OPTICAL STORAGE TECHNOLOGY:

APPLICATIONS AND IMPLICATIONS FOR ARCHIVES

by

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ABSTRACT

Optical storage technology has advanced to the point where one can store megabytes and terabytes in a very small physical space. The use of this form of mass electronic storage has the potential to affect the way archives conserve, preserve, store and make accessible the records in their custody. Thus, it is important for archivists to understand not only the technology, but the implications of its use on traditional archival methods and practices.

This study provides a description of the technology, conservation and preservation issues, and archival implications involved in the use of three optical storage systems: WORMs, Rewritables, and Optical Tape. Some of the technological, legal and archival problems associated with the use of these sytems by archival programs or institutions are discussed, and a few case studies involving the use of optical storage systems in archives are presented.

This thesis concludes that, while there are problems associated with the use of optical storage systems as archival conservation and preservation tools, the advantages presented by these systems outweigh their disadvantages.

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ACKNOWLEDGEMENTS

Once more unto the breach, dear friends, once more...
(Henry V, act 3, sc. 1, lines 1-2)

In many ways, writing this thesis **has** been a battle, one which I could not have survived without the help and support of my friends. There were many, many days when I did not know if I was ever going to see the end of this, but somehow my friends managed to get me to see this thesis through to its conclusion. I'll bet they're happier to see this thing over with than I am. I owe many thanks to the people who put up with me and my thesis angst these past two years. Here goes - (in no particular order) thanks to: Luciana Duranti for agreeing to supervise this thesis and giving me the criticism and support my thesis and I needed; the J-Club for the pool, Grad Centre visits and listening to me whine about life, the universe and this thesis; friends at VST for actually paying attention to my "nap time" sign; Bruna, Lyndon and Gerald for their e-mail; Anne for those 2-hour phone calls to Ontario; and most of all Andrea, Heather, Doug, and Ian for putting up with me during my thesis-writing angst, The Hard Drive That Ate My Thesis Crisis, wingeing about WORMs, and for boosting my flagging self-confidence on those innumerable days when I did not have any confidence at all. Thanks folks. I promise never to put any of you or myself through this ever again. And I really mean it this time.

INTRODUCTION

> "But without any doubt, optical storage in one form or another will be playing an increasingly important part in the computers of the next decade and beyond."[1]

In the future, people will take for granted both instant access to and compact storage of vast amounts of information. Present day technology is quite advanced in that respect. Optical storage technology has progressed to the point where megabytes and terabytes of information can now fit almost into the palm of one's hand. While the use of this technology brings forth some problems and issues involving both the technology and application of archival theory, the natural data permanence of WORM (Write Once Read Many times or Write Once Read Mostly) disk systems in particular offers some very practical solutions to today's archival storage, maintenance and information needs. Therefore archives and archivists must learn how to use optical storage technology to the full benefit of both the records and their users.

Compared to that of many office information processing products, optical disk technology has a relatively long history. Unlike personal computers, Local Area Networks (LANs), document scanners and fax machines, the optical disk has been around since the 1970s, being just one medium in a long line of electronic devices used to read and store encoded information. Devices such as

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[1] A. Bradley, Optical Storage for Computers: Technology and Applications, (Chichester, UK: Ellis Horwood Ltd., 1989), p. 191.

the photoelectric readers used to read punched cards, and the Hollerith cards initially used in the 1890 United States census were the beginning of the development of machine- oriented data storage devices. Although these early forms of data storage were of the non-eraseable variety, they were an expression of the technology of the day, rather than of user preference, and required both the user and the computer systems to adapt to and ultimately accept the concept of write-once data storage.

It did not take long, however, before user storage needs and technological development combined to produce a storage medium which had increased capacity and, eventually, eraseability. By the 1950s, the development of a reliable magnetic data storage medium not only was a significant improvement in both storage capacity and reliability, but over time offered the advantage of data erasure. Nonetheless, the practical limits of magnetic storage density started to become evident in the 1970s, and optical media began to be developed as the next generation of storage media.

Research on optical disk technology began in the early 1970s, and initially concentrated on the development of WORM technology. Once again, this was a function of the technology of the time rather than a consequence of the demands of users. WORM drives and media were introduced in the early 1980s, and became commercially available a few years later.[2] Extremely high-density storage was accomplished in 1989 with the introduction of optical tape- based systems. Optical tape is a high-density WORM-based storage medium with a one terabyte storage capacity on a 880m by 35m tape. The tape itself fits onto a 12"reel.[3] These products, however, were not meant to be the final formats for

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[2] W. Saffady, Optical Storage Technology 1992: A State of the Art Review, (Westport, CT: Meckler, 1992), p. 4.
[3] D. Pountain, "Digital Paper", Byte, 14:2 (February 1989), p. 276.

optical storage media, but rather development tools from which erasable storage, the ultimate and potentially more commercially acceptable goal, would emerge. The goal of producing rewritable optical disk systems was reached in 1988, when 5.25" rewritable optical disk systems were made available to consumers. Higher-density 3.50" disks have since become available, and integrated WORM and rewritable systems are just coming onto the market. The development of rewritable disk technology did not sound the death knell for WORMs, however, as they had developed their own niche in the information storage world. Future research and development will probably lead to both WORM and rewritable systems with even greater storage capacities in even smaller physical spaces.

The first efforts in the development of high capacity optical storage, however, focussed on photographic media, as "these were well developed and understood, and high resolution materials were already available."[4] Experiments using photographic film to create a mechanism which could enable digitally-encoded data to be written on a medium at a high density, to be retrieved later at a relatively high speed were initially performed at International Computers Limited (ICL). These experiments resulted in a device which employed a light beam that moved horizontally over photographic film. Data was written on the medium by turning the light beam on to record a "1" bit and turning it off to record a "0" bit. Once the film was developed, a permanent record of the data recorded on the medium was created. The data was retrieved by using the same light beam, this time left on, in conjunction with a photodetector to sense the changes in light intensity as they passed through the film. The necessity for a processing stage between the writing and reading of information on the film resulted in a read-only storage medium rather than a true

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4 Bradley, <u>Optical Storage for Computers</u>, p. 181.

WORM-type device. Although this particular device never made it past the experimental stage, it did introduce the idea of using changes in light intensity as a means by which information may be written on and read from a data storage medium.[5]

A similar system was produced and sold commercially by International Business Machines (IBM) under the name **Photochip**. It recorded information onto a glass plate, then loaded it into a jukebox-like machine which allowed the information to be read at special reading stations.[6] Although this system was not commercially successful, it set the stage for future commercial development of optical storage devices. The Photochip system also showed that high-density storage was not a pipe dream, but would soon be available.

Holography was the next stage in the development of optical storage technology. In the early 1970s, experiments were performed using the principle of "interference between light beams" as a basis for information storage. In very simple terms, holography is based on the idea that light beams from every point in the source combine to produce all the points in the image. These are called interference patterns and they hold all the information needed to reproduce the source from the image. If one can reproduce the "interference pattern and a light source identical to just one of those used to create the pattern... it is possible to recreate an image of all the light sources which produced the pattern. An interference pattern with this property is called a **hologram**."[7] This ability to reproduce the source, even though part of the original image was missing, was a strong selling point for holography-based data storage, as it would allow data to

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[5] Ibid, p. 181-182.
[6] Ibid, p. 182.
[7] Ibid, p. 196. A much more comprehensive, yet relatively easily understandable, description of holography is presented in Appendix 2 of Bradley's Optical Storage for Computers.

be recorded on imperfect media, yet suffer only a loss in contrast and brightness of presentation, not of data when the data were reproduced for reading purposes.

Although systems based on this form of optical storage technology never actually reached commercial production, a few research prototypes were created. In the late 1970s, a "cross between microfiche and computer data storage" called **Mnemos** was developed which stored photographic images on a rotating disk.[8] Mnemos took advantage of holograms' ability to reproduce relatively intact sources even when part of the original image is unreadable or absent, by using smaller images than those used on microfiche. This greater error tolerance allowed a 12" disk to hold several thousand images, as less room was needed for the individual images to be stored. Unfortunately, the reduced size of the images necessitated the use of very powerful laser light sources and high definition film for the disk, thus creating a system which was too demanding and expensive for the technology and the markets of that time.[9]

A similar product was created by Holofile, an American firm. Holofile also employed a photographic medium, but utilized a standard microfiche sized flat film, rather than a disk shaped storage medium. The Holofile product used a "two-dimensional array of light sources, ...called a page composer, [which] had 100 x 100 elements, and the pattern displayed by it was recorded as a single hologram." The microfiche-sized film had a recording capacity of 20,000 holograms, or the equivalent of approximately 25 megabytes of storage.[10] Holofile did not produce a commercial version of its product, as both the page composer and the high-powered laser it needed to read the recorded images were too expensive and too unreliable for the product to be

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8 Ibid, p. 182.
9 Ibid, p. 182.
10 Ibid, p. 182.

commercially viable.[11]

Although neither Mnemos or Holofile's product ever became commercially available, these two products demonstrate that the leap from purely experimental optical storage technology to research prototypes had been made. Optical storage was still far from the commercial marketplace, but prototypes created with commercial applications in mind were being developed, and this fact placed optical storage technology one step closer to creating a commercially viable product. At this point, all that was required to complete the process was for optical storage technology to evolve a little further to the point where marketable products would be created from the earlier prototypes.

The next step in the development of optical storage technology involved the marriage between holography and photochromic media. In the late 1970s, the Plessey Company, in the United Kingdom developed an optical storage medium based on photochromic principles similar to those used in sunlight-sensitive sunglasses. The film used in the storage medium became opaque when exposed to one specific wavelength of light, and revertrd to clear when exposed to another specific wavelength. Data were recorded on the light-sensitive medium by gas-filled lasers which acted as these light sources. The light-sensitive film was then placed on a clear substrate similar to that used for cinematic film tapes. Plessey's product also allowed for the use of a photographic emulsion rather than a photochromic medium, but this turned the product into a read-only rather than a WORM storage medium. Holographic optics were used to overcome the problem of media defects and to make the "location of the tape relative to the optical head less critical."[12] As a result, holograms could overlap each other without a critical loss of data when the

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11 Ibid, p. 183.
12 Ibid, p. 183.

recorded images were recreated. Unfortunately, the "low sensitivity of the photochromic material and the high cost of lasers of the right wavelength" made the commercial success of Plessey's product unlikely, and the project was abandoned.[13] Although Plessey's use of gas- filled lasers was an advance in optical technology, the unreliability of and the expense connected with multiple light sources forced developers to search for other ways to produce high-capacity optical storage media.

By the late 1970s, it had become evident that, in order to develop a commercially viable high-capacity optical storage medium, research and development would have to break away from photographic technology. The first product to do this was the **Unicon**, marketed by Precision Instruments. The Unicon introduced the now commonplace ablative method of encoding data by adapting the write laser to burn holes into a "very short wide polyester tape coated with a thin metal film". As with today's ablative techniques, a burnt hole represented one binary symbol, and a blank space represented its opposite. To record the next track, the laser was moved a short way across the tape, then the writing process was repeated. A typical model stored "800 megabytes with a data rate of 1 megabyte per second and average access time 8 seconds." The Unicon had moderate commercial success; it was particularly attractive to oil companies who utilized its high data storage capacity for the recording of seismic data.[14]

Regardless of its modest commercial success, as a high density optical storage medium, the Unicon represented the first break away from photographic technology towards the utilization of the ablative method of recording data that is used in today's optical storage media. Although the

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13 Bradley, Optical Storage for Computers, p. 183.
14 Ibid, p. 183.

developers' main goal was still the creation of rewritable media, the Unicon demonstrated that there was indeed a market for WORM-based high density data storage media, leaving the road free for more research and development in this area.

The successes and failures of these various experimental and commercial ventures, however, led researchers and developers to conclude that conventional rather than holographic optical disk technology would be the practical, commercially successful way of the future. Systems using conventional disk-shaped media would not only be able to provide acceptable data rate and access times, but would be able to access the data written to the disk using mechanical means which are less expensive and more reliable than those used by photographic and holographic systems.

Other optical disk-based systems also had a significant direct and indirect effects on the development of information storage systems. The development of the videodisk in the late 1970s affected the optical storage industry indirectly by generating the development of less expensive, more practical and reliable lasers, optical detectors, servo tracking and focus systems. The development and commercial success of Compact Audio disks and Compact Disc-Read Only Memory (CD-ROM), particularly their use of semiconductor lasers, also directly enhanced the evolution and advancement of optical storage technology.

Nonetheless, an issue which needed to be addressed was the need for reliable, defect-free optical media. The actual elements involved in the physical creation of the disks were not necessarily at issue, although oxidation of the substrates was an early problem, but rather that high- density data storage allowed for a very small margin when it came to defects which arose during the data-writing stage. Data are packed so closely on optical media, that a single physical defect can destroy many nearby data elements. This problem was relatively new, as on magnetic media the data elements are much bigger and spaced more widely, thus allowing for a much larger tolerance for media defects. While holographic technology seemed to be a solution to this problem because of its high capacity to tolerate media defects without affecting the reproduction of data, the industry's inability to produce a commercially viable product hindered this approach. Japanese manufacturers attempted to solve this problem by using bit-mapped images, as they took "advantage of the high degree of redundancy contained in written text" and utilized the human eye and brain as a error correction system.[15] Nonetheless, while this system was used somewhat successfully in Japan, it did not enjoy the same success in North America. Ultimately, the problems connected with making defect-free optical media were solved by the development of powerful error- correction codes.

Error correction codes had been use in magnetic storage systems for a considerable length of time. However, those codes demanded by lower data density magnetic storage media were not very powerful, as defects would only usually affect a few adjacent data elements, rather than many, as it was happening with high-density optical storage. If data errors were found in magnetic storage systems, the data were normally rewritten on a different part of the tape or disk. While such data redundancy would not seem to be a problem with the greater storage capacity offered by optical disk storage, nonetheless, complex error-correction algorithms were developed which reduced the amount of data redundancy originally thought necessary. The powerful processing capabilities demanded by these error correcting codes had become more readily and less expensively available, thus making it easy to provide these codes at a level which

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15 Ibid, p. 185.

was acceptable to the vast majority of customers and would allow more data to be stored on the disks correctly. The standard error rates of today's optical storage media are as follows:

"detected but uncorrected:	not more than 1 in 10^{12} bits read;
undetected errors:	not more than 1 in 10^{14} bits read."

Roughly speaking, this is the equivalent of one uncorrected error a year, or one undetected error in 100 years.[16]

The goal of optical disk research, the rewritable optical disk, was reached in 1989 with the introduction of a 5.25" rewritable disk. The dominant method of recording is Magneto/Optical (MO), a combination of magnetic and optical recording technologies, but phase change and dye- polymer have been introduced in a limited fashion. While they have not yet posed a serious challenge to magnetic media, it is not unreasonable to assume that rewritable disks will eventually develop to the stage where this will be a likely situation. WORMs, however, still have a higher storage capacity, and although this is also likely to change in the future, their non-eraseability will still have applications for archival purposes.

It is not possible to predict what path the technology of the future will follow. Nonetheless, it seems quite certain that optical storage technology in its various forms will continue to develop, and that it will become more commonly used as an information storage medium. Today's society is becoming more and more information- oriented, not only as a gatherer of information, but as a storer of it. The people living in the information age are increasingly dependent on easy, quick access to information from a wide variety of sources.

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16 Ibid, p. 33.

They want information fast and they want it all. Because of our needs, optical disk based storage systems will probably play an increasingly crucial role in the computer systems of the future, if not for their ability to store vast amounts of information in a small space, then for their relatively easy physical storage demands. Therefore, it is essential that archivists, as preservers and communicators of societal records, understand the characteristics of this storage medium and the ways in which they can use it to the best advantage of those they serve.

The overall aim of this study is to familiarise the archival community with the concept of optical storage technology and with the use of its products as conservation and preservation tools. Various kinds of optical storage systems currently available on the North American market will be described, the advantages and disadvantages offered by each type of system will be outlined, and the conservation and preservation requirements of optical storage media will be presented. This illustration will focus on WORMs, Rewritables and Optical Tape only, as these forms of optical storage media are the most applicable to large-scale archival purposes. They have been chosen because unlike CD-ROMs which are Read-Only devices, WORMs, Rewritables and Optical Tape have the ability to write new data to their respective media. Although CD-ROMs have their uses as portable database storage media, the inherent new data storage capacity of WORMs, Rewritables and Optical Tape is more suitable to the record keeping activities of public and private agencies, with a function similar to that of a high- performance hard disk drive.

This study will then examine some of the problems, both technological and archival, which may derive from the use of optical disk systems to both archivists and records creators. The legal issues associated with the storage of records on optical storage systems, and the preservation of both records on optical disks and the disks themselves will be discussed along with brief examinations of a few case studies involving the use of optical storage systems in various archives. The ultimate purpose of this study is to clarify questions regarding optical storage technology itself, its possible and present archival applications, and some of the issues and problems presented by storing records on this medium.

CHAPTER ONE:
THE TECHNOLOGY

> "Optical storage: a technology in which stored data is read by optical means."[1]

Optical disk storage media are not much different from magnetic storage media. Both come in disk and tape forms, and both are used for the purpose of storing and retrieving information. Where the two systems differ is in the way the information is stored and retrieved, and ultimately in the characteristics of the systems needed for its storage and retrieval.

Optical storage technology, as its name implies, utilizes optical means to read stored data. The optical means is a laser that digitally encodes bits of information by producing transformations in the medium's surface. While lasers are also used to write information on the medium, it is actually their heating properties which serve to encode data, rather than their optical properties. The latter are employed in the detection of the encoded data. Optical detection of data involves the recognition of "light transmitted or reflected (or, in principle, emitted) by the storage elements", and its "translat[ion] into a form which the computer can understand, which in practice means into an electrical signal."[2] Light is recognized by photoelectric detectors which respond either

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[1] A. Bradley, Optical Storage for Computers: Technology and Applications, (Chichester, UK: Ellis Horwood Ltd., 1989), p. 13.
[2] Ibid, p. 14.

directly to the intensity of light or indirectly to the polarization of light. For the most part, the reflectivity of signal elements recorded onto the medium is used to achieve data recognition, although the direction of polarization of the reflected light is also used in the detection of data stored on magneto-optical disks.

The fundamental elements which distinguish the types of optical storage media are the method by which information is recorded onto the storage medium, the medium itself and its performance characteristics. The four main types of optical storage media are WORMs, ROM (Read-Only Memory), Rewritable and Optical Tape. This study will deal with the first and latter two formats, because they are the most to suitable to archival purposes, as they deal with storing **new** data, rather than of published information as do CD- ROMs. WORMs, Rewritables and Optical Tape are used by public and private agencies to record **their own** information, rather than as a purely tool for information usually generated by others and disseminated. An analogy may be made comparing registers and volumes; both may be made of paper, but the register, a blank book, is used to enter **new** information, while the volume, a book of folios bound after having been written, is used as a reference tool, Therefore, only WORMs, Rewritables and Optical Tape will be addressed in this study.

WORM TECHNOLOGY

The first WORM drive available in the United States was the Gigadisc 1000, introduced by Alcatel Thompson in 1983. 1984 saw the introduction of the Optimem 1000 and an OSI Laser Drive 1200 from Optical Storage International, which later became Laser Magnetic Storage International. These first commercially available WORM drives have been superceded by second and third-generation systems.

The number of WORM systems available commercially has increased steadily since the mid-1980s. More than a dozen companies currently manufacture WORM systems, including Eastman Kodak, Hitachi, Laser Magnetic Storage International, Matsushita (Panasonic), Mitsubishi, Pioneer, Ricoh (Maxtor Corporation), Sony and Toshiba. Optimem, a pioneer in the field, ceased operations in 1991, and Optotech, one of the first to produce a commercially applicable 5.25" optical disk system, discontinued its WORM production in 1988. Optotech's WORM product line was obtained by Shugart, but it has never been actively marketed by the new company.[3] Japanese companies tend to introduce their products to their home markets before making any export arrangements for North American or European markets. Thus, at any given time there are more products available on the Japanese market than there are in the North American or European marketplaces. In most cases, there is a lapse of at least one year between the announcement of a new product and its commercial availability. On occasion, new product lines are announced, but they never actually appear on the marketplace.

Most WORMs available commercially use tellurium-based ablative recording technology, with dye-polymer based media as the second most popular form. The primacy of ablative recording technology may change in the near future as dye- polymer media are less expensive to produce than tellurium thin film based media. Dual alloy and thermal bubble media remain single vendor technologies. Most optical disk manufacturers sell blank media, although the medium itself may be manufactured by someone else. For example, Maxell, a Hitachi subsidiary, produces the recording media for Hitachi's WORM drives, and Ricoh, Maxtor Corporation's parent company, produces the recording media for its subsidiary. Other manufacturers will designate an alternate source for

[3] W. Saffady, Optical Storage Technology 1992: A State of the Art Review, (Westport, CT: Meckler, 1992), p. 17.

recording material. For example, Plasmon manufactures the disks for Panasonic drives, while Du Pont and Philips produce WORM disks for Laser Magnetic Storage International and Eastman Kodak. This type of production distribution is done to promote competitiveness and to conform to American government standards for alternate procurement sources.[4]

WORM systems present an efficient, accessible and archivally appropriate form for storing vast amounts of information. As their name suggests, they use lasers to encode information permanently onto an optical disk. Once data are written onto a WORM disk, they cannot be altered or deleted, making of it the ideal medium for permanent archival storage of information. WORM disks are about twice as thick as the conventional CD-ROM disks and consist of a "layer of recording material sandwiched between two plastic plates."[5] In most cases, the recording layer is either a tellurium alloy or a dye-polymer that has been deposited on a surface by a vapour plating process. Other transparent layers of plastic are placed on this surface to protect the recording surface. The entire disk itself is enclosed in a hard case protected by a "sliding metal shutter".[6] WORM disks can be double sided, but in order to either read or record on the disk's reverse side, it must be taken out of the drive and flipped over. WORM capacity ranges from 600 megabytes on some 5.25 inch disks to more than 10 gigabytes on a 14 inch disk. Numerous WORMs can be corralled in jukeboxes to create a truly massive information storage centre.[7]

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4 Ibid, p. 18.

5 S. Apiki and H. Eglowstein, "The Optical Option.", Byte, 14:10, (October 1989), p. 168.

6 Apiki and Eglowstein, "The Optical Option", p. 168 ; A. Elshami, CD-ROM Technology for Information Managers. (Chicago: American Library Association, 1990), p. 58.

7 Digital Equipment Corporation is currently marketing its RV64, which connects 64 two gigabyte WORM discs in a jukebox for a total capacity of 128 gigabytes per system. It is accessed by 4 optical players and was available for

The oldest and most common method of WORM recording is ablative pit technology. A high-powered laser either melts or vapourises the focus spot to create a hole in the medium. This produces a permanent pit in the metallic recording surface underneath. A pit is formed when "surface tension draws the melted metal aside so that it solidifies with a crater-like rim around the hole." Bubbles are formed when "the active layer[s] [are] vapourised by the heat of the laser beam but [are] contained by a plastic layer above" them.[8] Occasionally, the bubbles are intentionally burst open to form pits similar to those created by purely ablative technology. There is a problem with the vapourisation method, however, as it tends to allow the vapourised metal to be deposited on other parts of the disk, thus interfering with the writing and reading of the data on those parts of the disk. Fortunately, this problem can be eliminated by placing a protective plastic layer above the blast layer to contain the blast and prevent debris from affecting other parts of the disk. The blast then forms either a pit or a bubble on the surface of the recording layer. The actual data bits of information are established by the presence or absence of these pits or bubbles.

These holes also expose the layer underneath the recording material, thus creating a change of reflectivity between the pits and the unburned surface layer. The pit- burning/bubbling laser reads the data bits by shining a low power beam on the recording surface, using a photosensor to detect any changes in reflectivity.[9] The data bits are then translated via the head assembly into readable information by the WORM drive's computer system.

The most common material used for the recording layer in ablative

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$US 205,652. (Digital Equipment Introduces Improved Data Storage System", <u>Aviation Week and Space Technology</u>, 13 March 1989, p. 61.)

8 Bradley, <u>Optical Storage for Computers</u>, p. 23-24.

9 Apiki and Eglowstein, "The Optical Option", p. 168. ; Elshami, <u>CD-ROM Technology</u>, p. 21.

recording is tellurium thin film, as it "offers good thermal sensitivity for low-power recording, high signal-to-noise ration, limited thermal conductivity to prevent undesirable increases in pit sizes, good resolution for high density recording, and good media stability."[10] Tellurium thin film disks have an expected shelf stability, that is, the amount of time a disk can be stored unrecorded before recording accuracy is affected, of five years. They also have a storage stability, that is, the length of time one could expect to retrieve data with reasonable accuracy, of ten to forty years.

The bubble, or thermal-bubble technology, mentioned above was one of the first to hit the market, but is far from the dominant WORM variant available now. Currently, only one company, ATG Gigadisc, uses this technology for its product line. This form of recording technology was "briefly supported by the Optimem 1000, a first-generation WORM drive which could also be configured for ablative recording of tellurium thin films."[11] ATG Gigadisc claims its newest product line has a shelf stability of five years and a storage stability of thirty years. Its first- generation disks had a storage stability of ten years.

Dye-based optical recording is a popular and less expensive method of writing information to WORMs. It is also known as dye-polymer, dye-in-polymer (DIP) and organic dye binder media. Dye-polymer disks also use pit-burning technology, except that the medium facilitates sharper pit edges and thus sharper and clearer changes in reflectivity. Alternatively, information can be recorded by a laser which operates "at the dye's absorption wavelength" to bubble or deform the recording layer. The laser-readable changes in reflectivity in this recording technique occur between the "diffused and pure dye areas" of

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10 Saffady, Optical Storage Technology 1992, p. 5.
11 Ibid, p. 8.

the disk.[12] Bubbling or deforming allows the ablated material to fall around the rim of the pit rather than into the centre, as can happen with ablative pit technology. This allows the read laser to read the data bits much more clearly, thus reducing the number of errors written onto the disk. The 14" disks produced using this method have three times the capacity of the previous 12" disks.[13]

This method of recording information is used by Eastman Kodak, Pioneer and Ricoh, the latter of which sells its WORMs through Maxtor in the United States. Dye-polymer disks have an expected shelf stability of five years and a storage stability of fifteen years. Dye-polymer advocates claim this medium has "higher read/write speed[s], lower threshold energy requirements for pit formation, greater stability, and lower production costs" when compared to optical recording systems which utilize tellurium thin films.[14]

Another method of recording information on WORMs is by phase change technology. The disks used in this process are similar in construction to the tellurium thin film disks used in ablative recording. The disks are constructed of "tellurium and/or selenium compounds which are typically alloyed with small quantities of other metals."[15] Phase change differs from other recording methods in that the recording method does not change the shape of the surface of the recording medium. Instead of burning a pit in the disk, the drive laser alters the structure of the recording medium so that it changes the phase of reflected light.

At room temperature, certain tellurium alloys can exist in either

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12 Ibid, p. 6.
13 P. M. Artlip, "Different Optical Disk Formats Co- Exist to Provide End-User Applications Flexibility", IMC Journal, 24 (March/April 1988), p. 15.
14 Saffady, Optical Storage Technology 1992, p. 7.
15 Ibid, p. 8.

their crystalline or amorphous state, and are capable of being switched back and forth between either state. A low powered laser creates the shift to a crystalline state, while a higher powered laser causes the shift back to the amorphous state.[16] The optical reflectivity is different for each state, and is read in the same manner as the pits created by ablative pit technology, as the drive "detects phase changes in light from the read laser reflected off the disk surface."[17] Phase-change disks use the same reading technique as other WORM and CD-ROM systems, and are the only type of recording technique that can be used in both WORM and rewritable formats. Both forms of phase-change media use the same technology, except that when the disk is a WORM the phase- change is accomplished rapidly, thus making the transition irreversible.

Eastman Kodak and Matsushita produce phase change WORMs and their drives, the latter of which are sold in the United States by Panasonic (a Matsushita subsidiary) and by Plasmon Data Systems. Plasmon, however, uses a platinum recording layer rather than the traditional tellurium thin film. Phase-change disks have the usual shelf stability, and a storage stability of fifteen to fifty years, as claimed by Matsushita and Plasmon respectively.[18]

A variant of phase-change recording methods is "moth- eye" or texture change. The recording substrate is imprinted with a relief pattern that is smaller than the spots used for denoting bits of information. This substrate is then covered with a very thin layer of platinum. The platinum layer repeats the relief pattern, thus scattering light and lowering the reflectivity of the layer. To

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16 C. Dollar, Archival Theory and Information Technologies: The Impact of Information Technologies on Archival Principles and Methods, Informatics and Documentation Series 1. (Macerata, Italy: University of Macerata, 1992), p. 31. ; T. Hendley, CD-ROM and Optical Publishing Systems, Cimtech Publication 26, (Hatfield, Herts, U.K.: Cimtech/BNBRF, 1987), p. 31.

17 Apiki and Eglowstein, "The Optical Option", p. 168.

18 Saffady, Optical Storage Technology 1992, p. 8.

record a bit of information, the laser melts a spot on the surface of the substrate, creating a smooth area on the metal layer, and thus a change in reflectivity of the spot in question.[19] The read laser reads this change in reflectivity in the same way as those with information written by other recording techniques. The term "moth eye" comes from the impression that the relief pattern and its reflectivity resemble those of a moth's eye. "Moth eye" is not a common method of recording information on optical disks.

Dual alloy or bimetallic alloy medium is a variation of phase-change technology, except that data are recorded by fusing three alloy layers, creating a difference in the level of reflectivity between the fused and the non-fused areas. The medium consists of two metal alloys, often tellurium and bismuth, and selenium and antimony, in thin film form coating a polycarbonate substrate. The layers form a sandwich, with two layers of selenium and antimony surrounding a layer of tellurium and bismuth. All the layers are covered by a protective seal, thus the name "direct seal" is often used for this type of medium. To record information, the recording laser fuses the three layers, forming a four-element alloy spot which possesses a reflectivity distinctly different from the unused areas surrounding it. Generally speaking, the fused parts equal a 1 bit, the unfused parts a 0 bit.[20]

Currently, Sony is the only manufacturer using this technology, and only for the manufacture of WORMs. The shelf stability of this medium is analogous to the other recording methods, but its storage stability is estimated to be much higher. Sony claims its "Century Media" have a playback life of 100 years. While these disks may have direct applications for those users who require long-term storage of information, the question of whether the information on the

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19 Bradley, Optical Storage for Computers, p. 24.
20 Saffady, Optical Storage Technology 1992, p. 7.

disks will be accessible by future hardware and software must also be taken into consideration when analysing the potential and/or validity of such claims.

Although the methods of recording information may differ from WORM to WORM, the signal elements are still arranged serially on each form of disk. All signal elements are arranged on a track in either concentric circles, or more commonly, as a spiral reaching from the inside to the outside of the disk. These track(s) can be either spaced equally apart, or arranged in bands similar to those used on phonograph records. Data are divided into sectors along each track. Each sector has an identifying header similar to those used on magnetic disks. Most WORMs are preformatted with this sector identification information.

Writing information to a disk, however, requires that even more methods of control for accuracy and ease of retrieval be maintained. Consequently, controls have to be maintained over both the spaces between the written bits and the radial position of their tracks. Control of the radial position is particularly important as it is "impossible to make the axis of the rotation exactly concentric with the header pattern, and the error is usually much greater than the track spacing."[21] Radial position control is often achieved through the use of a "pre-groove" which is an extension of the preformatting process and produces a track which is narrower than the laser spots written to the disk. The writing laser either follows the groove and writes the bits on the groove, or writes on the areas between the grooves. These grooves are also used as "clock signals" to indicate spacing between elements, and aid the writing and reading of the signal elements.[22]

Preformatting also determines the track layout and thus the way

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21 Bradley, Optical Storage for Computers, p. 25.
22 Ibid, p. 25.

information written to the disk is arranged on the disk. Track layout is determined by disk rotation and is achieved in two ways: Constant Angular Velocity (CAV) or Constant Linear Velocity (CLV). CAV indicates that the disk rotates at a constant speed, and thus the information is written to the disk at a constant rate. Consequently, the spacing of the bits is increased as the track gets closer to the edge of the disk. This results in a greater recording density near the centre of the disk, which decreases as the track progresses towards the outer edge. The disparity in recording density can also necessitate changes in the energy used to write the information on the disks, because the written bits on the outer track are in laser range for a shorter time than those on the inner tracks. As a result, the writing power may have to be adjusted to compensate for this time differential if there is not a "sufficiently wide tolerance on the amount of energy used to change a signal element".[23] CAV written disks have a lower capacity than those written using CLV, but information can be written to the disk somewhat faster. There is a modified form of CAV, MCAV which maintains a constant disk speed, but varies the reading and writing rates to correspond with the track radius, thus maintaining a maximum writing capacity similar to that achieved with CLV.

CLV differs from CAV in that the disk rotates at a various speeds, depending on the radius of the track being written to. The difference in disk rotation speed keeps the spaces between written bits the same on each track regardless of whether its track is in the centre or at the edge of the disk. This process allows all tracks to be written to the maximum density the medium will permit, "typically increas[ing] the capacity of a disk by 50%."[24] These changes in speed, however, add to both the complexity of the system, as an additional servo

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23 Ibid, p. 26.
24 Ibid, p. 26.

system is needed to control the disk rotation speed, and the access time needed to retrieve the information. There is also a modified form of CLV, named MCLV, which divides the disk into bands, maintaining a uniform speed within each band, rather than with each track. This process does not achieve the full writing capacity of CLV, but it still achieves a greater rate than CAV.

CAV is the most common system of track layout in use for WORMs, but all of the above formats are used in commercially available systems. WORM drives are available, however, which are capable of operating in both CAV and CLV. Nonetheless, while WORMs vary in their method of track layout, Compact Audio and CD-ROMs use CLV exclusively.

Error detection is also a significant element of optical disk storage technology. It is vital to have such controls, as no storage system is perfect, yet perfection, or near it, is a requirement of any user of information storage systems. Undetected errors in the data stored on a user's optical disk can have very serious repercussions for the user, and thus powerful error detection codes have become a standard feature of optical storage systems. However, it is not economically or technologically practical to eliminate all errors. Therefore, a system can only hope to be able to minimize the errors to a level acceptable by those who will eventually read and use the stored data. The standard error rate for non-recoverable errors is not more than one in 10^{12} bits read and, for undetected errors, not more than one in 10^{14} bits read. These error rates are roughly the equivalent to one uncorrected error a year, or one undetected error in 100 years.[25]

Error detection and correction are achieved by redundancy in the coding of data. Errors are detected by the redundant coding of data, and by tests

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25 Ibid, p. 33.

which detect substandard coding such as low signal amplitude. Correction is carried out by either on-the-fly or retry methods. The former involves the correction of the data within the drive before it is transferred to the host, while the latter simply involves the repetition of the data transfer. Powerful error correction codes are the norm for optical disks, and, as a result, disks can have a data redundancy of 20-50%.[26]

Checking for errors can be achieved in two ways: either by checking the data on the revolution after it has been written, or by reading each bit soon after writing. The former is the more common process, and is similar to the methods used with magnetic disks. In this process, an entire sector or a whole track is checked for accuracy on the next pass of the write laser. The copied data are not compared to the original data, but the error correction codes are used to test the accuracy of the written bits. The latter method is the use of either the Direct Read After Write (DRAW) or Direct Read During Write (DRDW) methods. DRAW is an optical storage method used on WORMs to record information locally or on-site. During this procedure, the recording machine reads data after they are written to the disk, continuously comparing them with the incoming data stream. If an error is detected, the correct information is immediately rewritten to another part of the disk, as information on WORMs cannot be altered or erased, only augmented. DRDW systems check each bit "against the bit which should have been written at that location."[27] DRDW is more complex and slower than DRAW, but still faster than reading the data on a second revolution. Once errors are discovered, if they are beyond the parameters set out by the system's error correction codes, the correct data are then rewritten to the next available free sector of the disk or to a special section

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26 Ibid, p. 35.
27 Ibid, p. 35.

set aside for rewritten data.

Regardless of the variations in recording technology or base media, WORM disks are typically encased in a plastic cartridge to make handling easier and to limit physical and environmental damage to the disks themselves. Although the size of the cartridges may differ from system to system, at the present time the actual WORMs only come in three sizes: 5.25", 12" and 14". The Japanese market supported 8" disks for a brief time in the 1980s, but these were not very commonly used in North America.

Fourteen inch WORMs are currently manufactured by only one company, Eastman Kodak. As a result, Kodak is the creator of the de facto standard for this particular size of WORM disk and its accompanying drive systems. Its WORM cartridge is the "basis for the ISO CD 10085 standard for fourteen-inch [WORM] cartridges developed by the International Standardization Organization (ISO)."[28] The Kodak Model 6800 optical disk drive introduced in 1986 is named for the recording capacity of the original disk-- 6,800 megabytes or 6.8 gigabytes per double-sided disk. By 1989, storage capacity for the Model 6800 had been upgraded to 8.2 gigabytes, although this model did not become commercially available. In 1991, the double-sided disk capacity was increased to 10.2 gigabytes. The original system used dye-polymer recording media, but this was changed to phase-change technology for the 1991 version. Kodak offers upgrades for the older 6800s, allowing them to read and record on both 6.8 gigabyte and 10.2 gigabyte versions.[29]

The first commercially successful WORM systems were those with twelve-inch drives and media. Introduced to the commercial market in the mid-1980s, the recording capacity of 12" disk systems have risen steadily ever since.

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28 Saffady, Optical Storage Technology 1992, p. 20.
29 Ibid, p. 20-21.

The first generation of 12" WORMs had a recording capacity of two to four gigabytes of data per double-sided disk. By the late 1980s, however, second and third generation 12" systems offered recording capacities of 2.4 gigabytes to 6.4 gigabytes. WORM recording capacity had been expanded even further by the early 1990s, with the introduction of ATG's Gigadisc 9001. The Gigadisc 9001 has a 9 gigabyte recording capacity and is the "capacity leader among twelve-inch drives."[30] These increases in 12" WORM system recording capacities pushed Kodak's 14" WORM system to increase its recording capacity in order to maintain the competitive edge and market niche of their 14" product.

While 12" WORM systems may be commonly used, they are the least standardized. The recording technologies used for 12" WORM systems are thermal bubble, ablative and dual alloy. At the present time, all 12" WORM systems are proprietary, and there are no standards for the production of WORM systems or cartridges. There is an ANSI committee working on producing standards for 12" WORMs, but it is not expected to produce anything concrete before the mid-1990s.

The first 5.25" WORM system, the ISi 525WC, was introduced in 1985 by Information Storage Incorporated (ISi) with a single-sided recording capacity of 115 megabytes. By the late 1980s, dye-polymer and phase-change technologies were being used, and the double-sided recording capacities had increased to between 600 megabytes to 1.28 gigabytes.[31]

Prior to 1987-88, all 5.25" WORM products used proprietary recording media. In 1987 and 1988, a number of leading 5.25" WORM manufacturers launched products which used media that conformed to the ISO/IEC 9171 standards for 5.25" WORM cartridges. These standards specified

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30 Ibid, p. 24.
31 Ibid, p. 24.

the "magnetic clamp method, hub diameter, central hole diameter, tracking method, and other characteristics of optical disk cartridges."[32] Although adherence to the above mentioned standard would lead one to believe all compliant 5.25" WORMs were the same, the ISO/IEC standard supports two recording formats: Format A or composite servo (CCS) and Format B or sampled servo (SS). The two formats use different methods of "handling the control of servo signals which permit accurate tracking and focus of a drive's optical head during recording and playback." Format A achieves this tracking and focus via a grooved media, while Format B employs a succession of marks on each side of the centre of a track. Both formats may be compliant with the ISO/IEC standards, but they are incompatible with each other and thus require their own, non-interchangeable media.[33]

The basic configuration of WORM systems usually consists of a number of interdependent parts. To begin with, documents entering a WORM system must be in digitized form. Transferring non-digital documents to digital format can be achieved by scanning the original with document scanners, using either small hand-held models or larger ones which resemble photocopiers. A document conversion scanner system is comprised of four parts: "the generation of the digital image representation", compilation of the index data, allocation of the storage address and storage of the image on the disk.[34] Documents unsuitable for scanning can be transferred into digital format via a video recorder. The taped analogue material can then be transferred from non-digital to digital form. This method is particularly effective for photographs, slides and negatives,

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32 Ibid, p. 25. The manufacturers who have accepted this standard are Fujitsu, Hitachi, Laser Magnetic Storage International, Mitsubishi and Pioneer.
33 Ibid, p. 25.
34 G. Walter, "An Overview: Technology and Application Status of Optical Disk Systems", IMC Journal, 24 (July/August 1988), p. 10.

as they can be relatively easily placed on videotape, and then later transferred to a WORM disk.[35]

WORM systems also must have a control microcomputer to coordinate all the peripherals and the software programs which run the system. Peripherals include: a laser printer for creating hard copies of the stored images; a high resolution monitor for viewing the documents and text; and possibly Local Area Networks (LANs) for multiple use of the system and communication with outside interests. Traditional magnetic disk drives are also needed for storage of the database indexes, and database application, information retrieval and system software.[36] Most importantly, knowledgeable people are needed to operate and administer WORM systems for the systems to work effectively and efficiently.

While WORMs require little in terms of special storage or conservation considerations, they can, like anything else, be subject to damage. Disk integrity can be affected by the swelling, shrinking, bubbling or blistering of the pits, causing changes in reflectivity and eventual degradation of data. Oxidation of the reflective layer can also cause a similar deterioration of data.[37] Consequently, more time and testing is needed to determine the long-term stability of WORM disks for archival storage purposes.

As a relatively new technology, however, WORM systems are unproven in terms of their lasting ability. There are some estimates of the life span of the disks, but their ability to maintain archival quality records for extended periods of time has yet to be proven. Generally speaking, the life

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35 L. Howe, "The Use of Optical Disc for Archival Image Storage", Archives and Manuscripts, 18 (May 1990), p. 100-101.
36 B. Cinnamon, "Optical Disk Applications", IMC Journal, 24 (July/August 1988), p. 20.
37 A. Calmes, "To Archive and Preserve: A Media Primer", Inform, (May 1987), p. 17.

expectancy of WORM disks is between 10 to 100 years, depending on the source cited. Realistically, the current WORM life expectancy is in the range of 20 to 30 years, which is comparable to some electronic media, but still short of the 100 year life expectancy of microfilm. There have been, however, accelerated tests performed which claim that "no visual impairment occur[ed] after 100 successive copy generations of single video images."[38] Despite these findings, the accuracy of accelerated tests to predict WORM life expectancy is still in question, as it is unclear whether disk performance under normal use conditions can even be duplicated by such tests. Unfortunately, only time will tell whether WORMs will be able to live up to their accelerated test results and their commercial expectations.

REWRITABLE TECHNOLOGY

Rewritable optical disk technology has been the ultimate goal of the optical disk industry since its inception in the early 1970s. This goal was realized in 1988, with the introduction of Magneto-Optical (MO) disk systems to the North American market.[39] Panasonic introduced the first phase-change based rewritable disk drive in 1990.

The most common form of rewritable optical disk technology is Magneto-Optical (MO), also known as Thermal Magneto-Optical (TMO). This is a hybrid technology, because it stores information magnetically, as do magnetic media, but uses a laser to read and write the information to the disk. Magneto-opticals and WORMs use the same basic reading techniques, but MO disks use

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[38] Howe, "The Use of Optical Disc", p. 100. ; Howe cites as his source for this information: Library of Congress, LC Information Bulletin, 47(14), (Washington D.C.: Library of Congress, 1989), p. 124.
[39] Saffady, Optical Storage Technology 1992, p. 27. Rewritable optical disk drives were introduced in Japan in 1987.

the same principles as magnetic disks for recording purposes. MO disks are essentially "multilayered magnetic disks which employ vertical recording techniques instead of the horizontal-- sometimes described as longitudinal-- recording methodologies associated with conventional magnetic media."[40] Vertical recording techniques align the magnetic domains perpendicular to the disk's surface, while horizontal techniques arrange the domains parallel to the disk's surface. Horizontal recording allows for the domains to be placed much closer together, thus achieving a higher recording density than those arranged in parallel. Horizontal recording is also used by high-density floppy disk systems, particularly those which employ barium- ferrite media. MO disks are essentially "optically assisted magnetic media", which have the same benefits as WORM systems, their enormous storage capacity, the same stability of data and portability of medium, as well as the added adaptability of magnetic media.[41]

MO disks work on the same principle as magnetic media: bits are coded as either magnetically positive or negative. Initially, the magnetic orientation of the MO disk is uniform with the magnetic north pole down. The polarity is changed by coercive force, which is low at high temperatures but the opposite at low temperatures. By laser-heating a spot, which represents one bit of information, to 150 degrees Celsius "the resistance of the spot to changes in its magnetic field drops to nearly zero, and the spot is changed to north pole up".[42] Once this is achieved, the spot's magnetic domain is reoriented by an electromagnetic field. When the spot cools, its magnetic orientation is the opposite of what it had been previously. The use of heat in the recording and deletion process is where MO differs from purely magnetic media, as data

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40 Ibid, p. 10.

41 G. E. Kaebnick, "Rewriting the Future: Putting Rewritable Optical Disk on the Market", Inform 4 (May 1990), p. 17.

42 Ibid, p. 17.

recorded on the latter can be destroyed by the mere presence of a magnetic field, whereas data on a MO disk cannot be changed "even by a relatively strong magnetic field unless heated".[43]

To read the information recorded on the MO disk, the read laser reads the information by sensing the changes in magnetism, not the changes in reflectivity as is the case with WORMs. Data are erased by a less powerful laser which heats the area in question and reverses its magnetization to its original magnetic north pole down orientation. This action returns the bits to their zero bit state. Data are rewritten to the erased areas only on a subsequent disk rotation. At the present time, two passes are needed to erase and rewrite data to MO disks, but it is predicted that future developments will reduce this to one direct- overwriting pass.

A phenomenon known as the Kerr effect is responsible for the ability to retrieve information stored on a MO disk. Under the Kerr effect, a magnetic surface affects the polarization of reflected light by rotating it in either a clockwise or counterclockwise direction, depending on the orientation of the magnetic particles on the disk. These particles, representing bits of information, will be read by the laser and an optical pickup mechanism as either a one or a zero, based on the way they detect the rotation of reflected light from the magnetic particles.[44]

The medium used in MO disks is a multilayered medium comprised of layers of thin films combined with iron, certain rare-earths and transition-metals. Rare-earths elements are common in the earth's crust, but derive their

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43 J. A. McCormick, A Guide to Optical Storage Technology: Using CD-ROM, WORM, Erasable, Digital Paper, and Other High-Density Opto-Magnetic Storage Devices, (Homewood, IL: Dow Jones-Irwin, 1990), p. 77.

44 Saffady, Optical Storage Technology 1992, p. 11. ; Bradley, Optical Storage for Computers, p. 56.

name from the fact that they were found originally in rare minerals. They are the elements with the atomic numbers 21, 39, and 57-71. Terbidium, neodymium, dysprosium and gadolinium are examples of rare-earths elements used in MO recording media. Transition-metals are elements which have characteristics of both metals and non-metals. They are the elements with atomic numbers 22-28, 40-46 and 72-78. Examples used in MO technology include cobalt, platinum, titanium, chromium and zirconium. The most commonly used combination in commercially available products is terbium- ferrite-cobalt.[45]

Regardless of the elements used in the medium, the recording materials are all placed on the recording substrate in the same manner: either vacuum deposited or sputtered onto glass or plastic substrates. Glass substrates offer "superior uniformity, optical clarity, mechanical stability, scratch resistance, freedom from warpage and resistance to moisture absorption."[46] Plastic substrates are less expensive to produce and are lighter, thus facilitating faster rotation times.

There are, nonetheless, problems associated with MO recording media. Oxidation of the rare-earths and transition-metals, for example, causes the medium to age and deteriorate, resulting in an inability to retrieve the information stored on the disk. Terbium, in particular, oxidizes easily contributing to a decline in magnetic coercivity, recording sensitivity, bit error rates and playback stability. Multi-layer barrier coatings and oxidation-resistant alloys can, however, retard the aging process.[47]

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45 Saffady, Optical Storage Technology 1992, p. 12. Other possible MO media include: ferrite-cobalt, ferrite terbium, ferrite-silicon, ferrite-terbium-gadolinium and ferrite-terbium-indium. Iron-garnet media are touted by some to be the media of the next generation of MO disks.

46 Ibid, p. 12.

47 Ibid, p. 12.

The estimated lifetime for MO disks is considerably shorter than that touted for WORMs, and the periods of their shelf and storage stability are identical. For a rewritable disk to be useful, it must be able to both record and retrieve the information stored on it for an equal length of time. Most manufacturers claim a useful shelf and storage stability of ten years for disks with plastic substrates. Laboratory examples, however, suggest potentially longer lifetimes for such disks, and even more so for those utilizing glass substrates. For example, poly-carbonate plastic substrate disks produced by the NEC Corporation claim a life of fifteen years. Several other manufacturers, however, claim a life of 15-25 years for products using glass substrates.

Phase-change technology is the other recording method used in rewritable optical disks systems. The rewritable version of phase-change technology did not hit the market until 1990, and it is only marketed by Matsushita. The basic concepts utilized in rewritable phase-change technology are the same as those used in the WORM version, but in the rewritable version the transition between the amorphous and crystalline state of the recording medium is reversible. A laser heats a spot on the recording layer to just above its change of state, and rapid cooling of the point in question transforms the area from its crystalline to its amorphous state. The medium is more stable in its crystalline form, and thus tends to revert to it when it is heated to just below its melting point.[48]

Like its WORM counterpart, the reversible form of phase-change technology also relies heavily on the use of tellurium thin films alloyed with some other element, such as selenium, gadolinium, indium, antimony, germanium, tin or titanium. Matsushita's current product uses tellurium based media. Other

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48 Ibid, p. 13.

alloys are used, but these are currently only at the laboratory experimental stage, and far from commercial applications.[49]

Unlike MO technology systems, rewritable phase-change technology systems are able to support direct overwriting, as they do not need to reset their "spots" to a neutral state before they can be rewritten. This direct overwriting capability allows data to be written and erased in a single pass, rather than in the two passes MO disks need to perform the same function. This should give phase- change rewritables the advantage of faster read/write rates, but is counteracted by the slow amorphous-to- crystalline transition times which are currently a characteristic of phase-change media.[50] While this slow transition time condition may change in the future, phase- change rewritable optical disks currently have limited practicality in situations where quick writing and erasure of information is a practical necessity.

Like MO disks, phase-change rewritable disks have an expected shelf and storage capacity of ten years, although there are some experimental aging tests which suggest a longer lifespan may be possible. Phase-change media are, however, susceptible to "accidental erasures" at low temperatures, a characteristic not shared by their MO counterparts, which require both a high temperature and a surrounding magnetic field for data erasure to take place. Phase-change technology is also apparently less durable than MO and has a lower read/write capability. The MO disks used in the systems marketed by Sony and Ricoh have the capability to read and rewrite data at least a million times before data degradation sets in. Matsushita's comparable phase-change system only has a read/write capability of approximately 100,000 times before the onset of data

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49 Ibid, p. 13. Experimental alloys include: indium- selenium-lead, indium-selenium-thallium, indium-selenium- cobalt, indium-selenium-antimony, gallium antimonide-indium antimonide, silver-zinc, gold-germanium.

50 Ibid, p. 13.

degradation.[51] On the other hand, phase-change recording materials are largely unaffected by ambient temperatures and relative humidity encountered in most office environments, and are completely unaffected by magnetic fields.[52]

A third form of rewritable optical disk system is based on dye-polymer recording technology. Dye-polymer rewritables were developed by a small American company, the late Optical Data Incorporated (ODI), in the late 1980s, but have yet to become available commercially. Nonetheless, this form of rewritable optical disk system is one to watch for in the future as it purports to be read compatible with most CD-ROM systems. This capability would allow data to be written to a dye-polymer rewritable disk at one location, then be used somewhere else like with a regular CD-ROM disk. Such disks would have the advantages of both rewritability and a wider read capability.[53] This capacity also facilitates the creation of multifunction drives, a move which would make the use of optical disk technology simpler, more functional and more widely applicable.

Dye-polymer WORMs and rewritables both use dyed layers of plastic as their recording layers, but rewritables use two layers "made up of different materials sensitive to different frequencies of light" rather than one dye-polymer recording layer.[54] Information is written to the disk by shining the write laser through the top, or retention layer, through to the bottom or expansion layer, causing a bump to form in the polymer. The retention and expansion layers are colour sensitive, and only the write laser has the right frequency to shine through and write to the expansion layer. The bump created by this process represents a data bit. To erase information, a different laser on a different

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51 McCormick, A Guide to Optical Storage, p. 80. ; Bradley, Optical Storage for Computers, p. 58.
52 Saffady, Optical Storage Technology 1992, p. 14.
53 McCormick, A Guide to Optical Storage Technology, p. 81.
54 Ibid, p. 81.

frequency heats the retention layer immediately above the bump, smoothing out the bump and returning the recording layer to its original state.[55]

Rewritable dye-polymer media can be used with most of the current rigid and flexible substrates, and can be manufactured by a "thick-film, solvent-coating process that is similar to the well-established manufacturing techniques associated with magnetic media."[56] As with WORMs, dye-polymer rewritables should be easier and less expensive to manufacture as they do not require either vacuum deposition or thin film sputtering as do other forms of optical disk media. Dye-polymer rewritables should also be less susceptible to oxidation than other rewritables as they are composed of inert materials rather than the oxidation-susceptible metallic thin films.[57]

Thus far, however, only laboratory examples of dye- polymer rewritable technology have been unveiled. Prototype 3.5" and 5.25" dye-polymer rewritables with a single-sided storage capacity of 100 to 500 Mb were presented by ODI in the late 1980s, but commercial forms were never introduced. In 1988, Tandy Corporation announced it would be using ODI's media in their High-Intensity Optical Recorder (THOR). THOR, however, never made it to the consumer stage, and while other companies have flirted with the idea of using dye-based rewritable media, none have introduced any such consumer products. Prior to its dissolution in 1990, ODI signed over non- exclusive licensing rights to Du Pont Optical (PDO) and Teijin Limited, but none have produced any commercial rewritable systems as of yet. At this point in time, the immediate future of dye-polymer based rewritable optical disk systems is questionable.

Rewritable optical disks are very similar to WORMs in terms of

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55 Ibid, p. 81 ; Saffady, Optical Storage Technology 1992, p. 14. ; Bradley, Optical Storage for Computers, p. 56.

56 Saffady, Optical Storage Technology 1992, p. 14.

57 Ibid, p. 14.

their physical recording organization. Both WORMs and rewritables use similar preformatting, pregrooving and clock signals, and both types of optical storage media can use either CAV or CLV to record information to their respective disks. A proprietary non-standard 5.25" MO system manufactured by Maxoptix, however, supports a modified zoned constant angular velocity (ZCAV). Unlike regular CAV disks, ZCAV disks have more sectors and data on their longer outer tracks, rather than their shorter inner tracks.[58]

Error detection is also managed the same way it is on WORMs. Errors are detected on-the-fly, and to the same rates that are specified for WORM disks. At this time, rewritable systems can only detect write errors on the next revolution, as rewritable systems using DRDW are not yet available commercially.

Rewritable media come in two sizes: 5.25" and 3.5". Both sizes are intended to be used primarily as additions to desktop installations, unlike the larger WORMs. These sizes also conform nicely to the multifunctioning system concept which incorporates both WORM and rewritable drives within the same operating system.

The 5.25" rewritables are, like their WORM counterparts, encased in a rigid plastic cartridge. The capacity of these double-sided disks ranges from 512 Mb to 1 Gb, and most manufacturers of these sized disks have their product conform to the ISO 10089 standard for optical disk cartridges.[59] Those manufacturers which employ MO disks in their multifunctioning systems also

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58 Ibid, p. 29-30. In 1990, ZCAV was endorsed by a number of manufacturers, hoping to encourage an ISO standard based on the ZCAV format. The manufacturers included Maxoptix, Hewlett-Packard, Philips and Du Pont Optical, Optical Storage Corporation, and Mitsubishi.

59 Ibid, p. 29. Manufacturers which comply to this standard include Sony, Ricoh, Hitachi, Sharp, Hewlett- Packard and Panasonic.

comply to this ISO standard. The ISO standard uses the CCS format exclusively, unlike the comparable WORM standard which encompasses both CCS and SS recording formats. Phase- change media of this size are proprietary, with Panasonic's product offering a 1 Gb capacity per double-sided cartridge.

Although the 3.5" rewritables existed in laboratory form as early as 1985, it took until 1990 for them to become commercially available. The only 3.5" rewritables currently available employ MO recording technology, and physically look much like their floppy disk counterparts, except they are somewhat thicker. These drives are currently being manufactured by the following companies: Sony, IBM, and Mass Optical Storage Technologies (MOST), a subsidiary of Nakamichi Peripherals Corporation. A significant number of other manufacturers have expressed interest in these sized drives, indicating a larger market share for these drives in the future. The 3.5" rewritable optical disks may become the floppy disks of the future.

The 3.5" rewritable optical disk systems are unique in one respect; they are the first optical storage systems to post-date the ISO standards for the interchangeability of optical disk cartridges. Consequently, all 3.5" disks conform to the ISO 10090 standard, "which specifies a nominal recording capacity of 130 [Mb] per single-sided magneto-optical disk cartridge."[60] All but one manufacturer of 3.5" systems uses disks that conform to this standard. In 1991, MOST introduced a proprietary system which supports a 256 Mb cartridge. MOST drives also support the ISO standard cartridges; two separate cartridges are needed for each recording mode. All current 3.5" rewritable systems use the CCS recording format, but the ISO standard supports the use of a Discrete Block Format (DBF), which is similar to the SS recording format used

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60 Ibid, p. 34.

by some WORMs.[61]

As a whole, rewritable optical disk drives have faster access times than their WORM counterparts, but are still slower than similar magnetic disk drives. The average access time of a 5.25" rewritable drive is between 60-70 milliseconds, a time which is close to the access times of the slowest magnetic disk drives. The access times of the 3.5" rewritable drives is in the 50-70 millisecond range, but access times are expected to improve for both the rewritable and WORM based systems.[62]

OPTICAL TAPE

A third form of optical storage system is optical tape.[63] Optical tape systems have been in the experimental stages since the late 1970s, but have not progressed to the commercial stage as quickly as have other forms of optical storage systems. ICI ImageData, a British company, developed its "digital paper" product in the mid 1980s, but commercial application of the medium did not occur until 1989. Digital paper is a form of optical storage similar to WORMs, yet is more flexible and versatile in both its physical and functional abilities. As with WORMs, information recorded on digital paper is non-erasable, but digital paper can be cut into strips, disks, tapes or tags. The name "digital paper" is in itself misleading, as this is not a paper-based medium, but is constructed of a "dye polymer infra-red sensitive coating on a polyester-based substrate, capable of being recorded on by laser", and has a projected life span of

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61 Ibid, p. 34.
62 The average access time for 5.25" WORM drives is between 75-250 milliseconds, 12" drives 90-500 milliseconds, and 700 milliseconds for 14" WORMs.
63 Optical tape is also known by its brand name, Digital Paper. In the interest of variety, and as this system is proprietary, the two terms will be used interchangeably in this study.

30 years.[64]

Digital paper consists of a four-layer sandwich of substrate, reflective metal, active and protective layers. The substrate layer is made of a 25-27 micron deep polyester-based film (Mellinex), which provides the mechanical strength of the entire structure. The next layer is a thin coating of metal, similar to silver plastic balloon foil. This layer forms a passive mirror which is not affected by the recording process. The active layer is a transparent polymer made up of an infrared absorbing dye. Information is recorded by beaming an infrared laser at this layer. The dye absorbs the radiation emitted by the laser and converts it to heat energy, causing the polymer to form pits. This layer is a very poor conductor, thus allowing the laser's heat to be more concentrated to create sharper and smaller pits. As a result, the pits, and thus the data bits, can be packed more densely onto this particular medium than on a traditional WORM disk. A full tape, which measures 880m by 35mm and fits onto a 12 inch reel, holds a terabyte of data. The fourth layer is a transparent protective polymer. Commercial versions may also have a fifth polymer layer to protect and facilitate the smooth movement of digital paper lengths when used in reels and cassettes.[65]

As in other WORM systems, in order to read data, the pit-burning laser is beamed back at a lower intensity onto the recording layer. The laser then reads the changes in reflectivity caused by the pits in the recording layer. Digital paper disks, exploit what is termed the "Bernoulli effect", and thus must use a slightly different hardware system than traditional WORM disks or digital tape.

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64 "Digital Paper is Write-On", Canadian Data Systems, 20:6 (June 1988), p. 67. This is a conservative estimate, and ICI Imagedata predicts a lifespan similar to that of Sony's "Century Media". For more information on the lifespan of Optical Tape, see Chapter two.

65 D. Pountain, "Digital Paper", Byte, 14:2 (February 1989), p. 276.

The "Bernoulli effect" employs two digital paper disks which rotate back to back close to the underside of a fixed plate containing the recording heads. The spinning of the disks creates airflow currents that lift the disks toward the read/write heads without touching them. The disks are held at a constant 50 microns away from the heads, allowing the laser to keep a steady focus on the reflective layer. The disks cannot crash like hard disks, as hardware failure triggers airflow depressurization, causing the disks to fall away from the read/write heads, rather than into them.[66]

The only company currently marketing optical tape drive systems is a Vancouver-based company, CREO. The CREO system drive looks like a large magnetic tape drive, but has the capacity to store one terabyte of information on a tape 880m long and 35mm wide. Each tape has sets of 33 tracks, including a clock track, and information is recorded in parallel sequences along the track. While parallel, however, the actual placement of the tracks is across the tape rather than parallel with the edge, and uses oscillating head to read the data from the tape. This format allows for more data to be written to the tape and faster retrieval times. Once a set of 33 tracks has been written across the tape, the tape is skipped forward to the next unwritten part to allow the next set to be written, similar to the sector spacing process used on magnetic disks. Comparable to conventional optical disks, the space between bits is 1.5 microns in each direction, and the laser focus spot is approximately one micron across. The data rate is 3MB/second, and the average access time for information retrieval is 28 seconds. For even faster access, an address track is written along one edge of the tape, to be read by a separate stationary head.[67] The maximum search time, from one end of the tape to the other, can be achieved in one

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66 Ibid, p. 279-280.
67 Bradley, Optical Storage for Computers, p. 98-99.

minute.[68] The suppliers guarantee a storage stability of 20 years, if the medium is stored under proper conditions. This information is unsure however, as extensive testing results have not been confirmed, and as of now only one supplier exists for this medium. The product is being used, however, and one of CREO's main customers is the Canadian Centre for Remote Sensing which uses optical tape to store data it receives from its satellites. Optical tape systems are not inexpensive, as the CREO drive sells for about US$200,000 and a reel of tape for almost $10,000. When this is broken down into cost per megabyte, it comes to a few cents per megabyte as one reel stores the equivalent of 100 million pages, or 5,000 conventional magnetic storage tapes.[69]

Outside of its massive storage capacity, optical tape has another significant advantage over magnetic tape: it is not subject to erasure by magnetic fields. The tape itself is also stronger than comparable magnetic tape, and although both storage media must be periodically rewound to relieve stress caused by the incessant winding and rewinding, the stronger optical tape is more capable of handling these stresses and is less susceptible to any damage or mechanical distortions caused by this process. In addition, the CREO system has a built in software controller that keeps a running tab on the reliability of the data each time the data are accessed, and gives the operator advance warning when the data are starting to degrade. This feature has the advantage of allowing the tapes to be recopied only when it is necessary, rather than on a routine basis as is the present case with comparable magnetic media.[70]

The three types of optical storage media examined in this chapter,

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68 McCormick, A Guide to Optical Storage Technology, p. 88.
69 J. McCormick, The New Optical Storage Technology: Including Multimedia, CD-ROM, and Optical Drives, (New York: Irwin Professional Publishing, 1994), p. 128.
70 McCormick, A Guide to Optical Storage Technology, p. 87.

WORMs, Rewritables, and Optical Tape, are all currently in use in various public and private agencies. In addition, WORMs and Optical Tape in particular, have significant potential as archival storage and research media. Optical media not only support much of the material presently created or received during the normal course of affairs of individuals, agencies or organizations, but they will also be used more and more as an archival storage medium for electronic and paper records, as well as a research and preservation tool for almost any kind of record found in an archives. Consequently, familiarity with optical storage technology is essential to both its application to present matters and to an understanding of future ones.

CHAPTER TWO:

PRESERVATION OF OPTICAL MEDIA

> The storage life of media is a topic which is critical to the mission of an archives. Archivists would like to know how much longer a record might last in storage to plan necessary preservation.[1]

Everything deteriorates with age, and optical media are no exception to this rule. Preservation problems occur in every medium, and with the great storage capacity of optical storage media, data loss from media deterioration has the potential to affect a very large number of records. Although optical storage media have not been in existence for very long, there is a body of knowledge regarding media degradation and optimum environmental conditions for storage and handling. Optical storage media do not require as specific a storage environment as magnetic media, but there are nonetheless preservation, storage and handling concerns typical of optical media.

As a relatively new technology, optical storage systems are still unproven in terms of their lasting ability. Optical disks have only been available commercially for a decade or so, and optical tape has only been on the market since 1991, neither of which periods has been long enough to provide users with an experience-based estimate of media longevity. Consequently, what is known regarding the interaction of optical storage media with the environment is based

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[1] A. R. Calmes, "Relative Longevity of Various Archival Recording Media", in Proceedings of the International Symposium: Conservation in Archives, (Ottawa: National Archives of Canada/International Council on Archives, 1989), p. 207.

on a combination of previously collected knowledge about the materials used to make the media and the results of accelerated-aging tests.

Most of the elements used in the production of optical media have been studied for the past century and there is a considerable body of knowledge regarding their properties. For example, tellurium, the most common optical disk base material, was discovered in the eighteenth century, and over the years a certain familiarity with tellurium's reactions to various environmental conditions has been developed. A similar bank of knowledge exists for most of the other elements used in the manufacture of optical media.

However, the primary method used to determine the longevity and preservation criteria of optical media is accelerated-aging testing. The specific methodology used in accelerated-aging tests varies, but they all generally expose the disks to very hot and humid storage conditions. Such tests usually aim to sustain a temperature of 60°-120° Celsius and a relative humidity (RH) of 90% for a brief, but previously determined amount of time.[2] All changes which occur in the media as a result of this treatment are noted, and mathematical formulae are used to compute the rate at which similar changes might occur given normal use and storage conditions. Manufacturers' estimates regarding product reliability and storage recommendations are then based on these calculations.

The three most common accelerated aging techniques used to determine the longevity of optical media are: "steady- state elevated temperature and humidity with Arrhenius extrapolation; elevated levels of temperature plus corrosive gases (the "Battelle" test); and chemical stability investigations."[3] The

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2 W. Saffady, "Stability, Care and Handling of Microforms, Magnetic Media and Optical Disks", Library Technology Reports, 27:1 (January-February 1991), pp. 74.

3 R. A. McLean, J. F. Duffy, "ICI Optical Data Storage Tape", Presented at NASA Mass Storage Conference, 1991, p. 3.

Arrhenius Model is the main test used to determine the longevity of optical storage media as it "assumes that temperature and relative humidity are the crucial independent variables that over time affect the longevity of optical media."[4] Arrhenius tests are performed at "various constant conditions of temperature and humidity", and this, in the case of the tests performed by the National Institute of Standards and Technology (NIST), involves storing the disks at 70°C, 80°C, and 90°C and a RH of 90% for 4120-5711 hours. The test disks are then read at various points during the testing process. The test results have showed a linear increase in error rates as the environmental conditions worsened. This has made it possible to predict the error rate of disks at normal room temperatures.[5] Similar tests performed on optical tape have exposed sections of tape to an environment of 80°C, 90°C and 95°C and 70% RH for 51 days, and found a corresponding linear progression in error rates.[6]

The "Battelle Class II" test utilizes high temperatures in combination with corrosive gases, and is intended to duplicate the "aging of materials in cities and other locations where combustion byproducts form a mix of corrosive gases."[7] Before any testing, blank and written areas from the inner, middle and outer sections of the test tapes or disks are characterized with bit-error maps. The purpose of these maps is to provide a pre-test point of comparison against the bit-error rates of the same tapes and disks <u>after</u> the tests have been run. By using such controls, any changes in the test media can then be attributed to damage caused by the test's environmental conditions. In the actual

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4 Technology Research Staff, NARA, "Development of a Testing Methodology to Predict Optical Disk Life Expectancy Values", NIST Special Publication 500-200, (Washington, DC: NARA, 1991) p. 1.
5 Ibid., p. 1.
6 ICI Imagedata, "ICI Optical Data Storage Tape - An Archival Mass Storage Medium, July 1992", ICI Imagedata Internal Research Paper, 1992, p. 3.
7 McLean and Duffy, "ICI Optical Data Storage Tape", p. 6.

test, the test media is held in the mixed gas environment for 60 days, as previous tests run by the Battelle Institute have determined that a 60 days exposure under test conditions adequately reproduces the equivalent of 30 years exposure to a typical office environment. Mathematical formulae are then used again to determine the longevity of the test media.

Finally, chemical stability techniques include UV stability tests such as the "Blue Wool Test", which measures light fastness, and a test developed by Sony for its "Century Media", which exposes the sample to "120 hours of UVA light at 45°C and 60% RH and is the equivalent of 70 days of sunshine".[8] Temperature cycling tests are also used to determine the chemical and mechanical stability of the test medium. Chemical stability can also be determined by testing the solubility of the test material. In chemical stability tests on optical tape, samples were placed in a Soxhlet extraction by Delifrene, for two hours followed by another two hours in acetone, and also a Soxhlet extraction by ethanol for 72 hours: after this samples and extract were weighed and analyzed for signs of decomposition.[9] These forms of chemical stability tests are particularly effective in determining the stability of dye-polymer based materials.

However, there is not yet a working environment-based estimate of the lifespan or preservation needs of optical media. Despite the findings of accelerated-aging tests and previously collected knowledge of optical media production materials, the accuracy of lifespan estimates is still in question as it is unclear whether disk performance under normal use conditions can be duplicated accurately by accelerated-aging tests and whether the lack of **standardized** testing even allows for a comparative use of the results of such tests.

The lack of standardized testing is complicated further by the

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[8] Ibid, p. 4.
[9] Ibid, p. 5.

optical storage media industry's tendency to use in- house rather than independent testing facilities. Optical storage media testing is generally performed by the manufacturers of optical media rather than by independent testing agencies. As a result, while manufacturers' claims of product longevity are based legitimately on accelerated- aging tests, manufacturers do not often provide details regarding the specific conditions under which the tests were conducted. Test parameters, specifications regarding byte error rates for specific surface areas rather than the entire disk surface as a whole, test methods used, quality measurement approaches, mathematical models used to extrapolate media life expectancy at room temperature, criteria for data analysis and the experimental stress conditions imposed on the media being tested are rarely included in manufacturers' literature regarding the life expectancy of their products. The lack of knowledge regarding the exact test parameters thus makes it difficult not only to assess the estimated lifespan of any one specific disk or tape, but to compare the performance and life expectancy standards between different types and manufacturers of optical storage media. To complicate matters further, accelerated-aging tests are more likely to have been performed during the experimental and prototype stages of product development, and therefore may not reflect the qualities of the final commercial product. As a result, manufacturers claims regarding the longevity of their product have to be considered conservatively, rather than as an absolute product performance guarantee.

The lack of standardized testing, working-environment based estimates of the needs of media conservation, and the industry's reliance on manufacturer-directed testing all affect both the estimated lifespan of optical media and their specific preservation requirements. When assessing the life expectancy and preservation needs of optical storage media, one must also keep in mind that manufacturers' estimates regarding optical storage media lifespans generally come from a closed environment controlled by the manufacturers who have a vested interest in their product, not independent observers who may have a more objective view of the products at hand. Until the industry is capable of providing the user with objective, experience-based and time-tested life expectancy claims and preservation guidelines, the user will have to use a combination of "buyer beware", user experiences and a leap of faith to determine the validity of manufacturers' claims regarding their optical storage media. Time will be the final judge of the credibility of manufacturers' claims on the lifespans of their disks, but until the media have been available for 100 years, one will have to rely on past experiences with the production materials, researchers' estimates, user experiences and educated guesses to make our decisions on how to deal with the preservation problems presented by optical media.

MEDIA DEGRADATION

Media degradation can occur in three categories: chemical, magnetic and mechanical. The only difference between WORM and rewritable optical storage media deterioration is that only MO disks are subject to degradation by magnetic fields.

Oxidation is the primary form of chemical deterioration found in optical media. This problem was noted as far back as 1980, as was the relationship between oxidation and disk exposure to high heat and humidity environments.[10] The damage caused by oxidation can be quite severe, and is obviously detrimental to the retrieval of any data stored on disks affected by this process, as the data density of optical storage media precludes an ability to

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[10] Saffady, "Stability, Care and Handling", p. 74.

tolerate even small amounts of disk deterioration without a noticeable loss of data. Optical media store in the region of 150 to 400 million bits of information per square inch, as compared to 50 to 69 million bits per square inch for magnetic media. Therefore, a "tracking error of one-half micron (approximately 1/50,000th of an inch) in an optical disk system is enough to cause a stored bit to be read incorrectly", leaving little room for media degradation, and a lot of room for degradation-caused bit errors.[11] Powerful error-detection and error-correction codes can compensate for error rates "below five out of every 10,000 bytes", but once the error rate exceeds this number, the reliability of the data encoded on the disk becomes significantly compromised. Unfortunately, media degradation produces error rates in excess of those correctable by such codes. Thus, it becomes necessary to use human and electronic methods to either prevent, prolong, or monitor the degradation of optical storage media in order to manage the level of errors before they become too severe and the storage media become unusable or unreadable.

Despite efforts to the contrary, it impossible to escape the threat of oxidation damage to optical storage media as the materials used in their manufacture are prone to oxidation. Metallic thin films, the materials used to produce the recording layer of WORM disks for example, are inherently susceptible to oxidation from exposure to air. Continual exposure to air results in "pinhole formation and other forms of corrosion which can significantly alter the reflectivity, transmissiveness, signal-to-noise ratios, pit formation characteristics, bit-error frequencies and other recording and playback properties of optical

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11 National Archives and Records Administration, The National Archives and Records Administration and the Long- Term Usability of Optical Media for Federal Records: Three Critical Problem Areas, (Washington, DC: NARA, 1993), p. 2.

media."[12] An additional characteristic of disk oxidation is weight loss, and is "associated with the formation of unidentified volatile products."[13] Oxidation is inevitable, and as shown above, its effects have a serious impact on the retrievability and readability of any data stored on media affected by this process.

Oxidation of the reflective layer can also cause the recording layer to delaminate from the substrate. This form of damage can often be seen in a visual inspection of the disk, and is believed to be the result of damage to the seals on the inner and outer edges during either the placement of the disks in the ovens or from the physical stresses placed on the disks by the high temperature and RH environment inside the ovens. Fernando L. Podio, in his Development of a Testing Methodology to Predict Optical Disk Life Expectancy Values, determined that damage from oxidation and delamination tends to affect the outer and inner tracks more than the middle tracks of the disk.[14] Thus, it is imperative when testing optical media for deterioration, that several track areas be tested, as not all track sectors are subject to the same form or rate of deterioration.

Hydrolysis, a form of media degradation caused by a chemical reaction with water, occurs when the media are exposed to extremely high humidity environments. This form of degradation is common to magnetic tape formats, as it affects the binder in the recording and overcoat layers. While it is possible for all optical media to be susceptible to this form of media degradation, optical tape with its binder and overcoat layers is slightly more subject to hydrolysis. Tests performed on optical tape, however, have shown an absence of

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12 Ibid., p. 73.
13 Ibid., p. 74.
14 F.L. Podio, Development of a Testing Methodology to Predict Optical Disk Life Expectancy Values, NIST Special Publication 500-200, (Washington, DC: NARA, 1991), p. 28.

"binder hydrolysis in the optical tape recording layer after severe environmental exposure and extraction process" and only "minor hydrolysis present in the overcoat after 3 weeks at 80°C and 80% RH.[15] Nonetheless, hydrolysis is a form of media degradation that can affect optical media, and environments conducive to its development are not conducive to long-term storage and retrieval of data stored on optical media.

Although MO technology employs a different means to record information than WORM technology, MO disks are also affected by oxidation. Rare-earths and transition metals such as those used in MO recording media have well- documented adverse reactions to high temperature and RH environments. Oxidation of these classes of metals has been determined to be the chief cause of aging in MO media. For example, terbium, a rare-earths common to MO recording media oxidizes very easily. The oxidation of terbium- ferrite thin film was found to significantly alter the "magnetization, coercivity and other properties that affect recording and playback". In addition, the "exposure of terbium-ferrite-cobalt to high temperatures "initiate[d] an oxidation process" that significantly altered the disk's MO characteristics.[16] Accelerated-aging tests involving gadolinium-cobalt, gadolinium-ferrite and terbium-ferrite MO disks indicate that exposure to high humidity results in various types of bit errors, reduced recording sensitivity and coercivity. These particular tests determined that the bit errors were the result of "electrochemical corrosion associated with high humidity" environments alone, thus eliminating dual-sided recording, recording radius or characteristics of recorded data patterns as possible causes of such errors. As with WORMs, oxidation of MO disks tends to affect the outer and inner tracks more than the middle tracks.

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15 McLean and Duffy, "ICI Optical Data Storage Tape", p. 7.
16 Ibid., p. 74.

The fear of metal oxidation has, however, prompted optical storage media manufacturers to employ encapsulation and protective coatings-- "passivation layers"-- to extend the life of their products. Most tellurium-based WORMs manufacturers employ "air sandwiches" which consist of "two platters separated by an air-filled cavity" to protect their disks' sensitive recording layers.[17] The utilization of these "sandwiches" has been shown to improve the stable storage life of the disks by protecting them from environmental forces, at the cost of only a negligible impact on the disks' read/write properties. The problem with this type of encapsulation is that the protective barrier is only as effective as the seals used to secure the "sandwich". Once the seal has been broken or has deteriorated, the oxidation process begins. As there is no such thing as an unbreakable seal for these disks, oxidation is inevitable; "air sandwiches" only delay the process.

MO disks also reap significant benefits from the application of protective coatings to their recording layers. Silicon-based protective coatings have been used successfully to inhibit the oxidation process on terbium- ferrite-cobalt disks. Studies have also shown that aluminum nitride coatings on terbium-ferrite and terbium- ferrite-cobalt disks have a similar effect, suppressing pinhole formation and helping to prevent a loss of coercivity on MO disks exposed to high temperatures for long periods of time. These aluminum nitride protective coatings, however, have been found to be most effective when applied to both sides of the recording layer, rather than just one side.[18]

Metal alloying is another method by which oxidation can be suppressed, especially in WORMs. Tellurium and terbium thin films such as those used in WORMs can become less corrosion-prone when alloyed with

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[17] Ibid., p. 75.
[18] Saffady, "Stability, Care and Handling", p. 75.

oxidation-resistant metals. Oxidation resistance, and thus the useful lifetime of the disk, can be improved significantly when these thin films are alloyed with metals such as boron, silicon, chromium, aluminum, rhodium or phosphorous. Specifically, the addition of selenium "completely inhibited oxidation at extreme temperatures and relative humidities." Alloying thin films with lead was found to inhibit cracking, while the addition of platinum, titanium, beryllium, indium, boron, gadolinium or praseodymium suppressed the formation of pinholes in MO thin films made of terbium, iron and cobalt.[19]

Media degradation is not only found in the recording layers of optical storage media, but also in the substrates underneath the recording layers. Both WORMs and rewritable media coat their recording layers onto glass or plastic substrates, and unfortunately both types of substrates can suffer from defects which can affect their respective recording layers and thus the useful lifetime of the media. Glass substrates are purported to have superior "uniformity, optical clarity, mechanical stability, scratch resistance, freedom from warping, resistance to moisture absorption and ability to withstand high temperatures."[20] Plastic substrate advocates, however, claim their substrate is more economical to produce, an advantage they claim overrides plastic substrate-based disks' greater predisposition towards media degradation. Studies also show that optical recording materials on glass substrates are less vulnerable to oxidation than those on plastic substrates as plastic substrates tend to absorb more moisture than their glass counterparts. The less moisture absorbed by the disk, the less opportunity for oxidation to gain a foothold and ruin the disk.[21]

Although a user may have a preference for either plastic or glass

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19 Ibid., p. 75.
20 Ibid., p. 76.
21 Ibid., p. 76.

substrate disks, oxidation caused by defects in the substrate does not. Initial defects in either type of substrate can accelerate the oxidation process at the defect site. Defects affect both types of substrates, but occur more often in plastic substrates, as these have a higher incidence of initial defects and are more susceptible to "internal cracking, swelling, shrinkage, changes in tensile strength and formation of water-filled pockets".[22] However, some forms of plastic substrate disks are better than others. Polycarbonate substrates are the best among plastic substrates as they do not degrade quite as quickly and are somewhat less susceptible to moisture absorption than other types of plastic substrates. At the bottom of the list is polymethyl methacrylate (PMMA), which has an even greater tendency to absorb moisture than polycarbonate substrates, and is far more susceptible to oxidation than glass substrates. PMMA disks can also suffer from cold flow problems. Cold flow involves gravity changing the shape of an object, and is more commonly known to occur in extremely old stained glass windows. Over centuries, gravity has pulled the glass toward the bottom of the panes, resulting in thicker glass at the bottom and thinner glass at the top of the window. A similar effect can occur when PMMA disks are placed on an uneven surface. In such an environment the shape of PMMA disks may change enough to cause problems with information retrieval.[23] Regardless of the type of media, substrate materials have a significant impact on the storage and playback stability of their respective optical storage media, something users must keep in mind when choosing media for their optical storage systems.

Substrate materials, however, are not the only substrate- related factors which affect the storage stability of optical storage media. Substandard or defective whole substrates are actually responsible for most of the

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22 Ibid., p. 76.
23 Ibid., p. 77.

deterioration affecting the recording layer. Microscopic pits, surface roughness and other related defects in the substrate layer of tellurium-coated disks are a primary cause of bit errors. Pinhole formation in MO disks are caused mainly by microscopic defects in the plastic substrate. In MO disks in particular, these defects in the substrate layer "promote the interaction of moisture with MO recording materials, thereby contributing to pitting-like corrosion."[24] Dense smooth, uniform coating of the recording layer onto the substrate improves the resistance of the recording layer to oxidation and promotes the media stability of the disks. This is easier to achieve consistently on glass rather than plastic substrates, thus lowering the susceptibility of glass substrates to media degradation and increasing its media stability over that of plastic substrate-based disks. Strict quality control during disk production also assists in the elimination of substandard or defective substrate layers and the problems they cause in the later stages of disk production, use and eventually the promotion of media deterioration. Substrates are a significant element in the determination of an optical disks' longevity, an element which can be the determining factor in both the accuracy of the information written to the disk and the ability to retrieve that information reliably at some point in the future.

As an overall judgement, however, while plastic substrate disks are less expensive, disks intended for long-term storage of information should be placed on glass substrate disks, as they profess not only to have a greater ability to withstand the ravages of their storage environments but a lower incidence of initial defects than plastic substrate based disks. Optical media utilizing glass substrates may cost more, but they have a greater storage stability and are thus better candidates for long- term storage use than optical storage media utilizing

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24 Ibid., p. 76.

plastic substrates.

Magnetic deterioration is another form of media degradation which affects certain types of optical storage media. This form of media deterioration affects only MO disks, as they are the only type of optical storage media which employs magnetic properties to record data. Magnetic deterioration occurs when MO disks are exposed to high levels of magnetism combined with heat. The combination affects the magnetic orientation of the data encoded on the disks, making the data either unreadable or unreliable. If the magnetic field and heat source are strong enough, the information encoded on the disk can be completely erased. MO disks can be affected by magnetic fields stronger than 600 oersteds, but evidence suggests that the magnets have to be very close to the disk to initiate any deterioration. Magnets exceeding 600 oersteds, however, can be purchased in most hardware stores. Accidental erasure, either by human or magnetic means, nonetheless, is only a problem related to MO disks.

The lifespan of optical storage media is not only affected by "environmentally induced changes in [their] chemical and physical characteristics", but several other factors as well, making generalizations regarding the lifespan of optical storage media difficult to compile. Diversity of media construction and recording techniques are a significant factor in determining the useful lifespan of any optical storage medium. WORMs and rewritables employ a large variety of recording materials, equipment and methods of recording information. Optical disks can be constructed of metal alloys, metal-polymer combinations or dye-based materials; utilize glass or plastic substrates; or record information using ablative pits, bubbles, texture-change, dye-diffusion, phase change, alloy fusion or a combination of heat and magnetism. A 1986 NARA report prepared by the National Research Council (NRC) determined that at that time there were approximately 194,400 different combinations of optical storage media characteristics and recording techniques.[25] The large amount of diversity within the media characteristics and recording methods alone makes generalizations regarding disk lifespans not only difficult to compile, but to comprehend-- especially for those using or receiving disks from numerous sources or creators.

Media diversity goes deeper, however, than just the combinations used in the basic construction and recording techniques-- the actual formulations of the basic materials used in disk construction can also be proprietary. For example, several manufacturers may use tellurium thin films for their recording layers, but each manufacturer will use different tellurium alloys, and often tailor proprietary compounds specifically to one product or product line. Manufacturers of MO media often employ a similar tactic, utilizing a variety of formulations for their specific recording materials. MO disks in particular, often are formulated differently depending on the way the disk will be formatted. For example, most manufacturers use different media for disks formatted with 512 bytes than for those formatted with 1024 bytes per sector.[26] While manufacturers have performed accelerated- aging tests on their products, these tests are not standardized, and thus their results cannot be easily compared with tests performed on similar forms of optical storage media. In addition, the great diversity of disk materials, construction and recording techniques greatly exacerbates any attempts to create any base of general knowledge regarding the preservation of any one type of disk. Some generalizations can be made, of course, but anyone dealing with optical storage media must err on the side of caution, as the field's great diversity makes it impossible to do anything else without possible damage to the records stored on any one form of optical storage

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25 Ibid., p. 79.
26 Ibid., p. 79.

media.

As a consequence of this lack of standardized testing and diversity of media construction, recording technology and media formulations, the predicted storage lives of both WORMs and rewritables varies considerably. The useful storage life of WORMs ranges from 10 to 100 years, depending on the recording materials used, manufacturers' claims and the results of accelerated-aging tests. Tellurium-based ablative recording WORMs have a predicted storage stability of 10 to 40 years. The earlier first- generation disks were judged to have a storage/playback stability of 10 years or so, but more recently manufactured disks have an estimated lifespan of 30 to 40 years. The increased estimated storage/playback stability is due primarily to "improved tellurium alloys, media designs and manufacturing technologies."[27] Disks using thermal-bubble recording methods claim a similar storage/playback stability of 10 to 30 years. The first generation of Gigadisc 1000 WORMs have an estimated lifespan of 10 years, but later versions claim a storage life of 30 years. While Sony claims that its dual-alloy WORM "Century Media" have a storage/playback stability of 100 years, accelerated-aging tests have only confirmed a playback stability of at least 30 years. Dye-polymer disks have an expected storage stability of 15 years, as do those used in tellurium-based phase change media. The WORMs used in Plasmon's platinum-based phase change media are purported to have an useful lifespan of 50 years. Consequently, WORMs received by an archives could have an estimated storage life of anywhere from 10 to 100 years, making planning for effective conservation and preservation procedures a difficult task.

Optical tape, while the newest member of the WORM family, has the longest predicted lifespan. ICI Imagedata tests have calculated a media

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27 Ibid., p. 80.

lifetime of more than 30 years "in the presence of corrosive gasses" (the Battelle Test), and a chemically stable lifetime in excess of 300 years, under ideal storage conditions of 20°C and 60% RH. The latter prediction was based on results from Arrhenius testing and comparisons with the tests performed on Sony's "Century Media".[28]

Unlike WORMs or optical tape, however, rewritables must have an identical shelf and playback stability rate, as these disks must support both the recording of new data and the retrieval of old data. Overall, the reliable recording and playback life of MO disks ranges from 10 to 25 years depending on the substrate used and the manufacturers' claims. MO disks utilizing plastic substrates generally have a useful shelf and storage stability of 10 years. However, MO disks employing glass substrates have an estimated lifespan of 15 to 25 years. Rewritable disks using phase change recording technology have an estimated storage/playback stability of 10 years. Rewritables have a significantly shorter estimated lifespan than WORMs, a factor which must also be taken into consideration when determining the conservation and preservation plans regarding any institution's, agency's or archives' optical storage media needs and concerns.

Unfortunately, all this speculation regarding the lifespans and durability of optical storage media must take into consideration the continual growth and evolution of optical storage technology itself. The technology involved in both the creation of the disks and more importantly their drive systems is new and is constantly changing, making estimates regarding the lifespans of any one optical storage media a bit of a gamble at the best of times.

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28 "ICI Optical Data Storage Tape", p. 3, 6. ICI Imagedata prefers, however, to use a more conservative estimate of 100 years as this number takes into consideration more generously "the large errors associated with calculation of activation energies and extrapolation of such predictions."

As such, it is likely that the elements that make up an optical disk or tape will last longer than the systems needed to retrieve the data recorded on them. Thus, information stored on Sony's "Century Media" may be technically readable 100 years from now, but realistically, the optical disk drives and the software needed to read the data will have been long gone, rendering the information stored on the disks unreadable.

In terms of optical drive systems, the software and hardware comprising the drives typically have a useful life of approximately ten years. While manufacturers generally provide their next generation products with some backward comparability, this is not necessarily the case. The STORLORD optical disk storage system used by the National Archives of Canada (NAC) is an example of a manufacturer not providing this backward compatibility, leaving the user stuck with an obsolete, and eventually insupportable information storage system. In June 1992 the manufacturer of STORLORD released an upgraded but not downwardly compatible version of its disk drive. The manufacturer is required by law to support the previous disk drive system for seven years, but this "leaves the NAC with no obvious migration path."[29] Although manufacturers are required by law to support their products for seven years after the product has been discontinued, for archival purposes seven years hardly provides permanent access to the information stored on such systems. The discontinuation of equipment is not without other precedents, as the present unreadability of "seven-track magnetic tapes and hard- sectored eight-inch diskettes" prove beyond this the shadow of a doubt.[30] Therefore, users must be careful to choose reputable and stable manufacturers for their optical storage

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[29] Electronic Records Coordinating Committee, Historical Records Branch, Report of the Working Group on Conservation Standards and Technologies, (Ottawa: National Archives of Canada, 1992), p.5.
[30] Saffady, Optical Storage Technology 1992, p. 7.

systems, upgrade their equipment and migrate their data to keep both usable. Otherwise, the information stored on such obsolete systems becomes almost immediately unreadable and unusable.

As such, the hardware and software dependency of optical storage systems does not give the manufacturers of disks with long storage stability estimates any great edge over those of the competition. No matter what recording technology is used, is likely that if the information recorded on the optical disk or tape is intended to be readable for more than approximately ten years, the information will have to be translated to other, newer media in order to preserve the information written to the disks. Thus, the storage stability of the medium is not really a significant factor, as the information on it will likely have to be transferred long before the expected lifetime of the disks themselves have expired. The disks or tapes may last a hundred years, but if the hardware and software needed to read the information on them no longer exists, the longevity of the storage medium is insignificant, as the information it was storing has become unreadable. Unreadable information is useless, regardless of its storage medium and its longevity.

STORAGE AND HANDLING

Proper storage and handling of optical storage media is essential to guarantee and prolong its usefulness as an information storage medium. While optical storage media do not require as specific a storage environment as do comparable magnetic-based storage media, there are recommended storage and handling procedures for optical media. Despite the inherent hardiness of the medium, it is still subject to damage caused by improper storage and handling procedures or techniques.

Although we do not know the ideal temperature or RH conditions for long-term storage of optical storage media, we do know that hot and humid conditions promote oxidation and corrosion of WORMs, optical tape and rewritable disks, particularly those which use metallic thin films in their recording layers. Passivation layers and corrosion- inhibiting alloys provide some protection from oxidation, but as of yet there is no way to prevent oxidation from occurring; we are only able to postpone the inevitable. All-encompassing storage specifications for optical storage media are complicated by the great variety of combinations of recording technologies used by WORMs and rewritables. What we are left with are manufacturers' recommendations regarding conditions under which they believe their equipment will perform reliably. Manufacturers' recommendations for acceptable working conditions for their media range from 10°C to 60°C with a maximum rate of change of 10% to 20% per hour. Recommended RH ranges from 10-80% with a rate of change similar to those for temperature. The recommended environmental conditions for long-term storage are even broader, allowing a temperature of -10°C to 50°C and a RH of 10-90%.[31]

Although the estimated storage requirements for optical media are far less stringent than those needed for magnetic media, and fall within the range of environmental conditions found in the vast majority of homes and offices, this diversity can still present storage problems. Such a wide spectrum of acceptable storage environments presents the advantage of allowing the storage facility to be flexible in its storage environment, but also the disadvantage of presenting the storage facility with a wide variety of storage requirements for its various optical media. An assortment of storage requirements can be expensive to maintain,

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31 Saffady, "Stability, Care and Handling", p. 84. ICI Imagadata suggests a more specific 18 degrees C and 70% RH as the ideal storage conditions for optical tape. (ICI Imagedata, "ICI Optical Data Storage Tape", p. 6.)

particularly if individual media requirements do not fit easily into the storage specifications demanded by other media within the institution's holdings.

High temperatures and RH affect not only the recording layers of WORMs and rewritables, but also their substrate layers. As such, optical disks employing plastic or PMMA substrates should not be used in areas affected by high humidity as they tend to absorb moisture more readily than glass substrate based disks. Under such conditions, plastic or PMMA based disks would have a much higher rate of oxidation and corrosion than comparable glass substrate based disks.

Optical tape is similarly affected by high temperatures and humidities, as it is also based on a polyester substrate. High temperatures and relative humidities can cause the polyester base film to warp and become brittle, preventing the tape from being rewound onto its reel and being read by the optical reader. The Mellinex base layer used in optical tape is extremely stable, but care should be taken not to expose the media to conditions which would cause the base film to deteriorate.[32]

Circumstances of high humidity, however, are not only limited to geographic areas subject to natural high humidity conditions. High RH conditions can easily be generated inside an office environment by common office equipment and furnishings. Simply having liquids near the optical storage medium on a regular basis can increase the RH in that immediate area, especially if the liquids are accidentally spilled on the disks or tapes themselves. In addition, disks should not be stored near kettles or any other water vapour creating devices as this also increases the RH in the immediate vicinity of the tapes or disks.

32 ICI Imagedata " ICI Optical Storage Tape", p. 4.

Heat and direct sunlight also have a significant impact on the effectiveness and longevity of optical media. Optical storage media should not be stored in direct sunlight, near radiators or other intense heat sources, as this can affect both the recording and substrate layers. They also should not be stored on top of their drive systems, as this exposes the media to both heat and dust.

Dust and dirt are two of the most common elements in any office environment, and two of the most damaging to the proper use and storage of optical media. Dust and dirt affect the reflectivity of the disk, causing playback errors. Dust on a disk or tape causes the optical reader to skip, creating an effect roughly analogous to the skipping of a phonograph record. These conditions can make information retrieval more difficult if not occasionally impossible, thus severely limiting the usefulness of the media in question. Consequently, disks, tapes and their drive systems should not be placed near dust and dirt producing equipment such as photocopiers, printers and ash trays, unless one is prepared to clean the disks regularly or have the media affected by the dust and dirt created by these devices. In short, keep the disk storage area as clean and dust-free as possible, and only operate optical storage media on systems which are in good operating condition and are cleaned and maintained regularly.

Contaminants as a whole cause a significant amount of damage, both permanently to the disk and personally irritating to users of optical storage media. There is a reason most optical disks are stored in cartridges; to keep them as free as possible from possible contaminants. Consequently, users should not tamper with the disk cartridges, as this behaviour makes users as much of a contaminant as dust, dirt and spilled coffee and just as damaging to the effective operation of the optical media. While the cartridges are as tamper-proof as possible to prevent these sorts of problems, the cartridges are not hermetically sealed. As a result, dust, the perpetual enemy of optical disks, can indeed invade the cartridge and wreak havoc on the disk sheltered within. If this happens, the disks should be cleaned immediately with the **disk cleaner recommended by the manufacturer for the specific disk in question in the manner specified by the manufacturer**. There are so many different types of disks in the marketplace that swapping disk cleaners may not be a good idea and could actually cause more harm than good. It is better to be safe than sorry and follow the manufacturers' directions when attempting to clean optical storage media.

Although WORMs and rewritables are typically encased in cartridges to prevent their recording surfaces from scratches, skin oils, dust, fingerprints and other surface debris, they are still subject to damage from rough handling. Disks should not be squeezed, placed under heavy objects, bent, or otherwise wrenched out of shape. This is especially important when placing the disks in and out of their drives and when the disks are placed in storage. Care should be taken to ensure that disks are not wrenched in and out of their drives, are kept out of their drives until they are ready for recording or playback, and not left in their drives unless actually in use. Disks should be stored upright, or in boxes which "contain activated carbon and molecular sieves along with alkaline buffering" to capture and neutralize the oxidative and acidic gasses found in our polluted city air.[33]

Optical tape should be handled in a similar fashion, except that as a tape rather than enclosed disk, it must be handled more carefully. Optical tape has a strong polymer base which can withstand a significant amount of tension, but tugging and wrenching the tape will nonetheless damage the media. Like

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33 E-mail from William K. Hollinger to Archives Listserve 13 February 1994. Hollinger cites an article titled "Protection of Archival Materials From Pollutants: Diffusion of Sulfur Dioxide Through Boxboard", Journal of the American Institute for Conservation, 32:1 (Spring 1993) as his source for this information.

optical disks, optical tape should be stored upright, but supported from the inside and outside to equalize the pressure on the tape within its storage canister.

Placing any form of barcode, label, or ink on a disk is also not recommended. The solvents in the adhesives on the barcodes or labels have been known to eventually eat through the disk's protective layer, severely affecting the disk's read/write capabilities and lifespan of the disks. Marker and pen ink can cause the same problems, and thus should also be avoided.

While WORMs or dye-polymer/phase change-based rewritables are not affected by magnetic fields, MO disks are "subject to accidental erasure through inadvertent exposure to magnetic fields of sufficient coercivity".[34] While inadvertent erasure is unlikely, as a significant heat source is also necessary to alter data on such disks, exposure to any permanent magnets or objects which generate magnetic fields must be prohibited in areas using MO disks.

Optical disks in long-term storage should be inspected on a regular basis, annually or whatever is practical, to facilitate the detection of media deterioration. ICI Imagedata recommends a wind interval of five years for optical tape stored under ideal conditions. ICI Imagedata considers this to be a conservative estimate, and expects that "further analysis will extend this prediction to ten years or more."[35] Inspections should include the following: a visual inspection of the disk and its housing/cartridge, and the retrieval of a sample of the data stored on the medium. If the number of disks or tapes in storage is prohibitively large, a sample can be regularly tested, or a test/control media can be made using the same system and recording materials as the disk(s) or tape(s) in the holdings. If the test media is deteriorating, then the rest of the holdings corresponding to the test sample would then be inspected for damage.

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34 Saffady, "Stability, Care and Handling", p. 85.
35 ICI Imagedata, "ICI Optical Data Storage Tape", p. 8-9.

If deterioration is present, the data on the affected media should be copied or migrated as soon as possible. To avoid system and media obsolescence, data should be migrated regularly in order to extend the life of the information recorded on the optical storage media.

Optical storage media also require care during shipping. The ANSI 1987 environmental restriction standards for 5.25" WORMs recommend a shipping temperature of -20°C to 54°C. These recommendations are intended to correspond to conditions found during truck or train transport and are not intended to be of more than two weeks duration.[36] To prevent accidental exposure to magnetic fields while MO disks are in transit, there should be a three-inch barrier between the disks and the sides of the transport container. Luckily, there are special containers for just this purpose.[37] Once the disks or tapes have arrived at their destination, they should be allowed a 2 hour conditioning time before they are placed in their permanent storage containers, to slowly acclimatize the media to their new conditions. This practice should also be followed prior to the optical storage media being put into use. This procedure helps to lessen the impact of any temperature or humidity changes between the transport and storage conditions or the storage and use conditions. It also aids in preventing any condensation from forming on the disks or tapes as the result of such changes in temperature or humidity.[38]

A large part of an archives' duty is the preservation of the records

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36 U.S. General Services Administration, Information Resources Management Service, Applying Technology to Record Systems: A Media Guideline - May 1993, (Washington DC: General Services Administration, 1993), p. 37.
37 Saffady, "Stability, Care and Handling", p. 86.
38 The ANSI 1987 Environmental Restrictions for 5.25" WORMs also recommends temperature gradients of 10, 15 and 20 degrees Celsius for operation, storage and shipping respectively, and air pressure from 0.75 to 1.05 bars to prevent disks with "air sandwiches" from warping or splitting open. Applying Technology to Record Systems, p. 37.

entrusted to its care. All records, regardless of the media on which they are stored, deteriorate with age making the need for proper preservation, storage and handling of records a vital one in all archival institutions. With paper records, this entails maintaining proper temperature and humidity controls, the use of acid-free containers and light controls among other considerations. Like any other media, records stored on optical storage media also require certain environmental conditions to ensure the preservation of the disks and tapes and the data stored on them. Unlike paper, however, optical storage media also require the maintenance of the systems needed to read the disks and tapes as well as the medium itself. Optical storage media have the advantage of a huge storage capacity in a very small physical space, but are dependent on computer systems to access and read the stored data. The advantage of huge storage capacity, however, also has the disadvantage of huge data losses if either the media or the hardware and software systems needed to read the disks or tapes deteriorates. As such, the proper preservation, storage and handling of records stored on optical storage media are crucial issues as the data losses from media degradation could be vast.

Optical media have not been in existence for long enough to provide us with an adequate model regarding their longevity or potential deterioration problems. Nonetheless, we do possess a certain amount of knowledge regarding the chemical composition of the media and the results of accelerated-aging tests on the various types of optical storage media. Present estimates regarding longevity and deterioration patterns are all based on information gained from the above sources combined with the limited real-life experience users have had with optical storage media. We know that most of the metals used in the composition of optical storage media, tellurium in particular, are susceptible to oxidation. We also know that there is no way to prevent oxidation; we are only able to devise materials and practices capable of retarding the oxidation process. Unfortunately, most of the knowledge regarding accelerated-aging tests has been gained at the request of optical media manufacturers, and often at the prototype rather than the production stage of the media. This raises the question of the validity of the test results, as well as the applicability of these results to regular-use conditions. Standardized, impartial testing procedures and programs would facilitate greatly the legitimacy of manufacturer-based claims regarding media longevity and deterioration patterns.

In addition to oxidation, optical storage media substrates are susceptible to damage, especially polymer- based substrates. These particular types of substrates are more vulnerable to high temperature and humidity environments, and are more likely to exhibit defects which affect the reflectivity of the recording layer. Glass substrates are less prone to oxidation and do not exhibit the same level of defects, but are more expensive to produce. As such, the user is well advised to be aware of the substrate materials used in their optical storage media, as this affects the preservation, storage and handling demands of the media.

Diversity of media construction and the systems required to read the media also affect the preservation, storage and handling needs of optical storage media. At the present time, there are many different types of media and recording techniques available on the market. In addition, the fact that records submitted to an archives are at the end of their life cycle indicates that the formats used in both the media construction and recording techniques may be those which are no longer in common use. This problem can exacerbate the preservation and storage requirements of optical media within an archives, as each type of optical storage media may have slightly different preservation and storage needs. Fortunately, in terms of storage, optical media are remarkably hardy, and require much less maintenance and specialized environmental controls than most media. General office conditions are usually adequate for the long-term storage of optical media, provided the media are kept dust-free and are stored at somewhere between 18°C-20°C and 50-60% RH, the general consensus regarding optimum storage conditions for optical media.

The storage and handling requirements of optical storage media owe more to common sense than technical specifications. The media are between 18°C-20°C and 50-60% surprisingly rugged and is not subject to the same temperature and humidity conditions as are similar magnetic-based storage media. While excessively hot and humid conditions do promote oxidation and polymer substrate damage, environments common to most workplaces do not pose much of a threat to optical media. As long as the disks and tapes are kept contaminant free, are stored upright, and are not subject to being bent, scratched, warped or otherwise mishandled, they should last between 10 and 100 years, providing the hardware and software needed to read the disks or tapes are still available.

Generally speaking, optical storage media have a useful storage life of between 10 and 100 years. Sony's "Century Media" and ICI Imagedata's ICI 1012 Optical Tape have the longest predicted lifespans, 100 and possibly in excess of 300 years respectively. The others fall between 10-50 years, with glass substrate-based WORMs beating out polymer substrate-based MO disks. All this, of course, depends on the availablilty of the software and hardware needed to read the information stored on the various forms of optical storage media. System obsolescence can likely be guaranteed to occur every 10 years, but with system upgrades and backwardly compatible software, the information stored on an optical disk or tape should be accessible as long as the medium itself is undamaged. This situation, however, is an ideal one, and regarding the lack of standardization within the world of optical storage media, likely to be the exception rather than the rule in many cases. Optical storage media present a great window of opportunity for archivists in terms of making delicate records more accessible, solving storage problems, and providing a long-term stable storage media for data presently stored on less stable media, but if the software and hardware needed to read the records stored and migrated onto optical media are not available, all the preservation, storage and handling techniques in the world will not make the information stored on obsolete forms of optical media accessible.

CHAPTER THREE:
OPTICAL STORAGE MEDIA:
ARCHIVAL APPLICATIONS AND IMPLICATIONS

> Significantly, the use of optical disc technology has progressed within the span of a decade from a tentative field of investigation to a practical and effective means of assisting archivists and information specialists in the preservation and control of an important segment of the nation's cultural heritage... and spells a new chapter in providing access to the rich visual collections of the National Archives of Canada.[1]

There are many different ways archives can use optical storage technology, each with its own access, preservation and archival applications and implications. In one sense, records stored on optical media are no different from those stored on any other medium, however, the optical medium's dependency on mechanical means for access, storage and readability introduces a whole set of problems, advantages and disadvantages not necessarily presented by more traditional media. This dependence on system hardware and software makes both the preservation of and access to records, either initially stored on or later transferred to optical media, more complex than those records stored on other non-machine-readable media. Problems related to the regular migration of data, quality control, regulated access, copyright requirements, and other legal requirements, must be taken in to consideration in addition to the more obvious mechanical problems associated with machine readable records. Storing records

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[1] G. Stone and P. Sylvain, "ArchiVISTA: A New Horizon in Providing Access to Visual Records of the National Archives of Canada", Library Trends, 38:4 (Spring 1990), p. 750.

on optical media can have both great benefits and crushing disadvantages, and it behooves institutions, to be aware of all the factors involved in the preservation, access and implementation of any optical media program.

APPLICATIONS

The first consideration of any archivist dealing with records stored on optical media must be the appraisal of the records. This applies to both records stored on optical media by their creator(s) and those on a different medium destined to to be transferred by the archives to storage on optical media. As with records stored on any media, not all records delivered to an archives warrant permanent preservation. Records stored on WORMs and Optical Tape are no exception to this rule, despite the fact that records stored on these forms of optical media are unalterable and thus considered "permanent". Notwithstanding the tremendous storage capacity of optical media, not only is it impossible to keep physically and control intellectually every record created by any creator or agency, but this would defeat the purposes themselves of archival preservation.

However, the very "permanence" of records stored on WORMs and Optical Tape can present a problem when appraising them. Records stored on these two optical storage media cannot be erased, only augmented. As a result, if during the appraisal process the archivist determines that not all the records stored on one of these two media are worthy of permanent retention, there is not an easy way of disposing of the unwanted records. However, as records on these media are accessed by indexes often stored magnetically, the archivist can alter the indexes and finder programs to prohibit access to the unwanted records. Although this does not eliminate the number of records stored on the medium, it limits the need for establishing and maintaining intellectual control on all of them. This procedure can also be used as a way to limit access to records with access restrictions. A copy of the original index and finder programs would remain with the archivist or others who have the security clearances to see all related restricted records, while another abridged version would be made available to the general public. Unfortunately, this is not feasible if the indexes and finder programs are written onto the WORMs or Optical Tape. In these cases, it might be necessary to create new abridged versions of the search programs, and note in the fonds descriptions that this has indeed been done. In any case, the unwanted records will still remain on these "permanent" forms of optical media, a factor which archivists must take into consideration when appraising them.

One way to get around the drastic solution of keeping all or nothing would be to work with the agencies responsible for the creation of the records during the earlier stages of the records' life cycles. Appraisal of records intended for permanent retention could really begin before the records are placed on WORM disks or Optical Tape. As part of a well-designed electronic records system, vital records could be identified as soon after their creation as possible, then flagged for future transfer to non-eraseable optical media for permanent preservation. Otherwise, it is simply too easy for large amounts of non-valuable documents to be transferred onto non-eraseable optical media, and thus be permanently preserved.

Archivists must take an "active approach to the development and installation of electronic office systems" and work with records managers to choose software which will identify vital records at the time of their creation, and flag them for transfer to non-rewritable forms of optical storage media.[2] By

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[2] K. Gavrel, Conceptual Problems Posed By Electronic Records: A RAMP Study, Prepared by Katharine Gavrel for the General Information Programme at

providing guidelines for organising electronic records, archivists and records managers will not only facilitate the fast and efficient retrieval of current material, but will also expedite the ability of the system to separate the wheat from the chaff and preserve on WORMs or Optical Tape intended for the archives only those records valuable enough to be permanently preserved. Involving the users in both the development and implementation of such a program would also help the program, secure its proper implementation and restrict the system's and operators' ability to destroy valuable records.[3]

Technical analysis must, however, be combined with content analysis for proper appraisal to take place. Archivists must also realise the necessity for maintaining not only the technology required for access to both their own information and that which has been entrusted to archival custody, but the documentation connected with the systems. Identifying and preserving all system documentation, now called metadata, is necessary to preserve the context in which the information was gathered, information about the creator(s), the role played by all persons involved with the system, and the links between the system and other databases, sources of records and information.[4] Documentation provides access to both the codes used to represent the data stored on the optical media and the locational arrangement of the data on the disks or tapes, two elements vital to the understanding, interpretability and migratability of data. Optical media, or their accompanying software, equipped with Information Resource Dictionary Systems (IRDS) will have all the information elements necessary to place the entire system within its administrative, structural and functional context. This, in addition to an open systems architecture, is not only

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UNISIST, (Paris: Unesco, 1990), p. 21.
[3] Ibid, p. 21.
[4] Ibid, p. 27.

necessary to ensure future access to and interpretability of the data, but to allow information to pass successfully from one generation of optical disk-based access systems to the next and still retain its authenticity.[5]

MIGRATION

However, it has to be born in mind that no media is permanent; all deteriorate and/or can be destroyed. Paper can burn or deteriorate due to external and internal chemical factors, magnetic media can suffer from "sticky tape syndrome", and despite the use of oxidation resistant alloys and barrier coatings, optical disks will also eventually undergo chemical and physical changes which will make them unfit for both the recording of new data, or the retrieval and deciphering of earlier data. These changes to optical media may be caused by environmental factors, manufacturing defects, or by damage caused by improper handling of the disks themselves. Either way, the "permanent" storage capabilities of optical media are not very realistic. The lack of "permanency" is particularly significant to information stored on machine-readable media, as it is not most often the deterioration of the actual media that constitutes the main problem, but the unavailability of the technology needed to read the information stored on the media. With optical storage media, the medium itself is quite stable and does not require an environment more controlled than that of a normal office for storage purposes, but the hardware and software systems needed to read the media become obsolete every few years. Paper documents, as long as the writing has not faded too much, can be read with only the aid of a magnifying glass and a little guesswork. Optical media cannot be read without the appropriate technology. Therefore, the meaning of the concept of "permanence" has been

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[5] M. Hedstrom, "Optical Discs: Are Archivists Repeating the Mistakes of the Past?", Archival Informatics Newsletter, 2:3, (Fall 1988), p. 52.

changed by technology, and linked to the readability of data stored on various media. If the systems used to read the records are unsupportable, the records stored on the corresponding media may also be unreadable. Consequently, the material support of the record, especially if machine-readable, has become less significant as a factor in establishing the permanence of the record. In order for the data stored on optical media to be permanently accessible and readable, the concept of "data migration" must come into play. The medium becomes less important than the information recorded on it; thus the medium can be changed and the information transferred to another medium, as long as the particulars regarding the original medium and the formatting of the original record are recorded on the new medium.

Migrating data simply means transferring them from one medium to another. Usually this is performed as a conservation measure to save data stored on an obsolete or soon to be obsolete medium or machine-readable system. This is often done with records affixed to magnetic tape to allow the records to be read on the next generation of either computer software or hardware or audio systems. This procedure is analagous to re-recording music from a vinyl record to a tape cassette. In this example, the music is transferred from an older medium to a newer one in order to prolong its playability.

A similar process can be carried out with records on magnetic tape or disk in order to preserve their readability, and to make their conservation easier. Optical media do not require the specialized environmental controls that magnetic media do, thus migrating the data to optical media can make them more easily accessible but also more easily preserved physically.

Of course, the migration procedure would affect the status of transmission of the records, as they would no longer be in their original form once they have been migrated to the new media. This could present a problem regarding the legal value of records migrated and stored in this manner. At the present time, the only two media "generally admissible in evidence for all purposes for which the original record would have been admissible" are paper and microfilm.[6] Although records stored on microfilm and optical storage media share the characteristics of existing in a compact space which allows for easy retrieval, microfilm stores images using analog technology while optical media used digital technology. Microfilm stores "miniature likeness of an original document" while optical media store "data from which a document, like the original document in all visual respects may be produced."[7] As a result, records stored on optical media qualify as copies in the form of the original but under controlled circumstances can have the force of originals as do records stored on microfilm. For the most part, however, courts will accept copies reproduced from optical disk if the following elements are present:

> a) the original is no longer available;
> b) "the copy was made with the intention of standing in the place of the original;
> c) the absence of the original is adequately explained;
> d) the circumstances of the making of the original and of the copy are adequately explained."[8]

Nonetheless, the manner in which these elements are taken into account will vary with the evidentiary problems presented by each record and with the laws applicable to each case.

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[6] R. M. Anson-Cartwright et al., Records Retention: Law and Practice (Toronto: Thompson Professional Publishing, 1994), p. 6-9.
[7] Ibid., p. 6-9.
[8] Standards Committee on Microfilm and Electronic Image as Document Evidence -(CIIMS), "Draft: Microfilm and Electronic Image as Documentary Evidence", in R. M. Anson- Cartwright et al, Records Retention: Law and Practice (Toronto: Thompson Professional Publishing, 1994), p. C- 25, Appendix C.

As there are no standards for optical media records as documentary evidence, records stored on optical media do not come under the same statutory provisions as those for microfilmed records.[9] Prints from microfilmed records are "generally accepted as evidence for all purposes for which the original record would have been admissible." Since optical media do not employ the same technology as photographic film, prints generated from optical media are not considered to have the legal status of original records. At the present time there is a working group trying to establish a standard for records stored by digital means. The draft of CAN/CGSB-72.11-M92, a standard for microfilm and electronic image as documentary evidence, has been offered, but is not yet at its final stages. Until standards are in place for electronic images as documentary evidence, the legal admissibility of optical media records preserved by an archives depends on the following conditions being met:

a) use of the optical storage system as part of a regular, established archival practice in order to keep permanent record of the migration of the records in question, and storing records on optical media as part of the organization's "usual and ordinary course of business";
b) use of the optical storage system in relation to classes of documents;
c) destruction of the original records in the presence of an employee/archivist with the qualifications and authorization to oversee and perform such proceedings as an ordinary part of his or her duties;
d) preservation of detailed records regarding the operation of the optical storage system;
e) preservation of detailed records regarding the "methods and procedures for creating, verifying, storing and retrieving documents";
f) preservation of accurate and secure bibliographic and biographic information relating to the images stored on the image system;
f) and preservation of "originals of bills of exchange,

9 Anson-Cartright, Records Retention, p. 6-9.

> promissory notes, cheques receipts, instruments, agreements or other executed or signed documents for six years".[10]

Adherence to these conditions, if technology continues to advance as quickly as it has in the past few decades, is necessary for any organization's record keeping system, and any archives' data migration program if either are to preserve the legal admissibility of the officially stored records in their custody.

PRESERVATION AND ACCESS

Data migration onto optical storage media can also be used for the preservation of and access to fragile or delicate records. Such records can easily deteriorate further with use, and highest used records can become delicate or fragile simply as a result of being used often. By placing images of these records, or migrating/copying them onto optical storage media, both could be accessed without taking the originals out of their special preservation areas. Human contact with such items would be kept to a minimum, thus safeguarding the conservation and preservation needs of the original documents. The records, of course, would not be locked away permanently once the optical image had been made, but would be available to researchers whose work demanded that they see the detail of the original record. Copies made from the disk or tape would also allow for a wider dissemination without harming the original record by allowing for their placing on a local or wide area network. While computer-generated images are not as identical to the original, even if sometimes more detailed, via optical media would allow a certain degree of accuracy in concert with a great increase in the accessibility of fragile or delicate items.

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10 Ibid., p. C-23; Anson-Cartwright, Records Retention, pp 6-9, 6-10. For a more complete and detailed description of the suggested evidential requirements for imaging systems please see Appendix C of Anson-Cartwright, Records Retention, "Draft: Microfilm and Electronic Image as Documentary Evidence".

Optical storage media as a preservation tool have been used successfully in the Optical Digital Image Storage System (ODISS) project at the National Archives and Records Administration (NARA) in the United States, and in the ArchiVISTA project carried out by the National Archives of Canada (NAC) at the Canadian Museum of Caricature. Both projects were initiated to test the viability of optical storage systems as a solution to some of the preservation and reference problems associated with highly used, delicate records.

The ODISS project was initiated in 1984 as a way of solving the reference and preservation problems concerning one of the largest and most used collections of records in NARA's custody: the 82,000 cubic feet of Pension, Bounty Land Grant, and Compiled Military Service Records. These consist of "the military service and pension application records extending from the time of the American War for Independence... to ..the period just prior to America's entry into World War I."[11]

These records are heavily used and as a result have suffered significant damage. In 1983, for example, a staff of twenty-seven was needed to handle the 116,000 mail and the approximately 80 daily walk-in requests. A combination of the high use and age of the documents has resulted in the following problems: 65% have minor physical problems, 10% have major problems. In addition, 95% are either completely or partially handwritten and 42% suffer from low contrast and thus reduced legibility.[12] Previous attempts to microfilm parts of the collection were not successful, as the age and poor

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[11] W. M. Holmes, Jr., "The ODISS Project: An Example of an Optical Digital Imaging Application", in Proceedings of the International Symposium; Conservation in Archives (Ottawa; National Archives of Canada/International Council on Archives, 1989), p. 233.

[12] Holmes, "The ODISS Project" pp. 233-234.

condition of the documents resulted in poor quality products. Eventually, the microfilming project was halted as the condition of the records made it impossible to produce acceptable microfilm copies.

In 1984 NARA decided to try a pilot optical media project using some of the Pension, Bounty Land Grant and Compiled Military Service records. They represented the types of records which might benefit most from being scanned onto optical media as they were highest used, fragile, and because of their low contrast writing, difficult to microfilm successfully. The main purposes of the project were to:

a) determine the feasibility, costs and benefits of digital conversion of both original documents and microfilm copies;
b) identify what problems were to be encountered with such a system;
c) determine the most efficient procedures for accomplishing a conversion;
d find the optimal mix of automated conversion with human quality control and intervention to produce acceptable results;
e) determine the optimal scanning density for documents consistent with production legible images while minimizing storage requirements;
f) and determine public reaction and acceptance to the use of such a system.[13]

In addition to the purposes mentioned above, digital enhancement of the scanned copies would also have attested to the capability of the procedures to produce more readable copies. Once stored on optical media, the records could also be placed on either a local or wide area network, effectively increasing access to the optically stored copies, while protecting the more fragile originals. The basic challenge was to see if technology could assist in the preservation of and access to hundred and twenty year old handwritten records.

In 1985, a test sample using 400 cubic feet of documents from the

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13 Ibid., p. 235.

Tennessee Confederate Compiled Military Service Records (CMSR) was chosen, as these records were of an age and physical condition comparable to those in the larger collection. The CMSR records had also been microfilmed, and this would have provided a method of comparing the images stored on optical media with both the microfilmed copies and the original documents.

Part of the original objectives for the ODISS project was to test the feasibility, costs and benefits of migrating the CMSR documents onto optical disk. As such, the preparation of the documents for scanning was also part of the experiment. The document preparation procedures for scanning onto optical disk, however, were found to be similar to pre-microfilming procedures, except that particularly fragile documents were placed in polyester sleeves for protection during the scanning process. To scan the documents, four high speed grey scale scanners were used, three for paper records, one for microfilm. The Photomatrix scanner had the ability to scan 20 documents per minute at 200 dots per inch (dpi), a standard which was acceptable for 98% of the documents scanned. Two low speed scanners were also used for more fragile documents. A high resolution monitor attached to the system provided immediate feedback regarding the quality of the record just scanned. This allowed technicians to identify immediately those records which needed to be rescanned. The image enhancement feature allowed documents to be enhanced in three ways: character, which brightened the light parts of the document and darkened the document's dark parts; photograph, which increased clarity via half-tones; and a combination of both for records with significant problems in both areas.[14]

Although a throughput of 3800 pages per day was predicted, the necessity of hand positioning some documents and the different sizes of

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14 Ibid., p. 58.

documents allowed NARA staff to scan only1158 documents per day.[15] To achieve the amount of throughput initially expected, it was necessary to use automatically adjustable scanners. Once scanned, the images were stored on 12" WORM disks, each with the capacity to hold 80,000 images and preserved in a fifty disk jukebox with a capacity of 109 gigabytes or approximately 2.42 million document images.[16] The indexes were stored on magnetic disks, as this made it easier to both correct misfiled or mislabeled images and update the index.

The ODISS Project highlighted several advantages and disadvantages to the use of optical storage media as a preservation and access tool. One of the main advantages was the ability to access the documents much more quickly than previously. Indexes allowed researchers and archivists to find the records they needed and see them almost immediately. The placement of a retrieval station connected by communication lines in the Tennessee State Archives also allowed the collection to be accessed by users at a considerable distance from the actual documents. The image enhancement also enabled formerly low contrast documents to become more legible, although the amount of legibility still depended on the state of the original: despite the advanced technology offered by digital imaging, good images still cannot be made from very poor originals. Reduced handling of the delicate and fragile documents also aided in slowing down the deterioration of these documents, and helped prevent the deterioration of the more stable records as well. Storing the records on optical disk also allowed for a virtually unlimited number of exact copy prints to be made without any deterioration of the original document, as would be the case with photocopies made from the original records. Lastly, the experiment proved

[15] W.L. Hooton et al, Optical Digital Image Storage System Project Report (Final Report), NARA/TIP-90/10 (Washington, D.C.: NARA, 1991), p. 9-12.
[16] Holmes, "The ODISS Project", p. 238.

that the amount of space saved by storing records on optical disks would be considerable.

The ODISS Project also discovered some disadvantages to wholesale conversion from paper to optical media. For one, the cost for such a large conversion is considerable, and only the largest institutions would likely be able to afford such an undertaking as not only the cost of the system and the time must be considered, but also the cost of training the people to operate and maintain the system. Secondly, optical media, like any machine-readable media, are not "archival" as the technology needed to read the material stored on the optical media will become obsolete within 10-20 years. While the optical medium itself may last as long as microfilm, the systems needed to access them will not, thus rendering the information stored on the disks or tape inaccessible.

The ArchiVISTA system used by the National Archives of Canada (NAC) also successfully implemented a document imaging project using the 20,000 editorial cartoons and caricatures exhibited at the Canadian Centre for Caricature. The ArchiVISTA system was meant to provide "online visual access to a visual catalogue" of the collection, and allows researchers and the general public a new way to access documentary art and photography collections.[17]

In 1987 it was determined that the high-use caricature collection had begun to deteriorate to the point that it required immediate action to prevent the records from deteriorating further. Greg Hill, the conservator of the collection, recommended that the records be copied onto some "easily accessible medium for research purposes to minimize their handling".[18] Based on the results of previous pilot projects involving videodiscs in the late 1970s and early

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17 G. Stone and P. Sylvain, "ArchiVISTA: A New Horizon in Providing Access to Visual Records of the National Archives of Canada", Library Trends, 38:4 (Spring 1990), p. 737.
18 Ibid., p. 739.

1980s, NAC decided in 1988 to employ an optical storage media system utilizing an "80386-based IBM AT compatible microcomputer with a VISTA videoprocessor board, VGA controller, 19" 1024 x 768 image monitor, 14" data monitor and Laser drive 810 5.25" digital WORM optical disk drive."[19]

The original drawings were prepared for scanning by placing them into size and artist groupings prior to being scanned. This eliminated the need to readjust the scanner manually for each scan and assured continuity and authenticity regarding "image characteristics as a result of an artist's style and use of materials".[20] As with the ODISS system, the scanned images were presented on a monitor as they were being scanned, thus providing the scanner operator with the opportunity to adjust the image quality immediately, if needed, and then rescan the image. For each image the operator entered the following information: accession and item number, operator's name and scan date. The accession and item number were then linked to the corresponding record description held in the NAC's MINISIS database, and were also displayed on the upper right side of the image. The system also automatically gave each image a "frame tag number as well as the number and side of the optical disk" used.[21]

The ArchiVISTA system, however, only used the WORM disks for storage purposes, preferring videodisk technology for display and printing purposes. Each digital image was divided into "four NTSC video frames using a videoprocessor board and storing these, along with an overall frame of the original drawing, onto 1" "C" type videotape for mastering onto 12" videodisk."[22] The image was retrieved by recombining the four frames into one single high-resolution image.

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19 Ibid., p. 743.
20 Ibid., p. 743.
21 Ibid., p. 745.
22 Ibid., p. 747.

The database system used with the ArchiVISTA system was ZIM, a "fourth-generation language product of Zanthe Information Inc." ZIM provided a bilingual user interface, Boolean searching and "the ability to enter descriptive records composed of variable length and repeat fields either directly or through file transfers from MINISIS."[23] The database system also had a search screen which allowed the user to both browse and/or specify searches using subject, artist, publication, place, date or other unique item numbers as search fields. It takes the system seven seconds to retrieve an item, but NAC hopes to improve the search time. The entire collection of 20,000 images can be stored on two sides of a 12" videodisk, or approximately 30 5.25" WORMs.

The ArchiVISTA system has many of the same advantages and disadvantages as the ODISS project. One one hand, the equipment needed for such a project is expensive, time consuming, and ultimately, the optical disks used to store the images are not considered "archival". On the other hand, the ArchiVISTA system has the advantage of copying a relatively small number of images in comparison to the ODISS project, thus making the process simpler and faster to complete. All considered, the ArchiVISTA project has proven its worth by allowing researchers and staff to perform searches much faster and without contributing to the deterioration of the cartoons and caricatures.

IMPLICATIONS

One of the primary implications of both the ODISS and ArchiVISTA projects is that the transferring of text or images onto optical storage media is possible, and depending on the budget available, can be done on varying scales. Both projects also showed that standard microfilm procedures

23 Ibid., p. 747.

could be used to scan the records and maintain the same integrity of the document as is presently achieved with microfilming. The use of a LAN connection in the ODISS Project highlighted the possibility of increased access to records and of general dissemination of information regarding both the scanned records and the rest of the institutions' holdings. The image enhancement capabilities of the two systems also demonstrated the way optically stored records could be made more readable without causing any deterioration to the original. Conservation and preservation of the records was also enhanced by the systems' ability to generate copies or prints from the scanned records rather than the originals. Although neither project involved the migration of electronic records to optical disk, that too is a possibility for the conservation of machine-readable records.

Unfortunately, the optical storage systems used by NARA and NAC are expensive in terms of money, time and skills needed to run and maintain the systems. Although there are smaller optical storage media systems coming out on the market today, they still represent a fair investment for any archives. Again, any archives considering the implementation of an optical storage system must take into consideration the problems of system obsolescence, the legal issues presented by records scanned onto optical media, copyright legislation regarding the transmission of records via networks, and the lack of industry-wide standards for the production and recording of optical storage media. While the examples shown in this chapter involve national archives, similar techniques could easily be applied in other settings.

CONCLUSION

Optical storage systems have advantages and disadvantages as practical solutions to archival storage, conservation, preservation and information needs. The advantages have the potential to revolutionize the way archival information is accessed and stored. The disadvantages have the power to create havoc in any archives. Consequently, archivists must obtain a basic knowledge of the types of systems available on the market, the methods of preservation and conservation of optical media, and the ways in which these media can serve as records conservation, preservation, storage and access tools.

ADVANTAGES

One of the main advantages of optical disk systems is their ability to store vast amounts of information in a physically small amount of space. As seen with the ODISS Project, a warehouse of information can be contained on a relatively small number of disks, or Optical Tape. The stored data are then easy to manipulate, compare and analyse, and if on WORMs or Optical Tape, they are permanently affixed. Jukeboxes can be used to form a large database, and increase even further the potential uses of information stored in this manner. Local Area Networks (LANs), such as the one used in the ODISS Project, facilitate the dissemination of data and finding aids, thus increasing the records' accessibility to researchers. Copyright ownership of both the system software and material stored on the disks must be taken into consideration, however, as would possible restrictions on accessibility to the documents. The archives would disseminate only the data to which it had clear copyright, and limit access to restricted records or those records to which the archives did not have copyright privileges.

Processing and retrieving information is also easier with records stored on optical storage systems. For instance, the problems associated with manually misfiling documents and paper file maintenance would be eliminated. Optical media are immune to most environmental hazards, and thus the information stored on them is much more difficult to destroy or damage than that stored on paper or magnetic tape. Capturing documents is also simpler, as they can be scanned and placed within the system immediately, with savings to both processing and retrieval times.

Optical storage media also have the capacity to act as multi-media storage devices, as text, graphics, video and sound recordings can be supported by this technology. This capability would allow multi-media fonds to be kept together on disk, thus maintaining their integrity and original order even if the originals would have to be physically separated for conservation purposes. Finding aids for such fonds would also assist researchers, as all the necessary information about the fonds would be centralised, rather than in separate media-based finding aids. Moreover, archivists would be able to access fonds and related information from areas outside their own particular administrative divisions, and different divisions would have simultaneous control of all the repository's holdings.

The convenience of placing data on optical storage systems, however, could lead to lower standards of appraisal. A solution to this might be to use MO disks, an erasable form of optical disk, as an interim storage medium. MO disks could be used to store short-term documents, documents which are in process and not yet in their final form, or to temporarily store documents before they are transferred to non-eraseable media, that is before a definitive appraisal could be made. While this may sound like the ideal solution, MO disks are plagued with the same lack of standards and unproven lasting ability as non-erasable optical media and present similar problems to archivists and records managers alike.

DISADVANTAGES

There are also several disadvantages to using optical media systems for archival storage. The main drawback is the lack of industry-wide standards for producing the systems used to write or access optical media. At the present time, there aren't any standards for formatting information onto disks or tape, for interfacing with other optical media or hard drive systems, or for the hardware needed to use the optical media themselves. As a result, it is impossible to mix and match optical storage systems or the soft and hardware needed to run them. Some WORM systems are so proprietary, that some read a pit as a zero, and others as a one.[1] This lack of compatible hardware and software, or any standard production or writing formats, can create problems for archives as they would either have to maintain a large amount of optical storage systems to ensure future access to the data encoded on the disks or institute a program of regular migration of incoming electronic records to more stable formats.

This lack of standards and a stable technology create problems to archivists who might receive transfers of large amounts of outdated, unsupportable, obsolete optical storage systems. Life expectancy of up to 100 years notwithstanding, changes in technology easily make optical storage systems obsolete and the information stored in them inaccessible long before the disks or

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[1] D. Harvey, "State of the Media", Byte, 15:12 (November 1990), p. 280.

tapes are transferred to the archives.

CONSEQUENCES FOR THE ROLE OF THE ARCHIVIST

The presence of optical media records in an archives will affect the archivists' role, but only to the same extent as have other technological developments. Optical media are machine-readable storage devices, as are magnetic tape and floppy disks. The traditional archival functions of appraisal, arrangement and description, conservation and reference will still have to be done according to the same principles and methodologies, regardless of any advances in technology or on what on media the records exist. Appraisal will have to take into consideration both the contextual and technical components of the records, as always. Arrangement, for instance, will have to keep into account the locational indexes as they could be indicators to the original order of the records.[2] Description will have to take into consideration technical description of the hardware and software systems used, and the practicalities of obtaining physical access to the records. Conservation will have to follow the development of new technology and rely on the future generations of optical media and optical media-related systems. Despite the potential user friendliness of optical media-based multi-media integrative finding aids, reference archivists will still be needed to help researchers navigate their way through the records. Optical storage systems will have an impact on the way documents are handled within the archival context, but the best technological advantages will not be a substitute for traditional archival work. While the lack of industry-wide standards and of knowledge concerning the long-term viability of the disks themselves does hamper the use of optical media for long term storage purposes, archivists should

[2] C. Bailey, "Archival Theory and Electronic Records", Archivaria, 29 (Winter 1989-1990), p. 187.

become familiar with this technology. The opportunities presented by optical storage systems for archival use far outweigh the disadvantages, and archivists should commit themselves to understanding the technology so that they can contribute to the formulation and use of the standards needed to make the optical medium universally valid as records. Optical storage systems are simply another form of mass electronic storage, and as such, have the potential to positively affect the way archives conserve, preserve, and make accessible their records.

BIBLIOGRAPHY

Apiki, S. and H. Eglowstein. "The Optical Option." Byte, 14:10 (October 1989). pp. 160-174.

Artlip, P. M. "Different Optical Disk Formats Co-Exist to Provide End-User Applications Flexibility" IMC Journal 24 (March/April 1988). pp. 13-15.

Bailey, C. "Archival Theory and Electronic Records", Archivaria 29 (Winter 1989-1990). pp. 180-196.

Barr, R. D. "Microfilm or Optical Disk: The Choice is Between Systems, Not Media" IMC Journal 24 March/April 1988). pp. 7-8.

Bearman, D. Optical Media: Their Implications for Archives and Museums. Pittsburgh: Archives and Museum Informatics, 1989.

Bender, A. "Text Image management and Optical Disk System Design." Inform (February 1987). pp. 20-23.

Blais, R. "Entering the Optical Disk Era". The Archivist 18:1 (January-June 1991). pp. 15-16.

Bradley, A. Optical Storage for Computers: Technology and Applications. Chichester, England: Ellis Horwood Ltd., 1989.

Calmes, A. "Relative Longevity of Various Archival Recording Media", in Proceedings of the International Symposium: Conservation in Archives. Ottawa: National Archives of Canada / International council on Archives, 1989. pp. 207-232.

________. "To Archive and Preserve: A Media Primer." Inform (May 1987). pp. 14-17.

Canning, B. "Optical Disk Systems-- Pros and Cons". Administrative Management 48:3 (May 1987). p. 51.

Cinnamon, B. "Optical Disk Applications" IMC Journal 24 (July/August 1988). pp. 19-22.

"Digital Equipment Introduces Improved Data Storage System." Aviation Week and Space Technology 13 March 1989. p. 61.

"Digital Paper is write-on!" Canadian Data Systems 20:6 (June 1988). p. 67.

"Discus Rewritable: The Latest in Storage Technology." Byte 14:4 (April 1988). pp. 102, 104.

Dollar, C. M. Archival Theory and Information Technologies: The Impact of Information Technologies on Archival Principles and Methods. Informatics and Documentation Series, 1. University of Macerata, 1992.

Electronic Records Coordinating Committee, Historical Records Branch. Report of the Working Group on Conservation Standards and Technologies. Ottawa: National Archives of Canada, 1992.

Elshami, A. M. C-D ROM Technology for Information Managers. Chicago: American Library Association, 1990.

Frank, J. W. "Micrographics and Optical Disk-- Friends or Foes?" IMC Journal 24 (July/August 1988). pp. 7-9.

Gavrel, S. Conceptual Problems Posed By Electronic Records: A RAMP study. Prepared by Katharine Gavrel for the General Information Programme at UNISIST. Paris, Unesco, 1990.

________. "Preserving Machine-Readable Archival Records: A Reply to John Mallinson." Archivaria 22 (Summer 1986). pp. 153-155.

Granger, F. The Canadian Museum of Civilisation Optical Disk Project: A Report. Ottawa: Canadian Museum of Civilisation / National Museums of Canada, 1988.

Harvey, D. A. "Optical Storage Primer." Byte IBM Special Edition 15:11 (Fall 1990). pp. 121-130.

________. "State of the Media." Byte 15:12 (November 1990). pp. 275-77, 280-81.

Hedstrom, M. "Optical Disks: Are Archivists Repeating the Mistakes of the Past?" Archival Informatics Newsletter 2:3 (Fall 1988). pp. 52-52.

Helgerson, L. W. "Optical Storage Peripherals." Inform (February 1987). pp. 14-19.

Hendley, T. CD-ROM and Optical Publishing Systems. Cimtech Publication 26. Hatfield, Herts, U. K.: Cimtech/BNBRF, 1987.

Hollinger, W. "Protection of Archival Materials From Pollutants." E-mail to Archives Listserve, 13 February 1994.

Holmes, W. M. "The ODISS Project: An Example of an Optical Digital Imaging Application." in Proceedings of the International Symposium: Conservation in Archives. Ottawa: National Archives of Canada / International Council on Archives, 1989. pp.233-242.

Howe, L. "The Use of Optical Disk for Archival Image Storage" Archives and Manuscripts. 18 (May 1990). pp. 89-118.

ICI Imagedata. "ICI Optical Data Storage Tape - An Archival Mass Storage Medium, July 1992." ICI Imagedata Internal Research Paper, 1992.

Kaebnick, G. E. "Rewriting the Future: Putting Rewritable Optical Disk on the Market" Inform 4 (May 1990). pp. 14-18.

Kahin, B. "Copyright and Optical Disk." Archival Informatics Newsletter 2:2 (Summer 1988). p. 35.

Mallinson, J. C. "Preserving Machine-Readable Archival Records for the Millennia." Archivaria 22 (Summer 1986). pp. 147-152.

Michie, R. W. "A Fresh Can of WORMs." Inform (June 1989). pp. 26-30.

McCormick, J. A. A Guide to Optical Storage Technology: Using CD-ROM, WORM, Eraseable, Digital Paper, and Other High-Density Opto-Magnetic Storage Devices. Homewood, IL: Dow Jones-Irwin, 1990.

________. The New Optical Storage Tecnology: Including Multimedia, CD-ROM, and Optical Drives. New York: Irwin Professional Publishing, 1994.

McLean, R. A and J. F. Duffy. "ICI Optical Data Storage Tape", Paper Presented at NASA Mass Storage Conference, 1991

National Archives and Records Administration. The National Archives and RecordsAdministration and the Long-Term Usability of Optical Media for Federal Records: Three Critical Problem Areas. Washington, DC: NARA, 1992.

National Archives and Records Administration. National Archives' Strategy for the Development and Implementation of Standards for the Creation, Transfer, Access and Long-Term Storage of Electronic Records of the Federal Government. Technical Information Paper 90-80. Washington, DC: NARA, 1990.

National Archives and Records Administration. W. L. Hooton, et al., Optical Digital Image Storage System Project Report (Final Report). Technical Information Paper #91-10. Washington, DC: NARA, 1991.

National Archives and Records Administration and the National Association of Government Archives and Records Administrators. Digital Imaging and Optical Media Storage Systems: Guidelines for State and Local Government Agencies. Albany NY: NAGARA, 1991.

"Optical Disk May Preserve Millions of National Archives Documents". 34:7 Infosystems (July 1987). p. 14.

Podio, F. L. Development of a Testing Methodology to Predict Optical Disk Life Expectancy Values. NIST Special Publication 500-200. Washington, DC: NARA, 1991.

Pountain, D. "Digital Paper." Byte 14:2 (February 1989). pp. 274-280.

Roth, J. P., ed. Converting Information for WORM Optical Storage: A Case Study Approach. Westport, CT: Meckler, Ltd., 1990.

________. Rewritable Optical Storage Technology. Westport, CT: Meckler, Ltd., 1991.

Rush, W. jr. "A Quintet of WORMs." Byte 13:2 (February 1988). pp. 146-151.

Russell, L. "The CD-ROM Revolution." The Lawyers Weekly 25 September 1992. pp. 14-15.

________. "Standards Being Created for Optically Stored Data." The Lawyers Weekly. 25 September 1992. p. 17.

Ryan, B. "Entering a New Phase: Phase-Change Technology combines the Capacity of Magneto-Optical Storage with Enhanced Performance." Byte, 15:12 (November 1990). pp. 289-296.

Saffady, W. Optical Disks vs. Magnetic Storage. Westport, CT: Meckler, Ltd., 1990.

________. Optical Storage Technology 1989: A State of the Art Review. Westport, CT: Meckler, Ltd., 1989

________. Optical Storage Technology 1992: A State of the Art Review. Westport, CT: Meckler, Ltd., 1992

________. "Stability, Care and Hankling of Microforms, Magnetic Media and Optical Disks." Library Technology Reports (January-February 1991). pp 5-116.

Shaffer, J. and J. Schelin, D. Thomas, "Database and File Management Approach for Large Optical Disk Systems", in E. LaBudde, (ed.) Optical Disk Systems and Applications, Proc. of SPIE, the International Society for Optical Engineering. v. 421. Bellingham, WA: SPIE, 1983. pp. 20-30.

Shroeder, C. "Information Standards for Optical Disk Systems." Inform (February 1987). pp. 12-13.

Simon Fraser University, University Archives Document Imaging Project. Burnaby, BC: Simon Fraser University, 1993.

Skupsky, D. S. "Legal Requirements for Microfilm, Computer and Optical Disk Records-- International Perspectives." Records Management Quarterly (January 1991). pp. 32- 34.

Stone, G. and P. Sylvain. "ArchiVISTA: A New Horizon in Providing Access to Visual Records of the National Archives of Canada." Library Trends, 38:4 (Spring 1990). pp. 737-750.

Technology Research Staff, NARA. "Development of a Testing Methodology to Predict Optical Disk Life Expectancy Values." NIST Special Publication 500-200. Washington, DC: NARA, 1991.

United States General Services Administration, Information Resources Management Service, Applying Technology to Record Systems: A Media Guideline - May1993. Washington, DC: General Services Administration, 1993.

Vogelsgang, P. "Optical Digital Recording." in Proceedings of the International Symposium: Conservation in Archives. Ottawa: National Archives of Canada / International council on Archives, 1989. pp. 223-232.

Walter, G. "An Overview: Technology and Application Status of Optical Disk Systems" IMC Journal 24 (July/August 1988). pp. 10-13.