Standard ECMA-379

2nd Edition / December 2008

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

Rue du Rhône 114 CH-1204 Geneva T: +41 22 849 6000 F: +41 22 849 6001

Standard

ECMA-379

2nd Edition / December 2008

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

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.

This Ecma Standard has been adopted by the General Assembly of December 2008.

Table of contents

Section 1 — General

1 Scope

This Ecma Standard specifies an accelerated aging test method for estimating the life expectancy for 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 References

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	Data Interchange on 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	Data Interchange on 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	Data interchange on 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	Data Interchange on 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	Data Interchange on 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)

4 Definitions

For the purpose of this Ecma Standard the following definitions apply:

4.1 Archival

The 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

The 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 Bootstrap Method

The bootstrap method is a statistical method for estimating the sampling distribution by re-sampling with replacement from the original sample (see Annex E).

4.5 Eyring Method

Accelerated aging model based on the effects of temperature and relative humidity.

4.6 Error rate

The rate of errors on the sample disk measured before error correction is applied.

4.7 Incubation

Process of enclosing and maintaining controlled test sample environments.

4.8 Life expectancy (LE)

The length of time estimation that information is predicted to be retrievable in a system while in a specified environmental condition.

4.9 Maximum error rate

The maximum of the error rate 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.

4.10 Retrievability

The ability to recover physical information as recorded.

4.11 Stress

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

4.12 System

The combination of hardware, software, storage medium and documentation used to record, retrieve and reproduce information.

4.13 Uncorrectable error

An error in the playback data that was not corrected by the error correcting decoders.
For DVD-R/RW, +R/+RW, and DVD-RAM, an error that is uncorrected by the Reed-Solomon product code defined in ECMA-267 for DVD ROM systems.

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
LCL	lower confidence limit
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 their error rates 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 modelled by a statistical distribution;
- the Eyring model can be used to model acceleration with the two 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 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 their maximum PI Sum 8 (Max PI-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 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 6.5 shall not exceed 10^{-3} (See Annex F).

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 time-to-failure values at each stress condition are then regressed to find a histogram of the time-to-failure values at ambient condition using the bootstrap method.

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 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 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 is cleaned according to the instructions of the manufacturer of the disk.

7.3.2 Recording method

Specimen disks shall be recorded at 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 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 shall be calibrated as prescribed by its manufacturer using calibration disks approved by said manufacturer and as needed before disk testing.

A control disk shall 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 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. Each of the three test bands shall have more than 750(2EEh) ECC Blocks for 80 mm disks, and 2 400(960h) ECC Blocks for 120 mm disks.

Table 1 — Nominal radii of the three test bands

	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 (inc)		Number of specimens	Incubation duration	Total time	Intermediate RH	Min 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**	**Relative humidity**	**Duration**
	°C	**%**	**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}

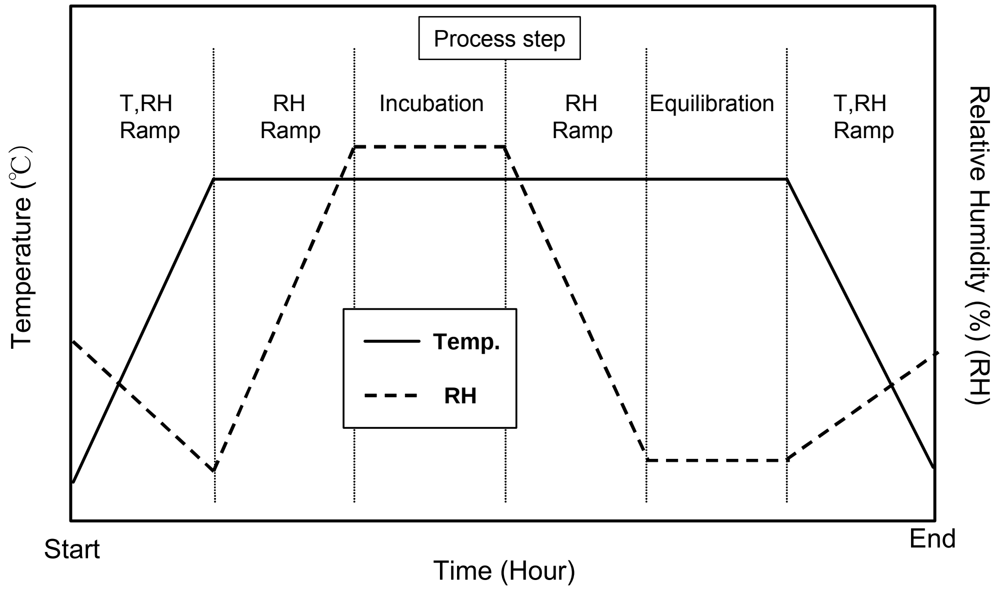

Figure 1 — Graph of typical transition (ramp) profile

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 respectively 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*	is 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 E: Bootstrap Method

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. Employ bootstrapping, using the residuals from the fit in step 4, to generate a simulation sample of 1 000 predicted times-to-failure at ambient condition;
6. For the ambient condition, plot a histogram of these 1 000 predicted times-to-failure;
7. For the ambient condition, compute the estimated 5% point of the 1 000 predicted times-to-failure.

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 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					
Disc #	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					
Disc #	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					
Disc #	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					
Disc #	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 −0,5)/n, 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	Disc #	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	0,025	-1,960
2	A7	26	121	274	589	781	588	6,3767	0,075	-1,440
3	A6	21	111	207	567	896	607	6,4085	0,125	-1,150
4	A12	24	136	267	444	719	614	6,4200	0,175	-0,935
5	A13	35	76	265	567	610	626	6,4394	0,225	-0,755
6	A18	26	109	238	421	641	645	6,4693	0,275	-0,598
7	A4	26	111	247	343	718	647	6,4723	0,325	-0,454
8	A19	26	111	253	378	638	649	6,4754	0,375	-0,319
9	A8	31	108	223	315	745	654	6,4831	0,425	-0,189
10	A20	31	91	206	367	728	656	6,4862	0,475	-0,063
11	A10	12	85	178	312	988	669	6,5058	0,525	0,063
12	A11	28	111	167	312	771	671	6,5088	0,575	0,189
13	A3	26	94	190	335	642	685	6,5294	0,625	0,319
14	A15	28	88	158	308	654	704	6,5568	0,675	0,454
15	A17	18	87	176	302	558	723	6,5834	0,725	0,598
16	A2	25	64	134	342	532	743	6,6107	0,775	0,755
17	A5	27	89	185	246	466	762	6,6359	0,825	0,935
18	A14	19	53	112	278	534	778	6,6567	0,875	1,150
19	A1	16	78	116	278	445	788	6,6695	0,925	1,440
20	A16	27	68	120	263	432	807	6,6933	0,975	1,960
						median	663	6,4960		

Group 2a		85°C/70%RH								
order number	Disc #	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	0,025	-1,960
2	B3	12	26	72	185	421	880	6,7799	0,075	-1,440
3	B13	10	27	89	175	385	880	6,7799	0,125	-1,150
4	B10	17	38	67	179	378	911	6,8145	0,175	-0,935
5	B15	28	39	125	172	278	959	6,8659	0,225	-0,755
6	B9	25	46	124	182	224	994	6,9017	0,275	-0,598
7	B4	20	43	120	166	219	999	6,9068	0,325	-0,454
8	B17	20	43	75	166	256	999	6,9068	0,375	-0,319
9	B7	21	30	89	155	221	1 035	6,9422	0,425	-0,189
10	B14	23	54	111	148	221	1 037	6,9441	0,475	-0,063
11	B8	22	26	72	125	267	1 043	6,9499	0,525	0,063
12	B20	10	19	28	121	268	1 046	6,9527	0,575	0,189
13	B18	22	26	50	172	229	1 058	6,9641	0,625	0,319
14	B12	8	15	36	144	189	1 059	6,9651	0,675	0,454
15	B11	28	58	88	120	268	1 065	6,9707	0,725	0,598
16	B19	13	38	78	124	189	1 078	6,9829	0,775	0,755
17	B1	10	20	67	112	156	1 117	7,0184	0,825	0,935
18	B2	8	20	47	84	188	1 118	7,0193	0,875	1,150
19	B5	32	45	76	103	267	1 126	7,0264	0,925	1,440
20	B16	25	53	88	130	188	1 149	7,0466	0,975	1,960
						median	1 040	6,9470		

Group 3a		65°C/85%RH								
order number	Disc #	Hours					Hours to failure(H)	ascending ln(H)	median rank	critical valu
		0	500	1 000	1 500	2 000				
1	C2	10	17	55	165	263	1 948	7,5746	0,025	-1,960
2	C15	25	65	89	184	256	1 972	7,5868	0,075	-1,440
3	C19	28	56	108	176	243	2 001	7,6014	0,125	-1,150
4	C6	10	14	45	154	231	2 031	7,6163	0,175	-0,935
5	C1	14	23	58	112	278	2 057	7,6290	0,225	-0,755
6	C11	21	38	89	148	227	2 075	7,6377	0,275	-0,598
7	C3	11	56	88	138	189	2 078	7,6392	0,325	-0,454
8	C4	18	28	78	117	243	2 106	7,6525	0,375	-0,319
9	C8	29	54	106	154	218	2 128	7,6629	0,425	-0,189
10	C7	31	53	111	156	211	2 151	7,6737	0,475	-0,063
11	C5	17	45	78	143	189	2 167	7,6811	0,525	0,063
12	C16	10	18	57	113	178	2 189	7,6912	0,575	0,189
13	C20	29	36	57	143	238	2 207	7,6994	0,625	0,319
14	C12	24	45	68	134	211	2 236	7,7124	0,675	0,454
15	C10	29	36	78	145	188	2 297	7,7394	0,725	0,598
16	C18	12	20	34	112	176	2 308	7,7441	0,775	0,755
17	C13	28	57	78	132	190	2 352	7,7630	0,825	0,935
18	C14	19	47	61	117	150	2 486	7,8184	0,875	1,150
19	C9	22	32	65	89	126	2 799	7,9370	0,925	1,440
20	C17	21	34	45	98	121	2 845	7,9533	0,975	1,960
		median					2 159	7,6577		

Group 4a		70°C/75%RH								
order number	Disc #	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	0,017	-2,128
2	D5	5	20	78	132	187	2 496	7,8224	0,050	-1,645
3	D20	12	56	66	124	249	2 550	7,8438	0,083	-1,383
4	D15	22	26	73	145	252	2 582	7,8563	0,117	-1,192
5	D2	25	93	134	154	211	2 596	7,8617	0,150	-1,036
6	D3	7	23	97	103	178	2 615	7,8690	0,183	-0,903
7	D6	5	15	52	112	167	2 644	7,8800	0,217	-0,784
8	D17	22	26	93	145	178	2 761	7,9233	0,250	-0,674
9	D28	20	28	45	111	243	2 787	7,9327	0,283	-0,573
10	D30	10	34	54	96	176	2 841	7,9519	0,317	-0,477
11	D9	22	34	67	132	189	2 847	7,9540	0,350	-0,385
12	D7	22	34	67	132	188	2 851	7,9554	0,383	-0,297
13	D4	10	20	56	89	155	2 920	7,9793	0,417	-0,210
14	D19	11	32	44	97	143	3 051	8,0232	0,450	-0,126
15	D10	23	27	54	121	152	3 129	8,0485	0,483	-0,042
16	D1	25	34	64	92	167	3 240	8,0833	0,517	0,042
17	D11	11	20	41	87	115	3 249	8,0861	0,550	0,126
18	D23	11	16	27	54	160	3 275	8,0941	0,583	0,210
19	D27	21	39	63	78	163	3 304	8,1029	0,617	0,297
20	D18	18	27	56	88	134	3 316	8,1065	0,650	0,385
21	D8	12	17	56	78	108	3 318	8,1071	0,683	0,477
22	D12	15	18	43	88	118	3 343	8,1146	0,717	0,573
23	D13	19	21	38	82	135	3 435	8,1418	0,750	0,674
24	D29	15	21	38	65	134	3 453	8,1470	0,783	0,784
25	D25	11	25	22	62	130	3 488	8,1571	0,817	0,903
26	D21	14	34	54	77	112	3 500	8,1605	0,850	1,036
27	D22	20	23	25	50	181	3 593	8,1867	0,883	1,192
28	D16	18	18	29	66	127	3 649	8,2022	0,917	1,383
29	D26	17	24	25	70	123	3 707	8,2180	0,950	1,645
30	D24	17	24	25	58	108	4 034	8,3025	0,983	2,128
					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 is then calculated from the equation:

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

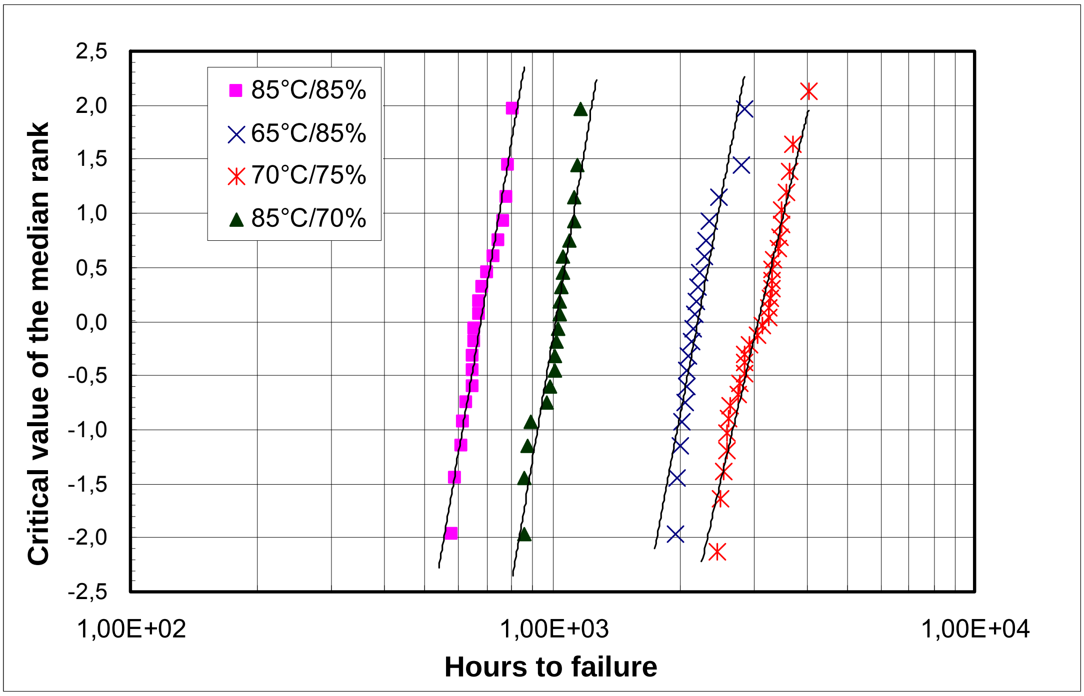

Figure B.1 — Lognormal plot of Table B.2

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	7,6577	65	0.00295727	85
4a	8,0659	70	0.00291418	75

Table B.4 — Coefficients of reduced Eyring equation

B	ΔH/k	ln(A)
-0,0437	8 355,7529	-13,1982

Step 5

Employ bootstrapping (see reference [3]), use the residuals in Table B.5 from the fit in step 4 to generate a simulation sample of 1 000 predicted times-to-failure at ambient condition (see Table B.6).

Table B.5 — Data for bootstrap method

Disc #	Stress condition			
	85°C/85%RH	85°C/70%RH	65°C/85%RH	70°C/75%RH
1	788	1 117	2 057	3 240
2	743	1 118	1 948	2 596
3	685	880	2 078	2 615
4	647	999	2 106	2 920
5	762	1 126	2 167	2 496
6	607	870	2 031	2 644
7	588	1 035	2 151	2 851
8	654	1 043	2 128	3 318
9	578	994	2 799	2 847
10	669	911	2 297	3 129
11	671	1 065	2 075	3 249
12	614	1 059	2 236	3 343
13	626	880	2 352	3 435
14	778	1 037	2 486	2 456
15	704	959	1 972	2 582
16	807	1 149	2 189	3 649
17	723	999	2 845	2 761
18	645	1 058	2 308	3 316
19	649	1 078	2 001	3 051
20	656	1 046	2 207	2 550
21				3 500
22				3 593
23				3 275
24				4 034
25				3 488
26				3 707
27				3 304
28				2 787
29				3 453
30				2 841

Table B.6 — Predicted times-to-failure at ambient condition by bootstrapping

Sampling number	Sampling data from each stress condition				Time-to Failure at 25°C/50%
	85°C/85%RH	85°C/70%RH	65°C/85%RH	70°C/75%RH	
1	607	1 035	2 207	3 488	576 977,5
2	654	999	2 031	3 318	337 248,5
3	704	1 078	2 001	3 240	246 008,5
4	645	1 046	2 236	3 593	514 837,2
5	723	1 046	2 128	2 582	127 316,4
6	762	1 065	2 486	3 318	263 109,5
7	778	1 058	2 151	3 453	223 679,1
8	645	1 078	2 799	2 615	292 286,6
9	704	1 046	2 308	2 841	203 964,6
10	654	1 118	2 057	2 496	164 119,1
11	807	880	1 948	2 851	92 163,5
12	685	1 035	2 106	4 034	524 689,5
13	743	1 078	2 128	2 582	117 060,7
14	762	1 059	2 078	3 318	206 072,8
15	685	911	2 236	3 240	290 891,6
⋮	⋮	⋮	⋮	⋮	⋮
984	607	1 037	2 075	3 051	366 307,9
985	647	911	2 207	2 847	245 130,1
986	647	1 126	2 189	2 851	269 443,1
987	685	1 059	2 297	2 550	166 622,3
988	723	1 046	2 106	3 488	289 685,3
989	762	1 078	2 128	3 343	219 133,3
990	762	870	2 352	3 249	209 012,2
991	743	994	2 352	4 034	445 445,1
992	649	1 043	2 106	2 787	228 892,0
993	588	1 035	2 189	3 304	550 507,4
994	647	1 126	2 001	2 496	164 949,0
995	588	1 046	2 128	2 761	323 337,4
996	626	1 043	2 057	2 615	211 581,1
997	704	1 126	2 799	3 707	574 192,4
998	626	1 058	2 352	2 847	323 242,9
999	588	959	2 352	3 318	591 577,5
1 000	614	1 117	2 128	2 615	245 446,7

Step 6

For the ambient condition, plot a histogram of these 1 000 predicted times-to-failure.

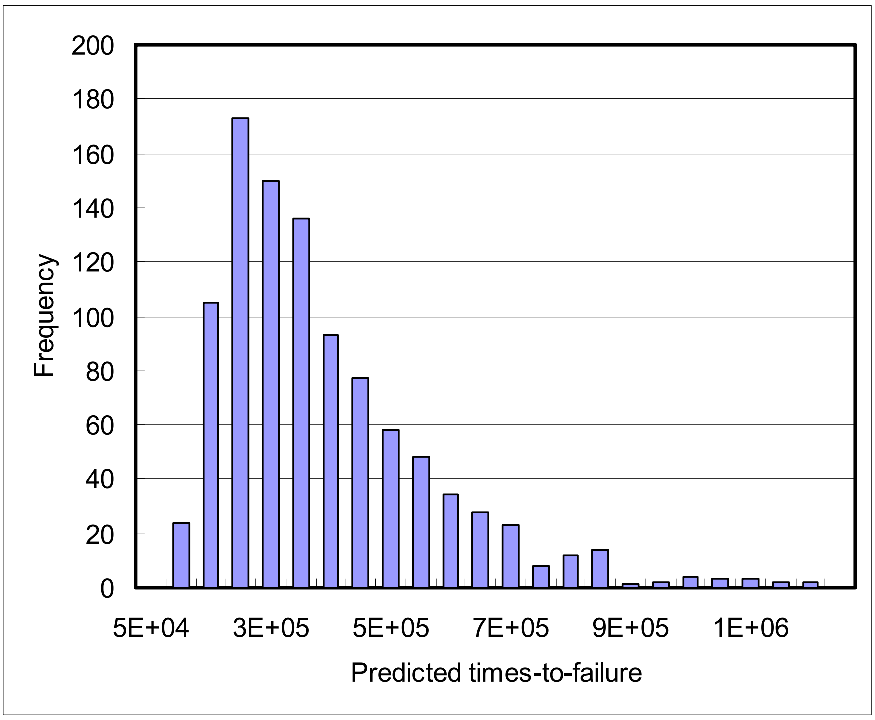

Figure B.2 — Histogram of predicted times-to-failure

Step 7

For the ambient condition, compute the estimated 5% point and median value of the 1 000 predicted times-to-failure.

5% point of 1 000 predicted times-to-failure = 110 741,6 h (12,6 years)

Median value of 1 000 predicted times-to-failure = 272 077,23 h (31,0 years)

Alternative steps 5-7, (without bootstrapping)

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 { (-13,1982) + (8 355,7529 × 1/358,15) + (-0,0437 × 85) } = 612,54 h

85°C/70%RH = Exp { (-13,1982) + (8 355,7529 × 1/358,15) + (-0,0437 × 70) } = 1 179,82 h

65°C/85%RH = Exp { (-13,1982) + (8 355,7529 × 1/338,15) + (-0,0437 × 85) } = 2 434,50 h

70°C/75%RH = Exp { (-13,1982) + (8 355,7529 × 1/343,15) + (-0,0437 × 75) } = 2 629,23 h

25°C/50%RH = Exp { (-13,1982) + (8 355,7529 × 1/298,15) + (-0,0437 × 50) } = 309 320,29 h

Calculating acceleration factor for each stress condition

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

Table B.7 — Acceleration factor for each stress condition

Stress	Calculated life using "best fit" B, ΔH/k, ln(A)	Acceleration factor
85°C/85%RH	612,54 h	504,98
85°C/70%RH	1 179,82 h	262,18
65°C/85%RH	2 434,50 h	127,06
70°C/75%RH	2 629,23 h	117,65
25°C/50%RH	309 320,29 h	

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 (12,63) = 305 590,1 h (34,9 years)

Table B.8 — Data for composite lognormal plot

Hours to Failure	Group#	normalized to 25C/50%RH (A)	Ln of (A)	Group#	Ascending (A)	order	media rank	critical value
788	1	397 924,04	12,89	2	228 036,86	1	0,0106	-2,3060
743	1	375 199,95	12,84	2	230 657,98	2	0,0217	-2,0205
685	1	345 911,12	12,75	2	230 657,98	3	0,0328	-1,8414
647	1	326 721,89	12,70	2	238 783,43	4	0,0439	-1,7072
762	1	384 794,56	12,86	3	247 400,36	5	0,0550	-1,5982
607	1	306 522,70	12,63	3	250 448,42	6	0,0661	-1,5054
588	1	296 928,09	12,60	2	251 364,77	7	0,0772	-1,4240
654	1	330 256,75	12,71	3	254 131,48	8	0,0883	-1,3511
578	1	291 878,29	12,58	3	257 941,55	9	0,0994	-1,2847
669	1	337 831,45	12,73	2	260 538,67	10	0,1106	-1,2236
671	1	338 841,41	12,73	3	261 243,61	11	0,1217	-1,1667
614	1	310 057,56	12,64	2	261 849,22	12	0,1328	-1,1134
626	1	316 117,32	12,66	2	261 849,22	13	0,1439	-1,0630
778	1	392 874,24	12,88	3	263 529,65	14	0,1550	-1,0152
704	1	355 505,74	12,78	3	263 910,65	15	0,1661	-0,9696
807	1	407 518,65	12,92	3	267 466,72	16	0,1772	-0,9260
723	1	365 100,35	12,81	3	270 260,76	17	0,1883	-0,8841
645	1	325 711,93	12,69	2	271 285,23	18	0,1994	-0,8436
649	1	327 731,85	12,70	2	271 809,46	19	0,2106	-0,8045
656	1	331 266,71	12,71	3	273 181,82	20	0,2217	-0,7666
1 117	2	292 850,40	12,59	2	273 382,12	21	0,2328	-0,7297
1 118	2	293 112,58	12,59	2	274 168,46	22	0,2439	-0,6938
880	2	230 714,73	12,35	3	275 213,85	23	0,2550	-0,6588
999	2	261 913,66	12,48	2	277 313,79	24	0,2661	-0,6246
1 126	2	295 209,99	12,60	2	277 575,91	25	0,2772	-0,5911
870	2	228 092,97	12,34	3	278 007,90	26	0,2883	-0,5583
1 035	2	271 351,99	12,51	2	279 148,57	27	0,2994	-0,5260
1 043	2	273 449,39	12,52	3	280 293,94	28	0,3106	-0,4943
994	2	260 602,78	12,47	2	282 556,02	29	0,3217	-0,4630
911	2	238 842,18	12,38	3	283 977,01	30	0,3328	-0,4323
1 065	2	279 217,26	12,54	4	288 851,15	31	0,3439	-0,4019
1 059	2	277 644,21	12,53	3	291 724,14	32	0,3550	-0,3719
880	2	230 714,73	12,35	1	291 751,68	33	0,3661	-0,3422
1 037	2	271 876,34	12,51	2	292 778,36	34	0,3772	-0,3128
959	2	251 426,62	12,43	2	293 040,47	35	0,3883	-0,2837
1 149	2	301 240,03	12,62	3	293 121,17	36	0,3994	-0,2548
999	2	261 913,66	12,48	4	293 555,56	37	0,4106	-0,2261
1 058	2	277 382,03	12,53	2	295 137,36	38	0,4217	-0,1976
1 078	2	282 625,55	12,55	1	296 799,29	39	0,4328	-0,1693
1 046	2	274 235,92	12,52	3	298 709,27	40	0,4439	-0,1411
2 057	3	261 356,27	12,47	4	299 906,52	41	0,4550	-0,1130
1 948	3	247 507,05	12,42	2	301 165,93	42	0,4661	-0,0850
2 078	3	264 024,47	12,48	4	303 670,06	43	0,4772	-0,0571
2 106	3	267 582,06	12,50	4	305 316,60	44	0,4883	-0,0292
2 167	3	275 332,54	12,53	1	306 389,74	45	0,4994	-0,0014
2 031	3	258 052,79	12,46	4	307 551,20	46	0,5106	0,0265
2 151	3	273 299,63	12,52	1	309 923,07	47	0,5217	0,0543
2 128	3	270 377,32	12,51	4	310 961,90	48	0,5328	0,0823
2 799	3	355 632,57	12,78	3	315 727,57	49	0,5439	0,1102
2 297	3	291 849,95	12,58	1	315 980,20	50	0,5550	0,1383
2 075	3	263 643,30	12,48	4	324 722,32	51	0,5661	0,1665
2 236	3	284 099,47	12,56	1	325 570,65	52	0,5772	0,1948
2 352	3	298 838,09	12,61	1	326 580,17	53	0,5883	0,2233
2 486	3	315 863,73	12,66	1	327 589,69	54	0,5994	0,2519
1 972	3	250 556,42	12,43	4	327 780,19	55	0,6106	0,2808
2 189	3	278 127,79	12,54	1	330 113,50	56	0,6217	0,3099
2 845	3	361 477,19	12,80	1	331 123,02	57	0,6328	0,3392
2 308	3	293 247,58	12,59	4	334 131,15	58	0,6439	0,3689
2 001	3	254 241,08	12,45	4	334 836,81	59	0,6550	0,3989
2 207	3	280 414,82	12,54	4	335 307,25	60	0,6661	0,4292
3 240	4	381 175,38	12,85	1	337 684,91	61	0,6772	0,4599
2 596	4	305 410,89	12,63	1	338 694,43	62	0,6883	0,4911
2 615	4	307 646,18	12,64	4	343 422,37	63	0,6994	0,5228
2 920	4	343 528,43	12,75	1	345 761,08	64	0,7106	0,5550
2 496	4	293 646,22	12,59	1	355 351,53	65	0,7217	0,5878
2 644	4	311 057,93	12,65	3	355 479,27	66	0,7328	0,6212
2 851	4	335 410,80	12,72	4	358 829,33	67	0,7439	0,6554
3 318	4	390 351,82	12,87	3	361 321,37	68	0,7550	0,6903
2 847	4	334 940,22	12,72	1	364 941,98	69	0,7661	0,7261
3 129	4	368 116,59	12,82	4	368 002,95	70	0,7772	0,7628
3 249	4	382 234,20	12,85	1	375 037,20	71	0,7883	0,8007
3 343	4	393 292,99	12,88	4	381 057,70	72	0,7994	0,8396
3 435	4	404 116,49	12,91	4	382 116,19	73	0,8106	0,8799
2 456	4	288 940,35	12,57	1	384 627,65	74	0,8217	0,9217
2 582	4	303 763,84	12,62	4	385 174,06	75	0,8328	0,9652
3 649	4	429 292,89	12,97	4	388 584,77	76	0,8439	1,0106
2 761	4	324 822,60	12,69	4	389 996,09	77	0,8550	1,0581
3 316	4	390 116,53	12,87	4	390 231,31	78	0,8661	1,1082
3 051	4	358 940,15	12,79	1	392 703,82	79	0,8772	1,1612
2 550	4	299 999,14	12,61	4	393 171,57	80	0,8883	1,2177
3 500	4	411 763,53	12,93	1	397 751,43	81	0,8994	1,2784
3 593	4	422 704,67	12,95	4	403 991,73	82	0,9106	1,3442
3 275	4	385 293,01	12,86	4	406 108,72	83	0,9217	1,4164
4 034	4	474 586,88	13,07	1	407 341,88	84	0,9328	1,4968
3 488	4	410 351,77	12,92	4	410 225,08	85	0,9439	1,5883
3 707	4	436 116,40	12,99	4	411 636,41	86	0,9550	1,6954
3 304	4	388 704,77	12,87	4	422 574,17	87	0,9661	1,8265
2 787	4	327 881,41	12,70	4	429 160,35	88	0,9772	1,9995
3 453	4	406 234,13	12,91	4	435 981,76	89	0,9883	2,2679
2 841	4	334 234,34	12,72	4	474 440,36	90	0,9994	3,2608
		median	**12,63**		Total	90		
		Deviation	**0,169**					
		95% confidence	0,0349					

Step 7

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

Calculate 5% lower limit of 12,63 median value with Standard deviation of 0,169

95% confidence = 0,0349

Calculate 95% survival probability with 95% confidence.

223 489,5 h = 25,5 years

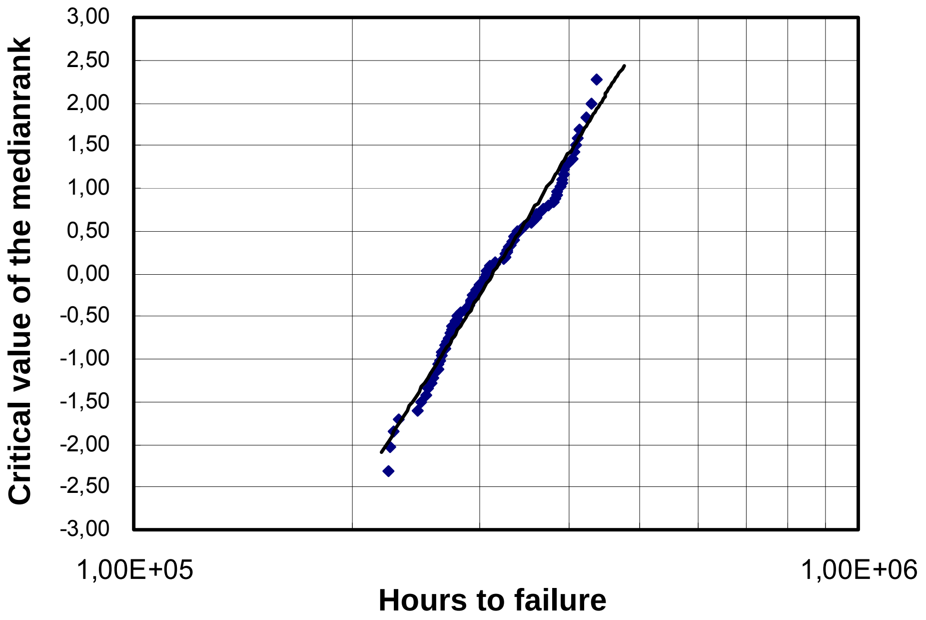

Figure B.3 — Plot of normalized data

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 ΔH (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 ΔH using these example times for the above stress conditions:

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

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

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

   Solving for B after solving for ΔH ($\Delta H = 1{,}0948 \times 10^{-19}$, 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

$$\ln(500) - \ln(262{,}800) = \left[\frac{1{,}0948\times10^{-19}}{1{,}3807\times10^{-23}}\times(-5{,}6189\times10^{-4})\right] + B\times35$$

B=-5,169×10^{-2}

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

   Solving for A after solving for ΔH and B (ΔH = 1,0948×10^{-19}, B = -5,169×10^{-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 Δ*H* and *B* with the calculated values and *Time* with the selected archival time

   Δ*H* = 1,0948×10^{-19}

   B = -5,169×10^{-2}

   Time = 30 years (262 800 h)

   Solve for A, A = 9,828×10^{-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

$$\ln(Time_{85,70}) = -11{,}5303 + \frac{1{,}0948\times10^{-19}}{(1{,}3807\times10^{-23})\times(85+273{,}15)} + (-5{,}169\times10^{-2}\times70)$$

   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)

Bootstrap method

The bootstrap method is a statistical method for estimating the sampling distribution by re-sampling with replacement from the original sample.

The following is an outline of the time-to-failure estimation of the optical disk at the Arrhenius model (uncontrolled ambient condition, 30 °C / 80 % RH) using bootstrap regression analysis. Figure E.1 is a regression line plot showing data computed from bootstrap samples, each bootstrap estimate of time-to failure gives the distribution of predicted time-to-failure at 30 °C / 80 % RH.

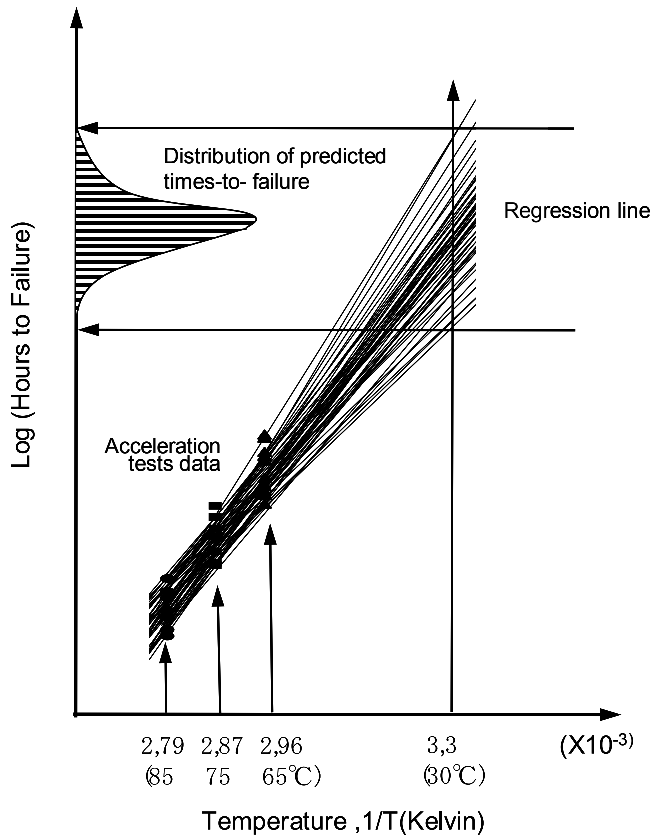

Figure E.1 — Regression lines computed from bootstrap sampling data with Arrhenius method

Step 1

For example data in Table E.1, a hypothetical data set was generated based on DVD-RAM experimental values. The data is offered solely as an example of the bootstrap mathematical methodology.

Randomly select the 3 sets of bootstrap sample data from each block of 3 stress conditions in Table E.1. For each, linear regression is performed with the ln (time-to-failure), as the dependent of the inverse number of absolute temperature (in Kelvin). Predict the time-to-failure of DVD-RAM at temperature 30 °C using the regression line.

Table E.1 — Estimated time to failure for example data

Disc #	Stress condition		
	85°C/80%RH	75°C/80%RH	65°C/80%RH
1	590	1 799	6 329
2	599	1 942	8 758
3	529	2 307	6 782
4	389	2 745	6 547
5	532	3 380	7 565
6	505	3 776	7 047
7	843	2 398	7 893
8	756	2 236	8 030
9	765	1 805	4 085
10	541	2 041	7 406
11	478	2 115	6 658
12	621	2 569	8 565
13	603	2 250	5 248
14	489	2 456	6 324
15	652	1 867	7 589
16	722	2 222	6 895
17	825	1 654	7 548
18	589	2 005	8 354
19	780	1 784	5 789
20	511	2 215	5 905
21		2 201	5 869
22		3 005	4 485
23		1 865	6 902
24		1 842	5 569
25		2 487	4 759
26			6 250
27			4 698
28			7 125
29			5 002
30			6 854

Step 2

Repeat 1 000 times of step 1 using Table E.1, the 1 000-touple of times-to-failure and compute the estimated 5 % point of the1 000 predicted times-to-failure.

Let the 1 000-touple of times-to-failure (Y) of DVD-RAM at temperature 30 °C be

$$Y = \{Y_1, Y_2, \cdots\cdots\cdots, Y_{1\,000}\}$$

and the descending order of Y be

$$\{Y^*_1, Y^*_2, \cdots\cdots\cdots, Y^*_{1\,000}\}$$

then Y^*_{50}, Y^*_{500} are the 5 % point and median value of the 1 000 predicted times-to-failure.

For the Arrhenius model (uncontrolled ambient condition, 30 °C/80 % RH), 5 % point and median value of 1 000 predicted times-to-failure are 217 077,7 h (24,8 years), 902 650,8 h (103 years), respectively.

Annex F
(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.

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

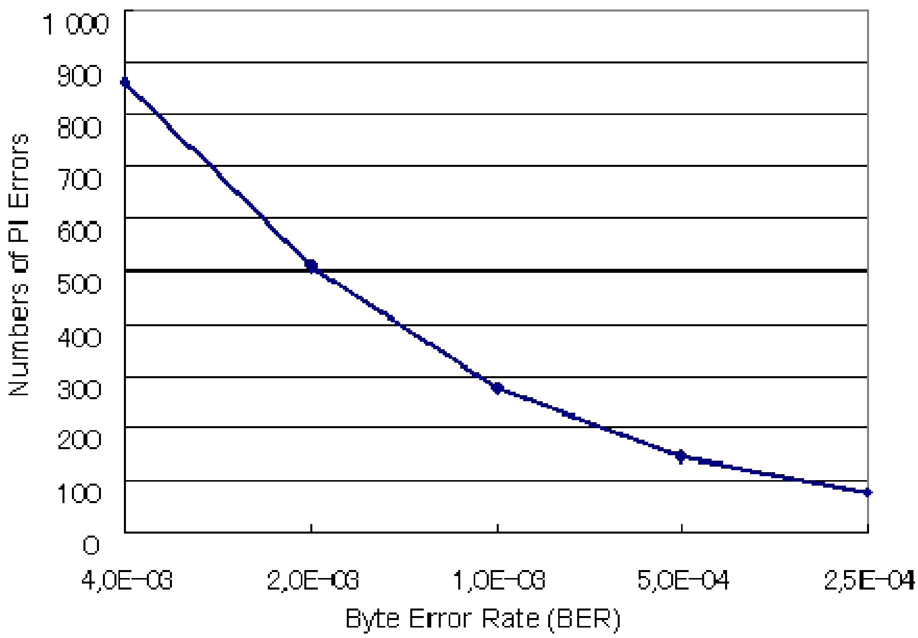

Figure F.1 — Relationship between BER and PI Sum 8

References

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