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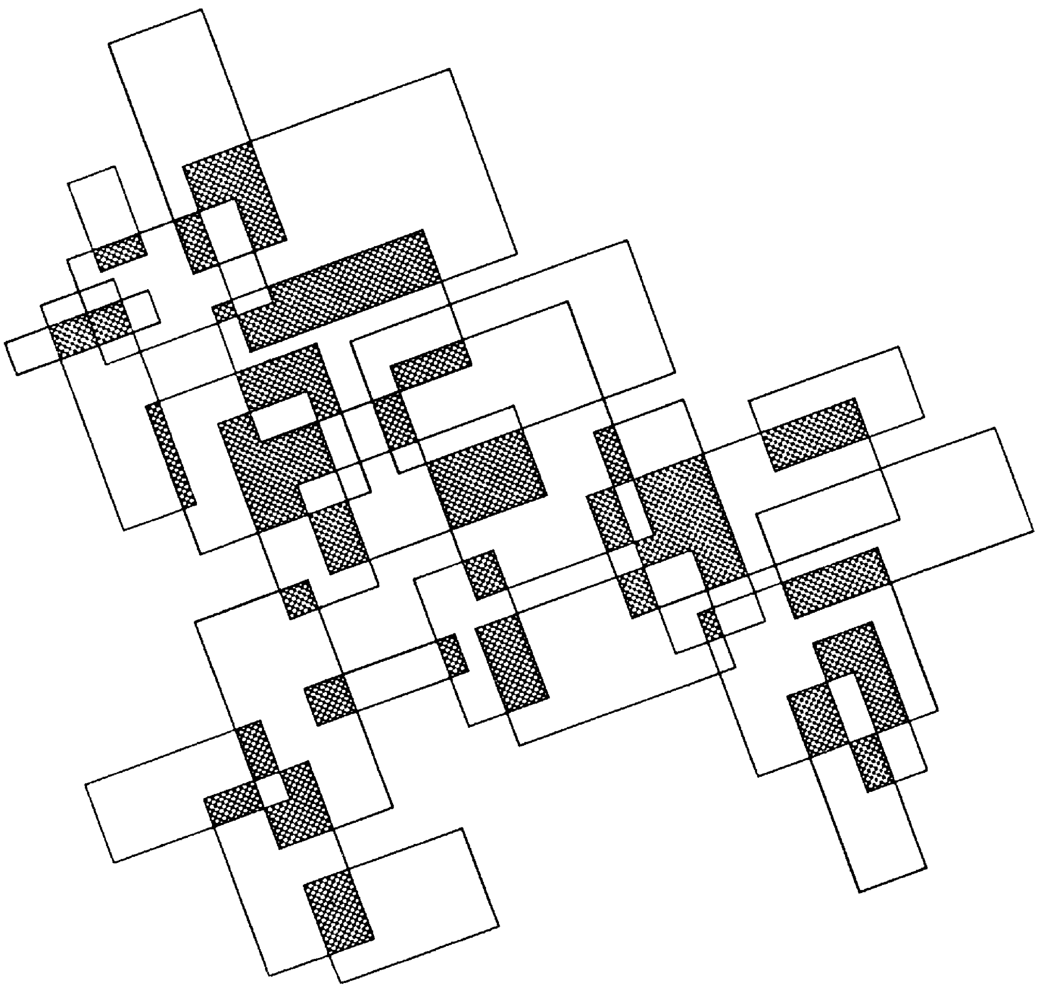
NIST Special Publication 500-263

Information Technology:

NIST/Library of Congress (LoC) Optical Disc Longevity Testing Procedure



NIST

National Institute of Standards and Technology

Technology Administration, U.S. Department of Commerce

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Information Technology:
NIST/Library of Congress (LoC) Optical Media Longevity Study

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November 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
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National Institute of Standards and Technology
William Jeffrey, Director

Reports on Information Technology

The Information Technology Laboratory (ITL) at the National Institute of Standards and Technology (NIST) stimulates U.S. economic growth and industrial competitiveness through technical leadership and collaborative research in critical infrastructure technology, including tests, test methods, reference data, and forward-looking standards, to advance the development and productive use of information technology. To overcome barriers to usability, scalability, interoperability, and security in information systems and networks, ITL programs focus on a broad range of networking, security, and advanced information technologies, as well as the mathematical, statistical, and computational sciences. This Special Publication 500-series reports on ITL's research in tests and test methods for information technology, and its collaborative activities with industry, government, and academic organizations.

National Institute of Standards and Technology
Special Publication 500-263
Natl. Inst. Stand. Technol.
Spec. Publ. 500-263
23 pages (November 2005)
CODEN: NSPUE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 2003

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov — Phone: (202) 512-1800 — Fax: (202) 512-2250
Mail: Stop SSOP, Washington, DC 20402-0001

Preface

The Information Access Division (IAD) of the Information Technology Laboratory (ITL) at the National Institute of Standards and Technology (NIST), in collaboration with the Preservation Research and Testing division at the Library Of Congress (LoC) has begun a collaboration to test the longevity of recordable optical media including DVD-R, DVD+R, DVD-RW, DVD+RW, CD-R. The details of this collaboration are presented in this report.

About the Library of Congress
The Library of Congress is the nation's oldest federal cultural institution and serves as the research arm of Congress. It is also the largest library in the world, with more than 130 million items on approximately 530 miles of bookshelves. The collections include more than 29 million books and other printed materials, 2.7 million recordings, 12 million photographs, 4.8 million maps, and 58 million manuscripts.

Preservation Research and Testing Division of the Library of Congress conducts scientific research to advance the preservation of the Library's collections by extending their useful life as long as possible. Besides traditional book and manuscript materials, these collections include a variety of other media, including photographs, motion picture film, magnetic tape, and digital optical media such as CDs and DVDs. This division is also responsible for establishing specifications, acceptable practices, and testing protocols for all materials used for the conservation and/or storage of the Library's permanent collections, as well as for specifying acceptable storage conditions, conservation practices and treatment processes that may have a direct or indirect impact on the longevity of the collections.

About NIST
Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Commerce Department's Technology Administration. NIST's mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life. NIST carries out its mission in four cooperative programs, the NIST Laboratories, conducting research that advances the nation's technology infrastructure and is needed by U.S. industry to continually improve products and services, the Baldrige National Quality Program, the Manufacturing Extension Partnership, and the Advanced Technology Program.

NIST has an operating budget of about $858 million and operates in two locations: Gaithersburg, Md., (headquarters—234-hectare/578-acre campus) and Boulder, Colo., (84-hectare/208-acre campus). NIST employs about 3,000 scientists, engineers, technicians, and support and administrative personnel. About 1,800 NIST associates complement the staff. In addition, NIST partners with 1,400 manufacturing specialists and staff at affiliated centers around the country.

The NIST/LoC Project Team:
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Acknowledgements:

The authors would like to thank members of NISTs Information Access Division (IAD) and the LoCs Preservation Research and Testing Division (PRTD) who supported, helped with or participated in this project.

1 Introduction

The preservation of digital information has become a critical issue for many organizations, not least the libraries and archives of the US Government. According to the National Digital Information Infrastructure and Preservation Program (NDIIPP), which is administered by the LoC, information is being produced in greater quantities and with greater frequency than at any time in history. Furthermore, according to the NDDIIP, electronic media, especially the Internet, make it possible for almost anyone to become a "publisher." The program asks how will society preserve this information and make it available to future generations? Optical media has become the medium of choice for digital storage in many government agencies as well as many organizations within the private sector

In June 2004, the Information Access Division of the National Institute of Standards and Technology (NIST) and the Preservation Directorate at the Library of Congress (LoC) agreed to perform a detailed investigation of the longevity of recordable Compact Disc (CD) and Digital Versatile Disc (DVD) media. This report outlines the procedural details of that investigation for estimating the life expectancy of information stored in CD-R, DVD-R and DVD+R, as well as DVD-RW and DVD+RW discs. The test procedure uses accelerated aging techniques and statistical analysis to estimate the life expectancy (LE) of current recordable DVD and CD media. This report also includes details of a 'shelf-life' test of recordable CD and DVD media, where blank media are aged artificially and their recording properties examined as the media is aged.

Only the effects of temperature and relative humidity on the media are considered. The standardized life expectancy estimated using this model is defined for discs maintained at 25 ºC and 50 % RH, but can be applied to give an estimate of the life expectancy at any moderate storage conditions. Discs exposed to more severe conditions of temperature and humidity are expected to experience a shorter life. The test plan does not attempt to model degradation due to exposure to light, corrosive gases, contaminants, or mishandling, nor does it account for variations in the playback subsystem. Furthermore, the compatibility of the recorder and the media will have a critical effect on the LE of media, including very stable media since error rates immediately after recording will impact the time before failure. For this study, great care was taken to ensure compatibility between the recorder and the media, thus ensuring low initial error rates.

The ISO standard, ISO 18927:2002 (Imaging materials – Recordable compact disc system -- Method for estimating the life expectancy based on the effects of temperature and relative humidity, first edition), was used as a basis for the aging of the media and the analysis of data in this study, and thus some of the content of this paper will be familiar to those familiar with the ISO 18927:2002 standard. However, significant adaptations were required to ensure that suitable error rates and data points were obtained for recordable media. Initial testing, carried out in 2004 and 2005, indicated that the stress conditions and durations described in ISO 18927:2002 (minimum of 500 hours per aging cycle at increased temperature and humidity conditions) may be too harsh, with the result that very high error rates were obtained after just one aging period. An approach whereby the incubation length for each aging cycle could be altered, depending on the error trends, was adopted.

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The joint NIST/LoC optical media longevity test plan started in 2004 and it is expected that this investigation will be completed in 2006, after which results and analysis will be disseminated in a suitable publication, within the guidelines and legal restrictions agreed by NIST and the LoC.

2 Technical Background

Recordable optical disc media contains an organic dye layer whose transparency can be altered either to absorb the energy from a laser beam or to allow the beam to pass through to a reflective layer behind the dye [1,2,3]. The nature of this organic dye is such that when the internal energies of its molecules reach a particular threshold, an irreversible chemical reaction occurs, and the dye layer loses its transparency. This property allows a high-energy beam to 'write' data by burning 'pits', in the form of dark marks, to the disc during recording. A low powered laser reads the data by either passing through the transparent dye layer (without causing any molecular change) to the reflective layer or by being absorbed by the nontransparent marks in the dye.

Due to the organic nature of the dye, degradation and breakdown of the transparent portion of dye layer will occur over a long period of time as a natural process. This process, which has its roots in chemical kinetics, can take several years in normal environment conditions [4]. Higher temperatures and humidity will accelerate this process by increasing the thermal and kinetic energies of the dye molecules.

The effect of these processes can be modeled using various techniques including the Eyring model, which has a theoretical basis in chemistry and quantum mechanics and can be used to model acceleration when many stresses are involved. For this study, the Eyring equation will be used to model the effect of two stresses, temperature and relative humidity, on the rate of a reaction or degradation, which can be related to the time-to-failure of the optical disc.

The Eyring model has found broad application and shall be the model for estimating life expectancies of Recordable DVD systems. The equation

$$t_{50} = AT^{a}e^{\Delta H/kT}e^{(B+C/T)RH}$$

where

t_{50} is the time to 50 % media failure;
A is the pre-exponential time constant;
T^{a} is the pre-exponential temperature factor;
ΔH is the activation energy per molecule;
k is Boltzmann's constant ($1{,}38 \times 10^{-23}$ J/K);
T is the temperature, K;
B, C is the RH exponential constants;
RH is the relative humidity, %;

was derived from the laws of thermodynamics and, in this form, can readily be seen to handle easily the two critical stresses of temperature and RH. For the temperature range used in this test, it is common practice to set a and C to zero [5].

The Eyring model equation then reduces to

$$t_{50} = Ae^{\Delta H/kT}e^{(B)RH}$$

3 Definitions

DVD-R:
Stands for Digital Versatile Disc – Recordable. A format of DVD which uses dye sublimation recording technology, and conforms with ISO/IEC DIS 23912:2005 *Information technology - 80 mm (1.46 Gbytes per side) and 120 mm (4.70 Gbytes per side) DVD Recordable Disk (DVD-R).* On DVD-R, data can be written to once and read many times.

DVD+R:
Stands for Digital Versatile Disc + Recordable. A format of a recordable DVD which uses dye sublimation recording technology, and conforms with ISO/IEC 17344:2005: *Information technology -- Data interchange on 120 mm and 80 mm Optical Disk using +R format -- Capacity: 4.7 and 1.46 Gbytes per side.* On DVD+R, data can be written to once and read many times.

DVD-RW:
Stands for DVD-ReWritable. A format of a re-writable DVD disc, which uses phase change recording technology, and conforms with ISO/IEC 17342:2004: *Information technology -- 80 mm (1.46 Gbytes per side) and 120 mm (4.70 Gbytes per side) DVD re-recordable disk (DVD-RW).* On DVD-RW, data can be written to several hundred times and read many times.

DVD+RW:
Stands for DVD+ReWritable. A format of a re-writable DVD disc, which uses phase change recording technology, and conforms with ISO/IEC 17341:2005: *Information technology -- Data interchange on 120 mm and 80 mm optical disk using +RW format -- Capacity: 4.70 Gbytes and 1.46 Gbytes per side.* On DVD+RW, data can be written to several hundred times and read many times.

CD-R:
Stands for Compact Disc – Recordable. An extension of the CD format allowing data to be recorded once on a disc by using dye sublimation technology. Defined by part II of the Orange Book standard. Orange Book is the set of specifications created by Philips and Sony to define the optical signal characteristics, physical arrangement, writing methods and testing conditions for CD-R (Orange Book Part II) and CD-RW (Orange Book Part III) discs.

Specimen:
An individual disc as used in this aging study.

Group:
A collection of specimens that are aged under the same accelerated aging condition.

Stress:
A condition of elevated temperature and relative humidity used to accelerate the aging process for optical media in this study.

ECC:
Stands for Error Correction Code, additional information added to data to allow errors to be detected and possibly corrected.

BLER:
Stands for BLock Error Rate, a measure of the average number of raw channel errors when reading or writing CD type media. BLER is a measure of the number of data blocks per second that contain detectable errors at the input of the C1 decoder.

E32:
Stands for Error 32. In a CD system, there are two stages or levels of error correction codec. Each stage of the codec can correct two bad symbols in a block. The first number in an "E" error always references the number of errors and the second number always references the codec level. For example, the error type E11 means one bad symbol was corrected in the first stage (C1) or level 1; E21 means two bad symbols were corrected in the C1 stage; E31 means that there were three or more bad symbols at the C1 stage. This block is uncorrectable at the C1 stage, and is passed to the C2 stage. E12 means one bad symbol was corrected in the C2 stage and E22 means two bad symbols were corrected in the C2 stage. E32 means that there were three or more bad symbols in one block at the C2 stage. This error is not correctable.

PI and PO:
Stands for Parity Inner and Parity Outer. Reed-Solomon Product Code (RS-PC) is a method of error correction employing a number (usually two) of groups of Reed-Solomon parity bytes computed from rows, columns, or diagonals of a rectangular data array. DVD uses two-group method of RS-PC for error correction. The redundant codes of rows and columns are called Parity of the Inner code (PI) and of the Outer code (PO) respectively. DVD discs correct small read errors using PI, that operates on rows, and corrects large read errors using PO, that operates on columns of the data array.

PIE:
Stands for Parity Inner Error. The number of error corrections made on incoming rows of data in the first pass of the decoder using the inner parity correction code. A row of an ECC Block that has at least 1 byte in error constitutes a PI error. PIE is measured over 8 ECC blocks. In any 8 consecutive ECC Blocks the total number of PI errors before correction shall not exceed 280, also called as PI Sum 8.

POE:
Stands for Parity Outer Errors. Parity outer fails. The decoder was unable to correct the data using the outer parity codes. It is measured over 1 ECC block.

Incubation Cycle:
A complete single incubation cycle includes the initial ramping to stress conditions, the maintenance at that stress condition and ramping back to ambient conditions. This is described in section 4 of this paper.

Life expectancy:
The length of time (usually measured in years), up to which, a disc is expected to provide access to data stored on it with no uncorrectable errors. For this study, and in general for optical media, it is the length of time before the level of correctable errors is such that the onset of uncorrectable errors is imminent. For CD type media, this means the length of time before BLER reaches 220 and for DVD type media, this means the length of time before PIE reaches 280.

Shelf life:
The length of time, up to which, a blank disc is expected to be suitable for recording.

EOL:
Stands for End of Life. The state of the disc when the level of correctable errors is such that the onset of uncorrectable errors is imminent. For CD type media, this means when BLER reaches 220 and for DVD type media, this means when PIE reaches 280. Also may be used to describe the point at which uncorrectable errors actually occur.

Time to failure:
From the point of view of this study, the time to failure is the time taken, in hours, for a specimen to reach the EOL.

4 Procedure

4.1 Procedural overview:

A sampling of one hundred recorded discs is divided into six groups (Table 2). Each group of discs is exposed to one of six stresses, which are combinations of temperature and relative humidity as described in section 4.3. After each period of incubation, each disc shall have its BLER (in the case of CD type media) or inner parity (PI) errors (in the case of DVD type media) measured (Fig. 1). Data collected at each test point for each individual disc will be used to determine a time to failure (usually measured in hours) for that disc. The times to failure for discs at each stress are fitted to a log-normal distribution to determine a mean time to failure for that stress. The resulting six mean times to failure are regressed against temperature and relative humidity according to an Eyring acceleration model. This model is then used to estimate the distribution of lifetimes at a preferred usage condition.

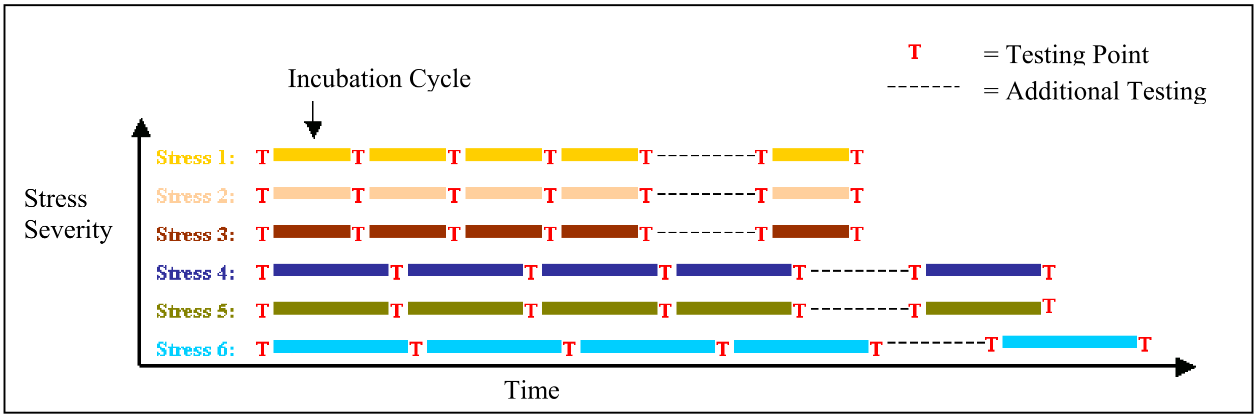

Fig. 1: Example of a testing and incubation timeline for the six stress conditions.

4.2 Test method:

The process of accelerated aging requires that discs in each stress condition be ramped from ambient conditions to that stress condition in an environmental chamber, maintained at that stress condition for a particular period of time and then ramped back to ambient conditions. This incubation cycle will occur a minimum of four times and possibly more during the course of testing. The ramp duration and conditions must be chosen to allow sufficient equilibration of absorbed moisture within the substrate. Large departures from equilibrium conditions can result in the formation of liquid water droplets inside the substrate or at its interface with the recording layer. Gradients in the water concentration through the thickness of the substrate must also be limited. These gradients drive expansion gradients, which can cause significant disc curvature.

In order to minimize the effects of moisture concentration gradients in large chambers, the ramp profile outlined in Table 1[6] is used. The ramp durations specified ensure minimal stress in the specimens. A complete incubation cycle, including the ramp and aging stages, are portrayed graphically for one of the stress conditions in Fig. 2.

Table 1 — Temperature and RH ramp profile[1]

Process step	Temperature (ºC)	RH (% RH)	Duration (hours)
start	at T_{amb}	at RH_{amb}	---
T, RH ramp	to T_{inc}	to RH_{int}	1.5 ± 0.5
RH ramp	at T_{inc}	to RH_{inc}	1.5 ± 0.5
incubation	at T_{inc}	at RH_{inc}	see Table 2
RH ramp	at T_{inc}	to RH_{int}	1.5 ± 0.5
equilibration	at T_{inc}	at RH_{int}	see Table 2
T, RH ramp	to T_{amb}	to RH_{amb}	1.5 ± 0.5
end	at T_{amb}	at RH_{amb}	---

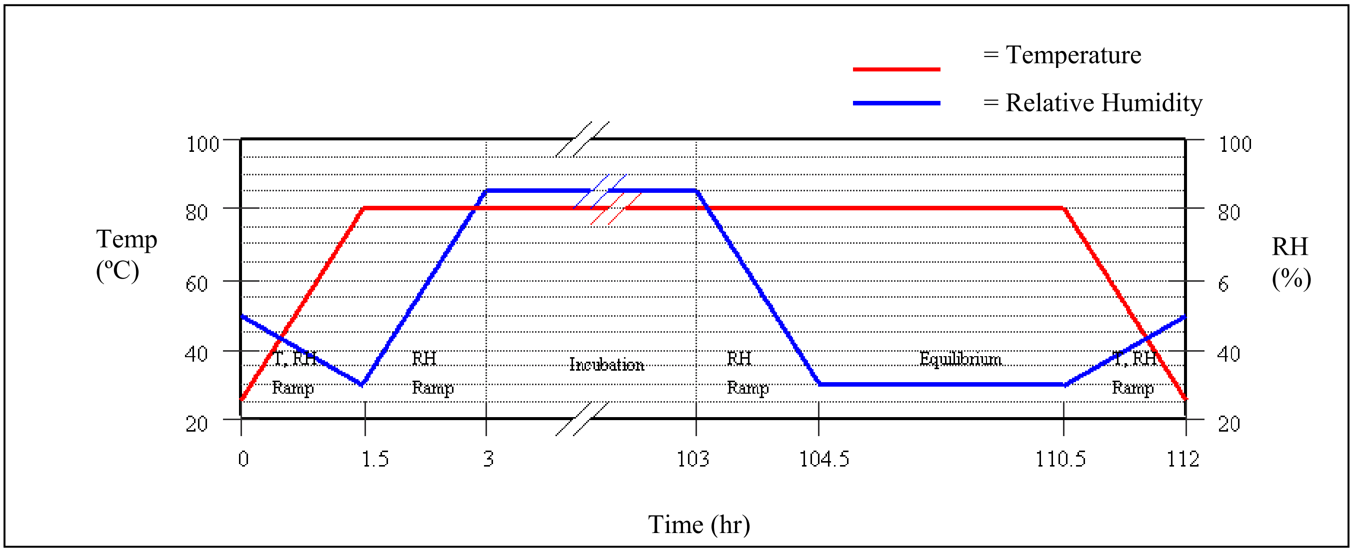

Fig. 2: Graphically portrays one incubation cycle at 80 ºC and 85 % RH.

A system independent of the chamber control system shall be used to monitor the temperature and the relative humidity conditions in the test chamber during the stress test for independent verification of every chamber conditions.

4.3 Test conditions:

The stress conditions used in this study are shown in Fig. 3. They include the five stress conditions specified in the ISO 18927:2002 standard, with an additional stress at 70 °C and 70 % RH. Table 2 specifies the temperatures, the relative humidity (RH), the initial incubation cycle durations, the minimum number of incubation cycles and the sample distributions for each stress condition. If necessary, more incubation cycles may be added or the duration of the incubation may be increased to determine the time to failure of the media at any specific stress. A separate group of specimens is used for each stress condition. This procedure constitutes a constant-stress test plan. All temperature stress points have an allowed range ±2 ºC and all relative humidity stress points have an allowed range of ±3 %RH.

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[1] T_{amb} and RH_{amb} are room ambient temperature and RH, T_{inc} and RH_{inc} are the stress incubation temperature and RH, RH_{int} is the intermediate RH that, at T_{inc}, supports the same equilibrium moisture sorption in polycarbonate as that supported at T_{amb} and RH_{amb} (see Table 2).

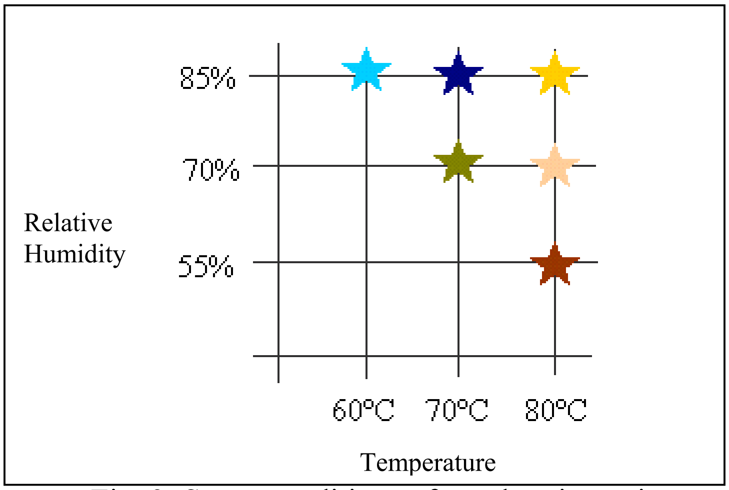

Fig. 3: Stress conditions of acceleration aging.

Table 2 - Summary of stress conditions

Group number	Number of specimens	Test stress (T_{inc}, RH_{inc})	Initial incubation cycle duration	Minimum # of cycles	Intermediate RH(RH_{int})	Equilibration duration
1	10	80 ºC, 85 %	100 h	4	31 %	6 h
2	10	80 ºC, 70 %	100 h	4	31 %	5 h
3	15	80 ºC, 55 %	100 h	4	31 %	4 h
4	15	70 ºC, 85 %	150 h	4	33 %	8 h
5	20	70 ºC, 70 %	150 h	4	35 %	7 h
6	30	60 ºC, 85 %	200 h	4	36 %	11 h

The intermediate RH (RH_{int}) in Table 2 is calculated assuming a 25 ºC and 50 % RH ambient. If the ambient conditions are different, the intermediate RH to be used is calculated using the equation:

$$RH_{\text{int}} = (0.24 + 0.0037T_{amb})/(0.24 + 0.0037T_{inc}) * (RH_{amb})$$

where

T_{amb} is the ambient temperature in units of ºC;
T_{inc} is the incubation temperature in units of ºC;
RH_{amb} is the ambient RH.

The stress conditions tabulated in Table 2 offer a sufficient combination of temperature and RH to satisfy the mathematical requirements of the Eyring model to demonstrate linearity of either natural logarithm (ln) of the max BLER (ln(max BLER)) versus time in the case of CD type media, or ln(max PI errors) versus time in the case of DVD type media, and produce a satisfactory confidence level to make the desired conclusions.

4.4 Test specimens:

Test specimens shall be nominally identical with regard to substrate groove structure, layer structure, coating composition, recording capacity, and age prior to test initiation. Media should be chosen from different lots and production lines in order to be representative of normal process variations. All discs shall be maintained within the manufacturer's shipping and at ambient storage conditions prior to recording. Table 3 and Table 4 describe the recordable CD and DVD media chosen as test specimens for this study.

Each Brand discs will be recorded disc-at-once with a single session recording. In other words, the disc shall be recorded such that the entire disc is written to in one pass without turning off the laser. Any CD type disc that, after recording, meets the Yellow Book (Philips-Sony Compact Disc Read Only Memory System Description) specification (also described in the ISO/IEC 10149 or EMCA-130 standards) can be included in the remainder of this study. Likewise, any DVD type media that, after recording, satisfies the DVD specification (described in ISO/IEC 16448:2002 or ECMA-267, third edition, April 2001 standards) can be included in the remainder of this study. Any specimen that exhibited unusual error rates immediately after recording is not included, and care must be taken to ensure that initial error rates were consistent through out the full diameter of the test specimen.

4.4.1 For CD-R discs:

Since the emergence of CD-R technology, a number of different dye types have been used as the recording layer, including Cyanine, Phthalocyanine, and Metallized Azo, or their hybrids [7]. However, due to current conditions in the dye market, a single dye type has become the most popular in CD-R media and is based on the Phthalocyanine dye. Several popular brands were tested in this study as shown in Table 3 below. Due to limitations with the CD analyzer, it is not possible to include CD-RW type media in this study. See appendix I for more detailed information on these media.

Table 3 — CD-R media included in this study[2]

Product Brand	Type	Bar code	Manufacturer name
NOT FOR	CD-R	NOT FOR	NOT FOR
PUBLIC	CD-R	PUBLIC	PUBLIC
DISCLOSURE	CD-R	DISCLOSURE	DISCLOSURE
	CD-R		
NOT FOR	CD-R	NOT FOR	NOT FOR
PUBLIC	CD-R	PUBLIC	PUBLIC
DISCLOSURE	CD-R	DISCLOSURE	DISCLOSURE

4.4.2 For recordable and rewritable DVD discs:

There are several different types of recordable DVD available, including DVD-R for general, DVD-R for Authoring, DVD+R, DVD-RW, DVD+RW, DVD-RAM and more recently dual layer DVD. Not all types are compatible with each other but could potentially be used in archival applications. In this study, we will examine DVD-R for general, DVD-RW, DVD+R and DVD+RW. Table 4 shows the media included in this study with more details in Appendix 1.

Table 4 — DVD media included in this study

Product Brand	Type	Bar code	Manufacturer name
NOT FOR	DVD-R	NOT FOR	NOT FOR
PUBLIC	DVD-R	PUBLIC	PUBLIC
DISCLOSURE	DVD-R	DISCLOSURE	DISCLOSURE

[2] CD analyzers used in this study are not capable of testing CD-RW type media.

	DVD-R		
NOT FOR	DVD-R	NOT FOR	NOT FOR
PUBLIC	DVD+R	PUBLIC	PUBLIC
DISCLOSURE	DVD+R	DISCLOSURE	DISCLOSURE
	DVD+R		
NOT FOR	DVD+R	NOT FOR	NOT FOR
PUBLIC	DVD+R	PUBLIC	PUBLIC
DISCLOSURE	DVD-RW	DISCLOSURE	DISCLOSURE
	DVD-RW		
NOT FOR	DVD+RW	NOT FOR	NOT FOR
PUBLIC	DVD+RW	PUBLIC	PUBLIC
DISCLOSURE	DVD+RW	DISCLOSURE	DISCLOSURE

4.4.3 For CD-ROM and DVD-ROM discs:

For comparison, 100 CD-ROM discs and DVD-ROM discs divided in to six groups are included and will be subjected to the same stresses and test conditions as the recordable discs. All CD-ROM discs are provided by LoC, while NIST provides all DVD-R, DVD+R, DVD-ROM and CD-R media.

4.4.4 For the shelf time test:

Media included in the shelf life study are the same brands of media used in the aging studies. Discs from each brand are split into six groups for each stress condition. After every aging period, one blank disc from each brand will be recorded and tested to determine its useful shelf life. Attempts to achieve one successful recording will continue until all the media is used up.

4.5 Analyses of the discs:

BLER (block error rate) for CD-R

The ratio of erroneous blocks to total blocks measured at the input of the first (C1) decoder (before any error correction is applied) as defined in ISO/IEC 60908. The maximum BLER is measured as the biggest number of BLER at anywhere on a disc.

Inner Parity Errors for DVD

Maximum of PI errors are less than 280 as defined by the DVD specification, or ISO/IEC 16448:2002 or ecma-267, third edition, April 2001.

4.6 Measurements and collecting data:

This study uses the measured maximum BLER for recordable CD and CD-ROM and the measured maximum inner parity (PI) errors for recordable DVD as a high-level estimate of the quality of the media at the time of measurement. The purpose of measuring BLER and PI errors is to establish a practical estimation of a compatible system's ability to read the recorded data without uncorrectable errors occurring.

However, the correlation between actual loss of information and the measured maximum BLER and PIE actually depends on several factors including the playback system as well as the media quality. A BLER of 220 and the PI errors of 280 are conservative levels chosen by the recordable CD and DVD specifications as a predictor of the onset of uncorrectable errors and thereby end of life.

4.6.1 Media recording and initial data:

There are many formats and speeds of discs (for example, 4X, 8X, 16X…) in the market and yet no unified standard for the drive write strategy. Therefore each recorder drive manufacturer develops their own drive to satisfy to the write/read requirements of recordable CD and DVD discs. As such, there is no guarantee that the recorder used to burn a disc is fully compatible with that disc. This can, and often does, lead to very high error rates immediately after recording the disc, which in turn can make aging analysis very difficult. It is therefore important to ensure that initial error rates are low by ensuring that the recording drive and the media are as compatible as possible[8,9].

To ensure recorder drive and media compatibility, four Disc Burning Stations (DBS) were built in the NIST laboratory with high-end computers and new recorder drives. Each drive must have the latest update to its firmware to ensure its best performance.

To determine the recorder with the highest level of compatibility with each brand of media, a limited number of recordings will be made for each brand by each recorder in the four DBS. The test specimens will then be burned as needed by the most compatible recorder and initial error rates monitored to ensure that the recorder continues to operate correctly.

For this study, media with a BLER (in the case of CD type media) below 40 and with PIE (in the case of DVD) below 100 are included.

4.6.2 Disc Burning Stations:

In an effort to ensure the integrity of the results, all disc burning station (DBS) computer configurations should be the same. For this investigation, each disc burning station (DBS) consists of a Pentium-4 processor workstation with the following specifications:

Intel Pentium-4 Processor 3.6 GHz w/ 800mhz FSB,
1GB DDR2-533 MHz dual channel RAM,
Seagate 120 GB 7200 rpm SATA hard drive w/ 8 MB cache,
Microsoft Windows XP Pro w/ doc and media.

All test specimens will be indexed so as to associate it with the particular DBS and DVD recorder drive used to record that brand (see appendix 1). The recording drives used in this study include the Sony DRU-510A, 700A, 800A, Pioneer DVR-A09, Plextor PX-716SA and NEC ND-2510A. The drive chosen for the particular brand of media will be the drive shown to be most compatible with that media.

Each DBS will be equipped with Roxio Easy Media Creator 7, version 7.5.0.47 ENU. The same image will be recorded on DVD media at the most compatible speed. The same image will be recorded on all CD media also at the most compatible speed.

4.6.3 Analyzer:

In order to monitor the change in the error rate during the aging, the discs are analyzed after each incubation cycle using optical disc analyzers. A CD analyzer capable of reading BLER (in the case of CD) and a DVD analyzer capable of reading PI error (in the case of DVD) are used.

For testing DVD: CATS SA300 DVD-R/RW PRO and CATS DVD+R/RW PRO from Audio Development are used to analyze the DVD media in this study. These systems measure recorded and unrecorded DVD discs and include the Pulstec SDP-1000 optical drive. All relevant parameters including inner parity error (PIE), outer parity error (POE), jitter, asymmetry and more are measured using this system.

For testing CD: CD CATS SA3 Advanced can measure all relevant parameters of CD discs. All measurements are performed according to optical disc industry standards. All relevant parameters including correctable BLER (including E11, E12, E21, and E22), uncorrectable E32 errors, jitter, asymmetry and more are measured using this system. Unfortunately, this system is not capable of testing CD-RW type media, which is why CD-RW media is not included in this study.

Continuous calibration of all testers must be performed to ensure the integrity of the results as testing is ongoing. Should the calibration test determine that the testers are not fully calibrated, the testers must be recalibrated and all testing performed since the testers were last shown to be calibrated must be repeated.

4.6.4 Collecting data

Test specimens are not analyzed in their entirety but analyzed at five test bands throughout the diameter of the test specimen. DVD test points are located at the following radii (in millimeters): 24.00 to 25.20, 31.95 to 33.15, 39.90 to 41.10, 47.85 to 49.05, and 55.8 to 57.00, from the inside to the outside of the disc. CD-R test points are at the following times (in minutes:seconds): 00:00 to 03:00, 19:00 to 22:00, 38:00 to 41:00, 57:00 to 60:00, 76:00 to 79:00.

The same tester will be used for any particular test specimen through out the study and each specimen will be indexed to associate it with the analyzer used to analyze that specimen.

4.7 Requirements of incubation condition:

The temperature and relative humidity levels used in this study are chosen to ensure that there is no change of phase of the moisture within the environmental chamber over the test temperature range, and such that no condensation occurs on cooler sections of the chamber such as observation windows, cable ports, wiper handles, and so on. Any droplets caused by such condensation could damage the media and/or influence the error rates. Furthermore, the temperature of the testing environment must not be so high so as to cause any plastic deformation within the disc structure.

Practical experience shows that 80 ºC and 85 % RH is the upper limit for control within most accelerated test cells. Table 2 shows the complete stress conditions used in this study.

Disc samples shall be uncovered and placed vertically within the chamber. Discs shall be aligned so that their surfaces are parallel to the chamber airflow. A space of at least 2 mm shall be maintained between discs.

4.7.1 Environmental Chambers:

A Parameter Generation and Control Inc (model: 9131-3119) 30 cubic feet environmental chamber is used to control precisely the temperature and relative humidity through various combination settings of temperatures (5 °C to 85 °C) and relative humidity (10 % to 95 %). The controlled accuracy is ± 0.2 °C for temperature and ±0.5 % for relative humidity.

4.8 Incubation time requirements:

Since there are six stress conditions to be implemented, the media from each brand will be split into six groups (see Table 2). Depending on the error rates observed as the testing progresses, one to three chambers would be required for this study. Based on initial incubation cycle durations and the number of media to be tested, all initial incubation cycle testing can be complete in the timeline shown in Fig. 4. The most severe stress (80 ºC, 85 %) will be conducted first and tested after incubation to determine if the incubation durations should be increased and to what extent. In such a case where the incubation time is increased extensively, additional chambers can be used. Increasing the incubation durations should not increase the total duration of the study since the limiting factor is the number of analyzers available to test the large numbers of media. There are two analyzers available for testing DVD media and one available for testing CD media.

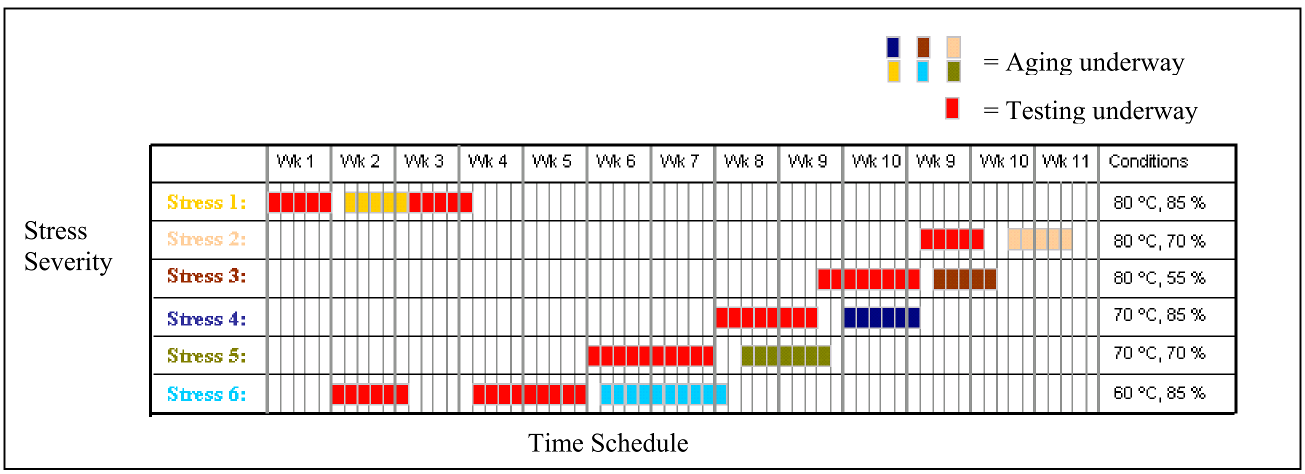

Fig. 4: Initial incubation cycle testing timeline.

4.9 Ten-step analysis outline for data:

The following is a brief outline of the steps required to estimate the life expectancy of information stored in a Recordable DVD system as a function of temperature and RH, as taken from the ISO 18927:2002 standard for CD-R and applies to this study also.

1) Determine the failure time for each specimen.
2) Determine, for each stress, the median rank of each specimen, and plot median rank versus failure time on a log-normal graph.
3) Verify that the plots for all stresses are reasonably parallel to one another. The log standard deviation for each stress may be calculated using standard techniques or estimated from straight lines drawn through the plots.
4) Calculate the log mean for each stress.

5) Regress log mean, temperature, and RH for all stresses using the reduced Eyring equation. Calculate the estimated log mean for the standardized temperature and RH(25 ºC and 50 % RH).
6) Determine the acceleration factor for each stress.
7) Normalize all the failure times by multiplying each failure time by the acceleration factor for its stress.
8) Combine all normalized failure times and censored data into one data set. For this entire set, make one composite log-normal plot.
9) Estimate the log mean and the log standard deviation at the usage conditions from this plot, or the combined data.
10) Calculate confidence intervals for the survival function.

5 Normative references

- ISO 18927:2002 Imaging materials – *Recordable compact disc systems – Method for estimating the life expectancy based on the effects of temperature and relative humidity,* first edition
- IEC 60908 (1999-02): *Compact disc digital audio system*. This document including amendments approximates the Philips-Sony Red Book
- ISO/IEC 10149:1995, *Read-Only 120 mm Optical Data Disks (CD-ROM)*
- EMCA130 2nd Edition - June 1996 *Data interchange on read-only120 mm optical data disks(CD-ROM)*
- *Orange Book, part B, -- Recordable Compact Disc System,* November 1990 (SONY and Philips Corp.)
- ISO/IEC 16448:2002 Information technology -- *120 mm DVD -- Read-only disk*
- ISO/IEC DIS 23912:2005 *Information technology - 80 mm (1.46 Gbytes per side) and 120 mm (4.70 Gbytes per side) DVD Recordable Disk (DVD-R)*
- ISO/IEC 17344:2005: *Information technology -- Data interchange on 120 mm and 80 mm Optical Disk using +R format -- Capacity: 4.7 and 1.46 Gbytes per side*
- ISO/IEC 17342:2004: *Information technology -- 80 mm (1,46 Gbytes per side) and 120 mm (4,70 Gbytes per side) DVD re-recordable disk (DVD-RW)*
- ISO/IEC 17341:2005: *Information technology -- Data interchange on 120 mm and 80 mm optical disk using +RW format -- Capacity: 4,7 Gbytes and 1,46 Gbytes per side*
- ECMA-267, 2001, 120 mm DVD - Read-Only Disk, 3rd edition
- ECMA-337, DVD+RW - Rewritable Optical Disks, 4.7 GB
- ECMA-338, DVD-RW - Rewritable Optical Disks, 4.7 GB
- IEEE 101-1995, *Guide for the statistical analysis of thermal life test data*

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[8] Slattery, O.T. *DVD-ROM Drive Compatibility Test for DVD-R(General), DVD-RW, DVD+R, DVD+RW and DVD-RAM Discs (Phase1),* NIST Special Publication 500-254, October 2003

[9] Slattery, O.T. *DVD Drive Compatibility Test for DVD-R (General) and DVD+R Discs, including DVD Creation Plan (Phase2),* NIST Special Publication 500-258, September 2004

[10] *Experimental Statistics*, National Bureau of Standards Handbook 91. Washington, DC, US: National Institute of Science and Technology, 1963.

Appendix I:

Disc code system for the Life Expectancy test

Jian Zheng @ July 26, 2005

Code Format: ABBnnnGgmmCst

Burner, DBS and tester
Group and Burning speed
Series number
Category and brand

Where

A C, A, B, D, or E stands for CD-R, DVD-R, DVD+R, DVD-RW or DVD+RW discs respectively.

BB Brand of the media as below Table
nnn Series number
Gg g is the group number of the specimen
Xmm mm is the burning speed
C the symbol of the burner, as shown in table below
s the number of the Disc Burning Station (DBS).
T the number of the tester. Tester 1 is AudioDev's SA3 CD CATS MLH2100 for CD; Tester 2 is AudioDev's SA300 DVD CATS Pro DPEP 1486 for DVD+R/RW; and Tester 3 is the DPER 1534 for DVD-R/RW.

Brand	BB
NOT FOR	**
PUBLIC	**
DISCLOSURE	**
	**
NOT FOR	**
PUBLIC	**
DISCLOSURE	**
	**

[Note] read out the disc information with Roxio DVDInfo Pro version 4.08 embedded in Roxio Easy Media Creator 7.5.
All CD-R discs use Short Strategy for burning, meaning all discs use Phthalocyanine dye.

Burner	Company and model	Serial number	Firmware revision
E	Sony DRU-510A	AE74DBFC	BB►1.1
F	Sony DRU-510A	AE74DBFC	BB►1.1
G	Sony DRU-700A	2004052000038341	VY08
H	Pioneer DVR-A09	ECD015716UJ	1.17►1.57
I	Pioneer DVR-A09	ECD015528UJ	1.17►1.57
J	Plextor PX-716SA	124136	1.07►1.08
K	Plextor PX-716SA	124246	1.07►1.08
L	_NEC ND-2510A (MadDog MD-8XDVD9)	46NGK89S211	2.05►2.F9
M	Sony DRU-800		
N	Sony DRU-800		

NIST/LC

Manufacturer and Brand Information Table for DVD Discs

ABB	Brand	Type	Order code	Bar code	Media code/Manufacturer ID (revision)
	DVD-R discs				
A**					
A**	NOT FOR		NOT FOR	NOT FOR	NOT FOR
A**	PUBLIC		PUBLIC	PUBLIC	PUBLIC
A**	DISCLOSURE		DISCLOSURE	DISCLOSURE	DISCLOSURE
A**					
	DVD+R discs				
B**					
B**	NOT FOR		NOT FOR	NOT FOR	NOT FOR
B**	PUBLIC		PUBLIC	PUBLIC	PUBLIC
B**	DISCLOSURE		DISCLOSURE	DISCLOSURE	DISCLOSURE
B**					
	DVD-RW discs				
D**	NOT FOR		NOT FOR	NOT FOR	NOT FOR
D**	PUBLIC		PUBLIC	PUBLIC	PUBLIC
	DVD+RW discs				
E**	NOT FOR		NOT FOR	NOT FOR	NOT FOR
E**	PUBLIC		PUBLIC	PUBLIC	PUBLIC
E**	DISCLOSURE		DISCLOSURE	DISCLOSURE	DISCLOSURE

Manufacturer and Brand Information Table for CD Discs

A**	Brand	Order code	Bar code	ATIP*	Capacity**	Manufacturer name	LBA
C**	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR
C**	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC
C**	DISCLOS URE	DISCLOS URE	DISCLOSURE	DISCLOSU RE	DISCLOSURE	DISCLOSURE	DISCLOS URE
C**							
C**	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR	NOT FOR
C**	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC	PUBLIC
C**	DISCLOS URE	DISCLOS URE	DISCLOSURE	DISCLOSU RE	DISCLOSURE	DISCLOSURE	DISCLOS URE

* ATIP Start Time of Lead In (Media Code) **Free Capacity/ ATIP Last Possible Start Time of Lead Out