Ecma International

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# Test Method for the Estimation of the Archival Lifetime of Optical Media

Standard

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## Introduction

Markets and industry have developed the common understanding that the property referred to as the archival life of data recorded to optical media plays an increasingly important role for the intended applications. The existing standard test methodologies for recordable media include Magneto Optical media and recordable compact disk systems. It was agreed that the project represented by this document be undertaken in order to provide a methodology that includes the testing of newer, currently available products.

The Optical Storage Technology Association (OSTA) initiated work on this subject and developed the initial drafts. Following that development, the project was moved to Ecma International TC31 for further development and finalization. OSTA and Ecma wish to thank the members and organizations in NIST, CDs21 Solutions, and DCAj for their support of the development of this document.

ECMA-379 1st Edition was fast-tracked to ISO/IEC JTC 1 in August 2007 and during this process, its editorial content was slightly modified. The approved ISO/IEC IS 10995 Standard was published by ISO/IEC in April 2008. ECMA-379 2nd Edition is technically identical with the published ISO/IEC Standard IS 10995 1st Edition. ECMA-379 3rd Edition is editorial amendment including corrections of some calculations, and Bootstrap method was deleted. Although Bootstrap method has no problem in itself, however, miscalculation might be caused depending on the data set conditions.

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

 

# Test Method for the Estimation of the Archival Lifetime of Optical Media

## Section 1 – General

## 1 Scope

This Ecma Standard specifies an accelerated aging test method for estimating the life expectancy 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. It may be applied to additional optical disk formats with the appropriate specification substitutions and may be updated by committee in the future as required.

This document includes;

- stress conditions
- assumptions
- ambient conditions
  - Controlled storage condition, e.g. 25 °C and 50 % RH, using the Eyring model
  - Uncontrolled storage condition, e.g. 30 °C and 80 % RH, using the Arrhenius model
- evaluation system description
- specimen preparation
- data acquisition procedure
- data interpretation

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, and variations in playback subsystems. Disks exposed to these additional sources of stress or higher levels of T and RH 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-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)*, 3rd edition (ISO/IEC 17341:2006)

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)*, 3rd edition (ISO/IEC 17344:2006)

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)*, 2nd edition (ISO/IEC 25434:2007)

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)* (ISO/IEC 26925:2006)

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)* (ISO/IEC 29642:2007)

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)

ISO 18927:2002, *Imaging materials – Recordable compact disc systems – Method for estimating the life expectancy based on the effects of temperature and relative humidity*

## 4 Terms and definitions

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

**4.1**
**archival (lifetime)**
ability of a medium or system to maintain the retrievability of recorded information for a specified extended period of years

**4.2**
**Arrhenius method**
accelerated aging model based on the effects of temperature

**4.3**
**baseline**
initial test analysis measurements (e.g., initial error rate) after recording and before exposure to a stress condition; measurement at stress time t=0 hours

**4.4**
**Eyring method**
accelerated aging model based on the effects of temperature and relative humidity

**4.5**
**error rate**
rate of errors on the sample disk measured before error correction is applied

**4.6**
**incubation**
process of enclosing and maintaining controlled test sample environments

**4.7**
**life expectancy (LE)**
length of time estimation that information is predicted to be retrievable in a system while in a specified environmental condition

**4.8**
**maximum error rate**
maximum of the error rate measured anywhere in one of the relevant areas on the disk.

NOTE 1 for DVD-R/RW and +R/+RW, this is the Maximum PI Sum 8, for DVD-RAM, this is the Maximum BER.

**4.9**
**retrievability**
ability to recover physical information as recorded

**4.10**
**stress**
temperature and relative humidity variables to which the sample is exposed for the duration of test incubation intervals

**4.11**
**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 implies 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 given a capital initial.

## 6 List of acronyms

BER byte error rate

LE life expectancy

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 4 stress conditions plus a control disk at room ambient condition. A minimum number of 20 disks will be included as a group for each stress condition as shown in Table 2.

Each stress condition's total time will be divided into interval time periods. Each disk in each group of disks will have their initial error rates measured before their exposure to stress conditions. Thereafter, each disk will be measured for its error rate after each stress condition incubation time interval. The control disk will 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 modeled by a statistical distribution,
- the Eyring model can be used to model acceleration with the two 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 retrievability of the information is attempted,
- the recorded format will be recognizable and interpretable by the reading software.

#### 7.1.3 Error Rate

Of all specimen media the Error rate shall be measured in the disk testing locations as defined in 7.5. For each sample the Maximum error rate 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.

Other disk formats not referenced in this document will have the maximum of their defined error rates determined.

Data collected at each time interval for each individual disk are then used to determine the estimated lifetime 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 at any in 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 $10^{-3}$ (See Annex E).

### 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 mean lifetimes are regressed against temperature and relative humidity according to an Eyring acceleration model.

## 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 shelf time.

## 7.3 Recording conditions

Before entering 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 recorded media minimum error rates. It is generally understood that optimally recorded media will yield the longest predicted life results. Media is deemed acceptable for entry into the aging tests when its error rate and all other media parametric specifications are found to be within its respective standard's specification limits.

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

The maximum recording speed shall be at the media's highest rated speed and this speed shall be reported.

### 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 h 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 that medium's standard or equivalent, 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 error rates, 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 error rate measured at the same time the stressed disks are measured initially and after each stress interval.

The mean and standard deviation of the control disk shall be established by collecting at least five measurements. Should any individual error rate reading 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

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. 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.

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

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

# 8 Accelerated stress test

## 8.1 General

Information properly recorded on an archival quality optical disk should have a life expectancy exceeding a predetermined number of years. Accelerated aging studies are used in order to conclude that a life expectancy exceeds the predetermined minimum number of years. This test plan is intended to provide the information necessary to satisfactorily evaluate the particular optical disk system including proposed archival quality optical disks.

## 8.2 Stress conditions

### 8.2.1 General

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

Four stress conditions and the minimum number of specimens for those stress conditions that shall be used are shown in Table 2. Additional specimens and conditions may be used if desired for improved precision.

The total time for each stress condition as given in Table 2 is divided into four equal incubation durations. The temperature and relative humidity during each incubation cycle shall be controlled as depicted in Table 3 and Figure 1. After each cycle of incubation all specimens shall be measured.

**Table 2 — Stress conditions for use with the Eyring Method**

| Test cell number | Test stress condition (incubation) | | Number of specimens | Incubation duration | Minimum Total time | Intermediate RH | Minimum equilibration duration |
|---|---|---|---|---|---|---|---|
| | Temp (°C) | %RH | | hours | hours | %RH | hours |
| 1a | 85 | 85 | 20 | 250 | 1 000 | 30 | 7 |
| 2a | 85 | 70 | 20 | 250 | 1 000 | 30 | 6 |
| 3a | 65 | 85 | 20 | 500 | 2 000 | 35 | 9 |
| 4a | 70 | 75 | 30 | 625 | 2 500 | 33 | 11 |

### 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 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 and +R/+RW disks indicates that an upper limit of 85 °C is practical for most applications.

### 8.2.3 Relative humidity (RH)

Experience indicates that 85 % 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 within the substrate, minimize substantial moisture gradients in the substrate and to end at ramp down completion with the substrate equilibrated to 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 ramp-down based on the diffusion coefficient of water in polycarbonate.

**Table 3 — T and RH transition (ramp) profile for each incubation cycle**

| 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 $RH_{amb}$

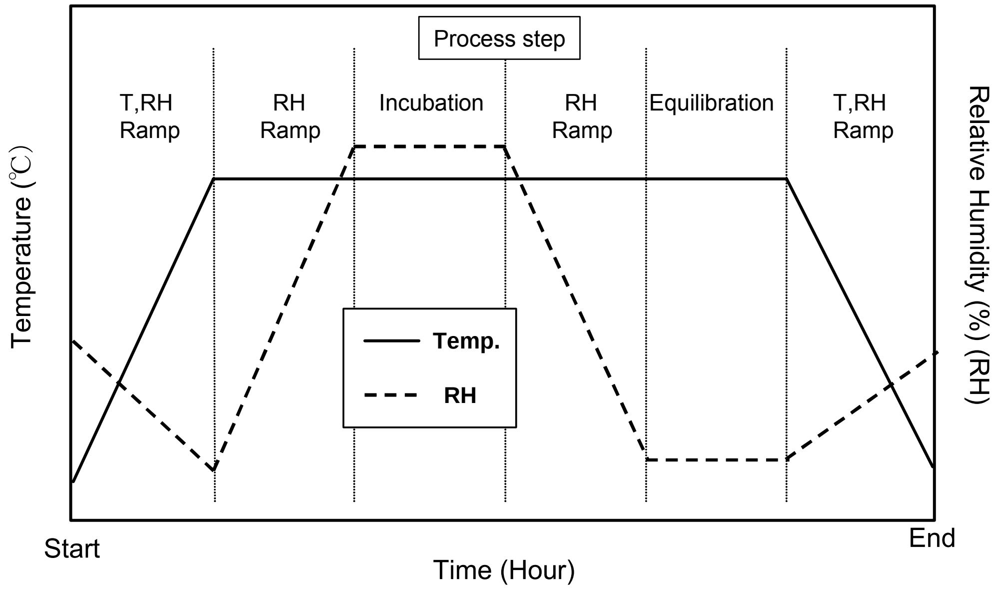


**Figure 1 — Graph of typical transition (ramp) profile**

## 8.3 Measuring Time intervals

For data collection, PI Sum 8 (DVD–R, DVD–RW, +R, +RW), or BER (DVD-RAM) measurements for each disk will occur: 1) before disk exposure to any stress condition to determine its baseline measurement and 2) after each cycle 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 specifies the temperatures, relative humidities, time intervals, minimum total test time, and minimum number of specimens for each stress condition. A separate group of specimens is used for each stress condition.

All temperatures may deviate ±2 °C of the target temperature; all relative humidities may deviate ±3 % RH of the target relative humidity.

The intermediate relative humidity ($RH_{int}$) in Table 2 is 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:

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

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 Tables 2 and 3 offer sufficient combinations of temperature and relative humidity to satisfy the mathematical requirements of the Eyring model to demonstrate linearity of either Max

PI Sum 8, or Max BER 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 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 error rate measurements.

## 9 Data Evaluation

### 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, and Max BER exceeding $10^{-3}$ for DVD-RAM.

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 data values of: PI Sum 8 or BER as a function 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 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:

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

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

### 9.3 Data analysis

Data Analysis is contained in the following Annexes:

Annex A: Data Analysis Steps Outline for Calculation of Media Life

Annex B: Analysis for Calculation of Media Life

Annex C: Uncontrolled Ambient Condition Media Life Calculation

Annex D: Truncated Test Method (Determination of Media Life Lower Bound)

## Annex A
(normative)

## Data Analysis Steps Outline for Calculation of Media Life

The following is an outline of steps to estimate the life expectancy value, as a function of ambient temperature and relative humidity, and used to determine if a disk will or will not exceed a life expectancy of X-years.

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

   For each stress condition, determine the median rank of each specimen, and plot the median rank versus time-to-failure on a lognormal graph.

3. Verify that the plots for all stress conditions are reasonably parallel to one another.

NOTE In the case where the plots are not determined to be reasonably parallel, 7.1.2 Assumptions shall be checked.

4. Using the *reduced* Eyring equation, carry out a least squares fit to the log failure times across all specimens and stress conditions.
5. Calculate acceleration factors for each stress condition.
6. For the ambient condition, calculate normalized time-to-failure for each disk.

For the ambient condition, calculate 95 % survival probability with 95 % confidence for lifetime.

# Annex B
(normative)

## Analysis for Calculation of Media Life

**Step 1**

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

For DVD-R/-RW, +R/+RW: PI Sum 8
For DVD-RAM: BER

Use the initial error rate measured prior to accelerated aging plus the error rates measured after each specified accelerated aging incubation interval.

For each specimen a linear regression is performed with the ln (measured error rates), 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 BLER of 220, or a Max PI Sum 8 of 280, or a Max BER of $10^{-3}$.

For example data, a purely hypothetical data set was generated. These values were completely fabricated for this assumption. The data is offered solely as an example of the mathematical methodology used in this test procedure.

**Table B.1 — Estimated time to failure for example data**

| Group 1a | 85°C/85%RH | | | | | |
|---|---|---|---|---|---|---|
| Disk # | Hours | | | | | Hours to Failure |
| | 0 | 250 | 500 | 750 | 1 000 | |
| A1 | 16 | 78 | 116 | 278 | 445 | 788 |
| A2 | 25 | 64 | 134 | 342 | 532 | 743 |
| A3 | 26 | 94 | 190 | 335 | 642 | 685 |
| A4 | 26 | 111 | 247 | 343 | 718 | 647 |
| A5 | 27 | 89 | 185 | 246 | 466 | 762 |
| A6 | 21 | 111 | 207 | 567 | 896 | 607 |
| A7 | 26 | 121 | 274 | 589 | 781 | 588 |
| A8 | 31 | 108 | 223 | 315 | 745 | 654 |
| A9 | 24 | 118 | 285 | 723 | 754 | 578 |
| A10 | 12 | 85 | 178 | 312 | 988 | 669 |
| A11 | 28 | 111 | 167 | 312 | 771 | 671 |
| A12 | 24 | 136 | 267 | 444 | 719 | 614 |
| A13 | 35 | 76 | 265 | 567 | 610 | 626 |
| A14 | 19 | 53 | 112 | 278 | 534 | 778 |
| A15 | 28 | 88 | 158 | 308 | 654 | 704 |
| A16 | 27 | 68 | 120 | 263 | 432 | 807 |
| A17 | 18 | 87 | 176 | 302 | 558 | 723 |
| A18 | 26 | 109 | 238 | 421 | 641 | 645 |
| A19 | 26 | 111 | 253 | 378 | 638 | 649 |
| A20 | 31 | 91 | 206 | 367 | 728 | 656 |

 

| Group 2a | 85°C/70%RH | | | | | |
|---|---|---|---|---|---|---|
| Disk # | Hours | | | | | Hours to Failure |
| | 0 | 250 | 500 | 750 | 1 000 | |
| B1 | 10 | 20 | 67 | 112 | 156 | 1 117 |
| B2 | 8 | 20 | 47 | 84 | 188 | 1 118 |
| B3 | 12 | 26 | 72 | 185 | 421 | 880 |
| B4 | 20 | 43 | 120 | 166 | 219 | 999 |
| B5 | 32 | 45 | 76 | 103 | 267 | 1 126 |
| B6 | 21 | 37 | 104 | 222 | 368 | 870 |
| B7 | 21 | 30 | 89 | 155 | 221 | 1 035 |
| B8 | 22 | 26 | 72 | 125 | 267 | 1 043 |
| B9 | 25 | 46 | 124 | 182 | 224 | 994 |
| B10 | 17 | 38 | 67 | 179 | 378 | 911 |
| B11 | 28 | 58 | 88 | 120 | 268 | 1 065 |
| B12 | 8 | 15 | 36 | 144 | 189 | 1 059 |
| B13 | 10 | 27 | 89 | 175 | 385 | 880 |
| B14 | 23 | 54 | 111 | 148 | 221 | 1 037 |
| B15 | 28 | 39 | 125 | 172 | 278 | 959 |
| B16 | 25 | 53 | 88 | 130 | 188 | 1 149 |
| B17 | 20 | 43 | 75 | 166 | 256 | 999 |
| B18 | 22 | 26 | 50 | 172 | 229 | 1 058 |
| B19 | 13 | 38 | 78 | 124 | 189 | 1 078 |
| B20 | 10 | 19 | 28 | 121 | 268 | 1 046 |

| Group 3a | 65°C/85%RH | | | | | |
|---|---|---|---|---|---|---|
| Disk # | Hours | | | | | Hours to failure |
| | 0 | 500 | 1 000 | 1 500 | 2 000 | |
| C1 | 14 | 23 | 58 | 112 | 278 | 2 057 |
| C2 | 10 | 17 | 55 | 165 | 263 | 1 948 |
| C3 | 11 | 56 | 88 | 138 | 189 | 2 078 |
| C4 | 18 | 28 | 78 | 117 | 243 | 2 106 |
| C5 | 17 | 45 | 78 | 143 | 189 | 2 167 |
| C6 | 10 | 14 | 45 | 154 | 231 | 2 031 |
| C7 | 31 | 53 | 111 | 156 | 211 | 2 151 |
| C8 | 29 | 54 | 106 | 154 | 218 | 2 128 |
| C9 | 22 | 32 | 65 | 89 | 126 | 2 799 |
| C10 | 29 | 36 | 78 | 145 | 188 | 2 297 |
| C11 | 21 | 38 | 89 | 148 | 227 | 2 075 |
| C12 | 24 | 45 | 68 | 134 | 211 | 2 236 |
| C13 | 28 | 57 | 78 | 132 | 190 | 2 352 |
| C14 | 19 | 47 | 61 | 117 | 150 | 2 486 |
| C15 | 25 | 65 | 89 | 184 | 256 | 1 972 |
| C16 | 10 | 18 | 57 | 113 | 178 | 2 189 |
| C17 | 21 | 34 | 45 | 98 | 121 | 2 845 |
| C18 | 12 | 20 | 34 | 112 | 176 | 2 308 |
| C19 | 28 | 56 | 108 | 176 | 243 | 2 001 |
| C20 | 29 | 36 | 57 | 143 | 238 | 2 207 |

| Group 4a | 70°C/75%RH | | | | | |
|---|---|---|---|---|---|---|
| Disk # | Hours | | | | | Hours to failure |
| | 0 | 625 | 1 250 | 1 875 | 2 500 | |
| D1 | 25 | 34 | 64 | 92 | 167 | 3 240 |
| D2 | 25 | 93 | 134 | 154 | 211 | 2 596 |
| D3 | 7 | 23 | 97 | 103 | 178 | 2 615 |
| D4 | 10 | 20 | 56 | 89 | 155 | 2 920 |
| D5 | 5 | 20 | 78 | 132 | 187 | 2 496 |
| D6 | 5 | 15 | 52 | 112 | 167 | 2 644 |
| D7 | 22 | 34 | 67 | 132 | 188 | 2 851 |
| D8 | 12 | 17 | 56 | 78 | 108 | 3 318 |
| D9 | 22 | 34 | 67 | 132 | 189 | 2 847 |
| D10 | 23 | 27 | 54 | 121 | 152 | 3 129 |
| D11 | 11 | 20 | 41 | 87 | 115 | 3 249 |
| D12 | 15 | 18 | 43 | 88 | 118 | 3 343 |
| D13 | 19 | 21 | 38 | 82 | 135 | 3 435 |
| D14 | 18 | 22 | 86 | 178 | 245 | 2 456 |
| D15 | 22 | 26 | 73 | 145 | 252 | 2 582 |
| D16 | 18 | 18 | 29 | 66 | 127 | 3 649 |
| D17 | 22 | 26 | 93 | 145 | 178 | 2 761 |
| D18 | 18 | 27 | 56 | 88 | 134 | 3 316 |
| D19 | 11 | 32 | 44 | 97 | 143 | 3 051 |
| D20 | 12 | 56 | 66 | 124 | 249 | 2 550 |
| D21 | 14 | 34 | 54 | 77 | 112 | 3 500 |
| D22 | 20 | 23 | 25 | 50 | 181 | 3 593 |
| D23 | 11 | 16 | 27 | 54 | 160 | 3 275 |
| D24 | 17 | 24 | 25 | 58 | 108 | 4 034 |
| D25 | 11 | 25 | 22 | 62 | 130 | 3 488 |
| D26 | 17 | 24 | 25 | 70 | 123 | 3 707 |
| D27 | 21 | 39 | 63 | 78 | 163 | 3 304 |
| D28 | 20 | 28 | 45 | 111 | 243 | 2 787 |
| D29 | 15 | 21 | 38 | 65 | 134 | 3 453 |
| D30 | 10 | 34 | 54 | 96 | 176 | 2 841 |

**Step 2**

For each stress condition, 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), where i is the time-to-failure order and n is the total number of specimens at the stress condition.

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; the median rank is converted to the probability of failure by multiplying by 100.

If linear axes are desired, the data can be linearized by plotting the critical value for the normal cumulative distribution of the median rank on the ordinate and the natural logarithm of the time-to-failure on the abscissa.

The critical value for the normal cumulative distribution of the median rank is the value of t for which F (t) (the cumulative distribution function) equals the median rank.

**Table B.2 — Median rank and the critical value for estimated time to failure**

| Group 1a | | 85°C/85%RH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ascending order number | Disk # | Hours | | | | | Hours to Failure(H) | ascending ln(H) | median rank | critical value |
| | | 0 | 250 | 500 | 750 | 1 000 | | | | |
| 1 | A9 | 24 | 118 | 285 | 723 | 754 | 578 | 6,3596 | 0,034 | -1,821 |
| 2 | A7 | 26 | 121 | 274 | 589 | 781 | 588 | 6,3767 | 0,083 | -1,383 |
| 3 | A6 | 21 | 111 | 207 | 567 | 896 | 607 | 6,4085 | 0,132 | -1,115 |
| 4 | A12 | 24 | 136 | 267 | 444 | 719 | 614 | 6,4200 | 0,181 | -0,910 |
| 5 | A13 | 35 | 76 | 265 | 567 | 610 | 626 | 6,4394 | 0,230 | -0,738 |
| 6 | A18 | 26 | 109 | 238 | 421 | 641 | 645 | 6,4693 | 0,279 | -0,585 |
| 7 | A4 | 26 | 111 | 247 | 343 | 718 | 647 | 6,4723 | 0,328 | -0,444 |
| 8 | A19 | 26 | 111 | 253 | 378 | 638 | 649 | 6,4754 | 0,377 | -0,312 |
| 9 | A8 | 31 | 108 | 223 | 315 | 745 | 654 | 6,4831 | 0,426 | -0,185 |
| 10 | A20 | 31 | 91 | 206 | 367 | 728 | 656 | 6,4862 | 0,475 | -0,061 |
| 11 | A10 | 12 | 85 | 178 | 312 | 988 | 669 | 6,5058 | 0,525 | 0,061 |
| 12 | A11 | 28 | 111 | 167 | 312 | 771 | 671 | 6,5088 | 0,574 | 0,185 |
| 13 | A3 | 26 | 94 | 190 | 335 | 642 | 685 | 6,5294 | 0,623 | 0,312 |
| 14 | A15 | 28 | 88 | 158 | 308 | 654 | 704 | 6,5568 | 0,672 | 0,444 |
| 15 | A17 | 18 | 87 | 176 | 302 | 558 | 723 | 6,5834 | 0,721 | 0,585 |
| 16 | A2 | 25 | 64 | 134 | 342 | 532 | 743 | 6,6107 | 0,770 | 0,738 |
| 17 | A5 | 27 | 89 | 185 | 246 | 466 | 762 | 6,6359 | 0,819 | 0,910 |
| 18 | A14 | 19 | 53 | 112 | 278 | 534 | 778 | 6,6567 | 0,868 | 1,115 |
| 19 | A1 | 16 | 78 | 116 | 278 | 445 | 788 | 6,6695 | 0,917 | 1,383 |
| 20 | A16 | 27 | 68 | 120 | 263 | 432 | 807 | 6,6933 | 0,966 | 1,821 |
| | | | | | median | | 663 | 6,4960 | | |

| Group 2a | | 85°C/70%RH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| order number | Disk # | Hours | | | | | Hours to Failure(H) | ascending ln(H) | median rank | critical value |
| | | 0 | 250 | 500 | 750 | 1 000 | | | | |
| 1 | B6 | 21 | 37 | 104 | 222 | 368 | 870 | 6,7685 | 0,034 | -1,821 |
| 2 | B3 | 12 | 26 | 72 | 185 | 421 | 880 | 6,7799 | 0,083 | -1,383 |
| 3 | B13 | 10 | 27 | 89 | 175 | 385 | 880 | 6,7799 | 0,132 | -1,115 |
| 4 | B10 | 17 | 38 | 67 | 179 | 378 | 911 | 6,8145 | 0,181 | -0,910 |
| 5 | B15 | 28 | 39 | 125 | 172 | 278 | 959 | 6,8659 | 0,230 | -0,738 |
| 6 | B9 | 25 | 46 | 124 | 182 | 224 | 994 | 6,9017 | 0,279 | -0,585 |
| 7 | B4 | 20 | 43 | 120 | 166 | 219 | 999 | 6,9068 | 0,328 | -0,444 |
| 8 | B17 | 20 | 43 | 75 | 166 | 256 | 999 | 6,9068 | 0,377 | -0,312 |
| 9 | B7 | 21 | 30 | 89 | 155 | 221 | 1 035 | 6,9422 | 0,426 | -0,185 |
| 10 | B14 | 23 | 54 | 111 | 148 | 221 | 1 037 | 6,9441 | 0,475 | -0,061 |
| 11 | B8 | 22 | 26 | 72 | 125 | 267 | 1 043 | 6,9499 | 0,525 | 0,061 |
| 12 | B20 | 10 | 19 | 28 | 121 | 268 | 1 046 | 6,9527 | 0,574 | 0,185 |
| 13 | B18 | 22 | 26 | 50 | 172 | 229 | 1 058 | 6,9641 | 0,623 | 0,312 |
| 14 | B12 | 8 | 15 | 36 | 144 | 189 | 1 059 | 6,9651 | 0,672 | 0,444 |
| 15 | B11 | 28 | 58 | 88 | 120 | 268 | 1 065 | 6,9707 | 0,721 | 0,585 |
| 16 | B19 | 13 | 38 | 78 | 124 | 189 | 1 078 | 6,9829 | 0,770 | 0,738 |
| 17 | B1 | 10 | 20 | 67 | 112 | 156 | 1 117 | 7,0184 | 0,819 | 0,910 |
| 18 | B2 | 8 | 20 | 47 | 84 | 188 | 1 118 | 7,0193 | 0,868 | 1,115 |
| 19 | B5 | 32 | 45 | 76 | 103 | 267 | 1 126 | 7,0264 | 0,917 | 1,383 |
| 20 | B16 | 25 | 53 | 88 | 130 | 188 | 1 149 | 7,0466 | 0,966 | 1,821 |
| | | | | | median | | 1 040 | 6,9470 | | |

**Table B.2 — Median rank and the critical value for estimated time to failure (continued)**

| Group 3a | | 65°C/85%RH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| order number | Disk # | Hours | | | | | Hours to failure(H) | ascending ln(H) | median rank | critical value |
| | | 0 | 500 | 1 000 | 1 500 | 2 000 | | | | |
| 1 | C2 | 10 | 17 | 55 | 165 | 263 | 1 948 | 7,5746 | 0,034 | -1,821 |
| 2 | C15 | 25 | 65 | 89 | 184 | 256 | 1 972 | 7,5868 | 0,083 | -1,383 |
| 3 | C19 | 28 | 56 | 108 | 176 | 243 | 2 001 | 7,6014 | 0,132 | -1,115 |
| 4 | C6 | 10 | 14 | 45 | 154 | 231 | 2 031 | 7,6163 | 0,181 | -0,910 |
| 5 | C1 | 14 | 23 | 58 | 112 | 278 | 2 057 | 7,6290 | 0,230 | -0,738 |
| 6 | C11 | 21 | 38 | 89 | 148 | 227 | 2 075 | 7,6377 | 0,279 | -0,585 |
| 7 | C3 | 11 | 56 | 88 | 138 | 189 | 2 078 | 7,6392 | 0,328 | -0,444 |
| 8 | C4 | 18 | 28 | 78 | 117 | 243 | 2 106 | 7,6525 | 0,377 | -0,312 |
| 9 | C8 | 29 | 54 | 106 | 154 | 218 | 2 128 | 7,6629 | 0,426 | -0,185 |
| 10 | C7 | 31 | 53 | 111 | 156 | 211 | 2 151 | 7,6737 | 0,475 | -0,061 |
| 11 | C5 | 17 | 45 | 78 | 143 | 189 | 2 167 | 7,6811 | 0,525 | 0,061 |
| 12 | C16 | 10 | 18 | 57 | 113 | 178 | 2 189 | 7,6912 | 0,574 | 0,185 |
| 13 | C20 | 29 | 36 | 57 | 143 | 238 | 2 207 | 7,6994 | 0,623 | 0,312 |
| 14 | C12 | 24 | 45 | 68 | 134 | 211 | 2 236 | 7,7124 | 0,672 | 0,444 |
| 15 | C10 | 29 | 36 | 78 | 145 | 188 | 2 297 | 7,7394 | 0,721 | 0,585 |
| 16 | C18 | 12 | 20 | 34 | 112 | 176 | 2 308 | 7,7441 | 0,770 | 0,738 |
| 17 | C13 | 28 | 57 | 78 | 132 | 190 | 2 352 | 7,7630 | 0,819 | 0,910 |
| 18 | C14 | 19 | 47 | 61 | 117 | 150 | 2 486 | 7,8184 | 0,868 | 1,115 |
| 19 | C9 | 22 | 32 | 65 | 89 | 126 | 2 799 | 7,9370 | 0,917 | 1,383 |
| 20 | C17 | 21 | 34 | 45 | 98 | 121 | 2 845 | 7,9533 | 0,966 | 1,821 |
| | | | | | | median | 2 159 | 7,6774 | | |

**Table B.2 — Median rank and the critical value for estimated time to failure (concluded)**

| Group 4a | | 70°C/75%RH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| order number | Disk # | Hours | | | | | Hours to failure(H) | ascending ln(H) | median rank | critical value |
| | | 0 | 625 | 1 250 | 1 875 | 2 500 | | | | |
| 1 | D14 | 18 | 22 | 86 | 178 | 245 | 2 456 | 7,8063 | 0,023 | -1,995 |
| 2 | D5 | 5 | 20 | 78 | 132 | 187 | 2 496 | 7,8224 | 0,056 | -1,590 |
| 3 | D20 | 12 | 56 | 66 | 124 | 249 | 2 550 | 7,8438 | 0,089 | -1,348 |
| 4 | D15 | 22 | 26 | 73 | 145 | 252 | 2 582 | 7,8563 | 0,122 | -1,166 |
| 5 | D2 | 25 | 93 | 134 | 154 | 211 | 2 596 | 7,8617 | 0,155 | -1,017 |
| 6 | D3 | 7 | 23 | 97 | 103 | 178 | 2 615 | 7,8690 | 0,188 | -0,887 |
| 7 | D6 | 5 | 15 | 52 | 112 | 167 | 2 644 | 7,8800 | 0,220 | -0,771 |
| 8 | D17 | 22 | 26 | 93 | 145 | 178 | 2 761 | 7,9233 | 0,253 | -0,664 |
| 9 | D28 | 20 | 28 | 45 | 111 | 243 | 2 787 | 7,9327 | 0,286 | -0,565 |
| 10 | D30 | 10 | 34 | 54 | 96 | 176 | 2 841 | 7,9519 | 0,319 | -0,470 |
| 11 | D9 | 22 | 34 | 67 | 132 | 189 | 2 847 | 7,9540 | 0,352 | -0,380 |
| 12 | D7 | 22 | 34 | 67 | 132 | 188 | 2 851 | 7,9554 | 0,385 | -0,293 |
| 13 | D4 | 10 | 20 | 56 | 89 | 155 | 2 920 | 7,9793 | 0,418 | -0,208 |
| 14 | D19 | 11 | 32 | 44 | 97 | 143 | 3 051 | 8,0232 | 0,451 | -0,124 |
| 15 | D10 | 23 | 27 | 54 | 121 | 152 | 3 129 | 8,0485 | 0,484 | -0,041 |
| 16 | D1 | 25 | 34 | 64 | 92 | 167 | 3 240 | 8,0833 | 0,516 | 0,041 |
| 17 | D11 | 11 | 20 | 41 | 87 | 115 | 3 249 | 8,0861 | 0,549 | 0,124 |
| 18 | D23 | 11 | 16 | 27 | 54 | 160 | 3 275 | 8,0941 | 0,582 | 0,208 |
| 19 | D27 | 21 | 39 | 63 | 78 | 163 | 3 304 | 8,1029 | 0,615 | 0,293 |
| 20 | D18 | 18 | 27 | 56 | 88 | 134 | 3 316 | 8,1065 | 0,648 | 0,380 |
| 21 | D8 | 12 | 17 | 56 | 78 | 108 | 3 318 | 8,1071 | 0,681 | 0,470 |
| 22 | D12 | 15 | 18 | 43 | 88 | 118 | 3 343 | 8,1146 | 0,714 | 0,565 |
| 23 | D13 | 19 | 21 | 38 | 82 | 135 | 3 435 | 8,1418 | 0,747 | 0,664 |
| 24 | D29 | 15 | 21 | 38 | 65 | 134 | 3 453 | 8,1470 | 0,780 | 0,771 |
| 25 | D25 | 11 | 25 | 22 | 62 | 130 | 3 488 | 8,1571 | 0,813 | 0,887 |
| 26 | D21 | 14 | 34 | 54 | 77 | 112 | 3 500 | 8,1605 | 0,845 | 1,017 |
| 27 | D22 | 20 | 23 | 25 | 50 | 181 | 3 593 | 8,1867 | 0,878 | 1,166 |
| 28 | D16 | 18 | 18 | 29 | 66 | 127 | 3 649 | 8,2022 | 0,911 | 1,348 |
| 29 | D26 | 17 | 24 | 25 | 70 | 123 | 3 707 | 8,2180 | 0,944 | 1,590 |
| 30 | D24 | 17 | 24 | 25 | 58 | 108 | 4 034 | 8,3025 | 0,977 | 1,995 |
| | | | | | | median | 3 185 | 8,0659 | | |

**Step 3**

Best-fit straight lines are 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.

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 16 %, 50 %, and 84 % failure based on the best fit straight line through the time-to-failure data. The estimated log standard deviation $\sigma$ 1is then calculated from the equation:

$$\sigma_1 = \ln[\frac{1}{2}\left(\frac{t_{50\%}}{t_{16\%}} + \frac{t_{84\%}}{t_{50\%}}\right)]$$

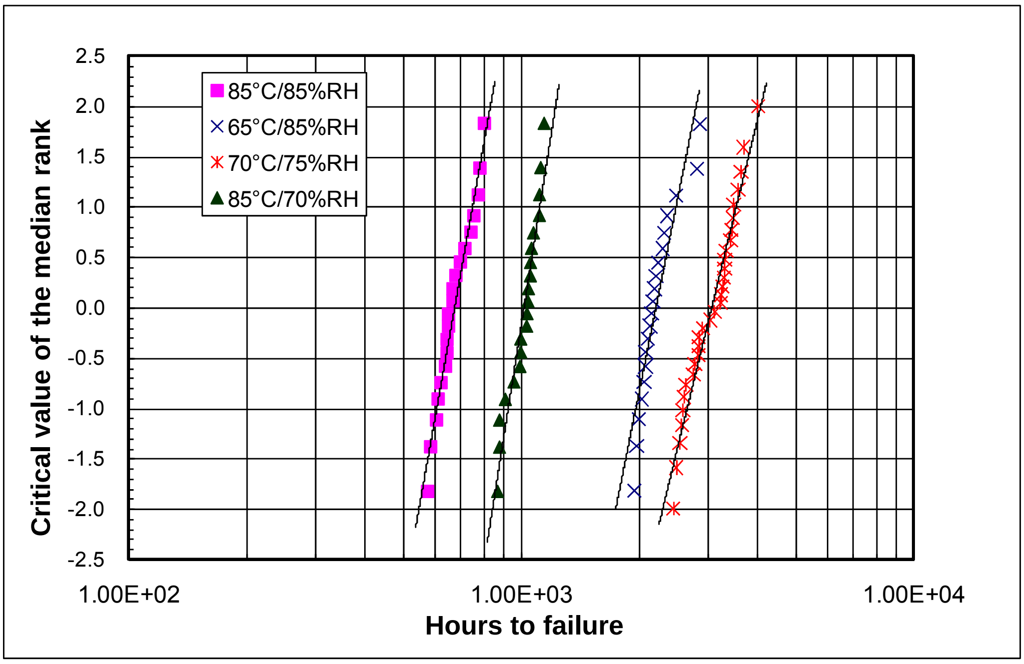


**Figure B.1 — Lognormal plot of Table B.2**

**Step 4**

Using the *reduced* Eyring equation, carry out a least squares fit to the log *median* failure times *for each stress condition* across all specimens and stress conditions.

**Table B.3 — Log mean for each stress condition**

| Group | Log *median* | Temp. | 1/T(Kelvin) | Humidity |
|---|---|---|---|---|
| 1a | 6,4960 | 85 | 0.00279213 | 85 |
| 2a | 6,9470 | 85 | 0.00279213 | 70 |
| 3a | 7,6774 | 65 | 0.00295727 | 85 |
| 4a | 8,0659 | 70 | 0.00291418 | 75 |

**Table B.4 -— Coefficients of reduced Eyring equation**

| B | ΔH/k | ln(A) |
|---|---|---|
| -0,0432 | 8 427,9450 | -13,4380 |

**Step 5**

Calculate acceleration factors for each stress condition

$Life_{stress}$ = Exp {ln(A) + (ΔH/k × 1/$Temp_{stress}$) + (B × $RH_{stress}$) }

$Temp_{stress}$ = Temperature (in Kelvin)

Calculating stress life using "best fit" B, ΔH/k, ln(A)

85°C/85%RH = Exp { (-13,4380) + (8 427,9450 × 1/358,15) + (-0,0432 × 85) } = 615,16 hours

85°C/70%RH = Exp { (-13,4380) + (8 427,9450 × 1/358,15) + (-0,0432 × 70) } = 1 176,01 hours

65°C/85%RH = Exp { (-13,4380) + (8 427,9450 × 1/338,15) + (-0,0432 × 85) } = 2 474,24 hours

70°C/75%RH = Exp { (-13,4380) + (8 427,9450 × 1/343,15) + (-0,0432 × 75) } = 2 650,56 hours

25°C/50%RH = Exp { (-13,4380) + (8 427,9450 × 1/298,15) + (-0,0432 × 50) } = 31 7891,70 hours

Calculating acceleration factor for each stress condition

Acceleration factor = (Calculated ambient life) divided by (calculated stress life)

**Table B.5 — Acceleration factor for each stress condition**

| Stress | Calculated life using "best fit" B, ΔH/k, ln(A) | Acceleration factor |
|---|---|---|
| 85°C/85%RH | 615,16 hours | 516,76 |
| 85°C/70%RH | 1 176,01 hours | 270,31 |
| 65°C/85%RH | 2 474,24 hours | 128,48 |
| 70°C/75%RH | 2 650,56 hours | 119,93 |
| 25°C/50%RH | 317 891,70 hours | |

**Step 6**

**Calculate normalized time-to-failure at 25 °C/50%RH for each disk**

Use the acceleration factor to calculate the normalized time-to-failure.
Log the normalized time-to-failure values.
Calculate median and standard deviation for all disks.

Median Exp (12,66) = 314 896,7 hours (35,9 years)

# Table B.6 — Data for composite lognormal plot

| Hours to Failure | Group# | normalized to 25C/50%RH (A) | ln of (A) | Group# | Ascending (A) | Ascending ln (A) | order | media rank | critical value |
|---|---|---|---|---|---|---|---|---|---|
| 788 | 1 | 407,206.88 | 12.92 | 2 | 235,169.70 | 12.37 | 1 | 0.0077 | -2.4208 |
| 743 | 1 | 383,952.68 | 12.86 | 2 | 237,872.80 | 12.38 | 2 | 0.0188 | -2.0791 |
| 685 | 1 | 353,980.60 | 12.78 | 2 | 237,872.80 | 12.38 | 3 | 0.0299 | -1.8827 |
| 647 | 1 | 334,343.72 | 12.72 | 2 | 246,252.41 | 12.41 | 4 | 0.0409 | -1.7400 |
| 762 | 1 | 393,771.12 | 12.88 | 3 | 250,279.04 | 12.43 | 5 | 0.0520 | -1.6258 |
| 607 | 1 | 313,673.32 | 12.66 | 3 | 253,362.56 | 12.44 | 6 | 0.0631 | -1.5296 |
| 588 | 1 | 303,854.88 | 12.62 | 3 | 257,088.48 | 12.46 | 7 | 0.0741 | -1.4458 |
| 654 | 1 | 337,961.04 | 12.73 | 2 | 259,227.29 | 12.47 | 8 | 0.0852 | -1.3711 |
| 578 | 1 | 298,687.28 | 12.61 | 3 | 260,942.88 | 12.47 | 9 | 0.0962 | -1.3033 |
| 669 | 1 | 345,712.44 | 12.75 | 3 | 264,283.36 | 12.48 | 10 | 0.1073 | -1.2410 |
| 671 | 1 | 346,745.96 | 12.76 | 3 | 266,596.00 | 12.49 | 11 | 0.1184 | -1.1832 |
| 614 | 1 | 317,290.64 | 12.67 | 3 | 266,981.44 | 12.49 | 12 | 0.1294 | -1.1291 |
| 626 | 1 | 323,491.76 | 12.69 | 2 | 268,688.14 | 12.50 | 13 | 0.1405 | -1.0781 |
| 778 | 1 | 402,039.28 | 12.90 | 2 | 270,039.69 | 12.51 | 14 | 0.1515 | -1.0298 |
| 704 | 1 | 363,799.04 | 12.80 | 2 | 270,039.69 | 12.51 | 15 | 0.1626 | -0.9838 |
| 807 | 1 | 417,025.32 | 12.94 | 3 | 270,578.88 | 12.51 | 16 | 0.1737 | -0.9398 |
| 723 | 1 | 373,617.48 | 12.83 | 3 | 273,405.44 | 12.52 | 17 | 0.1847 | -0.8975 |
| 645 | 1 | 333,310.20 | 12.72 | 3 | 276,360.48 | 12.53 | 18 | 0.1958 | -0.8567 |
| 649 | 1 | 335,377.24 | 12.72 | 3 | 278,416.16 | 12.54 | 19 | 0.2069 | -0.8174 |
| 656 | 1 | 338,994.56 | 12.73 | 2 | 279,770.85 | 12.54 | 20 | 0.2179 | -0.7792 |
| 1,117 | 2 | 301,936.27 | 12.62 | 2 | 280,311.47 | 12.54 | 21 | 0.2290 | -0.7422 |
| 1,118 | 2 | 302,206.58 | 12.62 | 3 | 281,242.72 | 12.55 | 22 | 0.2400 | -0.7062 |
| 880 | 2 | 237,872.80 | 12.38 | 2 | 281,933.33 | 12.55 | 23 | 0.2511 | -0.6710 |
| 999 | 2 | 270,039.69 | 12.51 | 2 | 282,744.26 | 12.55 | 24 | 0.2622 | -0.6367 |
| 1,126 | 2 | 304,369.06 | 12.63 | 3 | 283,555.36 | 12.56 | 25 | 0.2732 | -0.6031 |
| 870 | 2 | 235,169.70 | 12.37 | 2 | 285,987.98 | 12.56 | 26 | 0.2843 | -0.5701 |
| 1,035 | 2 | 279,770.85 | 12.54 | 2 | 286,258.29 | 12.56 | 27 | 0.2954 | -0.5378 |
| 1,043 | 2 | 281,933.33 | 12.55 | 3 | 287,281.28 | 12.57 | 28 | 0.3064 | -0.5060 |
| 994 | 2 | 268,688.14 | 12.50 | 2 | 287,880.15 | 12.57 | 29 | 0.3175 | -0.4748 |
| 911 | 2 | 246,252.41 | 12.41 | 2 | 291,394.18 | 12.58 | 30 | 0.3285 | -0.4439 |
| 1,065 | 2 | 287,880.15 | 12.57 | 4 | 294,548.08 | 12.59 | 31 | 0.3396 | -0.4136 |
| 1,059 | 2 | 286,258.29 | 12.56 | 3 | 295,118.56 | 12.60 | 32 | 0.3507 | -0.3835 |
| 880 | 2 | 237,872.80 | 12.38 | 3 | 296,531.84 | 12.60 | 33 | 0.3617 | -0.3538 |
| 1,037 | 2 | 280,311.47 | 12.54 | 1 | 298,687.28 | 12.61 | 34 | 0.3728 | -0.3245 |
| 959 | 2 | 259,227.29 | 12.47 | 4 | 299,345.28 | 12.61 | 35 | 0.3838 | -0.2954 |
| 1,149 | 2 | 310,586.19 | 12.65 | 2 | 301,936.27 | 12.62 | 36 | 0.3949 | -0.2665 |
| 999 | 2 | 270,039.69 | 12.51 | 3 | 302,184.96 | 12.62 | 37 | 0.4060 | -0.2379 |
| 1,058 | 2 | 285,987.98 | 12.56 | 2 | 302,206.58 | 12.62 | 38 | 0.4170 | -0.2095 |
| 1,078 | 2 | 291,394.18 | 12.58 | 1 | 303,854.88 | 12.62 | 39 | 0.4281 | -0.1812 |
| 1,046 | 2 | 282,744.26 | 12.55 | 2 | 304,369.06 | 12.63 | 40 | 0.4392 | -0.1531 |
| 2,057 | 3 | 264,283.36 | 12.48 | 4 | 305,821.50 | 12.63 | 41 | 0.4502 | -0.1251 |
| 1,948 | 3 | 250,279.04 | 12.43 | 4 | 309,659.26 | 12.64 | 42 | 0.4613 | -0.0972 |
| 2,078 | 3 | 266,981.44 | 12.49 | 2 | 310,586.19 | 12.65 | 43 | 0.4723 | -0.0694 |
| 2,106 | 3 | 270,578.88 | 12.51 | 4 | 311,338.28 | 12.65 | 44 | 0.4834 | -0.0416 |
| 2,167 | 3 | 278,416.16 | 12.54 | 4 | 313,616.95 | 12.66 | 45 | 0.4945 | -0.0139 |
| 2,031 | 3 | 260,942.88 | 12.47 | 1 | 313,673.32 | 12.66 | 46 | 0.5055 | 0.0139 |
| 2,151 | 3 | 276,360.48 | 12.53 | 4 | 317,094.92 | 12.67 | 47 | 0.5166 | 0.0416 |
| 2,128 | 3 | 273,405.44 | 12.52 | 1 | 317,290.64 | 12.67 | 48 | 0.5277 | 0.0694 |
| 2,799 | 3 | 359,615.52 | 12.79 | 3 | 319,401.28 | 12.67 | 49 | 0.5387 | 0.0972 |
| 2,297 | 3 | 295,118.56 | 12.60 | 1 | 323,491.76 | 12.69 | 50 | 0.5498 | 0.1251 |
| 2,075 | 3 | 266,596.00 | 12.49 | 4 | 331,126.73 | 12.71 | 51 | 0.5608 | 0.1531 |
| 2,236 | 3 | 287,281.28 | 12.57 | 1 | 333,310.20 | 12.72 | 52 | 0.5719 | 0.1812 |
| 2,352 | 3 | 302,184.96 | 12.62 | 4 | 334,244.91 | 12.72 | 53 | 0.5830 | 0.2095 |
| 2,486 | 3 | 319,401.28 | 12.67 | 1 | 334,343.72 | 12.72 | 54 | 0.5940 | 0.2379 |
| 1,972 | 3 | 253,362.56 | 12.44 | 1 | 335,377.24 | 12.72 | 55 | 0.6051 | 0.2665 |
| 2,189 | 3 | 281,242.72 | 12.55 | 1 | 337,961.04 | 12.73 | 56 | 0.6162 | 0.2954 |
| 2,845 | 3 | 365,525.60 | 12.81 | 1 | 338,994.56 | 12.73 | 57 | 0.6272 | 0.3245 |
| 2,308 | 3 | 296,531.84 | 12.60 | 4 | 340,721.13 | 12.74 | 58 | 0.6383 | 0.3538 |
| 2,001 | 3 | 257,088.48 | 12.46 | 4 | 341,440.71 | 12.74 | 59 | 0.6493 | 0.3835 |
| 2,207 | 3 | 283,555.36 | 12.56 | 4 | 341,920.43 | 12.74 | 60 | 0.6604 | 0.4136 |
| 3,240 | 4 | 388,573.20 | 12.87 | 1 | 345,712.44 | 12.75 | 61 | 0.6715 | 0.4439 |
| 2,596 | 4 | 311,338.28 | 12.65 | 1 | 346,745.96 | 12.76 | 62 | 0.6825 | 0.4748 |
| 2,615 | 4 | 313,616.95 | 12.66 | 4 | 350,195.60 | 12.77 | 63 | 0.6936 | 0.5060 |
| 2,920 | 4 | 350,195.60 | 12.77 | 1 | 353,980.60 | 12.78 | 64 | 0.7046 | 0.5378 |
| 2,496 | 4 | 299,345.28 | 12.61 | 3 | 359,615.52 | 12.79 | 65 | 0.7157 | 0.5701 |
| 2,644 | 4 | 317,094.92 | 12.67 | 1 | 363,799.04 | 12.80 | 66 | 0.7268 | 0.6031 |
| 2,851 | 4 | 341,920.43 | 12.74 | 3 | 365,525.60 | 12.81 | 67 | 0.7378 | 0.6367 |
| 3,318 | 4 | 397,927.74 | 12.89 | 4 | 365,906.43 | 12.81 | 68 | 0.7489 | 0.6710 |
| 2,847 | 4 | 341,440.71 | 12.74 | 1 | 373,617.48 | 12.83 | 69 | 0.7600 | 0.7062 |
| 3,129 | 4 | 375,260.97 | 12.84 | 4 | 375,260.97 | 12.84 | 70 | 0.7710 | 0.7422 |
| 3,249 | 4 | 389,652.57 | 12.87 | 1 | 383,952.68 | 12.86 | 71 | 0.7821 | 0.7792 |
| 3,343 | 4 | 400,925.99 | 12.90 | 4 | 388,573.20 | 12.87 | 72 | 0.7931 | 0.8174 |
| 3,435 | 4 | 411,959.55 | 12.93 | 4 | 389,652.57 | 12.87 | 73 | 0.8042 | 0.8567 |
| 2,456 | 4 | 294,548.08 | 12.59 | 4 | 392,770.75 | 12.88 | 74 | 0.8153 | 0.8975 |
| 2,582 | 4 | 309,659.26 | 12.64 | 1 | 393,771.12 | 12.88 | 75 | 0.8263 | 0.9398 |
| 3,649 | 4 | 437,624.57 | 12.99 | 4 | 396,248.72 | 12.89 | 76 | 0.8374 | 0.9838 |
| 2,761 | 4 | 331,126.73 | 12.71 | 4 | 397,687.88 | 12.89 | 77 | 0.8485 | 1.0298 |
| 3,316 | 4 | 397,687.88 | 12.89 | 4 | 397,927.74 | 12.89 | 78 | 0.8595 | 1.0781 |
| 3,051 | 4 | 365,906.43 | 12.81 | 4 | 400,925.99 | 12.90 | 79 | 0.8706 | 1.1291 |
| 2,550 | 4 | 305,821.50 | 12.63 | 1 | 402,039.28 | 12.90 | 80 | 0.8816 | 1.1832 |
| 3,500 | 4 | 419,755.00 | 12.95 | 1 | 407,206.88 | 12.92 | 81 | 0.8927 | 1.2410 |
| 3,593 | 4 | 430,908.49 | 12.97 | 4 | 411,959.55 | 12.93 | 82 | 0.9038 | 1.3033 |
| 3,275 | 4 | 392,770.75 | 12.88 | 4 | 414,118.29 | 12.93 | 83 | 0.9148 | 1.3711 |
| 4,034 | 4 | 483,797.62 | 13.09 | 1 | 417,025.32 | 12.94 | 84 | 0.9259 | 1.4458 |
| 3,488 | 4 | 418,315.84 | 12.94 | 4 | 418,315.84 | 12.94 | 85 | 0.9369 | 1.5296 |
| 3,707 | 4 | 444,580.51 | 13.00 | 4 | 419,755.00 | 12.95 | 86 | 0.9480 | 1.6258 |
| 3,304 | 4 | 396,248.72 | 12.89 | 4 | 430,908.49 | 12.97 | 87 | 0.9591 | 1.7400 |
| 2,787 | 4 | 334,244.91 | 12.72 | 4 | 437,624.57 | 12.99 | 88 | 0.9701 | 1.8827 |
| 3,453 | 4 | 414,118.29 | 12.93 | 4 | 444,580.51 | 13.00 | 89 | 0.9812 | 2.0791 |
| 2,841 | 4 | 340,721.13 | 12.74 | 4 | 483,797.62 | 13.09 | 90 | 0.9923 | 2.4208 |
| | | **median** | **12.66** | | | Total | 90 | | |
| | | **Deviation** | **0.168** | | | | | | |
| | | 95% confidence | 0.0347 | | | | | | |

**Step 7**

**Calculate 95 % survival probability for lifetime at 25 °C/50%RH**

Calculate 5 % lower limit of 12,66 median value with Standard deviation of 0,168

95 % confidence = 0,0347

Calculate 95 % survival probability with 95 % confidence.

230 721,0 hours = 26,3 years

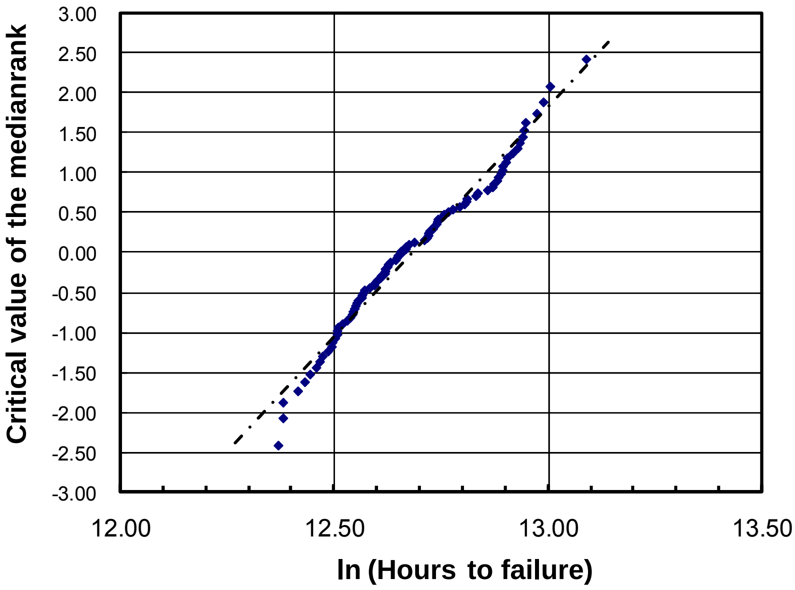


**Figure B.2 — Plot of normalized data**

# Annex C
(normative)

## Uncontrolled Ambient Condition Media Life Calculation

A test method for a storage or usage condition of higher temperature and relative humidity than 25 °C and 50 % relative humidity.

This test method follows the scope in this document except for the ambient storage condition, which will be based on an environment of 30 °C and 80 % relative humidity. This test method will also use a different stress test design that makes possible the use of the Arrhenius equation.

This test demonstrates with a certainty of 95 % that information stored on a recordable or rewriteable optical disk will be viable for a predetermined minimum number of years when storage conditions do not exceed 30 °C and 80 % relative humidity.

The same method and assumptions apply except where the ambient condition, stress design, and Eyring equation is addressed. The controlled ambient condition of 25 °C and 50 % relative humidity will be replaced by an expected harsher user environment of 30 °C and 80 % relative humidity.

The *reduced* Eyring equation: $t = Ae^{\Delta H / kT} e^{B \times RH}$ will be replaced by the Arrhenius equation: $t = Ae^{\Delta H / kT}$.

The ambient condition will be as stated above. The stress test design will be as follows:

**Table C.1 — Summary of Stress conditions for use with Arrhenius Method**

| Test cell number | Test stress condition (inc) | | Number of specimens | Incubation duration | Min total time | Intermediate RH | Min equilibration duration |
|---|---|---|---|---|---|---|---|
| | Temp (°C) | %RH | | hours | hours | %RH | hours |
| 1b | 85 | 80 | 20 | 250 | 1 000 | 30 | 5 |
| 2b | 75 | 80 | 25 | 425 | 1 700 | 33 | 7 |
| 3b | 65 | 80 | 30 | 600 | 2 400 | 35 | 10 |

Replace Step 4 in Annex A and B with:

**Step 4**

Using the Arrhenius equation, carry out a least squares fit to the log *median* failure times for each stress condition across all specimens and stress conditions.

# Annex D
(informative)

# Truncated Test Method
# (Determination of Media Life Lower Bound)

This test method is to confirm the target minimum life expectancy and to calculate the minimum test time required to do so when media survives at a certain stress condition.

It eliminates the problem with "flat line" data where media continues to survive. Media is tested until failure (normally at the higher stress conditions). A desired minimum number of years lifetime is chosen and the number of hours at the minimum stress condition (without failure) is calculated. When this number is reached, the minimum life target is verified.

Example: See Table D.1 (media survives at high temperature and lower RH)

Using 30 years at 25 ˚C, 50 % RH as a constraint:

The following is an outline of steps to estimate the minimal life expectancy using the reduced Eyring equation, as a function of ambient temperature and relative humidity.

1. Solve for coefficient $\Delta H$ (activation energy per molecule) of Eyring equation.

   Subtract two stress conditions with the same % RH.

$$\ln(Time_{Stress1}) - \ln(Time_{Stress2}) = [\ln A + \frac{\Delta H}{kT_{Stress1}} + B \times RH_{Stress1}] - [\ln A + \frac{\Delta H}{kT_{Stress2}} + B \times RH_{Stress2}]$$

   where $Time_{Stress1}$ is time to failure at stress1 condition, $Time_{Stress2}$ is time to failure at stress2 condition.

   Example using stress conditions of 85 °C, 85 % RH and 65 °C, 85 % RH

$$\ln(Time_{85,85}) - \ln(Time_{65,85}) = [\ln A + \frac{\Delta H}{kT_{85}} + B \times RH_{85}] - [\ln A + \frac{\Delta H}{kT_{65}} + B \times RH_{85}]$$

$$\Delta H = \{\ln(Time_{85,85}) - \ln(Time_{65,85})\} \times (-8,3607 \times 10^{-20})$$

   Solve for $\Delta H$ using these example times for the above stress conditions:

   At: 85 °C, 85 % RH $Time_{85,85}$ = 500 h at 65 °C, 85 % RH $Time_{65,85}$ = 1 852 h

   Solve for $\Delta H$ , $\Delta H = 1,0948 \times 10^{-19}$

2. Solve for coefficient B (RH exponential constant) of Eyring equation.

   Solving for $B$ after solving for $\Delta H$ ($\Delta H = 1,0948 \times 10^{-19}$, using the example above).

   Subtract two stress conditions with different Temperature and % RH

$$\ln(Time_{Stress1}) - \ln(Time_{Stress2}) = [\ln A + \frac{\Delta H}{kT_{Stress1}} + B \times RH_{Stress1}] - [\ln A + \frac{\Delta H}{kT_{Stress2}} + B \times RH_{Stress2}]$$

   Example using stress conditions at 85 °C, 85 % RH and 25 °C, 50 % RH.

$$\ln(Time_{85,85}) - \ln(Time_{25,50}) = [\ln A + \frac{\Delta H}{kT_{85}} + B \times RH_{85}] - [\ln A + \frac{\Delta H}{kT_{25}} + B \times RH_{50}]$$

Using the example of 500 hours at 85 °C, 85 % RH and solving for 30 years lifetime:

85 °C, 85 % RH $\underline{Time_{85,85} = 500\ h}$, 25 °C, 50 % RH $\underline{Time_{25,50} = 262\ 800\ h}$ (30 years = 30×8760)

Solve for *B*

$$\ln(500) - \ln(262{,}800) = [\frac{1{,}0948 \times 10^{-19}}{1{,}3807 \times 10^{-23}} \times (-5{,}6189 \times 10^{-4})] + B \times 35$$

$B = -5{,}169 \times 10^{-2}$

3. Solve for coefficient *A* (pre-exponential time constant) of Eyring equation.

   Solving for *A* after solving for $\Delta H$ and *B* ($\Delta H = 1{,}0948 \times 10^{-19}$, $B = -5{,}169 \times 10^{-2}$ using above)

   Eying equation logged:

   Example below using ambient condition of 25 °C, 50 % RH for 30 years

$$\ln(Time_{25,50}) = \ln A + \frac{\Delta H}{kT_{25}} + B \times RH_{50}$$

   Substitute $\Delta H$ and *B* with the calculated values and *Time* with the selected archival time

   $\Delta H = 1{,}0948 \times 10^{-19}$

   $B = -5{,}169 \times 10^{-2}$

   *Time* = 30 years (262 800 h)

   Solve for *A*, $A = 9{,}828 \times 10^{-6}$ .

4. Solve for third stress condition

   Solving time for a third stress condition (example: 85 °C, 70 % RH) that equals 30 years life expectancy at 25 °C, 50 % RH.

   Eying equation logged:

   $t$ = 358,15 Kelvin = 85 °C

   $RH$ = 70 = 70 % Relative Humidity

$$\ln(Time_{85,70}) = -11{,}5303 + \frac{1{,}0948 \times 10^{-19}}{(1{,}3807 \times 10^{-23}) \times (85 + 273{,}15)} + (-5{,}169 \times 10^{-2} \times 70)$$

   Solve for $Time_{85,70}$, $Time_{85,70}$ = 1 086 h

Therefore,

If:

1. Archival time is selected to be 30 years,

2. Disks fail at 500 h at 85 °C, 85 % RH

3. And disks fail at 1 852 h at 65 °C, 85 % RH

Then:

According to the acceleration model, disks must not fail before 1 086 h (at 85 °C, 70 % RH) to have a minimum of 30 years life expectancy at 25 °C, 50 % RH.

The failure time for the third stress condition is dependent on the failure times at the first two stress conditions and the archival years target selected.

**Table D.1 — Example using stress conditions of 85 °C, 85 % RH and 65 °C, 85 % RH**

| | | ln(hrs) | Years | ~ | ln(Hours) | Hours | ln(Hours) | Hours | ln(Hours) | Hours | ln(Hours) | Hours | ln(Hours) | Hours | ln(Hours) | Hours |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | | | | | | | | | | | | | | | |
| | 90 | | | | | | | actual | | | | | | | | actual |
| | 85 | | | | | | 7,52 | 1 852 | | | | | | | 6,21 | 500 |
| | 80 | | | | | | | | | | | | | | | |
| | 75 | | | | | | | | | | | | | | | target |
| %RH | 70 | | | | | | | | | | | | | | 6,99 | 1 086 |
| | 65 | | | | | | | | | | | | | | | |
| | 60 | | | | | | | | | | | | | | | |
| | 55 | | | | | | | | | | | | | | | |
| | 50 | 12,48 | 30,02 | | | | | | | | | | | | | |
| | 40 | | | | | | | | | | | | | | | |
| | 30 | | | | | | | | | | | | | | | |
| | | 25 | 25 | ~ | 60 | 60 | 65 | 65 | 70 | 70 | 75 | 75 | 80 | 80 | 85 | 85 |

Temperature - Celsius

# Annex E
(informative)

## Relation between BER and PI Sum 8

The byte error rate BER is the number of erroneous symbols divided by the total number of symbols. Because the length of one code word of the inner code is 182, number of erroneous symbol in one inner code word $N_{pi}$ can be expressed by binomial probability, and it is

$$N_{pi} = \sum_{i=1}^{182} {}_{182}C_i \times BER^i \times (1 - BER)^{182-i} \qquad (1)$$

The number of PI errors in 8 ECC blocks $N_{pis8}$ can be expressed by formula (2) because the length of the outer code word is 208.

$$N_{pis8} = 208 \times 8 \times N_{pi} \qquad (2)$$

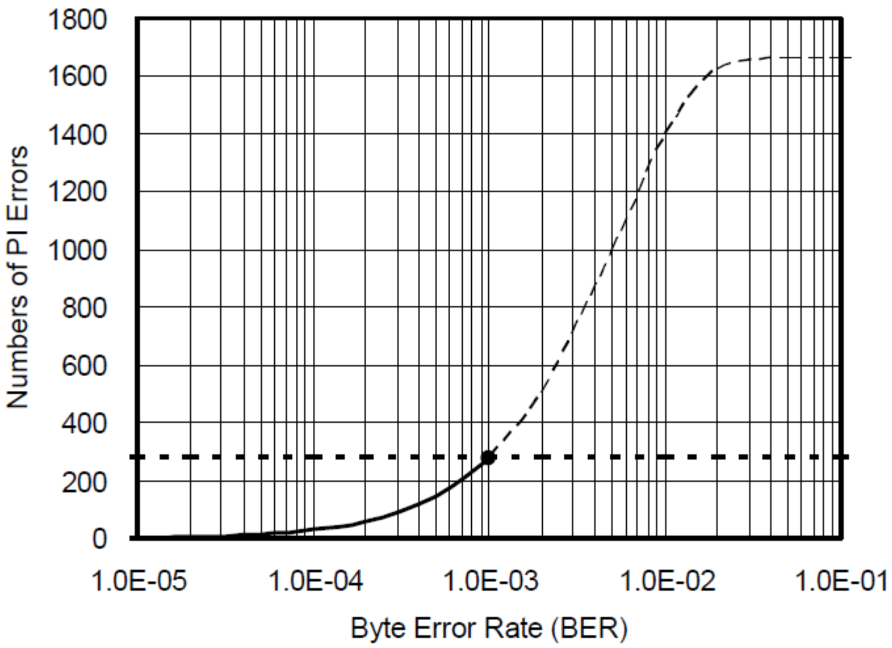


**Figure E.1 — Relationship between BER and PI Sum 8**

# Bibliography


[1] Experimental statistics, US National Bureau of Standards Handbook 91, 1963

[2] Applied Regression Analysis, Draper and Smith, Wiley Edition 2

[3] Statistical Methods for Reliability Data, Meeker, Escobar, 1998, John Wiley & Sons Inc.