Studie zur Haltbarkeit von Archivmedien

National Media Laboratory 1996

Für die Richtigkeit des Inhalts wird keine Haftung übernommen.

Die Studie beschreibt die Zeiträume über die bei bestimmten Umgebungsbedingungen Archivmedien lesbar bleiben.

1996 Media Stability Studies

NML Final Report

Task 5.1.1 & 5.1.2 Media Stability (Optical and Tape)

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December 1996

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EXECUTIVE SUMMARY

A series of disposition charts have been developed which provide a handy tool for determining the longevity of data storage media when stored under specific conditions. Life expectancies for magnetic tape, optical disc, paper, and film based storage media appear on the same chart for relative comparisons of material stabilities.

A study has been completed by Doculabs which investigates the reliability and stability of CD-R media. Several media manufacturers were recorded on several different writers and played back on several CD-ROM drives. No incompatibilities between any of the media/writer/reader combinations were observed. However, after accelerated aging of the media, two media vendors were completely unreadable. Both of these vendors use a cyanine dye in the manufacturer of their CD-R products which is less stable than phthalocyanine dye.

A statement was prepared regarding the longevity of videotape materials for the Library of Congress’ "Study of the Current State of American Television and Video Preservation."

Two presentations were prepared on the stability of digital data storage media in 1996. Copies of these presentations are attached.

MEDIA STABILITY STUDIES FINAL REPORT (1996)

1 Objectives

To study the environmental stability of magnetic tape and optical disc storage media.

To recommend procedures for the storage and handling of data storage media to ensure its longevity.

To estimate the life expectancy of various storage media and make recommendations regarding their suitability for archival storage purposes.

2 Background

A knowledge of storage media stability or media lifetimes is necessary in order to reliably archive mass storage media and develop mass storage strategies. NML has evaluated the archival stability of storage media for several years. NML’s efforts in this area have served to bring awareness to archival issues that manufacturers are now addressing. Results of investigations and information about archival stability have been used to make recommendations regarding archival performance and acceptable storage conditions.

3 Approach

Determining the long-term stability of media generally involves aging of the media at elevated temperatures and humidities. The media are removed from the accelerated aging environments at periodic intervals for testing. The changes in properties with time can be modeled using appropriate kinetic expressions. Once these models are established, life expectancies of media can be estimated if suitable end-of-life criteria are known. Details on specific experiments are summarized below.

3.1 Reliability/Stability of CD-R Media

A standard method for determining the life expectancy of CD-R media is yet to be established. However, a standard test method has been established for determining the life expectancy of CD-ROM media. Using the ANSI/NAPM IT9.21 Life Expectancy of Compact Disc (CD-ROM) method as a guideline, CD-R media were aged for 1 month at 80 ° C and 85% RH. To reduce thermal and hygroscopic stresses on the media, media were slowly ramped from room temperature to the aging conditions in accordance with the ANSI IT9.21 test procedure.

3.2 Cyclical Temperature/Humidity Aging of CD-ROM Media

One area that has received little attention in the literature is the effect of cyclical temperature and humidity variations on the longevity of CD-ROM media. The standard methods used for LE (life expectancy) determination involves elevated temperatures and humidities that are held constant. A study has begun to investigate the effects that temperature and humidity fluctuations have on the longevity of CD-ROM media.

CD-ROM discs produced by five different manufacturers—3M, Discovery, DMI, Nimbus, and Sony—are being aged in two separate environments:

- A static temperature/humidity environment: Discs are held at 80 ° C and 85% RH for 1 month.
- A dynamically varying temperature/humidity environment: Discs are exposed to an environment that varies between 50 to 80 ° C and 20 to 85% RH. (80 ° C & 20% RH ® 50 ° C & 85% RH ® 50 ° C & 20% RH ® 80 ° C & 85% RH ® 80 ° C & 20% RH ® etc). The storage environment is changed every 12 hours for a total aging period of two months. The twelve hour period is required to allow the polycarbonate substrate of the discs to achieve reasonable hygroscopic equilibrium (within 90%).

Aging at the static conditions has been completed. Aging in the dynamic environment will be completed in January, 1997. Results of this testing should be available in the spring of 1997.

4 Results

4.1 Media Stability Studies—Optical Disc

4.1.1 Reliability/Stability of CD-R Media

Doculabs has completed an investigation of the reliability/stability of CD-R media under sub-contract to NML. Doculabs recorded several different manufacturers’ CD-R discs using several different CD-R writers. They then checked the reliability of the recorded information when played back on eight different CD-ROM drive units. NML assisted in this study by aging the CD-R media, which was then checked for errors by Doculabs.

Media vendors studied were: HP, Kodak, Mitsui, Ricoh, TDK, Taiyo Yuden, and Verbatim. In addition, an extra set of one manufacturers’ discs were labeled with Avery CD-R labels. CD-R writers tested were: HP 4020i (2x), Yamaha CDD200 (2x), Yamaha (4x), Philips (2x), Sony (2x), Ricoh (2x), and Pinnacle (2x). CD-ROM readers tested were: Philips (6x), Plextor (8x), Mitsumi (4x), Sony (4x), Toshiba (2x), Matshita (1x), NEC (6x). A copy of the Doculabs report is available from NML.

Prior to aging, there were no incompatibilities between any of the media/writer/reader combinations. The CD-R analyzer indicated possible low level problems, though none were significant enough to render any discs unreadable. However, manufacturers of CD-R equipment should be concerned with possible "out of spec" scenarios that may cause problems in the future.

After aging, two media types were completely unreadable—Taiyo Yuden and TDK. These manufacturers use a cyanine dye, which is less stable that the phthalocyanine dye used by other manufacturers. To simplify testing, a small test population was used. As such, these results should be considered preliminary. In addition, the aging conditions chosen (80 C and 85% RH for 1 month) may have been unduly harsh to the cyanine dye. Further testing is planned to investigate the reproducibility of these test results.

The complete Doculabs report is attached to this report. Refer to "Attachment A: Doculabs Test Report: Compatibility of CD-R Media, Readers, and Writers." As part of this work a troubleshooting guide for the recording of CD-R media was also prepared by the SIGCAT Foundation—"Attachment B: CD Recording: A Troubleshooting Handbook."

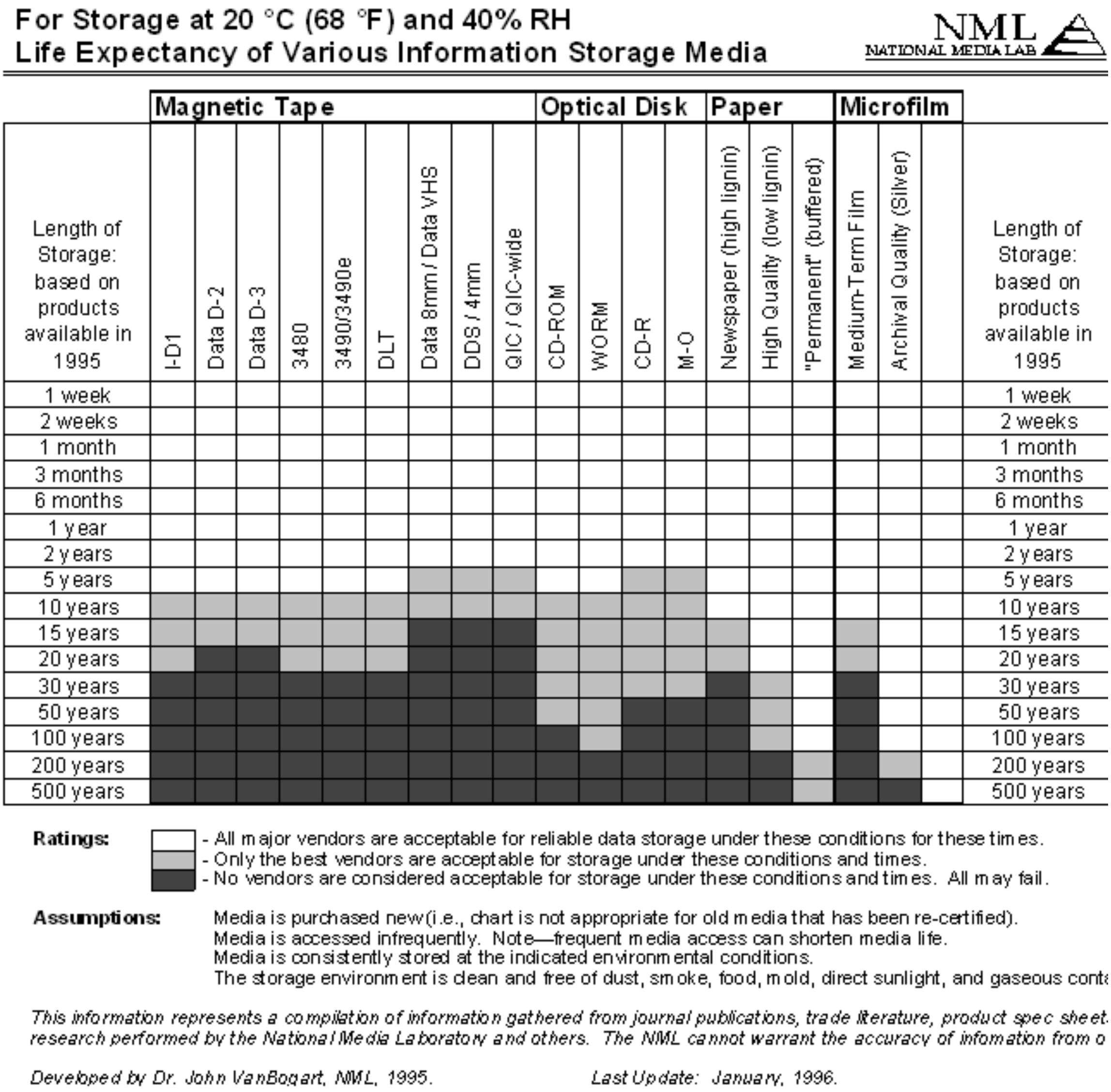
4.2 Media Stability Studies—Magnetic Tape

4.2.1 Disposition Charts

Knowledge of the failure mechanisms for magnetic tape has allowed the development of a series of Disposition Charts which show ranges of life expectancies for commercial tape products. For comparison purposes, the life expectancy values for optical disc products, film, and paper are also provided. These charts are intended as a tool for anyone responsible for archiving information on several different physical formats. The charts also help to point out to archivists that the longevity of electronic storage media is not as great as that of film and paper.

A range of life expectancies is presented on the charts for each medium. Media types differ in their stability depending on the manufacturer and quality of production. For a given storage condition, the best manufacturers’ best lot of media may last 50 years, whereas the worst manufacturers’ worst lot may last only 20 years. To ensure the survivability of stored information for a given length of time, one should choose storage conditions such that the length of time required falls in the "white zone" on the disposition chart.

For example, using the disposition chart in Figure 1, all 3480 cartridges should be expected to last at least 5 years when stored at conditions of 20 ° C and 40% RH. The best manufacturers’ 3480 cartridge should be expected to last 20 years when stored at these same conditions.



For Storage at 20 °C (68 °F) and 40% RH
Life Expectancy of Various Information Storage Media

NML NATIONAL MEDIA LAB

	Magnetic Tape									Optical Disk				Paper			Microfilm			
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)		Length of Storage: based on products available in 1995
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 week
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 weeks
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 month
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	3 months
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	6 months
1 year	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 year
2 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 years
5 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□	5 years
10 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	□	□	□	10 years
15 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	▒	□	□	15 years
20 years	▒	■	■	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	▒	□	□	20 years
30 years	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	■	▒	□	■	□	□	30 years
50 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□	50 years
100 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	▒	□	■	□	□	100 years
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□	200 years
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	■	□	500 years

Ratings:
□ - All major vendors are acceptable for reliable data storage under these conditions for these times.
▒ - Only the best vendors are acceptable for storage under these conditions and times.
■ - No vendors are considered acceptable for storage under these conditions and times. All may fail.

Assumptions:
Media is purchased new (i.e., chart is not appropriate for old media that has been re-certified).
Media is accessed infrequently. Note—frequent media access can shorten media life.
Media is consistently stored at the indicated environmental conditions.
The storage environment is clean and free of dust, smoke, food, mold, direct sunlight, and gaseous conta

This information represents a compilation of information gathered from journal publications, trade literature, product spec sheet research performed by the National Media Laboratory and others. The NML cannot warrant the accuracy of infomation from o

Developed by Dr. John VanBogart, NML, 1995. Last Update: January, 1996.

Figure 1: Disposition Chart for media stored at 20 C and 40% RH.

A sample chart is shown above for storage conditions of 20 C and 40% RH. The charts were compiled from information gathered from journal articles, trade literature, product specification sheets, and research performed by the National Media Laboratory.

All of the disposition charts that have been prepared are provided in Appendix A of this report.

4.2.2 Presentations on Media Stability

A presentation entitled "Magnetic Tape Storage" was given at NARA's 11th Annual Preservation Conference held March 14, 1996 in Washington, D.C. The information presented in this talk was specific to librarians and archivists who needed to deal with magnetic tape as an archival medium. The points covered by this talk were:

What is Tape?

What Can Go Wrong with Magnetic Tape?

How Long Will Tape Last?

What Can Be Done to Increase Longevity?

The Future of Tape

A full copy of this presentation is provided as Attachment C to this report.

A presentation entitled "Long-term Preservation of Digital Materials" was given at the National Preservation Office (NPO) conference on "Preservation and Digitisation: Principles, Practice and Policies" held September 3-5, 1996 at the University of York, England. The NPO, based at the British Library, is an independent center for preservation and security issues for libraries and archives in the United Kingdom. The information presented in this talk was specific to librarians and archivists who needed to deal with magnetic tape and optical disc as an archival medium. The life expectancies of these materials were discussed in detail. The author, John Van Bogart, was unable to attend the conference due to a scheduling conflict. The presentation was given by Dr. Seamus Ross, Assistant Secretary of the British Academy. A full copy of this presentation is provided as Attachment D to this report.

4.2.3 Miscellaneous Activities

In March, 1996, the Library of Congress conducted hearings on the "Current State of American Television and Video Preservation." Archivists, historians, tape manufacturers, tape restorers, and scientists were asked to make statements regarding the stability of videotape. Videotaped public hearings were conducted on March 6, 19, and 26 in Los Angeles, New York, and Washington, DC. A representative from NML could not attend the public hearings because of a scheduling conflict. However, John Van Bogart did submit a written statement. This statement appears in "Appendix B: General Comments on the Stability of Videotape."

In March, 1996, John Van Bogart was asked to participate in a workshop dealing with a tape problem in a flight recorder. Under certain conditions, tape could not be transported through the recorder and was suspected of sticking to the tape head. The recommendations prepared for JPL appears in "Appendix C: Recommendations to JPL Regarding Galileo Flight Tape Recorder Anomaly."

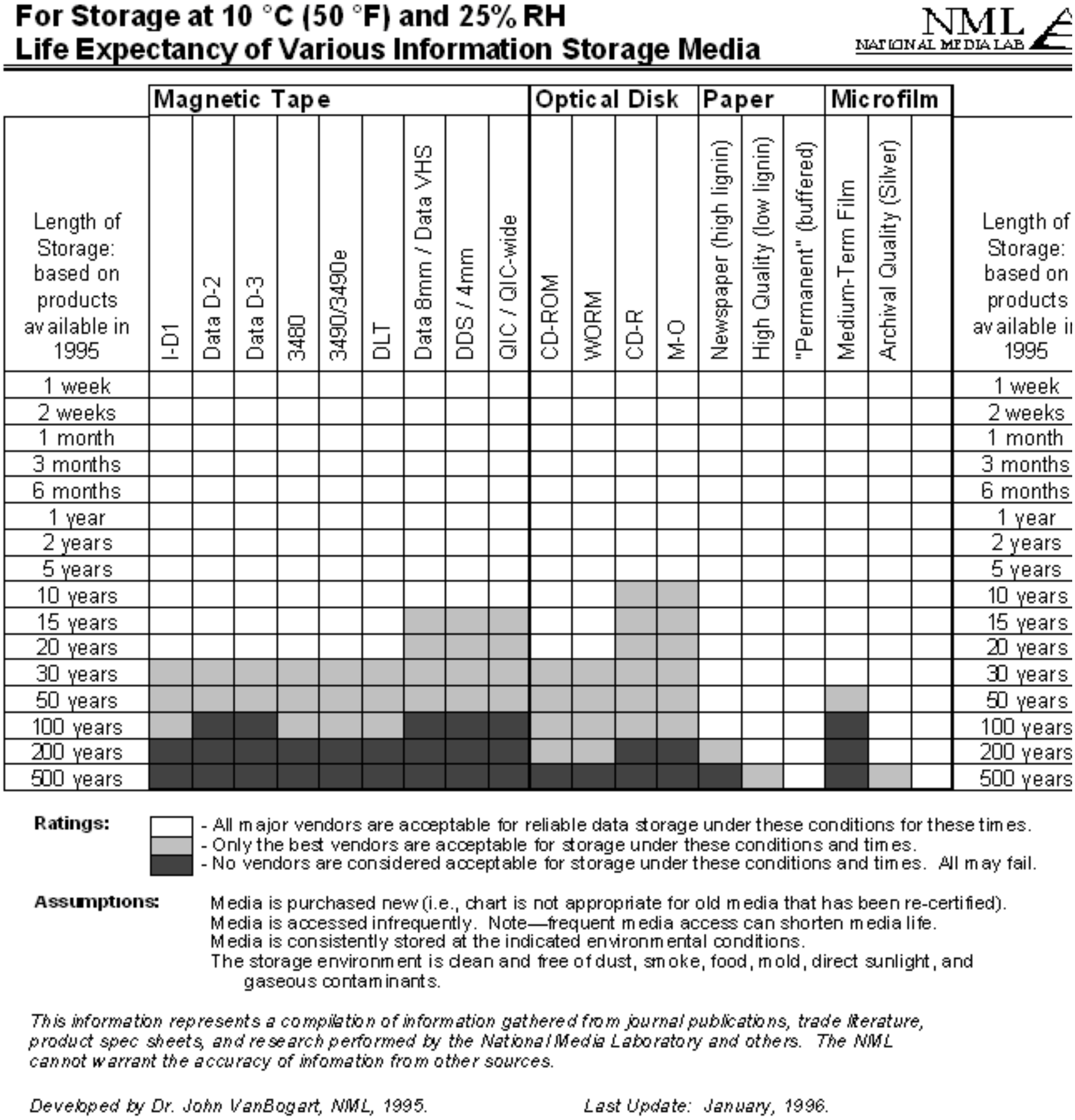
5 Conclusions and Recommendations

A series of disposition charts have been developed which provide a handy tool for determining the longevity of data storage media when stored under specific conditions. Life expectancies for magnetic tape, optical disc, paper, and film based storage media appear on the same chart for relative comparisons of material stabilities.

A study has been completed by Doculabs which investigates the reliability and stability of CD-R media. Several media manufacturers were recorded on several different writers and played back on several CD-ROM drives. No incompatibilities between any of the media/writer/reader combinations were observed. However, after accelerated aging of the media, two media vendors were completely unreadable. Both of these vendors use a cyanine dye in the manufacturer of their CD-R products which is less stable than phthalocyanine dye.

A statement was prepared regarding the longevity of videotape materials for the Library of Congress hearings on this subject. Two presentations were prepared on the stability of digital data storage media in 1996. Copies of these presentations are attached.

6 Appendix A: Disposition Charts



For Storage at 10 °C (50 °F) and 25% RH
Life Expectancy of Various Information Storage Media

NML NATIONAL MEDIA LAB

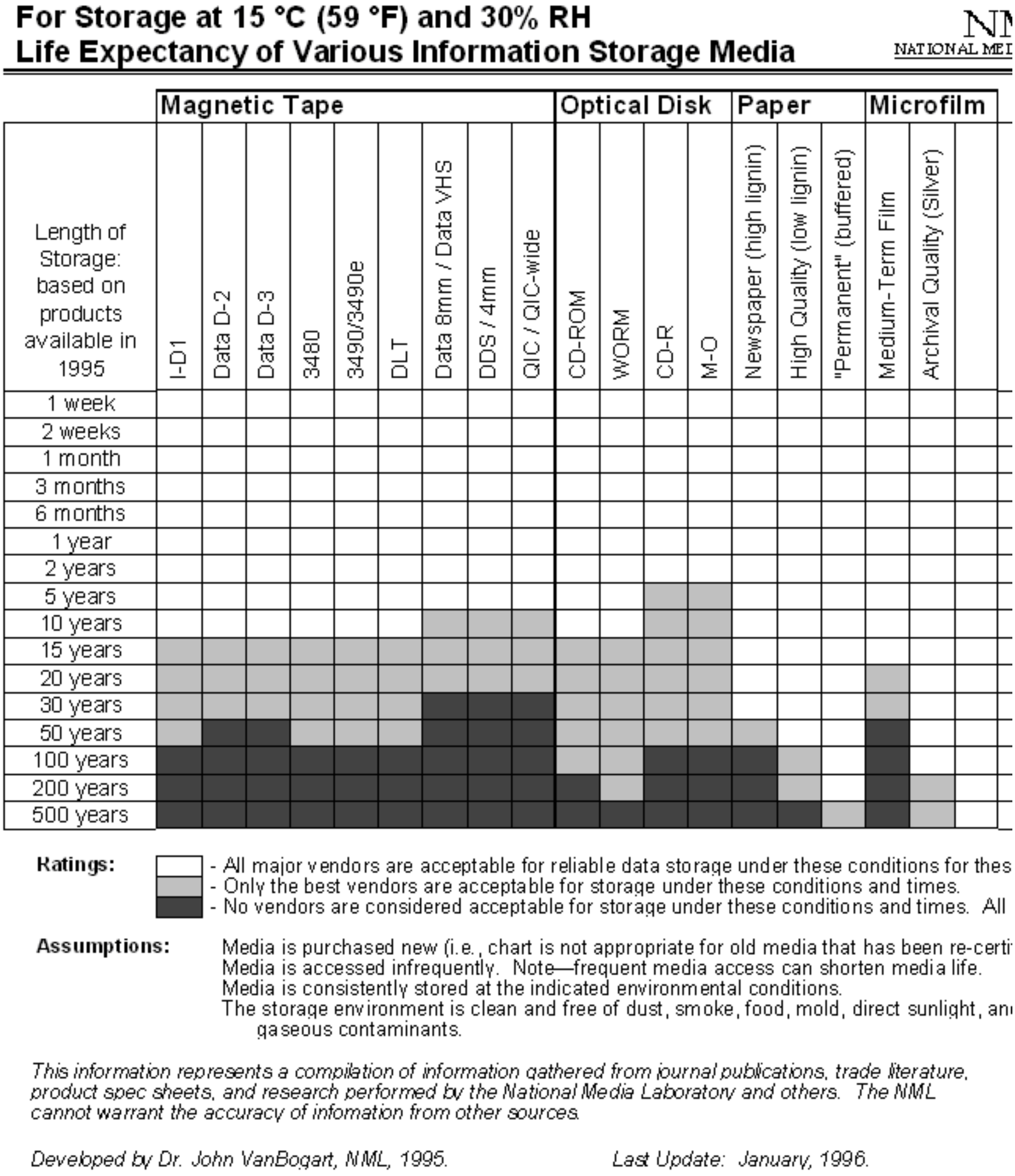
	Magnetic Tape									Optical Disk				Paper			Microfilm			
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)		Length of Storage: based on products available i
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 week
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 weeks
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 month
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	3 months
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	6 months
1 year	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 year
2 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 years
5 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	5 years
10 years	□	□	□	□	□	□	□	□	□	□	□	▒	▒	□	□	□	□	□	□	10 years
15 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□	15 years
20 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□	20 years
30 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	□	□	□	30 years
50 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	▒	□	□	50 years
100 years	▒	■	■	▒	▒	▒	■	■	■	▒	▒	▒	▒	□	□	□	■	□	□	100 years
200 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	▒	□	□	■	□	□	200 years
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	□	■	▒	□	500 years

Ratings:
□ - All major vendors are acceptable for reliable data storage under these conditions for these times.
▒ - Only the best vendors are acceptable for storage under these conditions and times.
■ - No vendors are considered acceptable for storage under these conditions and times. All may fail.

Assumptions:
Media is purchased new (i.e., chart is not appropriate for old media that has been re-certified).
Media is accessed infrequently. Note—frequent media access can shorten media life.
Media is consistently stored at the indicated environmental conditions.
The storage environment is clean and free of dust, smoke, food, mold, direct sunlight, and gaseous contaminants.

This information represents a compilation of information gathered from journal publications, trade literature, product spec sheets, and research performed by the National Media Laboratory and others. The NML cannot warrant the accuracy of infomation from other sources.

Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*



For Storage at 15 °C (59 °F) and 30% RH
Life Expectancy of Various Information Storage Media

	Magnetic Tape									Optical Disk				Paper			Microfilm		
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)	
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 year	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
2 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
5 years	□	□	□	□	□	□	□	□	□	□	□	▒	▒	□	□	□	□	□	□
10 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□
15 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	□	□	□
20 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	▒	□	□
30 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	□	□	□	▒	□	□
50 years	▒	■	■	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	■	□	□
100 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□
200 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	▒	□	■	▒	□
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□

Ratings:
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■ - No vendors are considered acceptable for storage under these conditions and times. All

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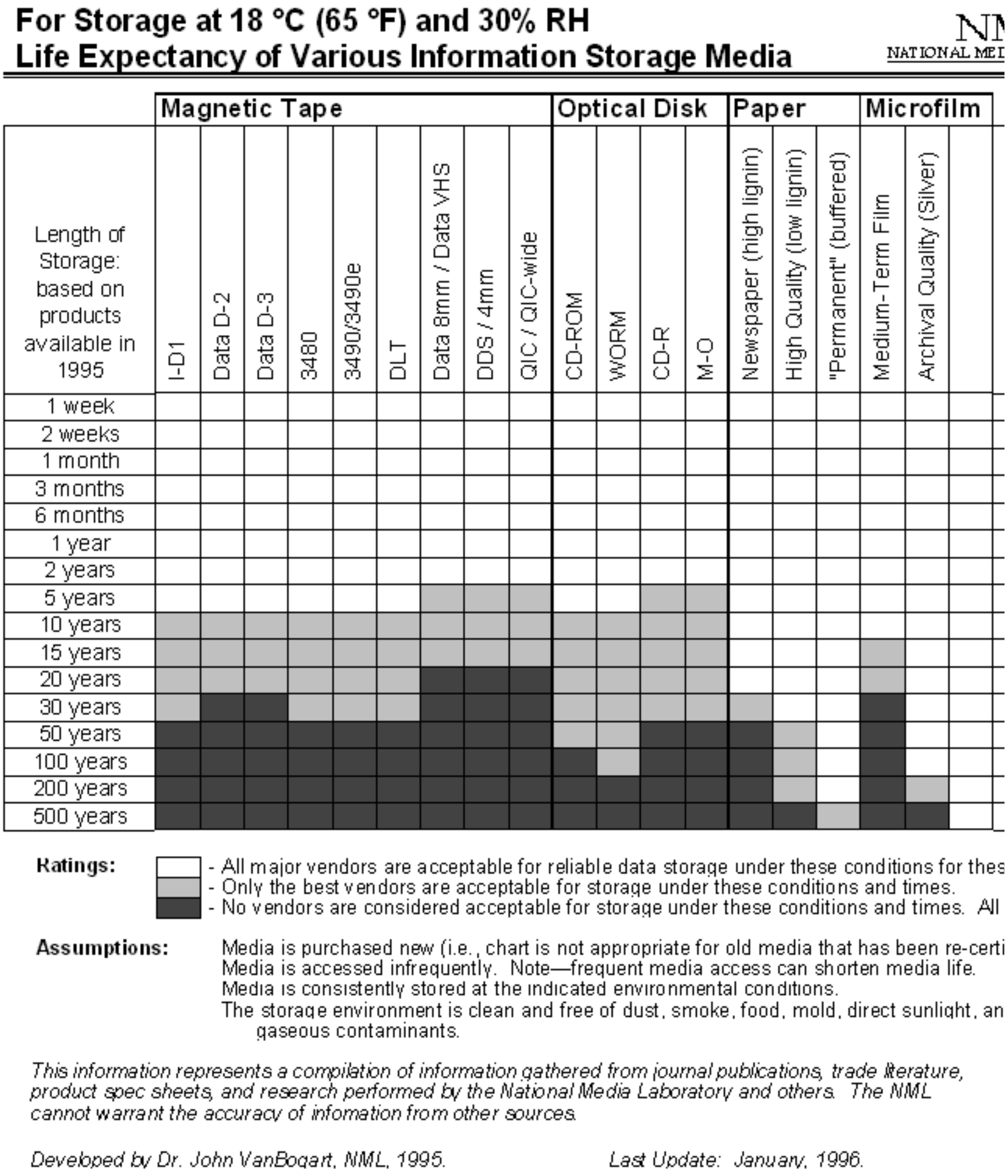

For Storage at 18 °C (65 °F) and 30% RH
Life Expectancy of Various Information Storage Media

NI
NATIONAL MEI

	Magnetic Tape									Optical Disk				Paper			Microfilm		
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)	
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 year	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
2 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
5 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□
10 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	□	□	□
15 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	▒	□	□
20 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	□	□	□	▒	□	□
30 years	▒	■	■	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	■	□	□
50 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□
100 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	▒	□	■	□	□
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	□	■	▒	□
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	■	□

Ratings:
□ - All major vendors are acceptable for reliable data storage under these conditions for thes
▒ - Only the best vendors are acceptable for storage under these conditions and times.
■ - No vendors are considered acceptable for storage under these conditions and times. All

Assumptions:
Media is purchased new (i.e., chart is not appropriate for old media that has been re-certi
Media is accessed infrequently. Note—frequent media access can shorten media life.
Media is consistently stored at the indicated environmental conditions.
The storage environment is clean and free of dust, smoke, food, mold, direct sunlight, an
gaseous contaminants.

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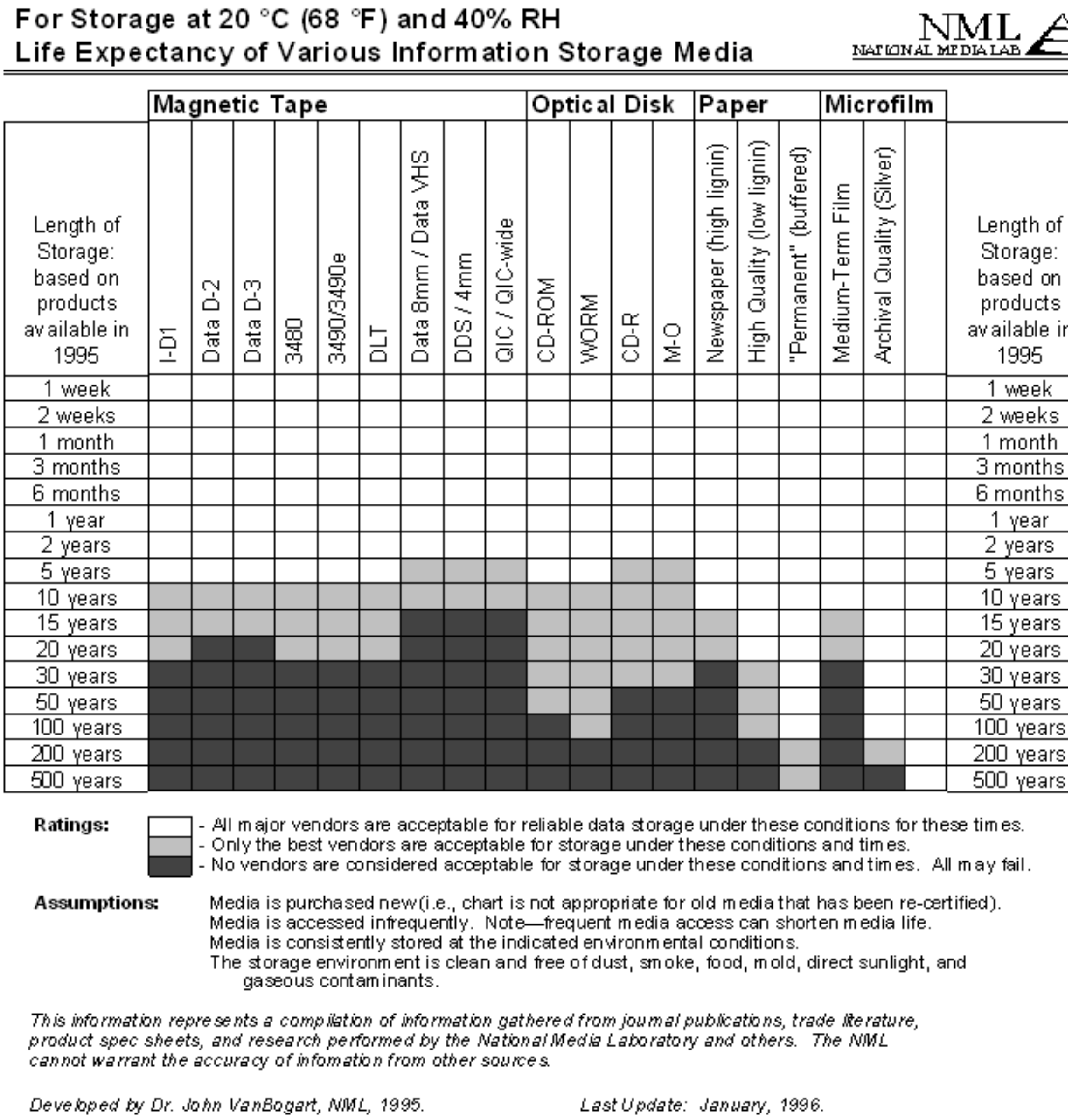
Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*



For Storage at 20 °C (68 °F) and 40% RH
Life Expectancy of Various Information Storage Media

NML NATIONAL MEDIA LAB

	Magnetic Tape									Optical Disk				Paper			Microfilm			
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)		Length of Storage: based on products available ir 1995
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 week
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 weeks
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 month
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	3 months
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	6 months
1 year	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 year
2 years	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 years
5 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□	5 years
10 years	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	□	□	□	□	10 years
15 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	▒	□	□	15 years
20 years	▒	■	■	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	▒	□	□	20 years
30 years	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	■	▒	□	■	□	□	30 years
50 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□	50 years
100 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	▒	□	■	□	□	100 years
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□	200 years
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	■	□	500 years

Ratings:

- □ - All major vendors are acceptable for reliable data storage under these conditions for these times.
- ▒ - Only the best vendors are acceptable for storage under these conditions and times.
- ■ - No vendors are considered acceptable for storage under these conditions and times. All may fail.

Assumptions:

Media is purchased new (i.e., chart is not appropriate for old media that has been re-certified).
Media is accessed infrequently. Note—frequent media access can shorten media life.
Media is consistently stored at the indicated environmental conditions.
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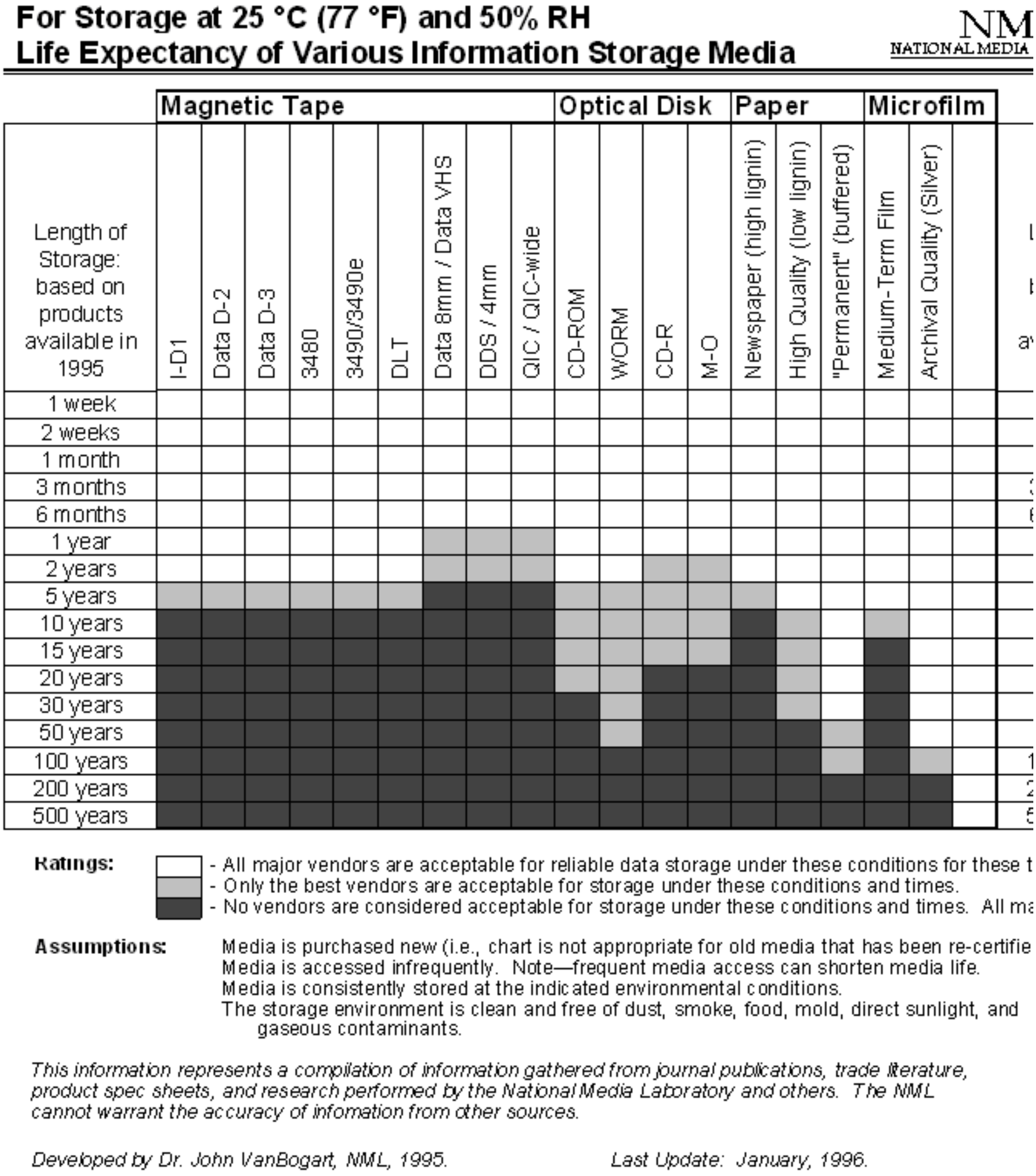
Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*



For Storage at 25 °C (77 °F) and 50% RH
Life Expectancy of Various Information Storage Media

NM
NATIONAL MEDIA

	Magnetic Tape									Optical Disk				Paper			Microfilm		
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)	
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
6 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
1 year	□	□	□	□	□	□	▒	▒	▒	□	□	□	□	□	□	□	□	□	□
2 years	□	□	□	□	□	□	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□
5 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	□	□	□
10 years	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	■	▒	□	▒	□	□
15 years	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	■	▒	□	■	□	□
20 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□
30 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	▒	□	■	□	□
50 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	■	▒	■	□	□
100 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□

Ratings:
□ - All major vendors are acceptable for reliable data storage under these conditions for these t
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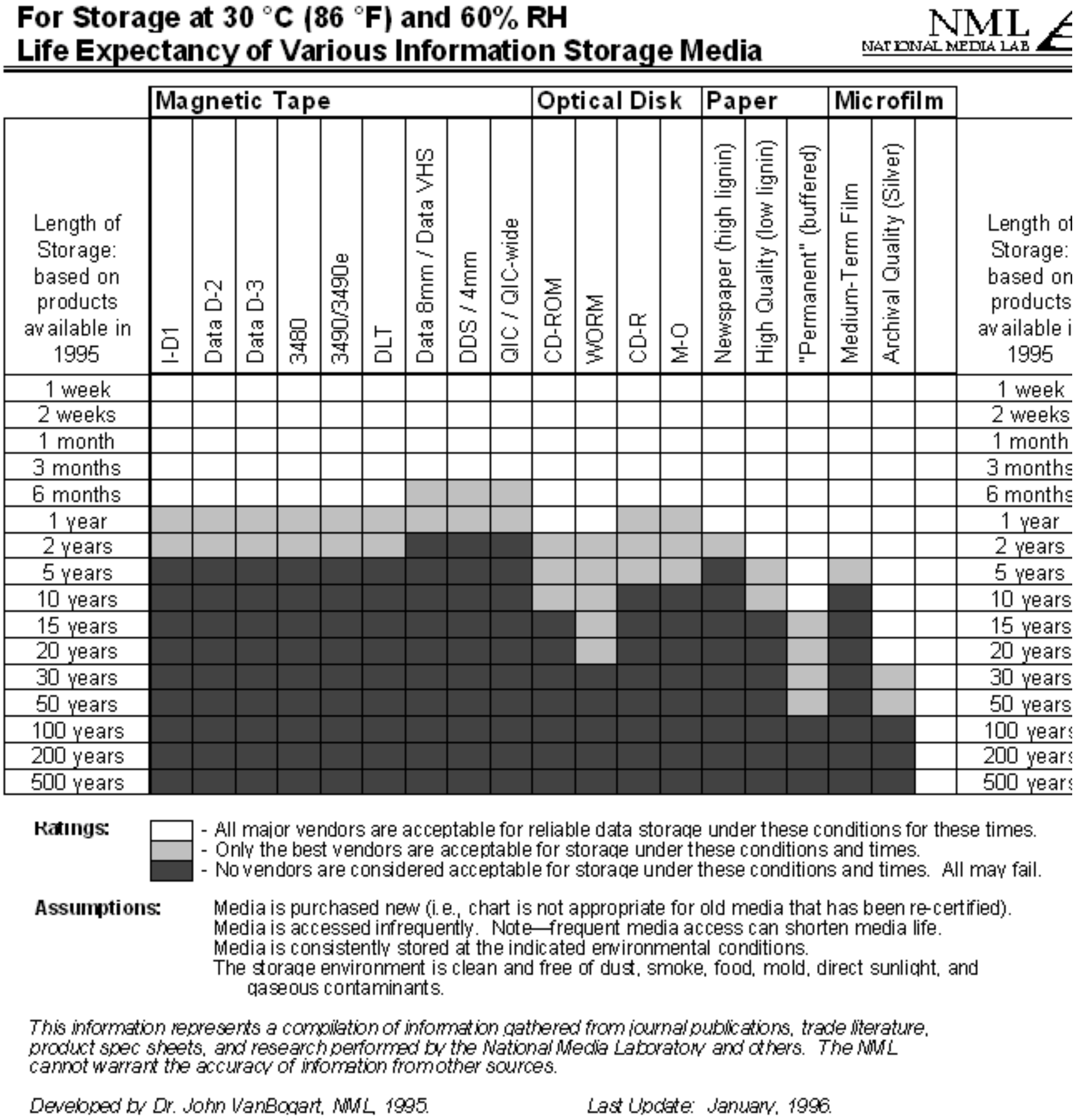
Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*



For Storage at 30 °C (86 °F) and 60% RH
Life Expectancy of Various Information Storage Media

	Magnetic Tape									Optical Disk				Paper			Microfilm			
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)		Length of Storage: based on products available i 1995
1 week	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 week
2 weeks	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	2 weeks
1 month	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	1 month
3 months	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	3 months
6 months	□	□	□	□	□	□	▒	▒	▒	□	□	□	□	□	□	□	□	□	□	6 months
1 year	▒	▒	▒	▒	▒	▒	▒	▒	▒	□	□	▒	▒	□	□	□	□	□	□	1 year
2 years	▒	▒	▒	▒	▒	▒	■	■	■	▒	▒	▒	▒	▒	□	□	□	□	□	2 years
5 years	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	■	▒	□	▒	□	□	5 years
10 years	■	■	■	■	■	■	■	■	■	▒	▒	■	■	■	▒	□	■	□	□	10 years
15 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	■	▒	■	□	□	15 years
20 years	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	■	▒	■	□	□	20 years
30 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□	30 years
50 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	▒	□	50 years
100 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□	100 year
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□	200 year
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	□	500 year

Ratings:
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▒ - Only the best vendors are acceptable for storage under these conditions and times.
■ - No vendors are considered acceptable for storage under these conditions and times. All may fail.

Assumptions:
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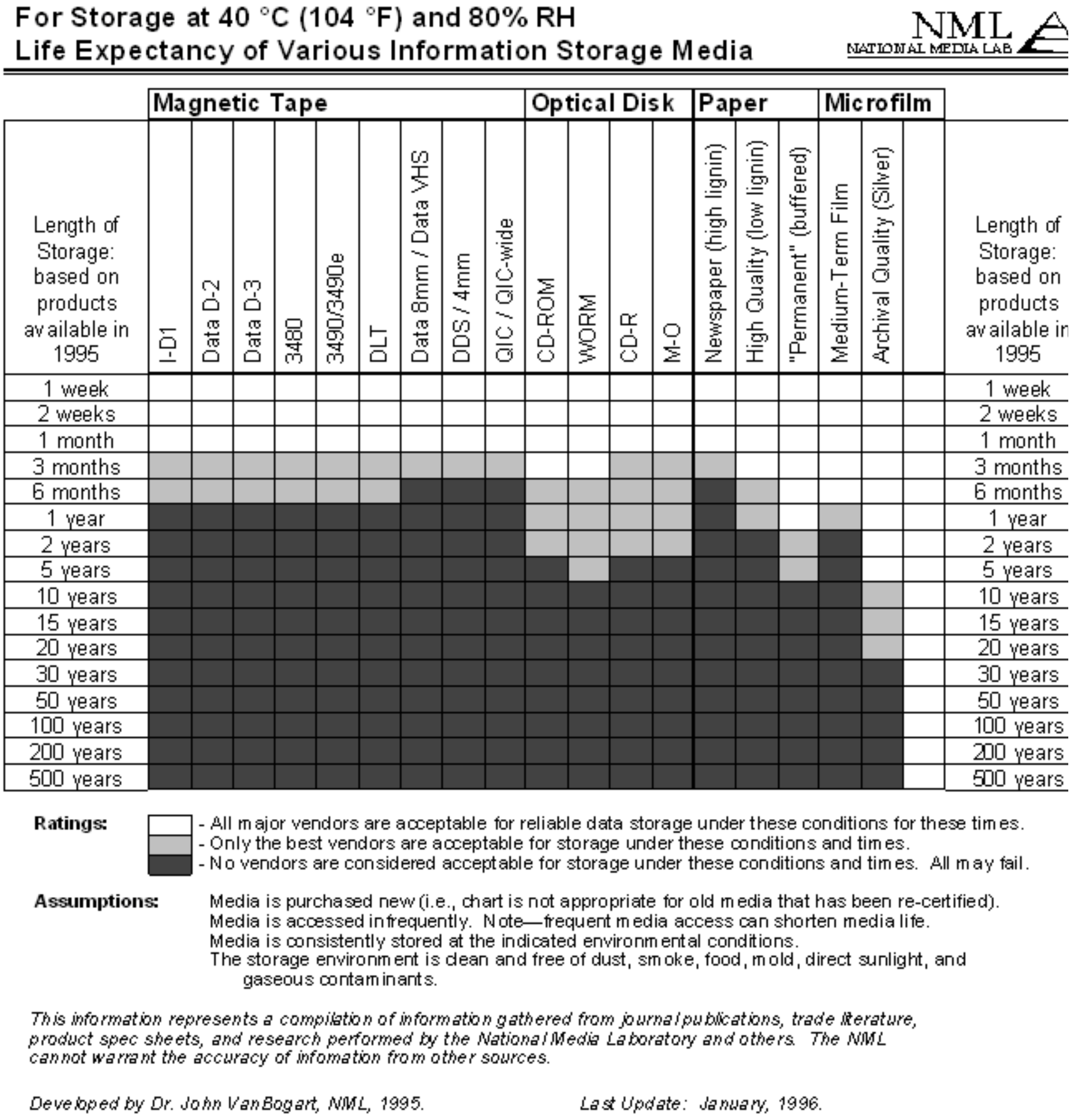
Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*



For Storage at 40 °C (104 °F) and 80% RH
Life Expectancy of Various Information Storage Media

NML
NATIONAL MEDIA LAB

	Magnetic Tape									Optical Disk				Paper			Microfilm			
Length of Storage: based on products available in 1995	I-D1	Data D-2	Data D-3	3480	3490/3490e	DLT	Data 8mm / Data VHS	DDS / 4mm	QIC / QIC-wide	CD-ROM	WORM	CD-R	M-O	Newspaper (high lignin)	High Quality (low lignin)	"Permanent" (buffered)	Medium-Term Film	Archival Quality (Silver)		Length of Storage: based on products available in 1995
1 week	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	1 week
2 weeks	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	2 weeks
1 month	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	1 month
3 months	▨	▨	▨	▨	▨	▨	▨	▨	▨	☐	☐	▨	▨	▨	☐	☐	☐	☐	☐	3 months
6 months	▨	▨	▨	▨	▨	▨	■	■	■	▨	▨	▨	▨	■	▨	☐	☐	☐	☐	6 months
1 year	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	■	▨	☐	▨	☐	☐	1 year
2 years	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	■	■	▨	■	☐	☐	2 years
5 years	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	▨	■	☐	☐	5 years
10 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	☐	10 years
15 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	☐	15 years
20 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	☐	20 years
30 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	30 years
50 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	50 years
100 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	100 years
200 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	200 years
500 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	☐	500 years

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Developed by Dr. John VanBogart, NML, 1995. *Last Update: January, 1996.*

7 Appendix B: General Comments on the Stability of Videotape

The following was submitted in response to the Library of Congress’ "Study of the Current State of American Television and Video Preservation" on April 26, 1996 by Dr. John W. C. Van Bogart of the National Media Laboratory, St. Paul, MN:

General Comments on the Stability of Videotape

Dr. John W. C. Van Bogart

National Media Laboratory

Building 235-1N-17

St. Paul, MN 55144-1000

Phone: 612-733-1918

FAX: 612-736-6843

As the Principal Investigator for Media Stability Studies at the National Media Laboratory, I have investigated the stability of magnetic videotape used for both analog and digital recording. The National Media Lab (NML) is an industry resource supporting the U.S. Government in the evaluation, development, and deployment of advanced storage media and systems. The NML endeavors to provide a broad perspective of current progress in storage issues, both from a commercial and a government perspective.

Videotape poses a special challenge to archivists, librarians, historians, and preservationists. As an information storage medium, videotape is not as stable as photographic film or paper. Properly cared for, film and paper can last for centuries, whereas most videotapes will only last a few decades.

Videotape recording technology consists of two independent components—the magnetic tape medium and the recorder. Neither component is designed to last forever. Images recorded on a videotape can be lost because of chemical degradation of the tape. However, access to images recorded on a tape can also be disallowed because the video format has become obsolete and a working recorder cannot be located.

Videotape Components

Videotape consists of several components. The layer which is responsible for recording the magnetic signal consists mainly of magnetic particles held together by a binder polymer. Lubricants, carbon black, head cleaning agents, and other components are also added to this layer to reduce wear, facilitate tape transport, dissipate static charge, and reduce dropouts. This relatively thin, paint-like, magnetic layer is supported on a thicker, stronger substrate film. A thin back coat layer can also be added to the other side of the substrate film to improve tape wind, facilitate transport, and dissipate static charge.

Over time, videotape properties can change unfavorably. Hydrolysis of the binder polymer can result in a less durable, more gummy magnetic layer resulting in an increase in dropouts. Loss of lubricant over time can result in increased wear of the magnetic layer during playback. The magnetic pigment can lose some of its magnetic signal resulting in poorer color reproduction and contrast on playback of analog recordings and dropouts in digital recordings. The backing film can creep and deform in improperly wound tape packs resulting in mistracking on playback.

Binder Polymer

The binder polymer has the function of securing the magnetic pigment to the tape backing and providing a smooth surface to facilitate transportation of the videotape through the recording system. Other components are added to the binder to help with tape transport and facilitate playback. A lubricant is added to the binder to reduce friction, which reduces the tension needed to transport the tape through the recorder and also reduces tape wear. A head cleaning agent is added to the binder to reduce the occurrence of head clogs which result in dropouts. Carbon black is also added to reduce static charges which attract debris to the tape.

The binder is responsible for holding the magnetic particles on the tape and facilitating tape transport. If the binder looses integrity—through softening, embrittlement, loss of cohesiveness, or loss of lubrication—the tape may become unplayable. Sticky tape and sticky shed are commonly used terms to describe the phenomenon associated with deterioration of the magnetic tape binder.

The binder polymers used in magnetic tape constructions are subject to a chemical process known as hydrolysis. In this process, long molecules are broken apart by a reaction with water to produce shorter molecules. The shorter molecules do not impart the same degree of integrity to the binder system as do the longer molecules. Water must be present for the hydrolysis reaction to occur. Videotapes stored in a high humidity will undergo a greater degree of hydrolysis that tapes stored in low humidities. Binder hydrolysis can lead to a softer than normal binder coating, higher friction, and/or gummy tape surface residues. Tape binder debris resulting from binder deterioration may result in head clogs which may produce dropouts on a videotape when played back.

Lubricant

Lubricants are normally added to the binder to reduce the friction of the magnetic top coat layer of videotape. A lower friction will facilitate tape transport through the recorder and reduce tape wear. In a videotape recorder, where the tape is usually wrapped around a rapidly rotating head, low friction is important as it prevents overheating of the tape.

Over time, the level of lubricant in videotape decreases as lubricants are partially consumed every time the tape is played. Lubricant levels also decrease over time even in unplayed, archived tape as a result of evaporation and degradation. The lubricants used in some tapes are oily liquids which are volatile and slowly evaporate away over time. Some lubricants are also subject to degradation by hydrolysis and oxidation, just like the binder polymer, and will loose their essential lubrication properties with time.

Magnetic Pigment

The magnetic pigment is responsible for storing the recorded video signal. If there is any change in the magnetic properties of the pigment, recorded signals can be irretrievably lost. The magnetic remanence is the property of a pigment that enables it to retain a magnetic field. A decrease in the magnetic remanence of the pigment over time can result in a lowered output signal. The coercivity characterizes the pigment's ability to resist demagnetization. A magnetic tape with a lower coercivity is more susceptible to demagnetization and signal loss.

Magnetic pigments differ in their stability—some particles retain their magnetic properties longer than others. So some videotapes will retain initial image quality longer than others. Iron oxide and cobalt-modified iron oxide pigments are the most stable pigment types of those used in videotapes. Metal particulate (MP) and chromium dioxide (CrO2) pigments provide a higher tape signal output and permit higher recording frequencies than the iron oxide pigments, but are not as stable as the iron oxide pigments. A loss in signal will manifest itself as a loss of hue and reduction in saturation for an analog video recording.

There is not much that can be done to prevent the magnetic deterioration that is inherent in the metal particulate and chromium dioxide pigment types. However, the rate of deterioration can be slowed by storing the tapes in cooler temperatures. The level of humidity has little direct effect on the deterioration of magnetic pigments. However, by-products of binder deterioration can accelerate the rate of pigment deterioration, so lower humidity would also be preferred to minimize the degradation of the magnetic pigment.

Tape Backing

The backing film, or substrate, is needed to support the magnetic recording layer, which is too thin and weak to be a stand-alone film layer. In some tape systems, a back coat is applied to the backside of the tape substrate layer. A back coat reduces tape friction, dissipates static charge, and reduces tape distortion by providing a more uniform tape pack wind on the tape reel.

The tape backing, or substrate, supports the magnetic layer for transportation through the recorder. Since the early 1960's, most videotapes have used an oriented polyethylene terephthalate (PET, DuPont Mylar™) film as a tape substrate material. PET has been shown, both experimentally and in practice, to be chemically stable. PET films are highly resistant to oxidation and hydrolysis. In archival situations, the polyester tape backing will chemically outlast the binder polymer. The problem with polyester backed videotapes is that excessive tape pack stresses, aging, and poor wind quality can result in distortions and subsequent mistracking when the tapes are played.

The Longevity of Videotape

The National Media Laboratory has been investigating the stability of magnetic tape since 1989. Several key magnetic, physical, and chemical properties of magnetic tapes aged in accelerated environments have been studied as a function of time. The experimental data collected have been modeled using relevant kinetic expressions. Once established, these models allow the estimation of life expectancies assuming that the videotapes are stored at specific temperatures and humidities.

There are several analog videotape formats—quadruplex, U-matic, Betamax, VHS, 8mm. Likewise, there are several digital videotape formats—D-2, D-3, D-5, digital BetaCam. Videotape longevity is determined in part by the design of the system used to play them. Furthermore, analog and digital videotapes differ in the way in which they fail. There are also several manufacturers of videotape who may have changed formulations several times over the years of production.

Videotape longevities are highly dependent on the particular recording format used, quality of the videotape, conditions under which the tapes are stored, care with which the tapes are handled, and the number of times the videotape is accessed over its lifetime. As such, it is very difficult to make a general statement regarding the life expectancy of videotape. However, extrapolation of kinetic models points to the benefit of proper storage conditions in increasing the longevity of videotape.

Storage and Handling

Individuals who are responsible for videotape collections must be aware of the specific care and handling requirements for magnetic tape. The instability of videotape, relative to film and paper, requires that special practices be implemented to ensure that the recorded images will be preserved. Storage recommendations such as those from SMPTE RP-103 (1982) of 70 ° F ± 4 ° F and 50% ± 20% are based on what is convenient for immediate playback of tapes and economical from an environmental control standpoint. Special storage environments may be required if the videotapes are to be preserved for longer than 10 years. For collections which must be preserved indefinitely, transcription from old media to new media is inevitable, both for reasons of media instability and obsolescence of the recording technology.

Storing videotape in a clean, controlled environment is the single, most important thing one can do to extend its life. High temperatures, high humidity, and the presence of dust and corrosive elements in the air all affect the physical components that make up magnetic tape and can result in videotape signal loss through decreased magnetic capability and deterioration of the binder or backing of the tape.

An understanding of videotape degradation mechanisms makes it clear as to how proper storage and handling can increase the life of videotape. Cooler storage temperatures slow the rate at which tape binders degrade and thus extend the life of the videotape. Lower relative humidities also reduce the rate and extent of binder hydrolysis.

All videotapes, regardless of format will last longer if the tape packs are wound properly and the tapes are stored at reduced temperatures and humidities. Models for binder hydrolysis prepared by the National Media Laboratory indicate that some videotapes will last twice as long when stored at 68 ° F & 30% RH rather than at 72 ° F & 50% RH. Be advised, however, that too low of a storage temperature may result in the migration of lubricants to the surface of some videotapes which can interfere with proper playback.

The best way to reduce the degree of tape backing distortion which can result in mistracking is to store videotapes in an environment that does not vary much in temperature or humidity. Each time the temperature or humidity changes, the tape pack will undergo expansion or contraction. These dimensional changes can increase the stresses in the tape pack which can cause permanent distortion of the tape backing. Mistracking can also arise if the tape experiences non-linear deformation as a result of non-uniform tape pack stresses. This normally results if the tape pack wind quality is poor as indicated by popped strands of tape—one to several strands of tape protruding from the edge of a wound roll of tape.

Analog versus Digital Videotape

The chief advantage of an analog recording for archival purposes is that the deterioration of the recording over time is discernible. This allows the aging videotape to be copied to a new tape before it reaches a point where the recording quality has degraded to an unacceptable level. Even in instances of severe tape degradation, where video quality is severely compromised by the presence of a high rate of dropouts, a portion of the original image will still be perceptible.

A digital videotape will show little, if any, deterioration in quality up until the time at which catastrophic failure occurs—large sections of recorded information will be completely missing. None of the original material will be detectable in these missing sections.

8 Appendix C: Recommendations to JPL Regarding Galileo Flight Tape Recorder Anomaly

April 9, 1996

Dennis Carpenter

JPL

MS 103-106

4800 Oak Grove Drive

Pasadena, CA 91109

Dear Dennis:

The team at JPL has done an excellent job analyzing the anomalies observed during routine communications with Galileo. For the most part, we feel that your findings are correct and that your scenarios for future operations are sound.

The problem certainly appears to be lubricant bleed, the residue of which collects on the dummy sapphire erase head which causes the tape to stick if parked for too long.

Lubricant Bleed

It still remains a curiosity as to why the tape is bleeding lubricant. Historically, we at NML have observed lubricant bleeding from tapes under the following conditions:

- The tape was exposed to low temperatures during shipping. Tape binder system components are less chemically compatible at lower temperatures. Lowered temperatures can provide a driving force for phase separation and migration of lubricants to the surface of a tape.

- The tape was exposed to higher than normal humidities. Lubricant bleed can be facilitated by humidity. In a high humidity environment, the equilibrium of the reversible esterification reaction is shifted to favor a higher concentration of fatty acids which are less compatible with the tape binder and can leach out onto the surface of the tape.
- The tape was poorly formulated. Excessive amounts of lubricant or chemically incompatible lubricant systems were incorporated in the tape when manufactured.

> The tape being use in the Galileo spacecraft does not appear to fall into any of the categories above, however. This raises an interesting question—is it possible that the dummy sapphire erase head is interacting with the tape in such a way as to exude lubricant from the tape? The fact that tape "goop" is collecting exclusively on the sapphire heads (based on ground recorder tests) indicates that there is something unique about the way the sapphire head interacts with the tape. We have not had any experience with sapphire materials, other than those used in some recorders as scraper blades (with a very different geometry). However, some questions come to mind:

- Is the sapphire head acting as it does in other recorders—as a scraper for debris removal and collection? The geometry of the dummy sapphire erase head is radically different from that of a sapphire scraper blade, however.
- Does the lubricant merely have an affinity for the sapphire, perhaps a result of the higher surface energy of the sapphire.
- The low surface roughness of the sapphire heads polished by use may result in higher friction and subsequently a greater dissipation of energy than the standard record heads. This may result in greater flash temperatures—the temperature at the immediate surface of the tape when the tape passes over the head—at the sapphire head. (See the attached analysis that demonstrates that flash temperature is a direct function of tape speed and friction). The greater flash temperatures may result in liquefaction (melting) of tape lubricants which then flow onto the sapphire heads. Analysis done by JPL indicates that the "goop" on the heads melts sharply at 42 ° C. Could the deposits on the sapphire heads be the result of high speed tape slewing resulting in flash temperatures above the melting point of the lubricant with subsequent liquefaction and outflow onto the head?

> Unfortunately, it is just a matter of time before catastrophic failure of the DMS system will occur. Lubricant will continue to bleed from the tape until:

- The tape adheres to the sapphire head with a cohesive force which cannot be exceeded by a forward slew of the tape. The fact that the tape exhibits residue after it becomes unstuck from the sapphire head suggests that a cohesive failure of the tape "goop" is occurring during the unstick procedure.
- The record and/or playback head gaps get clogged with tape lubricant debris which cannot be dislodged by a slewing of the tape. It is curious that the tape "goop" is currently residing on the sapphire head exclusively. This is unexpected from NML's experience with lubricant bleed. If and when the "goop" starts to migrate, more serious record/playback problems may result.

> There are methodologies for dealing with lubricant migration, binder hydrolysis, or "sticky tape." Unfortunately, none of these are feasible given the limitations in the design of the Galileo spacecraft. However, for the record, they are presented below:

- *Tape Thermal Treatments*: By heating tapes, lower molecular weight contaminants on the surface of the tape can be reabsorbed into the tape, allowing them to be played without difficulty. Unfortunately, the design of the Galileo spacecraft does not allow for heating of the DMS chamber.

- The recording industry has been removing old audio masters from storage vaults over the last decade to produce new CD audio discs. Unfortunately, in many cases, the archived discs have been quietly deteriorating during their years in storage. The high friction of the gummy tape surface causes the tapes to stick-slip on the heads and audibly squeal when played. Ampex has developed a procedure for dealing with this problem which involves a heating of the tapes to 50 ° C for several hours. This does not reverse the hydrolysis reaction (a much longer time would be required for the kinetics involved). Instead, at the higher temperatures, the low molecular weight "goop" on the surface of the tape is chemically more compatible with the tape binder and is reabsorbed into the tape.

- After heat treatment, the tapes play with little or no problem. However, this treatment is temporary and the tapes will resort to their initial condition in about a month. For more information refer to the following articles (I have sent copies of these articles to Ed Cuddihy):
- Philip De Lancie, "Sticky Shed Syndrome," **Mix**, May, 1990, p. 148.
- Scott Kent, "Binder Breakdown in Back-Coated Tapes," **Recording Engineer/Producer**, July, 1988, p. 81.
- Barry Fox, "Master Tape come to a Sticky End," **New Scientist**, September, 1990.
- *Use of Winder/Cleaners*: Commercially available winder/cleaners are available for removing "goop" from tapes. In a sense, the sapphire head in the Galileo DMS recorder is functioning as a scraping blade. If the debris being generated by the tape continues to collect at the sapphire head rather than on the record and playback heads, this is a good thing.

Future Operational Scenarios

Since the lubricant cannot be physically wiped from the tape (e.g., via a winder/cleaner), or reabsorbed into the tape (via a thermal treatment) the next best thing is to distribute the lubricant uniformly over the entire tape. The best way to do this is to keep the tape moving.

We recommend the following operating procedures to increase the operational life of the DMS recorder:

It is recommended that the tape recorder be kept in motion at all times, even during idle periods (when no data collection is occurring). During non-data collecting periods the DMS recorder should be continuously slewed at the slowest speed (7.68 Kbps; 0.74 ips) from BOT to within 10% of EOT and then back to BOT. Avoid going all the way to EOT to allow room for a forward motion unstick, if necessary. This will minimize the force associated with tape sticking as the tape will never be parked for longer than a few seconds when the tape direction is reversed. *A major assumption of this scenario is that there is sufficient power in the spacecraft to keep the tape continuously slewing at low speed*.

During periods of data collection, the recorder could be used at the data rates required for collection. Slower rates would be preferred, but higher rates could be used with the greater risk that the tape could stick with a greater force when the tape direction is reversed. Transmission of the data should be done at the slowest possible speeds that are practical. Recording and playback should be done over the entire BOT to within 10% EOT range without stopping. In other words, the tape should only be stopped and reversed at BOT and at within 10% of EOT to avoid depositing debris on the tape at anywhere but these tape positions.

This "constant motion" scenario would add approximately 1500 additional required tape passes over the remainder of the Galileo mission (approx. 3 a day for 500 days). The tape should be durable enough to handle these additional passes. However, you may want to check with Quantegy for a confirmation on this.

Suggestions for Future Work

- It is a mystery to us that the lubricant which is bleeding from the tape has an affinity for the dummy sapphire erase head and chooses to collect in this area of the tape transport. Future work is suggested to understand why this is happening. Is it merely coincidence at this point in time? Or does the tape "goop" truly have a preference for the dummy sapphire erase head for reasons of geometry and/or chemistry. NML experience with tape lubricant bleed has indicated that all transport components—heads, guide pins, and rollers—are ultimately contaminated with lubricant. Historically, the contamination has been independent of geometry and material (ferrite, stainless steel, aluminum, copper).
- Plug appropriate numbers into the equation for calculating tape surface temperatures provided in the attachment. (I have done this in the attachment, but I am uncertain as to the accuracy of the values used.) At the highest speed, 9.7 ips, what is the calculated tape surface temperature and how does it compare to 42° C?
- If you are interested, NML could run some tests on the Ampex 799 tape to determine if the solid state physics approach to tape sticking involving trapped charges is physically possible. We would need a few feet of a sample of the same age from the same lot of tape as that in Galileo.

Yours sincerely,

John Van Bogart	George Klechefski	Darlene Carlson
Principal Investigator	Principal Investigator	Manager
Media Stability Studies	Standards	Operations Support

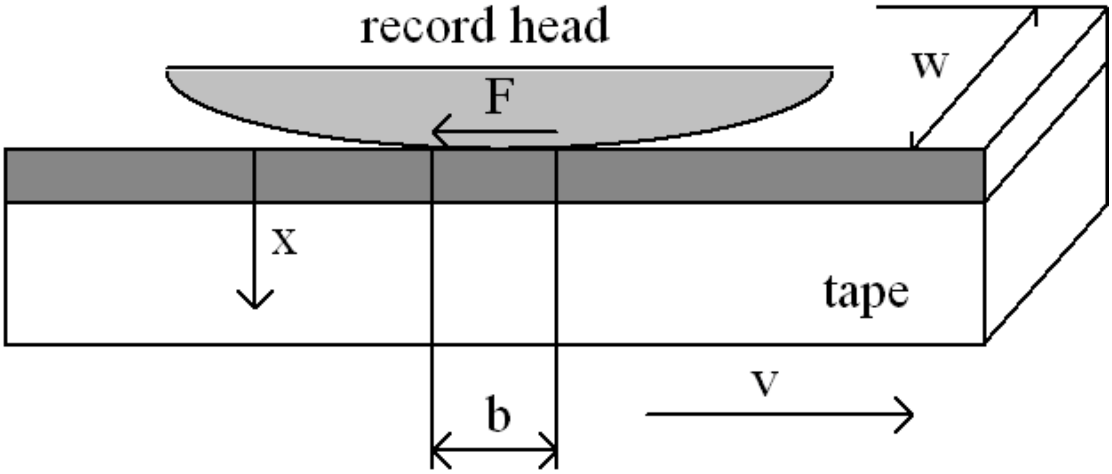
Cc: Ed Cuddihy, JPL

Jim Goins, 3M

Mike Johnson, JPL

Attachments: Analysis of the Maximum Tape Surface Temperature after Passing Across a Record Head

Analysis of the Maximum Tape Surface Temperature after Passing Across a Record Head



x - distance into tape from top surface

b - length of tape-head contact

w - width of tape

v - speed of tape

F - tension drop across record head

> P = F× v, power dissipated at tape/head interface. Dissipated over length of contact, b.
>
> q = P/(b× w), energy flux per unit area into tape at tape/head interface (assumed uniform over area of tape/head contact). Note that this assumes that ALL dissipated energy is going into the tape rather than the head, done here for simplicity. A factor could easily be applied to consider the fraction of energy that is actually dissipated by the tape.
>
> q = (F× v)/(b× w).

The differential equation that must be solved to determine the temperature at the surface of the tape is (from Bird, R. B., Stewart, W. E., and Lightfoot, E. N., Transport Phenomenon, Table 10.2-3, Equation A, (1960)):

$(¶T/¶t) = a×(¶^{2T/}¶x^{2})$ (1)

> where, a - thermal diffusivity for the tape. a ° k/(r×C_p), where k is the thermal conductivity of the tape; r is the density of the tape; C_p is the heat capacity of the tape at constant pressure.
>
> T(x,t) - temperature at position x at time t.
>
> t - time

Differential equation (1) above assumes that (1) there is no material flow, and (2) there is no net flow of energy down the length of the tape (z-direction) or across the width of the tape (y-direction). In other words, the above expression is valid for a solid tape where all energy flow is normal to the surface of the tape (i.e., in the x-direction).

Equation (1) must be solved subject to the following boundary conditions:

> At t = 0, $T = T_0$ at x = 0 (i.e., the initial tape surface temperature is T_0).
>
> At t > 0 and t <= (b/v), q = (F× v)/(b× w) at x = 0 (i.e., during the time that the tape is in contact with the head, the heat flux into the tape is a constant given by the total power dissipated divided by the area of contact).
>
> At t > (b/v), q = 0 at x = 0 (i.e., there is no further heat flux into the tape after the tape has passed the head.

Since we are really only concerned with the maximum tape surface temperature, we could restate the boundary conditions as,

> At t = 0, $T = T_0$ at x = 0 (i.e., the initial tape surface temperature is T_0).
>
> At t > 0, q = (F× v)/(b× w) at x = 0,

and solve for T at x = 0 and t = (b/v).

Since there is no possible way for the heat generated at the surface of the tape to diffuse through to the other side of the tape during the brief period of tape-head contact, the tape can be considered as a semi-infinite slab. Carslaw and Jaeger have solved this problem—a semi-infinite solid heated by a constant surface flux (H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, Oxford University Press, second edition (1959), page 75). Copies of appropriate pages from this reference are attached. The change in surface temperature at a function of time for a semi-infinite slab heated by a constant surface flux is given by:

$$DT\ (\text{at } x = 0) = (2q/k) \times (at/p)^{1/2} \quad (2)$$

Substituting (F× v)/(b× w) for q, and b/v for t in equation (2) will give the maximum increase in tape surface temperature as it passes by a record head. The maximum tape surface temperature is:

$$T_{\text{max-surface}} = T_0 + (2/k) \times (a/p)^{1/2} \times (F/w) \times (v/b)^{1/2} \quad (3)$$

T_0 - initial tape surface temperature

k - thermal conductivity at the surface of the tape

a - thermal diffusivity of the tape (defined earlier)

F - tension drop across the head

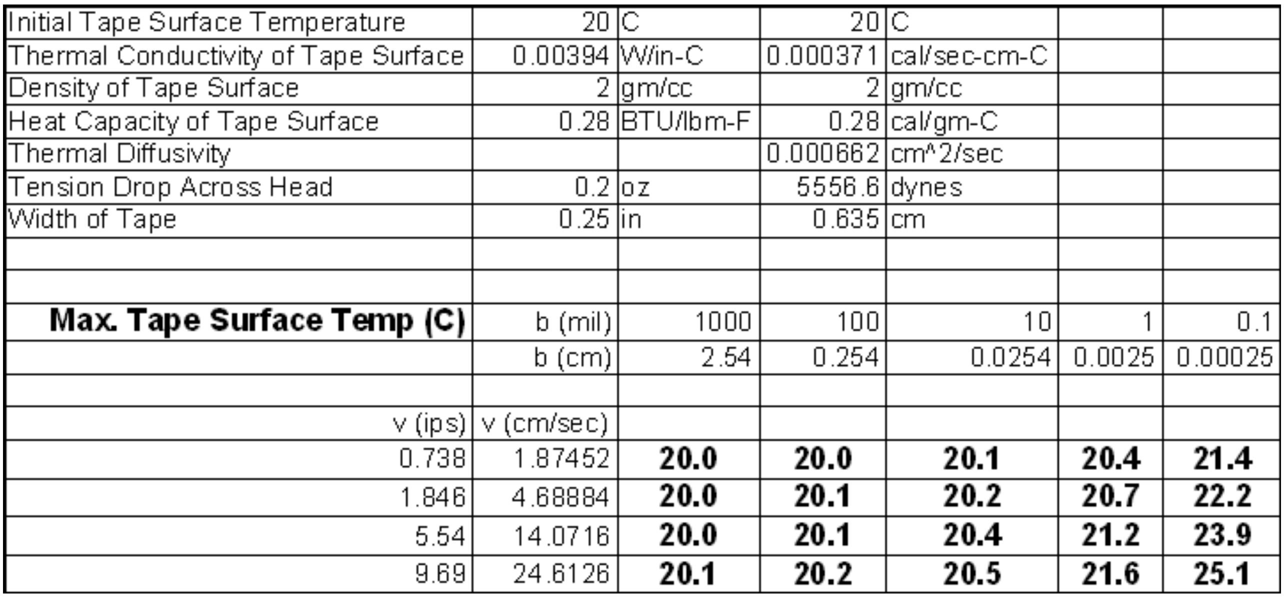
w - width of the tape

v - tape speed

b - "length" of tape-head contact (see illustration)

As you would have expected, the rise in tape surface temperature is directly proportional to the tension drop across the record head. But more importantly, the surface temperature of the tape is proportional to the square root of the tape velocity. Using this model, the rise in tape temperature at 9.7 ips would be 3.6 times larger than at .74 ips. Also note that if the "length" of tape-head contact decreases, warmer tape surface temperatures result.

Below is a spreadsheet where I have plugged reasonable numbers into Equation (3) above and calculated the maximum tape surface temperature. Unless the tension drop across the head is appreciably greater than that indicated (0.2 oz) or the area of tape-head contact is extremely small (b > 1 mil), the rise in the temperature at the surface of the tape is not expected to be any greater than 1-2 degrees C at all tape speeds.



Initial Tape Surface Temperature	20	C	20	C		
Thermal Conductivity of Tape Surface	0.00394	W/in-C	0.000371	cal/sec-cm-C		
Density of Tape Surface	2	gm/cc	2	gm/cc		
Heat Capacity of Tape Surface	0.28	BTU/lbm-F	0.28	cal/gm-C		
Thermal Diffusivity			0.000662	cm^2/sec		
Tension Drop Across Head	0.2	oz	5556.6	dynes		
Width of Tape	0.25	in	0.635	cm		
Max. Tape Surface Temp (C)	b (mil)	1000	100	10	1	0.1
	b (cm)	2.54	0.254	0.0254	0.0025	0.00025
v (ips)	v (cm/sec)					
0.738	1.87452	**20.0**	**20.0**	**20.1**	**20.4**	**21.4**
1.846	4.68884	**20.0**	**20.1**	**20.2**	**20.7**	**22.2**
5.54	14.0716	**20.0**	**20.1**	**20.4**	**21.2**	**23.9**
9.69	24.6126	**20.1**	**20.2**	**20.5**	**21.6**	**25.1**

- John Van Bogart, National Media Laboratory, 4/3/96

NOTE: Attached sheets are from H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, Oxford University Press, second edition (1959). Since their notation is radically different from the notation that I have used, I thought that I would summarize their notation below for clarification:

x - distance into solid from surface (x=0 at surface)

v - temperature

K - thermal conductivity at the surface of the tape

k - thermal diffusivity of the tape (defined earlier)

f - heat flux (per unit time per unit area)

t - time

9 Attachment A: Doculabs Test Report: Compatibility of CD-R Media, Readers, and Writers

10 Attachment B: CD Recording: A Troubleshooting Handbook

11 Attachment C: Magnetic Tape Storage

12 Attachment D: Long-term Preservation of Digital Materials