American Library Association.

What Is The Library of Congress?

- The largest center for information storage in the world.
- Collections include 19 million volumes and 58 million pieces of stored data on phonograph records, motion picture reels, computer tapes, manuscripts, maps, prints, and photographs.
- Three Canons of Selection established in the 1940s to define the collections:
  - —materials necessary to the Congress and to the U.S. Government officers in performance of their duties;
  - —materials that express and record the life and achievements of the people of the United States; and
  - —records of other societies and peoples, especially those of most immediate concern to the people of the United States.
- Less than 25 percent of the collection is in English.
- Serves five audiences:
  1. Congress—Library provides research support, policy analysis, and training through the Congressional Research Service;
  2. professional library world—Library provides cataloging and other bibliographic services and leadership on library technology;
  3. executive agencies—Library provides information resources;
  4. scholars—Library provides research collections and support; and
  5. creative world—Library protects products and preserves traditions.

SOURCE Charles A. Goodrum and Helen W Dalrymple, *The Library of* Congress (Boulder, CO Westview Press, 1982), p 337

THE ACID BOOK PROBLEM

The problem of acid deterioration of library books and other assets is not new. In 1898, an international conference was organized to discuss the poor quality and lack of permanence of paper made by recently developed wood pulping processes. [1] *Dur-*

[1] K. G. Schmude, "Can Library Collections Survive? The Problem of Paper Deterioration, *The Australian Library Journal, vol. 33, No.* 1, February 1984.

ing the 1930s a number of researchers began to study the problem more systematically, establishing a correlation between the acid content of paper and its lack of permanence, and began experimenting with new papermaking processes for making acid-free papers. In the 1950s, the Council on Library Resources became a leading supporter for research on paper permanence, eventually leading to standards for permanent paper.

Although there has been an awareness of the problem for almost 100 years, a more global sense of urgency has only recently developed. The rapid increase in the size of library collections beginning in the late 19th century has created for the libraries and other institutions a crisis of enormous proportions that is now "coming of age.

Although the materials and techniques used to make paper have changed, the underlying principles involved have changed little in 1,700 years. Materials containing cellulose (e. g., mulberry, flax, cotton, wood) are beaten and macerated in water creating pulp. The pulp is then formed in a mold and dried, leaving behind a mat of cellulose fibers. The water that remains after drying holds the matted fibers together. Additional substances are added in the processing that give paper its other familiar qualities. Sizing agents are added to reduce the penetration of liquids, making it possible to print without blotting. Fillers are sometimes added to make the paper whiter and opaque. Dyes, pigments, and strengtheners can also be added.

Paper can be extremely stable, maintaining its durability for centuries if taken care of properly. There are many examples of books published as far back as the 1500s that are still in fine condition. Paper permanence, the ability of paper to maintain its durability over time, has slowly declined over the years, however, to the point where we are lucky if the vast majority of "modern' papers, paper made since the mid-19th century last 50 years.

The more rapid deterioration of modern paper has been attributed to acids that accumulate in the paper. The source of the acids are chemicals that are either introduced during the papermaking process or are introduced subsequently from the environment. The acids attack the cellulose that makes up paper, breaking it into smaller and smaller pieces, until the paper has lost all of its durability.

Actually, the use of acid-producing materials in papermaking began as early as the late 17th century when European papermakers began to use alum (aluminum sulfate) in addition to animal gelatin as a sizing agent. Alum, in time, can be converted to sulfuric acid. Measurements of 400-y ear-old papers revealed that those with alum sizing have a higher acid content than those papers that just used animal gelatin or no sizing at all. [2]

How the Library of Congress Obtains Materials

1. *Copyright Office* receives about 130,000 books, 230,000 periodicals, and tens of thousands of sheets of music each year. It also receives maps, motion pictures, telephone directories, phonograph records, computer tapes, ballet notations, etc. All of these materials are received free of charge.
2. *Government Exchange* provides records of affairs from Federal, State, major cities, and foreign governments, as well as international government organizations. About 4 million publications are obtained through these channels each year. None of these materials are purchased. The Library obtains non-Federal materials by trading Federal publications.
3. *Gifts* include personal papers given outright or deposited with the Library. In 1980, about 1.8 million pieces were received.
4. *Purchased Materials* include:
   - newspapers —330 U.S. and 1,000 foreign;
   - foreign magazines—about 30,000;
   - foreign books—includes significant nonfiction and representative literature;
   - research materials for the CRS Library; and
   - blind and physically handicapped collection, this is the largest portion of the purchase budget, in 1980, about 1.9 million volumes were purchased for about $35 million.

SOURCE Charles A Goodrum and Helen W Dalrymple, *The Library of Cum gress* (Boulder, CO Westview Press, 1982), p 337

[2] W.J. **Barrows Research Laboratory, Inc., "Permanence/Durability of the Book, Vol. VII: Physical and Chemical Properties of Book Papers, 1507 -1949," 1974.**

It was not until a series of innovations in the 19th century, however, that the acid content of paper rose dramatically. Alum-rosin sizing was introduced in 1803, replacing gelatin and gelatin-alum sizing. Alum-rosin sizing required excess alum, increasing the amount of this acid producing substance in the paper. In the mid-19th century, rags and linen were replaced by wood as the major cellulose feedstock. Wood pulp contains lignin and hemicellulose that easily breakdown in air, causing discoloration and forming acidic compounds. In addition, wood cellulose is more susceptible to acid reactions than the cotton cellulose derived from rags and linen. By the end of the 19th century, chemical wood pulping processes were developed to remove lignin (because of the discoloration it caused) but did so by using acidic solutions. As a consequence of these innovations, paper produced since the mid- 19th century can have an acid content today 100 times greater than paper produced in the 1500s.[3]

The effect of this higher acid content can be devastating. In 1959, the William J. Barrow Research Laboratory, with support from the Council on Library Resources, measured the durability of books published in the United States between 1900 and 1949.4 A 500-book sample was taken from libraries in and around the Richmond, Virginia area where the Laboratory was located. The study determined that 39 percent of the books published between 1900 and 1939 had already become very weak; the pages would crack after moderate use and would probably become too brittle to handle at all in another 25 years. Furthermore, another 49 percent of the books had a durability less than that of newsprint, the weakest paper used for printing.

Numerous libraries have sampled their collections and found the same sobering statistics (e. g., University of California, Yale, and Stanford). Yale's study concluded that 43 percent of the libraries' 9 million books are brittle and another 44 percent have a high acid content.[5]

The extent of the problem nationwide is staggering. The Association of Research Libraries (ARL) has estimated that 75 million books in the Nation's research libraries alone are endangered. Although many of these are still in print and can be repurchased by libraries, the ARL estimates that over the next 20 years, at least 3.3 million volumes must be transferred to another format if the the information they contain is to be saved. [6]

[3] Ibid.

[4] W.J. Barrow, "Deterioration of Book Stock, Causes and Remedies," Randolph Church (cd.) (Richmond, VA: Virginia State Library 1959)

[5] Gay Walker, Head of the Preservation Department, Yale University Library, personal correspondence, July 10, 1987.

[6] Council on Library Resources, "Brittle Books: Reports of the Committee on Preservation and Access, Washington, DC, 1986.

APPROACHES FOR ADDRESSING THE ACID BOOK PROBLEM

Acid-Free Paper Production

The most obvious solution to the acid book problem is to make and use alkaline (acid-free) paper. New mass-producing technologies for such papers have been developed since the 1930s. Many university publishing houses now require the use of alkaline paper, and libraries have lobbied papermakers and publishers to move in this direction. However, there are a number of economic obstacles that impede the transition and it appears that only 15[7] to 25[8] percent of the book paper produced in the United States is alkaline. The prospects for producing more alkaline paper in the future will be discussed later in this report. Even if widespread use of acid-free paper occurred tomorrow, however, the problem remains of how to preserve the paper or the information that has already been accumulated,

Preservation Techniques

Libraries are no strangers to preservation. Over 40 institutions nationwide are actively *pursuing*

[7] C.J. Shahani and W.K. Wilson, "Preservation of Libraries and Archives, *American Scientist, vol. 75,* May-June 1987, referencing R.G. Johnson, "U.S. Alkaline Fine Papermaking To Experience Slow But Steady Growth, *Pulp and Paper,* December 1986.

[8] "Report on Library of Congress Conference on Paper for Book Longevity," Library of Congress Information Bulletin, vol. 40, No. 13, Mar, 27, 1981.

How the Library of Congress Selects Materials

- About 10 million items are received by the Library each year, of these about 1.5 million items are selected for inclusion in its collections.
- Selection policies are based on subject matter, four levels of retention (i.e., comprehensive, research, reference, minimal), specific decisions about a subject and specific decisions about individual items.
- Routine selection involves review by about 30 specialists. About 30 other people are involved in processing the book and getting it onto the shelves.
- Most domestic books are obtained through the Copyright Office. The Library retains the majority of hardback books, a sampling of paperbacks, and many college textbooks. Almost no texts for elementary or high school are retained.
- Most foreign books are selected after purchasing the same publications as the largest library in the country or by working with a single dealer in a particular country.

preservation programs,[9] spending millions of dollars each year. The nation-d libraries and archives of many other countries are also actively engaged.

Preservation involves a wide range of activities, including the general conservation of important and rare books and documents, environmental control, and the training of staff in proper storage and handling procedures. Many techniques have been developed and are in use today. Aside from the environment control techniques and general handling and storage procedures, many of these techniques are essentially manual operations performed one page at a time, are very time-consuming, and often require skilled practitioners. The size of the acid book problem now and in the future, however, dwarfs the current efforts and will require adapting existing techniques or developing new ones.

There are two aspects to dealing with the acid book problem—preserving the information that exists on materials that have already become brittle, and preserving those materials that have not yet become brittle. This study will focus on deacidification of materials before they become brittle and will not cover the technologies or techniques that have been developed to transfer the information to another media or format. However, a short discussion on paper strengthening follows here.

Strengthening

In cases where it is desirable to maintain the original format, embrittled materials can be handled by laminating or mounting, An early technique for laminating brittle paper was to sandwich it between finely woven silk, using starch or paraffin as an adhesive. During the 1930s, the National Bureau of Standards developed a technique that sandwiched brittle paper between two sheets of cellulose acetate, the cellulose acetate was bonded to the paper by heating and pressing. The Library of Congress developed a technique that encapsulates the paper between two sheets of polyester film (e. g., mylar) .10 The film is bonded around the edges but is not bonded to the paper, therefore, the technique is reversible.

Although these techniques can be automated to some extent, they can only be done a single sheet at a time. Books would have to be unbound and then rebound. Costs are high and the process is usually limited to preserving rare books.

New techniques are being developed that would actually strengthen the paper by polymerization. This essentially reverses the breakdown of cellulose fibers by forming physical links between the broken cellulose fibers, restoring the paper's flexibility. Of course, this is a short-term solution for acidic papers unless deacidification is also part of the treatment.

Deacidification

For materials that have not yet become brittle, techniques have been developed to neutralize the acids that cause the paper to deteriorate and to deposit an alkaline buffer that acts as a reserve to neutralize any acids that may continue to form. The objective is to extend the life remaining in the pa-

[9] "Millions of Books Disintegrating in Nation's Libraries, Anderson *Daily Bulletin*, Oct. 23, 1986.

[10] C.J. Shahani and W.K. Wilson, "Preservation of Libraries and Archives," *American* Scientist, vol. 75, May-June 1987.

Photo credit: Library of Congress

Manual book deacidification technique treats one page at a time.

per at the time it is treated. The history of the development of single sheet, spray and mass deacidification techniques, including the contributions of the William J. Barrows Research Laboratory, are described in greater detail in other documents.[11]

Most of the deacidification techniques in use today are manual liquid solution processes. Sheets of paper are either dipped in or sprayed with a solution containing one or more alkaline compounds. The compounds precipitate out of solution, neutralizing the acids. Excess precipitate is deposited as a buffer. The alkaline compounds are normally magnesium or calcium carbonates and the solvents can be aqueous or non-aqueous.

Current manual techniques are time-consuming and expensive. The paper must be treated one page at a time. Books must be unbound if they are dipped into the solution. Each page must be tested to make sure that inks, colors, etc. are compatible with the solvents being used. Some solvents not only dissolve the alkaline compounds used to neutralize the acids but will also dissolve certain inks and pigments and other book materials. These processes are painstaking operations and demand highly skilled practitioners. They are normally used only for rare books where the value of maintaining the original format is greater than the cost of treatment.

[11] See C. J. Shahaniand W. K. Wilson, "Preservat **ion of Libraries and Archives, "** *American Scientist,* **vol.** *7.5,* **hfay-June** 1987, pp. *240-251 ;* **and** George M. Cunha, **" Mass** Deacidification **for Libraries,** *Library Technology Reports,* **.May-<June 1987,** pp. **363-477**

The lack of financial resources, time, and manpower make it impossible for most of these preservation processes to be of much use in tackling the more general acid book problem. Over the last 10 to 15 years, mass deacidification techniques have been under development that would treat many books at once. Such techniques would not only increase the number of books that could be treated, from tens of thousands to hundreds of thousands if not a million books per year, but would also lower the cost of treatment per book.

Estimated processing costs for various mass deacidification techniques currently under development range from $2 to $6 per book. These estimates, however, typically do not include the initial capital investment costs (which can be quite substantial) or the costs associated with handling large volumes of books. Book handling will also present a variety of technical and logistic problems that must be considered. Nevertheless, preservationists are looking forward to the development of cost-effective mass deacidification processes.

There are two mass deacidification systems in operation in North America (one at Princeton University and one at the Canadian National Library and Archives) and a few under development (one of these is the Library of Congress' system). Some processes are also under development in Europe.

The two operating systems use the non-aqueous liquid solution developed by Wei T'o Associates. Princeton University uses Wei T'o spray and has developed a semi-automated system. Books are

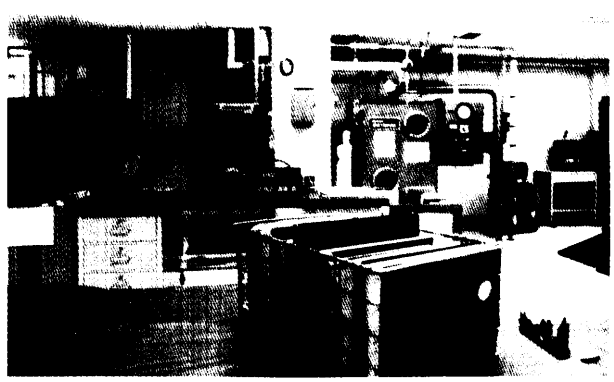

Photo credit: Library of Congress

Wei T'o deacidification system used at the Canadian National Library and National Archives.

treated one at a time in an exhaust hood. The pages are turned manually while an automated spray moves back and forth across the page. The system treats about 1,000 books per year. The Canadians are using a system developed by Wei T'o Associates. Ten to twenty books are placed in a chamber which is then filled with the deacidifying solution. The system was built as a pilot plant to test its feasibility; however, the National Library and National Archives of Canada are now using it in production, treating about 40,000 books per year. A process developed by the Bibliotheque Nationale in France is very similar to the Canadian system and began operations during the fall of 1987.

The Library of Congress is developing a vapor phase process which is the main subject of this report. A pilot plant capable of treating 300 books at a time has been built. Tests on the system began in 1987. Another process under development is called the 'Bookkeeper. Originally developed by the Koppers Co., Inc., the process uses a dispersion to deposit ultra-fine alkaline particles. A pilot-scale system has been designed and awaits demonstration. As this report was being written, another firm proposed a new vapor phase process. OTA has collected available information about all of the processes and has evaluated their relative advantages and disadvantages.

Combined Strengthening/Deacidification

Deacidification techniques are effective for books and paper that are not yet brittle. They cannot, however, restore lost durability. An ideal tool for the preservationist is a process that both deacidifies and strengthens books en masse. It would be very desirable to combine the deacidification processes under development with the strengthening techniques that are also being developed. Such techniques are under development in Europe.

One combined strengthening/deacidification process is operating (at a very small scale) and two are under development. The Austrian National Library has a small-scale system to treat its newspaper collection using an aqueous process with calcium hydroxide for deacidification and methyl cellulose for strengthening. The German Library in Leipzig is developing a different strengthening process using this same aqueous deacidification chemistry. Strengthening will be accomplished by depositing a new layer of paper composed of cotton cellulose fibers. The British Library has begun development of a polymerization process for strengthening. Depending on the chemical used, the process could also be used to deacidify. None of these combined processes have been developed far enough to be considered for mass book preservation in the near future.

FINDINGS

The Library Process and Program

The Library of Congress has recognized the problem of acid deterioration of books and other paper materials for a long time. The Library staff have invested considerable effort in the investigation of deacidification processes and have selected the DEZ process as the one that meets their needs. Selection of the DEZ process by the Library of Congress has followed a logical procedure comparing alternatives on the basis of criteria established by the Library for its collection. Since the late 1970s decision to pursue the diethylzinc **(DEZ) process,** most of the Library's effort has been devoted to perfecting this process and solving the engineering, safety, and other problems associated with the chemical treatment plant.

The Library of Congress has built a second DEZ pilot plant and has begun a series of engineering and process effectiveness experiments as of this writing. The Library staff have done early planning but have not made firm decisions yet about the management, design, construction, and operation of a full-scale facility. A total system including book selection, handling, and transportation is planned, but has yet to be designed. Final plans for contracting and management of the full-scale plant also are needed. The Library of Congress needs to consider important details of project planning and manage-

ment soon in order to more accurately predict costs, capacity, and operational results of this major undertaking.

Technological Effectiveness

The DEZ process developed by the Library of Congress extends the life remaining in the paper at the time it is treated. The Library claims that the process will extend the life of acid book paper three to five times its life if left untreated. These claims are based on fold endurance tests that have been made on a variety of test papers. But it is not clear how long the life of an actual book in the Library's collection will be extended.

The Library intends, as part of its current pilot-plant tests, to analyze the overall benefits to all books to be expected with DEZ treatment. The results of those tests are needed to quantitatively project the benefits of the entire program. Some scientists would also urge more tests on older papers typical of the Library's collection.

Safety

DEZ is a hazardous substance that must be handled carefully and in accordance with strict safety procedures. DEZ will spontaneously ignite if exposed to air. Fire is the principal hazard, and there is a remote chance of explosion. However, DEZ has been used safely for other purposes. There is no unusual fire hazard, however, once the books are treated.

The early engineering development of the DEZ process by the Library and NASA Goddard resulted in an accident caused by inadequate management of engineering and safety procedures. Careful attention to safety and good chemical process engineering standards have been followed with the design, construction, and plans for operation of a second pilot plant with Texas Alkyls in Houston. OTA finds these initial efforts adequate, but pilot plant tests now underway are needed to demonstrate all safety aspects. As of this writing a series of engineering experiments is underway at the Houston pilot plant.

The fill-scale plant, if built, will need equal or greater engineering attention, especially related to safety standards and practices during operations. Scale-up design will encounter additional engineering problems. Safety practices must be developed for a new site, new plant management, new operators, and a new community setting.

cost

To accurately and completely define costs, capacity, and operations for a full-scale DEZ facility, some basic decisions and plans remain to be made. These plans include a total system design, including not only the full-scale DEZ facility but also the procedures for book selection, handling and transportation, and final plans for contracting and management.

For the purpose of this OTA study, the Library of Congress estimated the capital cost of the full-scale DEZ deacidification facility at $4.9 million without a contingency and the annual operating costs for a capacity of 1 million books per year at $1.8 million. These costs do not include a number of items that have not yet been detailed enough to make estimates (e. g., book transportation) or are not considered now by the Library to be applicable (e. g., engineering development at the pilot plant). OTA considers that actual costs could vary considerably from these estimates once the important engineering and planning decisions listed above have been made. OTA also believes it useful to add rough estimates of the missing items and contingencies for unknown factors and thus arrive at a more inclusive budgetary estimate.

The most critical factor in per-book costs is the capacity of the final plant. The vacuum chamber cycle time has a major influence on capacity as do transportation and book handling factors. These latter parts of the system need to be defined. Costs for transportation and handling are also very rough at this time. OTA has attempted to factor in these uncertainties to arrive at its own estimate, OTA has also used a +/-20 percent range of numbers because of the uncertainty of these costs. OTA's resulting per *book cost estimate is from $3.50 to $5.00*

including amortization and interest on capital assuming a 1 million books per year plant capacity.

Alternative Processes

Although the problem of deteriorating paper has been known for almost 100 years, only one mass deacidification plant has been operating anywhere for any length of time. The Wei T'o process has been used by the National Archives of Canada for the past 7 years at a capacity of about 40,000 books per year. There are no deacidification facilities that can handle the large number of books (over 1 million books per year) envisioned for the Library facility. Other systems are in operation at a much smaller scale, are designed for a pilot plant scale, or are only ready for testing on a pilot plant scale.

Of those processes for which OTA had sufficient data, two of them, Bookkeeper and Wei T'o, merit some consideration as alternatives to DEZ.

In general, the effectiveness of deacidification processes has not been unambiguously established. OTA has found no independent tests and evaluations of the Wei T'o and Bookkeeper processes data on treatment results have been developed by the firm or organization that is promoting the process. This is also true of the Library of Congress. (However, the Library of Congress' Laboratory is highly regarded as a leader in the field and tests of DEZ treatment effectiveness are far more extensive than those conducted on the alternative processes.) Without some independent tests with standard procedures, comparisons of the final results of alternative processes will always be uncertain.

By comparison to Bookkeeper and Wei-T'o on a pilot plant scale (50 to 150 books per day), the Library of Congress' pilot plant at Texas Alkyls appears to be considerably more expensive. Whether the cost difference would be significant for a larger scale cannot be determined without further pilot plant tests (not yet done at all for Bookkeeper) and complete design for the large-scale plant.

ORGANIZATION OF THIS REPORT

The remainder of this report is presented in two parts. Part I addresses the Library of Congress' program for mass deacidification of books and other library materials. It analyzes the work completed to date and the specific plans to build and operate a large-scale chemical treatment plant over the next few decades. That plant is expected to deacidify over 1 million books per year.

Part II addresses possible alternatives to the proposed Library of Congress' deacidification system and other issues related to the value of deacidification and the costs and results of other approaches. This part includes discussions of acid-free paper production; the effectiveness and costs of competing processes; and an evaluation of chemical treatment results to be expected.