INTERNATIONAL

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Test Method for the Estimation of Lifetime of Optical Media for Long-term Data Storage

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Introduction

Markets and industry have developed a common understanding that the property referred to as the lifetime of data recorded to optical media plays an increasingly important role for the intended applications. Disparate standardized test methodologies exist for Magneto Optical media and recordable compact disk and DVD systems. It was agreed that the project represented by this document be undertaken in order to provide a common methodology, applicable for various purposes, that includes the testing of currently available writable CD and DVD optical media.

ISO/IEC JTC 1/SC 23/JWG 1, which is a Joint working group among ISO/TC 42, ISO/TC 171 and ISO/IEC JTC 1/SC 23, initiated work on this subject and developed the initial drafts with assistance from Ecma International TC31.

This Ecma Standard has been adopted by the General Assembly of December 2010.

Test Method for the Estimation of Lifetime of Optical Media for Long-term Data Storage

1 Scope

This Ecma Standard specifies an accelerated aging test method for estimating the lifetime of the retrievability of information stored on recordable or rewritable optical disks.

This test includes details on the following formats: DVD-R/RW/RAM, +R/+RW and CD-R/RW. It may be applied to additional optical disk formats, with substitution of the appropriate specifications, and may also be updated by committee in the future as required.

This document includes:

– stress conditions

  Basic stress condition and Rigorous stress condition testing for use with the Eyring Method and testing for use with the Arrhenius Method

– ambient storage conditions in which the lifetime of data stored on optical media is estimated

  - Controlled storage condition, e.g. 25 °C and 50 % RH, representing well-controlled storage conditions with full-time air conditioning. Eyring Method is used to estimate the lifetime under this storage condition.

  - Harsh storage condition, e.g. 30 °C and 80 %RH, representing the most severe conditions in which users handle and store the optical media. Arrhenius Method is used to estimate the lifetime under this storage condition.

– evaluation system description

– specimen preparation and data-acquisition procedure

– definition of and method for estimating lifetime of stored data on specified media

– data analysis for lifetime of stored data

– reporting format for estimated lifetime of stored data

The methodology includes only the effects of temperature (T) and relative humidity (RH). It does not attempt to model degradation due to complex failure-mechanism kinetics, nor does it test for exposure to light, corrosive gases, contaminants, handling, or variations in playback subsystems. Disks exposed to these additional sources of stress or higher levels of temperature and relative humidity are expected to experience shorter usable lifetimes.

2 Conformance

Media tested by this methodology shall conform to all normative references specific to that media format.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ECMA-130 Data Interchange on Read-only 120 mm Optical Data Disks (CD-ROM) (ISO/IEC 10149:1995)

ECMA-267 120 mm DVD - Read-Only Disk, 3rd edition (ISO/IEC 16448:2002)

ECMA-268 80 mm DVD – Read-Only Disk, 3rd edition (ISO/IEC 16449:2002)

ECMA-330 120 mm (4,7 Gbytes per side) and 80 mm (1,46 Gbytes per side) DVD Rewritable Disk (DVD-RAM), 3rd edition (ISO/IEC 17592:2004)

ECMA-337 120 mm and 80 mm - Optical Disk using +RW Format - Capacity: 4,7 and 1,46 Gbytes per side (Recording speed up to 4X), 4th edition (ISO/IEC 17341:2009)

ECMA-338 80 mm (1,46 Gbytes per side) and 120 mm (4,70 Gbytes per side) DVD Re-recordable Disk (DVD-RW) (ISO/IEC 17342:2004)

ECMA-349 120 mm and 80 mm Optical Disk using +R Format - Capacity: 4,7 and 1,46 Gbytes per Side (Recording speed up to 16X), 4th edition (ISO/IEC 17344:2009)

ECMA-359 80 mm (1,46 Gbytes per side) and 120 mm (4,70 Gbytes per side) DVD Recordable Disk (DVD-R) (ISO/IEC 23912:2005)

ECMA-364 120 mm and 80 mm Optical Disk using +R DL Format - Capacity: 8,55 and 2,66 Gbytes per Side (Recording speed up to 8x), 3rd edition (ISO/IEC 25434:2008)

ECMA-371 120 mm and 80 mm Optical Disk using +RW HS Format - Capacity: 4,7 and 1,46 Gbytes per Side (Recording speed 8X) 2nd edition (ISO/IEC 26925:2009)

ECMA-374 120 mm and 80 mm Optical Disk using +RW DL Format – Capacity: 8,55 and 2,66 Gbytes per Side (Recording speed 2,4x) 2nd edition (ISO/IEC 29642:2009)

ECMA-382 120 mm (8,54 Gbytes per side) and 80 mm (2,66 Gbytes per side) DVD Recordable Disk for Dual Layer (DVD-R for DL) (ISO/IEC 12862:2009)

ECMA-384 120 mm (8,54 Gbytes per side) and 80 mm (2,66 Gbytes per side) DVD re-recordable disk for dual layer (DVD-RW for DL) (ISO/IEC 13170: 2009)

ECMA-394 Recordable Compact Disc Systems CD-R Multi-Speed

ECMA-395 Recordable Compact Disc Systems CD-RW Ultra-Speed

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1
Arrhenius method
accelerated aging model based on the effects of temperature only

4.2
baseline
initial test analysis measurements (e.g., initial data errors) after recording and before exposure to a stress condition, i.e. measurement at stress time t=0 hours

4.3
basic stress conditions
accelerated aging conditions for estimating the lifetime of data stored on optical media in a reasonable amount of time and labour

4.4
B_5 Life
5 percentile of the lifetime distribution (i.e. 5 % failure time) or 95 % survival lifetime

4.5
(B_5 Life)$_L$
95 % lower confidence bound of B_5 life

4.6
B_{50} Life
50 percentile of the lifetime distribution (i.e. 50 % failure time) or 50 % survival lifetime

4.7
controlled storage condition
well-controlled storage conditions with full-time air conditioning (25 °C and 50 % RH) in which the lifetime of data stored on optical media may be extended

4.8
Eyring method
accelerated aging model based on the effects of temperature and relative humidity

4.9
data error
data error on the sample disk measured before error correction is applied

4.10
harsh storage condition
most severe conditions in which users handle and store the optical media (30 °C and 80 % RH) in which the lifetime of data stored on optical media may be shortened

4.11
incubation
process of enclosing and maintaining controlled test-sample environments

4.12
maximum data error
maximum data error measured anywhere in one of the relevant areas on the disk:

- for DVD-R/RW and +R/+RW, this is the Maximum PI Sum 8,

- for DVD-RAM, this is the Maximum BER, and

- for CD-R/RW, this is the Maximum C1 Ave 10.

4.13
retrievability
ability to recover physically-recorded information as recorded

4.14
rigorous stress conditions
accelerated aging conditions for estimating the lifetime of data stored on optical media with higher confidence

4.15
stress
temperature and relative humidity variables to which the sample is exposed for the duration of test incubation intervals

4.16
system
combination of hardware, software, storage medium and documentation used to record, retrieve and reproduce information

5 Conventions and notations

5.1 Representation of numbers

A measured value is rounded off to the least significant digit of the corresponding specified value. For instance, it follows that a specified value of 1,26 with a positive tolerance of + 0,01 and a negative tolerance of - 0,02 allows a range of measured values from 1,235 to 1,275.

5.2 Names

The names of entities, e.g. specific tracks, fields, zones, etc. are capitalized.

6 List of acronyms

BER byte error rate

BLER block error rate

PI parity (of the) inner (code)

Section 2 — Test and Evaluation

7 Measurements

7.1 Summary

7.1.1 Stress Incubation and Measuring

A sampling of disks will be measured at four stress conditions for the Basic stress condition testing or five stress conditions for the Rigorous stress condition testing for use with the Eyring Method, or three stress condition for the Basic stress condition testing or four stress conditions for the Rigorous stress condition testing for use with the Arrhenius Method.

Each stress condition's total time will be divided into sub-interval time periods. Each disk in each group of disks will have its initial data errors measured before their exposure to stress conditions. Thereafter, each disk will be measured for its data errors after each stress condition incubation sub-interval time period.

The control disk for monitoring of tester can also be measured following each incubation time interval.

7.1.2 Assumptions

This Standard makes the following assumptions for applicability of media to be tested

specimen life distribution is appropriately modelled by a statistical distribution,

the Eyring Method can be used to model acceleration with the both stresses involved (temperature and relative humidity),

the dominant failure mechanism acting at the usage condition is the same as that at the accelerated conditions,

the compatibility of the disk and drive combination will affect the disk's initial recording quality and the resulting archival test outcome,

a hardware and software system needed to read the disk will be available at the time the retrieval of the information is attempted,

the recorded format will be recognizable and interpretable by the reading software.

7.1.3 Data Error

Of all specimen media, the data errors shall be measured in the disk testing locations as defined in 7.5. For each sample the Maximum Data Error shall be determined.

Each DVD-R/RW, +R/+RW disk will have its Maximum PI Sum 8 (Max PI Sum 8) determined.

Each DVD-RAM disk will have its Maximum Byte Error rate (Max BER) determined.

Each CD-R/RW disk will have its Maximum C1 Ave 10 (Max C1 Ave 10) determined.

Data collected at each time interval for each individual disk are then used to determine the predicted time to failure for that disk at that stress condition.

7.1.3.1 PI Sum 8

Per ISO/IEC 16448:2002, a row in an ECC block that has at least 1 byte in error constitutes a PI error. PI Sum 8 is measured over 8 ECC blocks in any 8 consecutive ECC blocks. The total number of PI errors, also called PI Sum 8, before error correction shall not exceed 280.

7.1.3.2 BER

The number of erroneous symbols shall be measured in any consecutive 32 ECC blocks in the first pass of the decoder before correction. The BER is the number of erroneous symbols divided by the total number of symbols included in the 32 consecutive ECC blocks. The maximum value of the BER measured over the area specified in 7.5 shall not exceed 10^{-3}.

7.1.3.3 C1 Ave 10

IEC 60908:1999 specifies that the BLER averaged over any 10 seconds shall be less than 3×10^{-2}. At the standard (1X) data transfer rate, the total number of blocks per second entering the C1-decoder is 7 350.

Thus, the number of C1 errors per second before error correction which is averaged over any 10 seconds, called C1 Ave 10, shall not exceed 220.

7.1.4 Data Quality

Data quality is checked by plotting the median rank of the estimated time to failure values with a best-fit line for each stress condition. The lines are then checked for reasonable parallelism.

7.1.5 Regression

The log predicted time to failure values shall be calculated using linear regression.

Multiple linear regression is used for the Eyring Method and linear regression is used for the Arrhenius Method.

7.2 Test specimen

The disk sample set shall represent the construction, materials, manufacturing process, quality and variation of the final process output.

Consideration shall be made to shelf life. Disks with longer shelf time before recording and testing may impact test results. Shelf time shall be representative of normal usage.

7.3 Recording conditions

Before media are entered into accelerated aging tests, they shall be recorded as optimally as is practicable, according to the descriptions given in the related standard. OPC (optimum power control) during the writing process shall serve as the method to achieve minimum data errors. It is generally assumed that optimally-recorded media will yield the longest predicted lifetime. Media is deemed acceptable for entry into the aging tests when their data errors and all other media parametric specifications are found to be within their respective standard's specification limits.

The choice of recording hardware is at the discretion of the recording party. It may be either commercial drive-based or speciality recording tester based. It shall be capable of producing recordings that meet all specifications.

The recording speed used for testing shall be reported.

NOTE It is expected that lifetime of data on a disk may be affected by recording conditions including recording speed.

7.3.1 Recording test environment

When performing the recordings, the air immediately surrounding the media shall have the following properties:

temperature: 23 °C to 35 °C

relative humidity: 45 % to 55 %

atmospheric pressure: 60 kPa to 106 kPa

No condensation on the disk shall occur. Before testing, the disk shall be conditioned in this environment for 48 hrs minimum. It is recommended that, before testing, the entrance surface be cleaned according to the instructions of the manufacturer of the disk.

7.3.2 Recording method

Specimen disks shall be recorded in a single session and finalized.

7.4 Playback conditions

7.4.1 Playback tester

All media shall be read by the playback tester as specified in each of the medium's standard and at their specified test conditions.

Specimen media shall be read as described in the format standards identified in Clause 3.

7.4.2 Playback test environment

When measuring the data errors, the air immediately surrounding the disk shall have the following properties:

temperature: 23 °C to 35 °C

relative humidity: 45 % to 55 %

atmospheric pressure: 60 kPa to 106 kPa

Unless otherwise stated, all tests and measurements shall be made in this test environment.

7.4.3 Calibration

The test equipment should be calibrated as prescribed by its manufacturer using calibration disks approved by said manufacturer and as needed before disk testing. A control disk should be maintained at ambient conditions and its data error should be measured at the same time the stressed disks are measured, both initially and after each stress sub interval.

The mean and standard deviation of the control disk shall be established by collecting at least five measurements. Should any individual data error differ from the mean by more than three times the standard deviation, the problem shall be corrected and all data collected since the last valid control point shall be re-measured.

7.5 Disk testing locations

7.5.1 Rigorous stress condition testing

All data areas on a disk shall be tested.

7.5.2 Basic stress condition testing

Testing locations shall be a minimum of three bands spaced evenly from the inner, middle and outer radius locations on the disk as indicated in Table 1. The total testing area shall represent a minimum of 5 % of the disk capacity. For DVDs and +R / +RW disks, each of the three test bands shall have more than 750 ECC blocks for 80 mm disks, and 2 400 ECC blocks for 120 mm disks. For CDs, each of the three test bands shall have more than 5900 sectors.

Table 1 — Nominal radii of the three test bands (Unit; mm)

	DVD- R / RW, +R / +RW disk (Single Layer / Dual Layer)		DVD- RAM disk		CD-R/RW disk
	80 mm	120 mm	80 mm	120 mm	120 mm
Band 1	25,0	25,0	24,1-25,0	24,1-25,0	25,0
Band 2	30,0	40,0	29,8-30,8	39,4-40,4	40,0
Band 3	35,0	55,0	34,6-35,6	54,9-55,8	55,0

8 Accelerated stress test

8.1 General

Accelerated stress testing is used in order to estimate the lifetime of the optical disk. All information needed for this testing is provided in this document.

8.2 Stress conditions

8.2.1 General

Stress conditions for this test method are increases in temperature and relative humidity (RH). The stress conditions are intended to accelerate the chemical reaction rate from what would occur normally at ambient storage or usage conditions. The chemical reaction is considered to be degradation in some desired material property that eventually leads to disk failure.

Regarding use of the Eyring Method, five stress conditions for the Rigorous stress condition testing, and the minimum number of specimens for those stress conditions that shall be used, are shown in Table 2. Four stress conditions for the Basic stress condition testing, and the minimum numbers of specimens are also shown in Table 3. Additional specimens and conditions may be used, if desired for improved precision.

Regarding use of the Arrhenius Method, stress conditions are given in Table C.1 and Table C.2 in Annex C.

The total time for each stress condition as given in Table 2 and Table 3 is divided into five and four equal incubation sub-intervals respectively. The temperature and relative humidity (RH) during each incubation sub-interval shall be controlled as given in Table 4 and shown in Figure 1. All specimens shall be measured after each sub-interval of incubation.

Table 2 — Rigorous stress conditions for use with the Eyring Method

Test cell number	Test stress condition (incubation)		Number of specimens	Maximum incubation sub-interval time	Minimum total incubation time	Intermediate RH	Minimum equilibration duration time
	Temp (°C)	% RH		hours	hours	% RH	hours
A	85	80	20	300	1 500	30	7
B	85	70	20	400	2 000	30	6
C	85	60	20	600	3 000	30	5
D	75	80	20	600	3 000	32	8
E	65	80	30	800	4 000	35	9

Table 3 — Basic stress conditions for use with the Eyring Method

Test cell number	Test stress condition (incubation)		Number of specimens	Maximum incubation subinterval time	Minimum total incubation time	Intermediate RH	Minimum equilibration duration time
	Temp (°C)	% RH		hours	hours	% RH	hours
A	85	80	20	250	1 000	30	7
B	85	70	20	250	1 000	30	6
C	65	80	20	500	2 000	35	9
D	70	75	30	625	2 500	33	11

NOTE Incubation duration should be decided according to media characteristic.

8.2.2 Temperature (T)

The temperature levels chosen for this test plan are based on the following:

There shall be no change of phase within the test system over the test-temperature range. This restricts the temperature to greater than 0 °C and less than 100 °C,

The temperature shall not be so high that plastic deformation occurs anywhere within the disk structure.

The typical substrate material used for media is polycarbonate (glass transition temperature ~150 °C). The glass transition temperature of other layers may be lower. Experience with high-temperature testing of DVDs, +R/+RW disks and CD disks indicates that an upper limit of 85 °C is practical for most applications.

8.2.3 Relative humidity (RH)

Experience indicates that 80 % RH is the generally accepted upper limit for control within most accelerated test cells.

8.2.4 Incubation and Ramp Profiles

The relative humidity transition (ramp) profile is intended to avoid moisture condensation on the substrate, minimize substantial moisture gradients in the substrate and to end at ramp-down completion with the substrate equilibrated to the ambient condition. This is accomplished by varying the moisture content of the chamber only at the stress incubation temperature, and allowing sufficient time for equilibration during the ramp down based on the diffusion coefficient of water in polycarbonate.

Table 4 — T and RH transition (ramp) profile for each incubation sub-interval

Process step	Temperature °C	Relative humidity %	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}	—

amb = room ambient *T* or *RH* (T_{amb} or RH_{amb})
inc = stress incubation *T* or *RH* (T_{inc} or RH_{inc})
int = intermediate relative humidity (RH_{int}) that at T_{inc} supports the same equilibrium moisture absorption in polycarbonate as that supported at T_{amb} and RH_{amb}

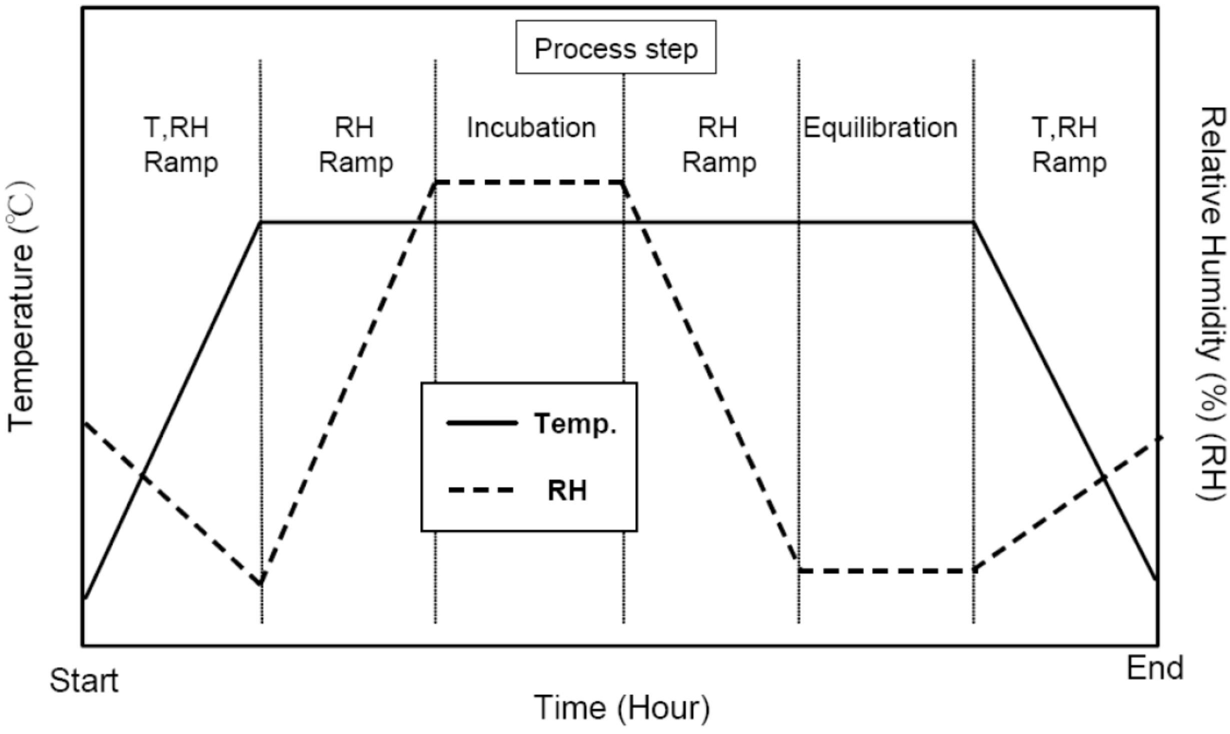

Figure 1 — Graph of typical transition (ramp) profile

8.3 Measuring Time intervals

For data collection, PI Sum 8 (DVD-R, DVD-RW, +R, +RW), BER (DVD-RAM), or C1 Ave 10 (CD-R, CD-RW), measurements for each disk will occur: 1) before disk exposure to any stress condition to determine its baseline measurement and 2) after each sub-interval of incubation. The length of time for intervals is dependent on the severity of the stress condition.

Using each disk's regression equation, the failure time for each disk shall then be computed for the stress condition it was exposed to.

8.4 Stress Conditions Design

Table 2 for the Rigorous stress conditions and Table 3 for the Basic stress conditions specify the temperatures, relative humidities, Maximum Incubation sub-intervals, minimum total incubation time, and minimum number of specimens for each stress condition. A separate group of specimens shall be used for each stress condition.

All temperatures shall be maintained within ± 2 °C of the target temperature; all relative humidities shall be maintained within $\pm 3\,\%$ RH of the target relative humidity.

The intermediate relative humidity in Table 2 and Table 3 are calculated assuming 25 °C and 50 % RH ambient conditions. If the ambient is different, the intermediate relative humidity to be used is calculated using the equation:

$$RH_{\text{int}} = \frac{0{,}24 + 0{,}0037 \times T_{\text{amb}}}{0{,}24 + 0{,}0037 \times T_{\text{inc}}} \times RH_{\text{amb}}$$

where: T_{amb} and T_{inc} are the ambient and incubation temperature in units of °C;

RH_{amb} is the ambient relative humidity;

RH_{int} is the intermediate relative humidity.

The stress conditions tabulated in Table 2, Table 3 and Table 4 offer sufficient combinations of temperature and relative humidity to satisfy the mathematical requirements of the Eyring Method to demonstrate linearity of either Max PI Sum 8, Max BER, or Max C1 Ave 10, or their logs respectively, versus time, and to produce a satisfactory confidence level to make a meaningful conclusion.

8.5 Media Orientation

Media subjected to this test method shall be maintained during incubation in a vertical position with a minimum of 2 mm separation between disks to allow air flow between disks and to minimize deposition of debris on disk surfaces, which could negatively influence the data error measurements.

9 Lifetime Estimation

9.1 Time to failure

All disks subjected to stress conditions shall have their time to failure calculated at the stress condition they have been subjected to. Failure criteria values are: Max PI Sum 8 exceeding 280 for DVD-R/RW, +R/+RW, Max BER exceeding 10^{-3} for DVD-RAM and Max C1 Ave 10 exceeding 220 for CD-R/-RW.

Material degradation manifests itself as data errors in the disk, providing a relationship between disk errors and material degradation. The chemical changes are generally expected to cause test data to have a distribution that follows an exponential function over time. Therefore, test values of: PI Sum 8, BER or C1 Ave 10 as functions of time are expected to exhibit an exponential distribution.

The best function fitting an error trend can be found by regression of the test data against time, for example, with a least squares fit. The time to failure per disk type can be calculated using the error trend function and the failure criteria.

9.2 Accelerated Aging Test Methods

9.2.1 Eyring acceleration model (Eyring Method)

Using the Eyring model, the following equation is derived from the laws of thermodynamics and can be used to handle the two critical stresses of temperature and relative humidity.

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

where

t is the time to failure;
A is the pre-exponential time constant;
T^a is the pre-exponential temperature factor;
Δ*H* is the activation energy per molecule;
k is the Boltzmann's constant (1,3807 × 10^{-23} J/molecule degree K);
T is the temperature (in Kelvin);
B, *C* are the *RH* exponential constants;
RH is the relative humidity;

For the temperature range used in this test method, "a" and "*C*" shall be set to zero. The Eyring model equation then reduces to the following equation.

$$t = Ae^{\Delta H / kT} e^{B \times RH}$$

or, $$\ln(t) = \ln(A) + \frac{\Delta H}{kT} + B \times RH$$

9.2.2 Arrhenius accelerated model (Arrhenius Method)

The Arrhenius Method uses only temperature stress for accelerated aging.

The time to failure is assumed to be governed by the following Arrhenius model equation.

$$t = Ae^{\Delta H / kT}$$

$$\ln(t) = \ln(A) + \frac{\Delta H}{kT}$$

9.3 Data Analysis

Data analysis is contained in the following Annexes:

Annex A: Outline of Media Life Estimation Method and Data Analysis Steps

Annex B: Media Life Estimation for the Controlled Storage Condition (Eyring Method)

Annex C: Media Life Estimation for the Harsh Storage Condition (Arrhenius Method)

Annex D: Interval Estimation for B_5 Life using Maximum Likelihood

9.4 Result of Estimated Media Life

Estimated lifetime based on the data analysis shall be reported as follows.

(1) Number and title of this standard

(2) Ambient storage condition for lifetime estimation

25 °C / 50 % RH (Controlled storage condition) or 30 °C / 80 % RH (Harsh storage condition)

(3) Stress and testing condition

Rigorous stress condition testing or Basic stress condition testing

(4) The recording speed used for testing shall be reported. (see 7.3)

(5) B_{50} Life, B_5 Life and 95 % lower confidence bound of B_5 Life (= (B_5 Life)$_L$)

NOTE In case a more precise analysis is required or a large estimate $\hat{\sigma}$ is found, the 95% lower confidence bound of B_5 Life should be computed according to annex D.

Annex A
(normative)

Outline of Media Life Estimation Method and Data Analysis Steps

A.1 Data analysis for media life estimation

A.1.1 Assumptions for data analysis

Data analysis for lifetime estimation is based on the following assumptions.

- The lifetime of data recorded on an optical disk has a lognormal distribution.
- The Eyring Method is used for the Controlled storage condition (25 °C, 50 % RH). (see Annex B)
- The Arrhenius method is used for the Harsh storage condition (30 °C, 80 % RH). (see Annex C)

A.1.2 Lognormal model and point estimation of $\ln \hat{B}_5$ and $\ln \hat{B}_{50}$

As lifetime *t* is distributed with lognormal distribution $LN(\mu, \sigma^2)$, log lifetime $y\,(=\ln t)$ follows normal distribution $N(\mu, \sigma^2)$, where μ and σ^2 are the expected values of y and variance, respectively.

$$y = \mu(\mathbf{x}) + \sigma \cdot z$$

$$= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \sigma \cdot z$$

z denotes percentile of $N(0, \sigma^2)$, and $\beta_0 = \ln A,\ \beta_1 = \Delta H / k,\ \beta_2 = B.$

The *p* percentile of the lifetime distribution, or B_P Life, is widely used in reliability engineering. The point estimation of $\ln B_p$ is described as

$$\ln \hat{B}_p = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + z_{p/100}\hat{\sigma}\ .$$

Then the point estimates of the 5 percentile and 50 percentile of the lifetime distribution are given by

$$\ln \hat{B}_5 = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1{,}64\hat{\sigma}$$

$$\ln \hat{B}_{50} = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20}.$$

where, $\{x_{10}, x_{20}\}$ denotes the Controlled storage condition (25 °C and 50 % RH)

A.1.3 Interval estimation for optical disk

For interval estimation of $\ln \hat{B}_p$ for an optical disk, one may consider only the lower bound. $(100-\alpha)$ % lower confidence bound of log lifetime $\ln \hat{B}_p$ is given by the following equation.

$$(\ln \hat{B}_p)_L = \ln \hat{B}_p + z_{\alpha/100}\sqrt{Var\left[\ln \hat{B}_p\right]})$$

where, $Var\left[\ln \hat{B}_p\right]$ denotes variance of $\ln \hat{B}_p$ (see Annex D)

When $\hat{\sigma}$ is relatively small, we can put $\sqrt{Var\left[\ln \hat{B}_p\right]} \cong \hat{\sigma}$. Then the 95% lower confidence bound of B_5 Life becomes as follows.

$$(B_5 \text{ Life})_L = (\exp(\ln \hat{B}_5))_L = \exp(\ln \hat{B}_5 - 1.64\sqrt{Var\left[\ln \hat{B}_5\right]})$$

$$\cong \exp(\ln \hat{B}_5 - 1.64\hat{\sigma})$$

NOTE In case a more precise analysis is required or a larger estimated $\hat{\sigma}$ is found, the 95% lower confidence bound of B_5 should be analyzed according to Annex D.

A.1.4 Estimation of β and σ using the least squares method

The multiple linear regression model for i th specimen is described as follows.

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i \quad (i = 1 \sim n)$$

where, ε_i denotes errors, and n denotes total number of specimens.

The estimate $\hat{y}_i$ is given as

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_{1i} + \hat{\beta}_2 x_{2i}.$$

Also, the sum of the squared residual errors Se is computed as

$$Se = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2.$$

The regression coefficients of $\hat{y}_i$ can be obtained by applying the least squares method to Se. The estimates $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ are obtained by solving 110 linear regression equations of group A, B, C, D and E.

The estimate $\hat{\sigma}^2$ of variance is given as follows.

$$\hat{\sigma}^2 = \frac{Se}{(n-2-1)} = \frac{\sum (y_i - \hat{y}_i)^2}{(n-2-1)}$$

where $n-2-1$ is the number of degrees of freedom.

The estimated regression coefficients $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ and variance of residual errors $\hat{\sigma}_2$ are obtained using regression analysis of statistics software tools.

B_{50} Life, B_5 Life and the 95% lower confidence bound of B_5 Life are described as follows.

$$B_{50} \text{ Life} = \exp(\ln \hat{B}_{50})$$

$$= \exp(\hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20})$$

$$B_5 \text{ Life} = \exp(\ln \hat{B}_5)$$

$$= \exp(\hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1{,}64\hat{\sigma})$$

where, $\{x_{10}, x_{20}\}$ denotes the Controlled storage condition (25 °C and 50 % RH)

Also, 95% lower confidence bound of B_5 Life becomes

$(B_5 \text{ Life})_L \cong \exp(\ln \hat{B}_5 - 1.64\hat{\sigma})$, when $\hat{\sigma}$ is relatively small. (see A.1.3)

A.2 Data analysis steps for lifetime estimation

The following is an outline of steps to estimate the media lifetime using the least squares method for the Eyring Method, as a function of ambient temperature and relative humidity.

1. For each specimen, ordered by increasing time to failure values, compute (via linear regression) the predicted time to failure.
2. (Steps 2 and 3 are for data quality check)

   For each stress condition, the specimens are ordered by increasing time to failure values in order to determine the median rank of each specimen.

3. Plot the median rank versus time to failure on a lognormal graph. Verify that the fitting lines for all stress conditions are reasonably parallel to one another.

NOTE In the case where the fitting lines are not determined to be reasonably parallel, the assumptions made in Clause 7.1.2 shall be checked.

4. Multiple regression coefficients and the standard error can be calculated using the least squares method across all data of the log failure times, which were obtained at the five or four stress conditions. This calculation can be performed by multiple regression analysis of statistics software tools.
5. B_{50} Life, B_5 Life and 95% lower confidence bound of B_5 Life at the Controlled storage condition are calculated using the multiple regression coefficients and standard error.

For the conventional acceleration factor method, in addition to above steps 1 to 3, following steps 4 to 7 are used

4. Calculate regression coefficients using the log mean failure time.
5. Calculate acceleration factors from the difference between the estimated log mean at each stress condition.
6. Calculate the normalized time to failure at the ambient condition for each specimen group using the acceleration factors, and plot these data on a lognormal graph.
7. B_{50} Life, B_5 Life and 95% lower confidence bound of B_5 Life at the Controlled storage condition are calculated using $\hat{\mu}$ and $\hat{\sigma}$ obtained from the fitting line.

NOTE Data analysis steps using the Arrhenius Method are almost the same as the Eying Method. Single regression for Harsh storage temperature can be used for the Arrhenius Method.

Annex B
(normative)

Media Life Estimation for the Controlled Storage Condition (Eyring method)

In this annex, two media life estimation methods by the least squares method using all data and the conventional acceleration factor method for the Rigorous stress condition testing are shown.

B.1 Data analysis and lifetime estimation using the least squares method

Step 1

Determine the time to failure for each specimen at the stress applied following the procedure described below. Data Error to be measured is as defined in 7.1.3:

For DVD-R/-RW, +R/+RW:	Max PI Sum 8
For DVD-RAM:	Max BER
For CD-R/-RW:	Max C1 Ave 10

Use the initial data errors measured prior to accelerated aging plus the data errors measured after each specified accelerated-aging incubation sub-interval.

For each specimen, a linear regression is performed with the ln (measured data errors) as the dependent variable and time as the independent variable. The time to failure of the specimen is calculated from the slope and intercept of the regression as the time at which the specimen would have a Max PI Sum 8 of 280, a Max BER of 10^{-3}, or Max C1 Ave 10 of 220.

Table B.1 shows calculations leading to an estimated time to failure from a hypothetical data set. The data for five stress conditions (Group A, Group B, Group C, Group D and Group E) are offered solely as an example of the mathematical methodology used in this test procedure.

Step 2

For each stress condition, the specimens are ordered by increasing log time to failure values.

The median rank of the specimens is calculated using the estimate $(i-0{,}3)/(n+0{,}4)$, where i is the time to failure order and n is the total number of specimens at the stress condition.

Table B.2 shows the ordered log time to failure and the median rank for the example data.

Table B.1 — Ordered estimated time to failure for example data (Rigorous stress conditions)

Order Number	Group A 85℃/80%RH	Group B 85℃/70%RH	Group C 85℃/60%RH	Group D 75℃/80%RH	Group E 65℃/80%RH
1	429	613	864	1728	5455
2	451	640	913	1882	5730
3	476	649	915	1907	5908
4	484	675	945	1989	6114
5	493	679	951	2020	6326
6	495	696	993	2076	6431
7	501	703	994	2129	6544
8	512	709	998	2151	6632
9	521	719	1009	2180	6711
10	526	732	1014	2227	6779
11	534	739	1027	2277	6860
12	540	743	1030	2318	6935
13	542	747	1037	2352	7038
14	548	751	1049	2404	7108
15	557	766	1069	2443	7202
16	576	778	1080	2512	7285
17	579	785	1098	2589	7362
18	586	804	1125	2590	7454
19	618	856	1222	2776	7562
20	645	896	1249	2891	7569
21					7710
22					7827
23					7955
24					8067
25					8250
26					8405
27					8546
28					8700
29					8953
30					9452

Table B.2 — Log time to failure and median rank for example data

Group A	85℃/80%RH		
Order Number	Time to Failure(h) (=H)	ln(H)	Median Rank
1	429	6.0611	0.034
2	451	6.1115	0.083
3	476	6.1654	0.131
4	484	6.1822	0.181
5	493	6.2005	0.23
6	495	6.2046	0.279
7	501	6.2166	0.328
8	512	6.2383	0.377
9	521	6.2558	0.426
10	526	6.2653	0.475
11	534	6.2804	0.525
12	540	6.2913	0.574
13	542	6.2953	0.623
14	548	6.3063	0.672
15	557	6.3226	0.721
16	576	6.3561	0.77
17	579	6.3613	0.819
18	586	6.3733	0.869
19	618	6.4265	0.917
20	645	6.4693	0.966
Mean	531	6.2692	

Group B	85℃/70%RH		
Order Number	Time to Failure(h) (=H)	ln(H)	Median Rank
1	613	6.4184	0.034
2	640	6.4615	0.083
3	649	6.4754	0.131
4	675	6.5147	0.181
5	679	6.5206	0.23
6	696	6.5453	0.279
7	703	6.5554	0.328
8	709	6.5639	0.377
9	719	6.5779	0.426
10	732	6.5958	0.475
11	739	6.6053	0.525
12	743	6.6107	0.574
13	747	6.6161	0.623
14	751	6.6214	0.672
15	766	6.6412	0.721
16	778	6.6567	0.77
17	785	6.6657	0.819
18	804	6.6896	0.869
19	856	6.7523	0.917
20	896	6.7979	0.966
Mean	734	6.5943	

Group C	85℃/60%RH		
Order Number	Time to Failure(h) (=H)	ln(H)	Median Rank
1	864	6.7616	0.034
2	913	6.8167	0.083
3	915	6.8189	0.131
4	945	6.8512	0.181
5	951	6.8575	0.23
6	993	6.9007	0.279
7	994	6.9017	0.328
8	998	6.9058	0.377
9	1009	6.9167	0.426
10	1014	6.9217	0.475
11	1027	6.9344	0.525
12	1030	6.9373	0.574
13	1037	6.9441	0.623
14	1049	6.9556	0.672
15	1069	6.9745	0.721
16	1080	6.9847	0.77
17	1098	7.0012	0.819
18	1125	7.0255	0.869
19	1222	7.1082	0.917
20	1249	7.1301	0.966
Mean	1029	6.9324	

Group D	75℃/80%RH		
Order Number	Time to Failure(h) (=H)	ln(H)	Median Rank
1	1728	7.4549	0.034
2	1882	7.5403	0.083
3	1907	7.5534	0.131
4	1989	7.5953	0.181
5	2020	7.6106	0.23
6	2076	7.6381	0.279
7	2129	7.6632	0.328
8	2151	7.6739	0.377
9	2180	7.6871	0.426
10	2227	7.7085	0.475
11	2277	7.7308	0.525
12	2318	7.7484	0.574
13	2352	7.7632	0.623
14	2404	7.7850	0.672
15	2443	7.8008	0.721
16	2512	7.8287	0.77
17	2589	7.8592	0.819
18	2590	7.8594	0.869
19	2776	7.9286	0.917
20	2891	7.9695	0.966
Mean	2272	7.7199	

Group E	65℃/80%RH		
Order Number	Time to Failure(h) (=H)	ln(H)	Median Rank
1	5455	8.6043	0.023
2	5730	8.6535	0.056
3	5908	8.6841	0.089
4	6114	8.7183	0.122
5	6326	8.7525	0.155
6	6431	8.7689	0.188
7	6544	8.7864	0.22
8	6632	8.7997	0.253
9	6711	8.8115	0.286
10	6779	8.8216	0.319
11	6860	8.8335	0.352
12	6935	8.8443	0.385
13	7038	8.8591	0.418
14	7108	8.8690	0.451
15	7202	8.8822	0.484
16	7285	8.8936	0.516
17	7362	8.9041	0.549
18	7454	8.9165	0.582
19	7562	8.9309	0.615
20	7569	8.9319	0.648
21	7710	8.9503	0.681
22	7827	8.9653	0.714
23	7955	8.9816	0.747
24	8067	8.9955	0.78
25	8250	9.0180	0.813
26	8405	9.0366	0.845
27	8546	9.0532	0.878
28	8700	9.0711	0.911
29	8953	9.0997	0.944
30	9452	9.1540	0.977
Mean	7296	8.8864	

Step 3

The data can be plotted in different ways. If lognormal graph paper is employed, the data is plotted with time to failure on the abscissa and median rank on the ordinate.

NOTE On most lognormal graph paper, the actual ordinate scale is the probability of failure, and the median rank is converted to the probability of failure by multiplying by 100.

Figure B.1 shows lognormal plots of specimen groups A, B, C, D and E from Table B.2. Each best fit straight line is drawn through the plotted data. If the lines are judged to be reasonably parallel, the assumption of equivalent log standard deviation applicable to the individual data sets is verified.

An estimate of the log standard deviation can be obtained from the graphical treatment of the failure data. First, for each stress, estimate the times corresponding to 15,9 % and 84,1 % failure based on the best-fit straight line through the time to failure data. The estimated log standard deviation $\hat{\sigma}$ is then calculated as follows.

$$\hat{\sigma} = (\ln t_{0,841} - \ln t_{0,159}) / 2$$

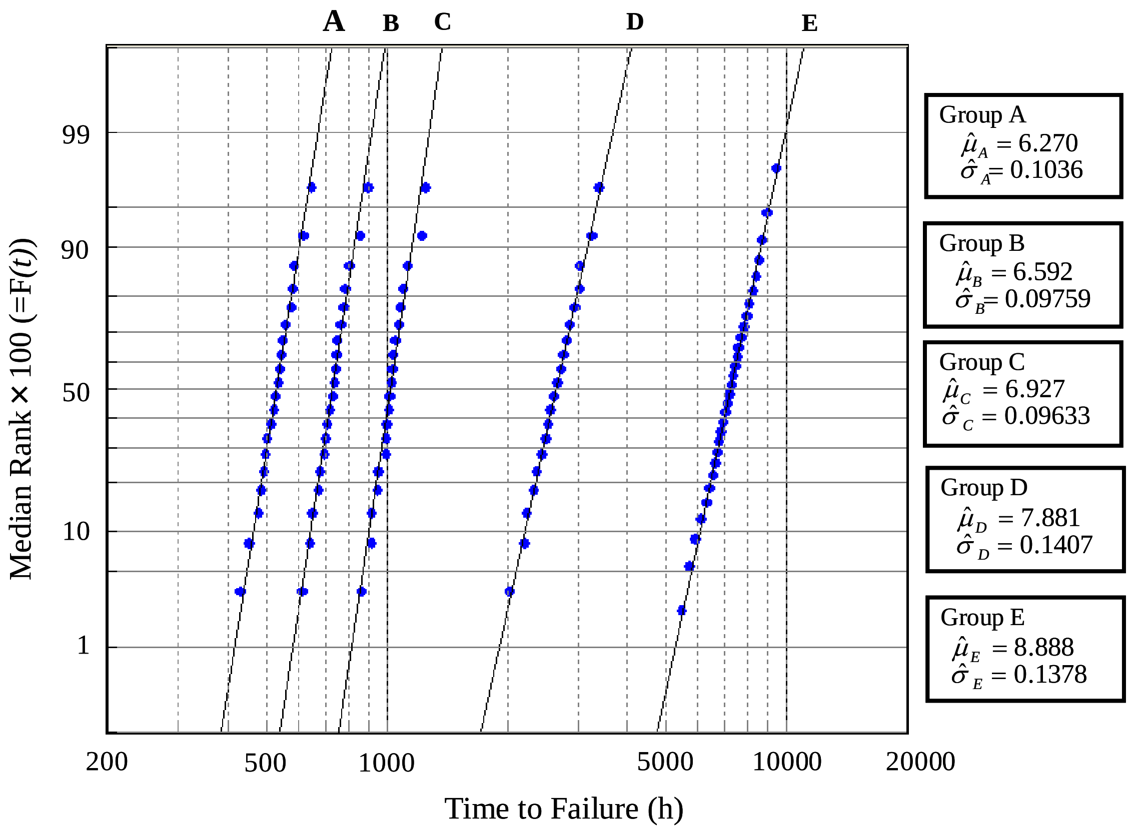

Figure B.1 — Best fit lines of specimen group A, B, C, D and E on lognormal paper (Verify that the fitting lines for all stress conditions are reasonably parallel to one another)

The averaged log standard deviation estimate $\hat{\sigma}_m$ of five groups is then calculated as

$$\hat{\sigma}_m = (\hat{\sigma}_A + \hat{\sigma}_B + \hat{\sigma}_C + \hat{\sigma}_D + \hat{\sigma}_E)/5$$

$$= (0{,}1036 + 0{,}09759 + 0{,}09633 + 0{,}1407 + 0{,}1378) / 5 = 0{,}1152$$

Step 4

Table B.3 shows all 110 sample data points belonging to specimen groups A, B, C, D and E for regression analysis. The regression coefficients and error variance are calculated by applying the least squares method to 110 failure data that were obtained under the five stress conditions. Table B.4 shows the result of regression analysis of the statistics software tool. Residual error estimate $\hat{S}e$, variance estimate $\hat{\sigma}^2$, standard error estimate $\hat{\sigma}$, and regression coefficient estimates $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ are quickly obtained. Other statistics tools also can be used for regression analysis.

NOTE The standard error estimate $\hat{\sigma}$ (=0,13169) at the controlled storage condition is fairly large in comparison with the averaged estimate $\hat{\sigma}_m$ of the five specimen groups. Variation in the best-fit lines among the five groups and the lognormal distributions of each group are among the anomalies that may affect the log standard error.

Table B.3 — 110 sample data for regression analysis

Number	ln t	x_1	x_2	
1	6.061055	0.002792	80	
2	6.111467	0.002792	80	
3	6.165418	0.002792	80	
4	6.182176	0.002792	80	
5	6.200509	0.002792	80	
6	6.204558	0.002792	80	
7	6.216606	0.002792	80	
8	6.238325	0.002792	80	
9	6.255750	0.002792	80	
10	6.265301	0.002792	80	Group A
11	6.280396	0.002792	80	
12	6.291310	0.002792	80	
13	6.295266	0.002792	80	
14	6.306275	0.002792	80	
15	6.322565	0.002792	80	
16	6.356108	0.002792	80	
17	6.361302	0.002792	80	
18	6.373320	0.002792	80	
19	6.426488	0.002792	80	
20	6.469250	0.002792	80	
1	6.418365	0.002792	70	
2	6.461468	0.002792	70	
3	6.475433	0.002792	70	
4	6.514713	0.002792	70	
5	6.520621	0.002792	70	
6	6.545350	0.002792	70	
7	6.555357	0.002792	70	
8	6.563856	0.002792	70	
9	6.577861	0.002792	70	
10	6.595781	0.002792	70	Group B
11	6.605298	0.002792	70	
12	6.610696	0.002792	70	
13	6.616065	0.002792	70	
14	6.621406	0.002792	70	
15	6.641182	0.002792	70	
16	6.656727	0.002792	70	
17	6.665684	0.002792	70	
18	6.689599	0.002792	70	
19	6.752270	0.002792	70	
20	6.797940	0.002792	70	
1	6.761573	0.002792	60	
2	6.816736	0.002792	60	
3	6.818924	0.002792	60	
4	6.851185	0.002792	60	
5	6.857514	0.002792	60	
6	6.900731	0.002792	60	
7	6.901737	0.002792	60	
8	6.905753	0.002792	60	
9	6.916715	0.002792	60	
10	6.921658	0.002792	60	Group C
11	6.934397	0.002792	60	
12	6.937314	0.002792	60	
13	6.944087	0.002792	60	
14	6.955593	0.002792	60	
15	6.974479	0.002792	60	
16	6.984716	0.002792	60	
17	7.001246	0.002792	60	
18	7.025538	0.002792	60	
19	7.108244	0.002792	60	
20	7.130099	0.002792	60	

Number	ln t	x_1	x_2	
1	7.454918	0.002872	80	
2	7.540276	0.002872	80	
3	7.553358	0.002872	80	
4	7.595322	0.002872	80	
5	7.610634	0.002872	80	
6	7.638060	0.002872	80	
7	7.663173	0.002872	80	
8	7.673915	0.002872	80	
9	7.687122	0.002872	80	
10	7.708528	0.002872	80	Group D
11	7.730831	0.002872	80	
12	7.748371	0.002872	80	
13	7.763199	0.002872	80	
14	7.785036	0.002872	80	
15	7.800846	0.002872	80	
16	7.828687	0.002872	80	
17	7.859160	0.002872	80	
18	7.859351	0.002872	80	
19	7.928609	0.002872	80	
20	7.969480	0.002872	80	
1	8.604288	0.002957	80	
2	8.653471	0.002957	80	
3	8.684063	0.002957	80	
4	8.718337	0.002957	80	
5	8.752500	0.002957	80	
6	8.768885	0.002957	80	
7	8.786365	0.002957	80	
8	8.799662	0.002957	80	
9	8.811503	0.002957	80	
10	8.821630	0.002957	80	
11	8.833463	0.002957	80	
12	8.844336	0.002957	80	
13	8.859079	0.002957	80	
14	8.868976	0.002957	80	
15	8.882172	0.002957	80	Group E
16	8.893573	0.002957	80	
17	8.904087	0.002957	80	
18	8.916506	0.002957	80	
19	8.930890	0.002957	80	
20	8.931860	0.002957	80	
21	8.950273	0.002957	80	
22	8.965335	0.002957	80	
23	8.981556	0.002957	80	
24	8.995546	0.002957	80	
25	9.017968	0.002957	80	
26	9.036582	0.002957	80	
27	9.053219	0.002957	80	
28	9.071078	0.002957	80	
29	9.099744	0.002957	80	
30	9.153982	0.002957	80	

Table B.4 — Regression analysis results

Regression coefficients			Sum of squared residual errors	Standard deviation of residual errors
$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{S}_e$	$\hat{\sigma}$
-35,3479	15 777,96	-0,02979	1,86350	0,13197

Step 5

$\ln \hat{B}_{50}$ and $\ln \hat{B}_5$ at the Controlled storage condition (25 °C/50 %*RH*) are obtained using the regression coefficient estimates $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ and standard error estimate $\hat{\sigma}$ which were obtained in Step 4.

Then B_{50} Life, B_5 Life and 95% lower confidence bound of B_5 Life at the Controlled storage condition (25 °C /50 % RH) can be calculated using $\ln \hat{B}_{50}$ and $\ln \hat{B}_5$ (see A.1.3).

$$\ln \hat{B}_{50} = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20}$$

$$= - 35{,}3479 + 15\ 777{,}96 \times 0{,}003354 - 0{,}02979 \times 50$$

$$= 16{,}0823$$

B_{50} Life = exp (16.0823) =9 648 593 hours (1101 years)

$$\ln \hat{B}_5 = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1.64\hat{\sigma} = \ln \hat{B}_{50} - 1{,}64\hat{\sigma}$$

$$= 16{,}0823 - 1{,}64 \times 0{,}13197$$

$$= 15{,}8659$$

B_5 Life = exp (15,8659) = 7 770 875 hours (887 years)

95% lower confidence bound of B_5 Life: (B_5 Life)$_L$

$$= (\exp(\ln \hat{B}_5))_L = \exp(\ln \hat{B}_5 + z_{5/100}\sqrt{Var[\ln \hat{B}_5]}) \cong \exp(\ln \hat{B}_5 - 1.64\hat{\sigma})$$

$$= \exp(15{,}8659 - 1.64 \times 0{,}13197) = \exp(15{,}6495)$$

= 6 258 580hours (714 years)

B.2 Data analysis and lifetime estimation using the conventional acceleration factor method (Step 4-7)

Step 4

Table B.5 shows log mean time to failure for each stress group A, B, C, D, and E (see Table B.2)

Table B.5 — Log mean failure time for each stress condition

Group	Log mean	Temp	1/T	% RH
A	6,2692	85	0,002792	80
B	6,5943	85	0,002792	70
C	6,9324	85	0,002792	60
D	7.7199	75	0,002872	80
E	8,8864	65	0,002957	80

To determine the coefficients *A*, Δ*H*/ *k and B* of the reduced Eyring equation, the regression analysis is done using five log mean values obtained at the temperature and relative humidity in Table B.5

$$\log mean_i = \ln(A) + (\frac{\Delta H}{k}) \times (\frac{1}{T_i}) + B \times RH_i + \varepsilon_i$$

where, i = 1 ~ 5

The estimate values are determined as follows.

$$\ln(\hat{A}) = \hat{\beta}_0 = -35{,}6889$$

$$\Delta\hat{H} / k = \hat{\beta}_1 = 15\,904{,}21$$

$$\hat{B} = \hat{\beta}_2 = -0.029978$$

Step 5

The acceleration factors are calculated from the difference between estimated log mean at each stress condition and that at the controlled storage condition (25 °C /50 % RH). They are listed in Table B.6

Table B.6 — Calculated lifetime and acceleration factors for each stress condition

Stress condition	Calculated lifetime			Acceleration factor
	1/T	Ln (lifetime)	Lifetime (h)	
85℃/80%RH	0,002792	6,3202	556	18 685
85℃/70%RH	0,002792	6,6199	750	13 846
85℃/60%RH	0,002792	6,9196	1 012	10 261
75℃/80%RH	0,002872	7,5957	1 990	5 218
65℃/80%RH	0,002957	8,9467	7 682	1 352
25℃/50%RH	0,003354	16,1557	10 383 119	

Step 6

Using the acceleration factors on Table B.6, calculate normalized time to failure at 25 °C / 50 %RH for each specimen group A, B, C, D and E. Table B.7 shows data for a composite lognormal plot. Figure B.2 shows a lognormal plot using the composite data of Table B.7. From the fitting line for those data, the log mean ($\hat{\mu} = 16{,}15$) and standard deviation ($\hat{\sigma} = 0{,}1324$) can be obtained. These values are almost same as the values which were calculated in Table B.7.

Table B.7 — Data for composite lognormal plot

Time to Failure	Group	Normarized to 25℃/50%RH	Ln	Group	Accending	Order	Median Rank
429	A	8012443	15.89651	E	15.7432	1	0.0063
451	A	8426726	15.94692	E	15.79238	2	0.0154
476	A	8893839	16.00087	E	15.82297	3	0.0245
484	A	9044142	16.01763	A	15.8327	4	0.0335
493	A	9211476	16.03596	E	15.85725	5	0.0426
495	A	9248845	16.04001	A	15.88312	6	0.0516
501	A	9360953	16.05206	E	15.89141	7	0.0607
512	A	9566482	16.07378	E	15.90779	8	0.0697
521	A	9734643	16.0912	B	15.91875	9	0.0788
526	A	9828066	16.10075	E	15.92527	10	0.0879
534	A	9977542	16.11585	A	15.93707	11	0.0969
540	A	10087039	16.12676	E	15.93857	12	0.1060
542	A	10127018	16.13072	E	15.95041	13	0.1150
548	A	10239126	16.14173	A	15.95382	14	0.1241
557	A	10407287	16.15802	E	15.96054	15	0.1332
576	A	10762293	16.19156	B	15.96185	16	0.1422
579	A	10818346	16.19675	A	15.97216	17	0.1513
586	A	10949138	16.20877	E	15.97237	18	0.1603
618	A	11547043	16.26194	B	15.97581	19	0.1694
645	A	12051526	16.3047	A	15.97621	20	0.1784
613	B	8487790	15.95414	E	15.98325	21	0.1875
640	B	8861640	15.99724	A	15.98825	22	0.1966
649	B	8986257	16.01121	C	15.99069	23	0.2056
675	B	9346261	16.05049	E	15.99799	24	0.2147
679	B	9401646	16.0564	E	16.00789	25	0.2237
696	B	9637034	16.08112	A	16.00997	26	0.2328
703	B	9733958	16.09113	B	16.01509	27	0.2418
709	B	9817036	16.09963	B	16.021	28	0.2509
719	B	9955499	16.11364	E	16.02108	29	0.2600
732	B	10135501	16.13155	A	16.0274	30	0.2690
739	B	10232425	16.14107	E	16.03248	31	0.2781
743	B	10287811	16.14647	A	16.03695	32	0.2871
747	B	10343196	16.15184	E	16.043	33	0.2962
751	B	10398581	16.15718	B	16.04573	34	0.3053
766	B	10606276	16.17696	C	16.04585	35	0.3143
778	B	10772431	16.1925	C	16.04804	36	0.3234
785	B	10869356	16.20146	A	16.05204	37	0.3324
804	B	11132436	16.22537	E	16.05542	38	0.3415
856	B	11852444	16.28804	B	16.05574	39	0.3505
896	B	12406296	16.33371	A	16.06296	40	0.3596
864	C	8865428	15.99767	B	16.06424	41	0.3687
913	C	9368213	16.05283	A	16.06691	42	0.3777
915	C	9388735	16.05502	E	16.0698	43	0.3868
945	C	9696562	16.08728	E	16.07077	44	0.3958
951	C	9758127	16.09361	A	16.07792	45	0.4049
993	C	10189086	16.13683	B	16.07824	46	0.4139
994	C	10199347	16.13783	C	16.0803	47	0.4230
998	C	10240390	16.14185	C	16.08663	48	0.4321
1009	C	10353260	16.15281	E	16.08918	49	0.4411
1014	C	10404565	16.15776	A	16.09421	50	0.4502
1027	C	10537957	16.17049	B	16.09616	51	0.4592
1030	C	10568740	16.17341	E	16.10424	52	0.4683
1037	C	10640566	16.18018	B	16.10568	53	0.4774
1049	C	10763697	16.19169	D	16.10888	54	0.4864
1069	C	10968915	16.21058	B	16.11108	55	0.4955
1080	C	11081785	16.22081	B	16.11645	56	0.5045
1098	C	11266482	16.23734	E	16.12047	57	0.5136
1125	C	11543526	16.26164	B	16.12179	58	0.5226
1222	C	12538835	16.34434	A	16.12776	59	0.5317
1249	C	12815879	16.3662	C	16.12984	60	0.5408

Time to Failure	Group	Normarized to 25℃/50%RH	Ln	Group	Accending	Order	Median Rank
1728	D	9019222	16.01487	C	16.13085	61	0.5498
1882	D	9822901	16.10023	A	16.13295	62	0.5589
1907	D	9952244	16.11331	E	16.13446	63	0.5679
1989	D	10378769	16.15527	C	16.13487	64	0.5770
2020	D	10538914	16.17059	B	16.14156	65	0.5861
2076	D	10831952	16.19801	A	16.14497	66	0.5951
2129	D	11107416	16.22312	C	16.14583	67	0.6042
2151	D	11227376	16.23387	C	16.15077	68	0.6132
2180	D	11376638	16.24707	E	16.15688	69	0.6223
2227	D	11622800	16.26848	B	16.15711	70	0.6313
2277	D	11884935	16.29078	C	16.16351	71	0.6404
2318	D	12095230	16.30832	B	16.16606	72	0.6495
2352	D	12275916	16.32315	C	16.16643	73	0.6585
2404	D	12546937	16.34499	C	16.1732	74	0.6676
2443	D	12746870	16.3608	E	16.17549	75	0.6766
2512	D	13106751	16.38864	C	16.18471	76	0.6857
2589	D	13512304	16.41911	B	16.18998	77	0.6947
2590	D	13514883	16.4193	E	16.19213	78	0.7038
2776	D	14484070	16.48856	D	16.19424	79	0.7129
2891	D	15088313	16.52943	A	16.19814	80	0.7219
5455	E	7372725	15.8133	C	16.20359	81	0.7310
5730	E	7744402	15.86248	D	16.20732	82	0.7400
5908	E	7984979	15.89307	E	16.20999	83	0.7491
6114	E	8263399	15.92735	C	16.21383	84	0.7582
6326	E	8550584	15.96151	C	16.23036	85	0.7672
6431	E	8691841	15.9779	E	16.23865	86	0.7763
6544	E	8845106	15.99537	A	16.2409	87	0.7853
6632	E	8963504	16.00867	D	16.24928	88	0.7944
6711	E	9070276	16.02051	B	16.25265	89	0.8034
6779	E	9162595	16.03064	C	16.25465	90	0.8125
6860	E	9271658	16.04247	D	16.2646	91	0.8216
6935	E	9373024	16.05335	D	16.29202	92	0.8306
7038	E	9512234	16.06809	E	16.29289	93	0.8397
7108	E	9606843	16.07799	B	16.29832	94	0.8487
7202	E	9734449	16.09118	D	16.31713	95	0.8578
7285	E	9846068	16.10258	D	16.32788	96	0.8668
7362	E	9950138	16.1131	C	16.33736	97	0.8759
7454	E	10074481	16.12552	D	16.34108	98	0.8850
7562	E	10220441	16.1399	C	16.35921	99	0.8940
7569	E	10230357	16.14087	D	16.36249	100	0.9031
7710	E	10420478	16.15928	D	16.38479	101	0.9121
7827	E	10578610	16.17434	D	16.40233	102	0.9212
7955	E	10751609	16.19057	D	16.41716	103	0.9303
8067	E	10903080	16.20456	D	16.439	104	0.9393
8250	E	11150317	16.22698	D	16.45481	105	0.9484
8405	E	11359808	16.24559	D	16.48265	106	0.9574
8546	E	11550377	16.26223	D	16.51312	107	0.9665
8700	E	11758516	16.28009	D	16.51331	108	0.9755
8953	E	12100459	16.30875	D	16.58257	109	0.9846
9452	E	12774885	16.36299	D	16.62344	110	0.9937
		Mean	16.15021				
		Deviation	0.131013				

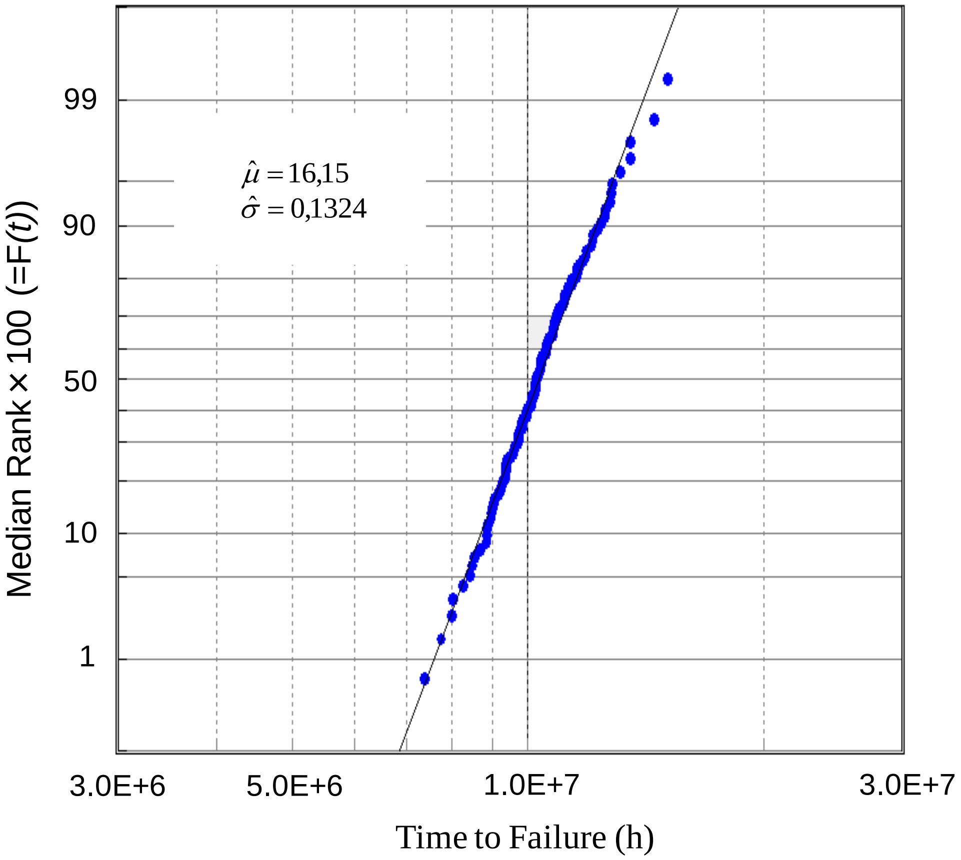

Figure B.2 — Plot on lognormal paper for composite data

Step 7

B_{50} Life, B_5 Life and the 95% lower confidence of B_5 Life at the Controlled storage condition (25 °C/50 % RH) can be calculated as follows.

B_{50} Life = exp ($\hat{\mu}$) = exp (16,15) = 10 324 187 hours (1 179 years)

B_5 Life = exp ($\hat{\mu} - 1.64\hat{\sigma}$) =exp (16,15 - 1,64 $\times$ 0,1324)=exp(15,933)

=8 309 118 hours (949 years)

95% lower confidence bound of B_5 Life: (B_5 Life)$_L$

$$= (\exp(\ln \hat{B}_5))_L = \exp(\ln \hat{B}_5 + z_{5/100}\sqrt{Var[\ln \hat{B}_5]}) \cong \exp(\ln \hat{B}_5 - 1.64\hat{\sigma})$$

= exp (15,933 - 1.64 $\times$ 0,1324) =exp(15,716)

= 6 687 348 hours (763 years)

Annex C
(normative)

Media Life Estimation for the Harsh Storage Condition (Arrhenius method)

C.1 Stress conditions and data analysis steps for the Arrhenius method

Here, a test method is shown for the Harsh storage condition at higher temperature and relative humidity than that of the Controlled storage condition (25 °C and 50 % RH).

This test method follows the scope in this document, which is based on an environment of 30 °C and 80 % RH representing the most severe condition in which users handle and store the optical media. This test method also uses a different stress test design that makes possible the use of the Arrhenius method.

The same assumptions and data analysis method apply for the ambient storage condition, stress design, and Eyring equation. The controlled storage condition of 25 °C and 50% RH is replaced by an expected harsher user environment of 30 °C and 80% RH.

Table C.1 and C.2 show summary of stress design for the Arrhenius Method.

Table C.1 — Rigorous stress condition testing for use with the Arrhenius Method

Test cell number	Test stress condition (incubation)		Number of specimens	Maximum incubation sub-interval time	Minimum total incubation time	Intermediate RH	Minimum equilibration duration time
	Temp (°C)	% RH		hours	hours	% RH	hours
A	85	80	20	300	1 500	30	5
B	80	80	20	400	2 000	31	7
C	75	80	20	600	3 000	32	8
D	65	80	30	800	4 000	35	10

Table C.2 —Basic stress-condition testing for use with the Arrhenius Method

Test cell number	Test stress condition (incubation)		Number of specimens	Maximum incubation sub-interval time	Minimum total incubation time	Intermediate RH	Minimum equilibration duration time
	Temp (°C)	% RH		hours	hours	% RH	hours
A	85	80	20	250	1 000	30	5
B	75	80	20	425	1 700	33	7
C	65	80	30	600	2 400	35	10

Regarding data analysis steps in Annex A and B**,** step 4 is replaced as follows.

Regression coefficients and the standard error can be calculated using the least squares method across all log time to failure data, which were obtained at the four or three stress conditions. This calculation can be performed by regression analysis of statistics software tools.

C.2 Data Analysis

Step 1 and Step 2

For each stress condition, the specimens are ordered by increasing time to failure values. The median rank of the specimens is calculated using the estimate $(i-0{,}3)/(n+0{,}4)$. Table C.3 shows the result of ordered time to failure and median rank for three stress groups of A (85 °C), B (80 °C), C (75 °C) and D (65 °C), where relative humidity (RH) is kept constant 80 %.

Table C.3 – Ordered time to failure and median rank for example data (Rigorous testing)

Sample Number	Sample Group and Stress Conditions (80 %RH)							
	Group A (85 ℃)		Group B (80 ℃)		Group C (75 ℃)		Group D (65 ℃)	
	Time to Failure(h)	Median Rank	Time to Failure(h)	Median Rank	Time to Failure(h)	Median Rank	Time to Failure(h)	Median Rank
1	429	0,034	1015	0,034	1728	0,034	5455	0,023
2	451	0,083	1040	0,083	1882	0,083	5730	0,056
3	476	0,132	1080	0,132	1907	0,132	5908	0,089
4	484	0,181	1203	0,181	1989	0,181	6114	0,122
5	493	0,23	1151	0,23	2020	0,23	6326	0,155
6	495	0,279	1165	0,279	2076	0,279	6431	0,188
7	501	0,328	1193	0,328	2129	0,328	6544	0,22
8	512	0,377	1215	0,377	2151	0,377	6632	0,253
9	521	0,426	1230	0,426	2180	0,426	6711	0,286
10	526	0,475	1239	0,475	2227	0,475	6779	0,319
11	534	0,525	1260	0,525	2277	0,525	6860	0,352
12	540	0,574	1295	0,574	2318	0,574	6935	0,385
13	542	0,623	1310	0,623	2352	0,623	7038	0,418
14	548	0,672	1425	0,672	2404	0,672	7108	0,451
15	557	0,721	1360	0,721	2443	0,721	7202	0,484
16	576	0,77	1388	0,77	2512	0,77	7285	0,516
17	579	0,819	1420	0,819	2589	0,819	7362	0,549
18	586	0,868	1472	0,868	2590	0,868	7454	0,582
19	618	0,917	1540	0,917	2776	0,917	7562	0,615
20	645	0,966	1625	0,966	2891	0,966	7569	0,648
21							7710	0,681
22							7827	0,714
23							7955	0,747
24							8067	0,78
25							8250	0,813
26							8405	0,845
27							8546	0,878
28							8700	0,911
29							8953	0,944
30							9452	0,977

Step 3

Figure C.1 shows lognormal plot of groups A, B and C in Table C.1. Each best-fit straight line is drawn through the plotted data. If the lines are judged to be sufficiently parallel, the assumption of equivalent log standard deviation among the individual data sets is verified.

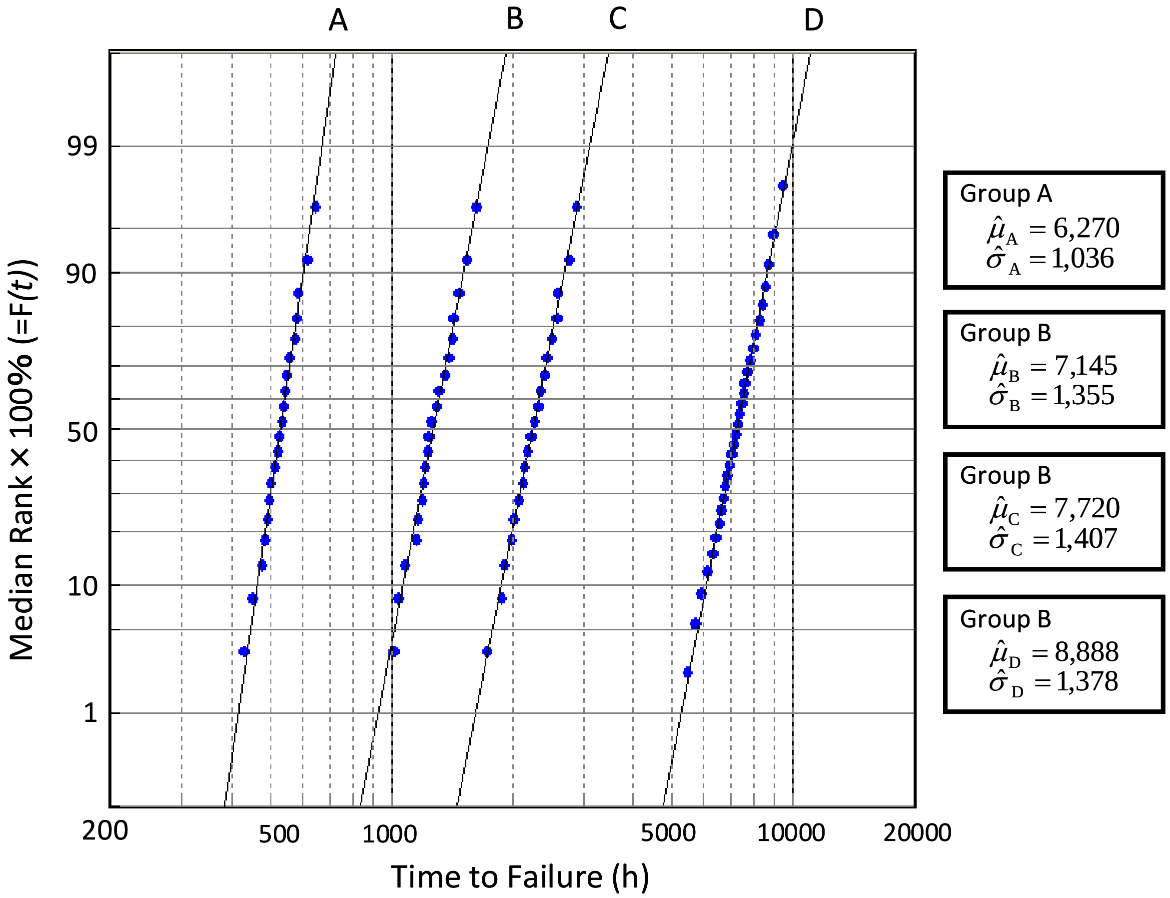

Figure C.1 — Best fit lines of group A, B, C and D on lognormal paper (Verify that the fitting lines for all stress conditions are reasonably parallel to one another)

Step 4

Table C.4 shows total 90 sample data belong to specimen group A, B, C and D for regression analysis. Regression coefficients and error variance are calculated by applying the least squares method to 90 failure data sets which were obtained under the four stress conditions.

Table C.5 shows the result of regression analysis by the statistics software tool. Residual error estimate $\hat{S}e$, standard error estimate $\hat{\sigma}$, and regression coefficient estimates $\hat{\beta}_0$ and $\hat{\beta}_1$ are obtained.

Table C.4 — 90 sample data for regression analysis

Group A

Number	$\ln t$	x_1
1	6.06105	0.002792
2	6.11147	0.002792
3	6.16542	0.002792
4	6.18218	0.002792
5	6.20051	0.002792
6	6.20456	0.002792
7	6.21661	0.002792
8	6.23832	0.002792
9	6.25575	0.002792
10	6.26530	0.002792
11	6.28040	0.002792
12	6.29131	0.002792
13	6.29527	0.002792
14	6.30628	0.002792
15	6.32257	0.002792
16	6.35611	0.002792
17	6.36130	0.002792
18	6.37332	0.002792
19	6.42649	0.002792
20	6.46925	0.002792

Group B

Number	$\ln t$	x_1
1	6.92264	0.002832
2	6.94698	0.002832
3	6.98472	0.002832
4	7.09257	0.002832
5	7.04839	0.002832
6	7.06048	0.002832
7	7.08423	0.002832
8	7.10250	0.002832
9	7.11477	0.002832
10	7.12206	0.002832
11	7.13887	0.002832
12	7.16627	0.002832
13	7.17778	0.002832
14	7.26193	0.002832
15	7.21524	0.002832
16	7.23562	0.002832
17	7.25841	0.002832
18	7.29438	0.002832
19	7.33954	0.002832
20	7.39326	0.002832

Group C

Number	$\ln t$	x_1
1	7.45492	0.002872
2	7.54028	0.002872
3	7.55336	0.002872
4	7.59532	0.002872
5	7.61063	0.002872
6	7.63806	0.002872
7	7.66317	0.002872
8	7.67391	0.002872
9	7.68712	0.002872
10	7.70853	0.002872
11	7.73083	0.002872
12	7.74837	0.002872
13	7.76320	0.002872
14	7.78504	0.002872
15	7.80085	0.002872
16	7.82869	0.002872
17	7.85916	0.002872
18	7.85935	0.002872
19	7.92861	0.002872
20	7.96948	0.002872

Group D

Number	$\ln t$	x_1
1	8.60429	0.002957
2	8.65347	0.002957
3	8.68406	0.002957
4	8.71834	0.002957
5	8.75250	0.002957
6	8.76889	0.002957
7	8.78636	0.002957
8	8.79966	0.002957
9	8.81150	0.002957
10	8.82163	0.002957
11	8.83346	0.002957
12	8.84434	0.002957
13	8.85908	0.002957
14	8.86898	0.002957
15	8.88217	0.002957
16	8.89357	0.002957
17	8.90409	0.002957
18	8.91651	0.002957
19	8.93089	0.002957
20	8.93186	0.002957
21	8.95027	0.002957
22	8.96533	0.002957
23	8.98156	0.002957
24	8.99555	0.002957
25	9.01797	0.002957
26	9.03658	0.002957
27	9.05322	0.002957
28	9.07108	0.002957
29	9.09974	0.002957
30	9.15398	0.002957

Table C.5 — Results of regression Analysis

Regression coefficients		Sum of squared residual errors	Standard deviation of residual errors
$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{S}_e$	$\hat{\sigma}$
-36,2289	15 271,92	2,32868	0,16267

Step 5

Using regression coefficient estimates $\hat{\beta}_0$ and $\hat{\beta}_1$ and standard error estimate $\hat{\sigma}$ in Table C.5, $\ln \hat{B}_5$ and $\ln \hat{B}_{50}$ can be calculated (see A.1.2).

Then B_5 Life, B_{50} Life and the 95% lower confidence bound of B_5 Life at the Harsh storage condition (30 °C and 80 % RH) using calculated values of $\ln \hat{B}_5$ and $\ln \hat{B}_{50}$ are obtained as follows (see A.1.3).

$$\ln \hat{B}_{50} = \hat{\beta}_0 + \hat{\beta}_1 x_{10}$$

$$= -36{,}2289 + 15\ 271{,}92 \times 0{,}0032987$$

$$= 14{,}14856$$

B_{50} Life = exp (14,14856) = 1 395 217 hours (159 years)

$$\ln \hat{B}_5 = \hat{\beta}_0 + \hat{\beta}_1 x_{10} - 1{,}64\hat{\sigma}$$

$$= 14{,}14856 - 1{,}64 \times 0{,}16267$$

$$= 13{,}88178$$

B_5 Life = exp (13,88178) = 1 068 512 hours (122 years)

95% lower confidence bound of B_5 Life: $(B_5\ \text{Life})_L$

$$= (\exp(\ln \hat{B}_5))_L = \exp(\ln \hat{B}_5 + z_{5/100}\sqrt{Var[\ln \hat{B}_5]}) \cong \exp(\ln \hat{B}_5 - 1.64\hat{\sigma})$$

$$= \exp(13{,}88178 - 1{,}64 \times 0{,}16267) = \exp(13{,}6615)$$

= 818 309 hours (93 years)

Annex D
(informative)

Interval Estimation for B_5 Life using Maximum Likelihood

D.1 Lower confidence bound

Lifetime estimation analysis (point estimation and simple interval estimation) for B_5 Life and B_{50} Life are described in Annex A. In this annex, a more precise analysis method for interval estimation is introduced. One may consider only the lower bound of the confidence interval to estimate lifetime.

D.2 Maximum likelihood method

In order to log lifetime y ($=\ln t$) is followed the normal distribution described in A.1.2, the likelihood function of parameters β and σ can be defined by the following equation.

$$L(\boldsymbol{\beta},\sigma) = \prod_{i=1}^{k}\prod_{j=1}^{n_i} f(y_{ij} \mid \boldsymbol{x}_i)$$
$$= \prod_{i=1}^{k}\prod_{j=1}^{n_i} \frac{1}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{1}{2}\left(\frac{y_{ij}-\boldsymbol{x}'\cdot\boldsymbol{\beta}}{\sigma}\right)^2\right\}$$

where, k denotes the number of specimen groups, n_i denotes the number of specimens in the specimen group j .

The log likelihood function is then

$$\ln L(\boldsymbol{\beta},\sigma) = -\ln\sqrt{2\pi}\sigma\sum_{i=1}^{k} n_i - \sum_{i=1}^{k}\sum_{j=1}^{n_i} y_{ij} - \frac{1}{2\sigma^2}\sum_{i=1}^{k}\sum_{j=1}^{n_i}(y_{ij}-(\beta_0+\beta_1 x_{1i}+\beta_2 x_{2i}))^2$$

The maximum likelihood estimators of β and σ can be obtained by maximizing the third member of the equation.

The estimates $\hat\beta_0$, $\hat\beta_1$ and $\hat\beta$ are coefficients in the multiple regression equation, and the estimate $\hat\sigma$ is the standard deviation.

The point estimation of $\ln \hat B_p$ can be obtained using the estimates $\hat\beta_0$, $\hat\beta_1$, $\hat\beta_2$ and $\hat\sigma$ *as*

$$\ln \hat B_p = \hat\beta_0 + \hat\beta_1 x_1 + \hat\beta_2 x_2 + z_{p/100}\hat\sigma.$$

Then the point estimates of 5 percentile and 50 percentile of the lifetime distribution are

$$\ln \hat B_5 = \hat\beta_0 + \hat\beta_1 x_{10} + \hat\beta_2 x_{20} - 1{,}64\hat\sigma$$, and

$$\ln \hat B_{50} = \hat\beta_0 + \hat\beta_1 x_{10} + \hat\beta_2 x_{20}$$

where $\{x_{10}, x_{20}\}$ denotes the Controlled storage condition (25 °C and 50 %RH).

Interval estimation for $\ln \hat{B}_p$ of optical disk, one may consider only lower bound. Therefore, $(100-\alpha)$ % lower confidence bound of log lifetime $\ln \hat{B}_p$ is given as

$$(\ln \hat{B}_p)_L = \ln \hat{B}_p + z_{\alpha/100}\sqrt{Var\left[\ln \hat{B}_p\right]}) .$$

As the variances of $\ln \hat{B}_5$ and $\ln \hat{B}_{50}$ are represented by $Var[\ln \hat{B}_5]$ and $Var[\ln \hat{B}_{50}]$ respectively, the 95 % lower confidence bounds of $\ln \hat{B}_5$ and $\ln \hat{B}_{50}$ are given as follows.

$$\left(\ln \hat{B}_5\right)_L = \ln \hat{B}_5 \ -1{,}64\sqrt{Var[\ln \hat{B}_5]}$$

$$\left(\ln \hat{B}_{50}\right)_L = \ln \hat{B}_{50} -1{,}64\sqrt{Var[\ln \hat{B}_{50}]}$$

Where, $Var[\ln \hat{B}_5]$ and $Var[\ln \hat{B}_{50}]$ can be calculated by the following equations.

$$Var[\ln \hat{B}_5] = \begin{bmatrix} 1 & x_{10} & x_{20} & -1.64 \end{bmatrix} \begin{bmatrix} \mathrm{var}[\hat{\beta}_0] & \mathrm{Cov}[\hat{\beta}_0, \hat{\beta}_1] & \mathrm{Cov}[\hat{\beta}_0, \hat{\beta}_2] & \mathrm{Cov}[\hat{\beta}_0, \hat{\sigma}] \\ & \mathrm{var}[\hat{\beta}_1] & \mathrm{Cov}[\hat{\beta}_1, \hat{\beta}_2] & \mathrm{Cov}[\hat{\beta}_1, \hat{\sigma}] \\ & & \mathrm{var}[\hat{\beta}_2] & \mathrm{Cov}[\hat{\beta}_2, \hat{\sigma}] \\ & & & \mathrm{var}[\hat{\sigma}] \end{bmatrix} \begin{bmatrix} 1 \\ x_{10} \\ x_{20} \\ -1.64 \end{bmatrix}$$

$$Var[\ln \hat{B}_{50}] = \begin{bmatrix} 1 & x_{10} & x_{20} \end{bmatrix} \begin{bmatrix} Var[\hat{\beta}_0] & Cov[\hat{\beta}_0, \hat{\beta}_1] & Cov[\hat{\beta}_0, \hat{\beta}_2] \\ & Var[\hat{\beta}_1] & Cov[\hat{\beta}_1, \hat{\beta}_2] \\ & & Var[\hat{\beta}_2] \end{bmatrix} \begin{bmatrix} 1 \\ x_{10} \\ x_{20} \end{bmatrix}$$

NOTE $Conv\left[\hat{\beta}_a, \hat{\beta}_b\right]$ denotes covariance between $\hat{\beta}_a$ and $\hat{\beta}_b$.

Then, 95 % lower confidence bounds of B_5 Life is obtained as follows.

$$(B_5\ \text{Life})_L = (\exp(\ln \hat{B}_5))_L = \exp(\ln \hat{B}_5 - 1{,}64\sqrt{Var\left[\ln \hat{B}_5\right]})$$

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