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Imaging materials — Information stored on magneto-optical (MO) discs — Method for estimating the life expectancy based on the effects of temperature and relative humidity

National foreword

This British Standard is the UK implementation of ISO 18926:2012. It supersedes BS ISO 18926:2006 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CPW/42, Photography.

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Imaging materials — Information stored on magneto-optical (MO) discs — Method for estimating the life expectancy based on the effects of temperature and relative humidity

Matériaux pour l'image — Information stockée sur disques opto-magnétiques (MO) — Méthode d'estimation de l'espérance de vie basée sur les effets de la température et de l'humidité relative

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18926 was prepared by Technical Committee ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO 18926:2006), of which it constitutes a minor revision with the following changes:

- the original Annex A has been removed and the remaining annexes have been reidentified;
- in Clause 3, references to ISO/IEC 17346:2005, ISO/IEC 22092:2002 and ISO/IEC 22533:2005 have been added;
- in 6.2.4, Table 2, the bottom line temperature has been changed from 25 °C to 23 °C;
- in 7.3, Formula (4), the temperature has been changed from 25 °C to 23 °C;
- in Annex B, the temperature in the first sentence of the paragraph above Table B.6 has been changed from 298,1 K to 296,1 K;
- in Annex B, the temperature in the second paragraph below Figure B.5 has been changed from 25 °C to 23 °C.

Introduction

This International Standard is one of a series of standards dealing with the physical properties and stability of imaging materials.

Imaging materials — Information stored on magneto-optical (MO) discs — Method for estimating the life expectancy based on the effects of temperature and relative humidity

1 Scope

This International Standard specifies a test method for estimating the life expectancy (LE) of information stored on rewritable and write-once magneto-optical media. Only the effects of temperature and relative humidity on the media are considered.

2 Purpose and assumptions

2.1 Purpose

The purpose of this International Standard is to establish a methodology for estimating the life expectancy of information stored on magneto-optical discs. This methodology provides a technically and statistically sound procedure for obtaining and evaluating accelerated test data.

2.2 Assumptions

The validity of the procedure defined by this International Standard relies on five assumptions:

- the failure mechanisms acting at the usage conditions are the same as those at the accelerated conditions;
- the linearity of the byte error rate (BER) estimated over the accelerated and design conditions is valid;
- all failure mechanisms have been accounted for and appropriately modelled;
- failure caused by reversible effects such as surface dust is not included;
- failure from repairable parts such as external cartridge components is not included.

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.

ISO/IEC 10089:1991, *Information technology — 130 mm rewritable optical disk cartridge for information interchange*

ISO/IEC 10090:1992, *Information technology — 90 mm optical disk cartridges, rewritable and read only, for data interchange*

ISO/IEC 11560:1992, *Information technology — Information interchange on 130 mm optical disk cartridges using the magneto-optical effect, for write once, read multiple functionality*

ISO/IEC 13549:1993, *Information technology — Data interchange on 130 mm optical disk cartridges — Capacity: 1,3 gigabytes per cartridge*

ISO/IEC 13963:1995, *Information technology — Data interchange on 90 mm optical disk cartridges — Capacity: 230 megabytes per cartridge*

ISO/IEC 14517:1996, *Information technology — 130 mm optical disk cartridges for information interchange — Capacity: 2,6 Gbytes per cartridge*

ISO/IEC 15041:1997, *Information technology — Data interchange on 90 mm optical disk cartridges — Capacity: 640 Mbytes per cartridge*

ISO/IEC 15286:1999, *Information technology — 130 mm optical disk cartridges for information interchange — Capacity: 5,2 Gbytes per cartridge*

ISO/IEC 17346:2005, *Information technology — Data interchange on 90 mm optical disk cartridges — Capacity: 1,3 Gbytes per cartridge*

ISO/IEC 22092:2002, *Information technology — Data interchange on 130 mm magneto-optical disk cartridges — Capacity: 9,1 Gbytes per cartridge*

ISO/IEC 22533:2005, *Information technology — Data interchange on 90 mm optical disk cartridges — Capacity: 2,3 Gbytes per cartridge*

AITCHISON, J. and BROWN, J.A.C., *The Lognormal Distribution*, Cambridge University Press, 1957

4 Terms and definitions

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

4.1
baseline
condition representing the disc at time of manufacture

NOTE This is customarily the initial parameter measurement taken prior to any application of stress. The designation is usually $t = 0$ for a stress time equal to zero hours.

4.2
byte error rate
BER
number of bytes in error divided by number of bytes tested

NOTE BER refers to the raw byte error rate, without benefit of any error correction or sector re-allocation.

4.3
censored data
time at which a specimen is removed from life testing due to any reason other than having reached end-of-life

4.4
end-of-life
occurrence of any loss of information

4.5
information
signal or image recorded using the system

4.6
$F(t)$
probability that a random unit drawn from the population fails by the time t, or the fraction of all units in the population which fail by time t

4.7
life expectancy
LE
length of time that information is predicted to be retrievable in a system under extended-term storage conditions

4.7.1
standardized life expectancy
SLE
minimum life span, predicted with 95 % confidence, of 95 % of the product stored at a temperature not exceeding 23 °C and a relative humidity (RH) not exceeding 50 %

4.8
magneto-optical disc
any disc conforming to the ISO/IEC standards contained in Clause 3

NOTE Double-sided media are considered to be composed of two discs, one per side. In general, a magneto-optical disc is one that uses thermo-magnetic properties for recording and opto-magnetic properties for reading.

4.9
$R(t)$
probability that a unit drawn from the population will survive at least time t, or the fraction of units in the population that will survive at least time t

NOTE $R(t) = 1 - F(t)$

4.10
retrievability
ability to access information as recorded

4.11
stress
experimental variable to which the specimen is exposed for the duration of the test interval

NOTE In this International Standard, the stress variables are confined to temperature and relative humidity.

4.12
system
combination of recording medium, hardware, software and documentation necessary to retrieve information

4.13
test cell
device that controls the stress to which the specimen is exposed

4.14
test pattern
distribution of 1’s and 0’s within a sector

5 Measurements

5.1 Summary

A sampling of 80 discs is baseline tested for the BER, then divided into five groups according to a specified plan. Each group of discs is subjected to one of five combinations of temperature and relative humidity (stress). During the exposure to the stress condition, discs are periodically removed from the environmental test cell according to a set plan. These discs are then retested for BER and subsequently returned to the test cell for additional increments of exposure at the same stress.

For each disc, the time to reach end-of-life (loss of any information or BER 5×10^{-4}), is then determined or estimated. For each stress condition, the resulting service life data are fitted to a lognormal distribution for that stress. These five sets of parameters (lifetime, temperature and relative humidity) are regressed to fit an Eyring acceleration model. This model is then used to estimate the distribution of lifetimes at a standardized set of conditions.

5.2 Byte error rate (BER)

The objective of measuring the BER is to establish a practical estimation of the system’s ability to read previously written bits using a standard drive. This International Standard considers BER to be a reasonable estimate of the performance of the system. A change in the BER in response to the time at the accelerated temperature and humidity is the principal degradation parameter.

The true end-of-life for any data storage media is any loss of information. Ideally, each specimen is tested until actual failures occur. The first occurrence of any disc degradation that results in uncorrectable errors is considered to signal the actual end-of-life.

Realistically, testing until all discs have failed is impractical. For the purposes of this International Standard, the maximum average BER shall be $5,0 \times 10^{-4}$ if actual failures do not occur during testing. This is very system dependent and its use here is an arbitrary level chosen as a conservative prediction of the onset of unacceptable errors and thereby the end of disc life. All BER measurements are made with the system error correction switched off.

5.3 Test equipment

5.3.1 General

Any disc drive system that conforms to ISO/IEC standards (see Clause 3) may be used. The tester shall be capable of reporting errors occurring prior to the implementation of error correction systems.

5.3.2 Calibration and repeatability

A control disc shall be maintained and measured before and after each data collection interval. For each test drive, a control chart shall be maintained for this control disc with plus or minus three sigma action limits. The mean and standard deviation of the control disc shall be established by collecting at least five measurements. If any individual BER reading lies outside the action limits, the problem shall be corrected and all data collected since the last valid control point shall be remeasured.

If it becomes necessary to replace the test drive, the new drive shall be calibrated using the control disc and compared to the replaced drive. If a statistical difference exists between the control disc BER means, subtract the new disc mean from the old disc mean and add this correction factor to all subsequent BER measurements made with the new drive.

5.4 Test specimen

A test specimen is any disc that conforms to ISO/IEC specifications referenced in Clause 3 and contains representative data written over 100 % of the user area. Representative data may be real data or random test data.

6 Accelerated stress test plan

6.1 General

A well manufactured magneto-optical disc should last several years or even decades. As such, it is not practical to conduct life studies under normal usage conditions. It is then necessary to conduct accelerated aging studies in order to determine the estimated potential for life of this medium. To be successful, these studies shall be planned ahead of time in order to be of sound design both technically and statistically.

Many accelerated life test plans follow a rather traditional approach in sampling, experimentation and data evaluation. These “traditional plans” share the following characteristics:

- the total number of specimens is evenly divided amongst all of the accelerated test cells;
- the specimen from each test cell is evaluated at the same increment of time;
- the Arrhenius relationship is used as the acceleration model;
- the Least Squares method is used for all regressions;
- the calculated life expectancy is for the mean or median life rather than for the first few failure percentiles.

Statisticians, on the other hand, have devoted considerable attention to developing "optimum test plans" for an ideal situation. These plans have the following characteristics:

- two and only two acceleration levels for each stress;
- a large number of specimens distributed mostly amongst the lowest stress levels;
- the need to know the failure distribution, a priori, in order to develop the plan.

The maximum effectiveness of a plan can either be estimated before the test starts or determined after the results have been obtained. As each MO system will have different characteristics, a specific detailed optimum plan is impossible to forecast.

This test plan borrows from the optimum plan, the traditional plan, previous experience with the systems, test equipment and accelerated test stresses to put together a "compromise test plan". Modification of this plan is required to design the best plan for other applications. The methodology shall be applicable to all MO media assessments.

6.2 Stress conditions

6.2.1 General

As mentioned in 6.1, an optimum test plan utilizes only two stress levels for each parameter evaluated, since in an ideal case the relationship between changes in the parameter investigated and changes in stress are known. The compromise test plan documented in this International Standard does not make such an assumption; therefore, three different stress levels per parameter shall be used so that the linearity of the parameter function versus the stress level may be demonstrated.

The test plan shall have the majority of test specimens placed at the lowest stress condition. This minimizes the estimation error at this condition and results in the best estimate of the degradation rate at a level close to the usage condition. The greater number of specimens at the lower stress also tends to equalize the number of failures observed by test completion.

For implementing the test plan documented in this International Standard, five stress conditions shall be used. The minimum distribution of specimens among the stress points that shall be used is shown in Table 1.

Table 1 — Summary of stress conditions

Test cell number	Test stress $T_{\mathrm{inc}}/\mathrm{RH}_{\mathrm{inc}}$	Number of specimens	Interval duration h	Minimum total time h
1	80 °C/85 % RH	10	500	2 000
2	80 °C/70 % RH	10	500	2 000
3	80 °C/55 % RH	15	500	2 000
4	70 °C/85 % RH	15	750	3 000
5	60 °C/85 % RH	30	1 000	4 000

6.2.2 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 would restrict the temperature to greater than 0 °C and less than 100 °C.
- The level of temperature shall not be so high that either plastic deformation or excessive softening of thermoset adhesives occurs.

A common substrate material for magneto-optical discs is polycarbonate (glass transition temperature approximately 150 °C). Experience with high temperature testing of MO discs indicates that an upper limit of 80 °C is practical for most applications.

6.2.3 Relative humidity (RH)

Practical experience shows that 85 % RH is the upper limit within most accelerated test cells. This is due to the tendency for condensation to occur on cool sections of the chamber (such as observation windows, cable ports, wiper handles, etc.). Droplets may become dislodged and entrained in the circulating air within the chamber. If these droplets fall on the test specimen, false error signals could be produced.

6.2.4 Rate of stress change

The process, described in this International Standard, requires that temperature and relative humidity be gradually changed (ramped) from permitted testing conditions to accelerated stress conditions and back again a number of times during the course of testing. The ramp duration and conditions shall be chosen to allow sufficient equilibration of absorbed substrate moisture.

Large departures from equilibrium conditions may result in the formation of liquid water droplets inside the substrate or at its interface with the thin film layers. Gradients in the water concentration through the thickness of the substrate shall also be limited. These gradients drive expansion gradients which can cause significant disc deflection.

In order to minimize moisture concentration gradients, the ramp profile specified in Table 2 shall be used. The objects of the profile are:

- to avoid any situation that may cause moisture condensation within the substrate;
- to minimize the time during which substantial moisture gradients exist in the substrate;
- to stay within specified rates of temperature and humidity change;
- to produce, at the end of the specified profile, a disc which is sufficiently equilibrated to proceed directly to testing without delay.

Discs bonded with thermoplastic adhesives may be close to, or above, their softening temperatures. By including a 2 h step at 50 °C/85 % RH, these adhesives have an opportunity to set before continuing the ramp to ambient conditions.

Table 2 — Temperature and relative humidity transition (ramp) profile

Process step	Temperature °C	Relative humidity % RH	Duration h
Start	at T_{amb}	at RH_{amb}	—
T, RH ramp	to T_{inc}	to RH_{inc}	0,1/°C
Incubation	at T_{inc}	at RH_{inc}	See Table 1
T, RH ramp	50	85	0,1/°C
Adhesive set	50	85	2
RH ramp	50	35	5
T, RH ramp	23	50	2,5

6.2.5 Independent verification of chamber conditions

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

6.2.6 Specimen placement

Fully assembled specimens (includes cartridge and shutter) shall be placed uncovered, either vertically or horizontally, within the test chamber. Discs shall be aligned so that their surface is parallel to the chamber airflow. A space of at least 5 mm shall be maintained between cartridges. Cartridged discs shall be stressed with the shutter closed.

6.3 Accelerated test cell sample population

In order to estimate the log mean and log standard deviation of a lognormal distribution, (see Aitchison and Brown in Clause 3) at least ten failures shall be observed. Observing at least ten failures may not be a problem for a realistic test time at 80 °C/85 % RH but becomes more difficult at milder stress temperature and relative humidity combinations. Assigning a larger percentage of the specimens to the milder stresses increases the chance of observing the necessary number of failures within a practical time interval.

Specimens that have not failed at the end of the test duration shall be time censored. This is also known as *Type I censoring* (see Reference [2], page 233).

If ten failures are not observed by the end of the test duration, then failures may be estimated. To compute the estimated failure time for each disc, it is necessary to first determine a transformation of the BER, such as ln(BER), that results in a linear time dependence. Standard linear regression techniques shall be used to find the best fit to the transformed data. The failure time for each disc shall then be computed by interpolation or extrapolation using each disc's regression equation.

6.4 Time intervals

6.4.1 General

For a test plan where the "exact time-to-failure" is to be the result of extrapolated rate data, no fewer than five time intervals for data collection are required. The baseline measurement (at $t = 0$) is one of these data points. Within a stress condition, the intervals shall be constant.

As the stress conditions get milder, the intervals become longer. Longer time intervals provide the opportunity for more failures to occur at the milder stress conditions.

6.4.2 Test plan

Table 1 specifies the temperatures, relative humidities, time intervals, minimum total time and specimen distributions for each stress condition. A separate group of specimens is used for each stress condition. This constitutes a "constant stress" test plan.

All temperatures have a permitted range of ± 2 °C; all relative humidities have a permitted range of ± 3 % RH.

The stress conditions tabulated in Table 1 offer sufficient combinations of temperature and relative humidity to satisfy the mathematical requirements of the Eyring model (see 7.2), to demonstrate linearity of BER versus time, and to produce a satisfactory confidence level to make meaningful conclusions.

6.4.3 Measurement conditions

Discs shall be equilibrated to the environment in which they will be tested. Foreign surface contaminants shall be cleaned from the disc prior to testing.

7 Data evaluation

7.1 Lognormal distribution model

7.1.1 General

The lognormal distribution model shall be used for characterizing the failure rate distribution. The lognormal distribution model has been found to be very flexible and to fit many applications in the corrosion of thin metal films. It is likely to be the best distribution model for cases in which the dominant failure mechanism relies on chemical reactions or diffusion. Experience has shown that the life distribution of MO discs may be modelled by the lognormal distribution (see, for example, Reference [3]). The lognormal equation is:

$$\mathrm{F}(t) = \frac{1}{\sqrt{2\pi}} \int_{0}^{t} \frac{1}{\sigma_\mathrm{l}\, x}\, \mathrm{e}^{-\frac{1}{2}\left(\frac{\log_\mathrm{e}(x)-\mu_\mathrm{l}}{\sigma_\mathrm{l}}\right)^2} \mathrm{d}x \tag{1}$$

where

t is the time;

σ_l is the log standard deviation;

x is a variable representing specimen failure time;

μ_l is the log mean;

loge(x) is the natural logarithm of x.

7.1.2 Model validity

The accuracy of life estimates and confidence limits depend on how well a model fulfils a few basic assumptions. One important assumption for the lognormal model is that the log standard deviation has the same value at all stress levels. It is essential to verify this assumption.

One test method that is available with almost all life time data analysis computer packages is a comparison of log standard deviation confidence limits. If the confidence interval for the log standard deviation at each accelerated stress level overlaps the confidence interval at the usage stress levels, statistically the parameters are not significantly different.

If a statistically significant difference exists among the stress level log standard deviation parameters, examine the estimates and confidence limits for each scale parameter and determine how they differ. It may be appropriate to edit data due to different failure modes, testing error or simple human error.

A listing of computer packages, along with their key features, which can be useful for life expectancy data analysis is given by Nelson[2] on pages 237 to 239. Equivalent software may be used.

7.2 Eyring acceleration model

The Eyring model has found broad application and shall be the model for estimating the life expectancies of MO discs.

The following equation was derived from the laws of thermodynamics and, in this form, can be readily seen to easily handle the two critical stresses of temperature and relative humidity.

$$t_\mathrm{c} = AT^\mathrm{a}\mathrm{e}^{\Delta H/kT}\mathrm{e}^{(B + C/T)\mathrm{RH}} \quad (2)$$

where

t_c is the time to 50 % failure;

A is the pre-exponential time constant;

T^a is the pre-exponential temperature factor;

ΔH is the activation energy per molecule;

k is Boltzman's constant;

T is the absolute temperature, in Kelvin;

B, C are the relative humidity exponential constants;

RH is the relative humidity.

For the temperature ranges used in this International Standard, it is common practice to set "a" and "C" to zero (see Reference [4]). The Eyring model equation then reduces to the following:

$$t_\mathrm{c} = A\mathrm{e}^{\Delta H/kT}\mathrm{e}^{(B)\mathrm{RH}} \quad (3)$$

7.3 Acceleration factor

Once the log mean and log standard deviation have been determined for each acceleration stress, then the Eyring model shall be solved by a maximum likelihood regression of temperature, relative humidity and log mean to determine the estimated log mean at the storage or usage condition of interest (i.e. 23 °C and 50 % RH). The difference between the usage log mean and the accelerated stress log mean is used to compute the acceleration factor for that stress relative to the usage condition.

$$\text{acceleration factor} = \frac{\text{log mean (23 °C/50 % RH)}}{\text{log mean (accelerated stress)}} \quad (4)$$

By multiplying the failure times at each accelerated stress condition by the appropriate acceleration factors, the data are normalized to the usage condition of interest. This normalized data shall then be plotted on the same lognormal distribution graph to determine the estimated distribution of failures at the usage condition.

Annex C shows an example of MO lifetime calculations using computer generated data for the lifetime model.

7.4 Survivor analysis

Once the failure distribution $F(t)$ is known for time t, then the survival fraction $R(t)$ shall be calculated from the relationship $[R(t) = 1 - F(t)]$. From the definition, $R(t)$ is the probability that any given disc will survive at least time t, or the percentage of the entire population that will survive at least time t.

A plot of the survival fraction $R(t)$ versus time is useful for graphically representing the characteristics of the specimen tested. The confidence intervals of the survivor function shall be calculated using the method of asymptotic normal approximation. From these results, one shall state the fraction of product surviving at least time t, the statistical confidence level used, and the storage temperature and relative humidity combination chosen for the model.

The life expectancy statement shall include the caveat that only the effects of temperature and relative humidity are included. For a standardized life expectancy, SLE, this would read: "At a storage condition of 23 °C and

50 % RH, 95 % of the product evaluated will last a minimum of x years with 95 % confidence, considering only the effects of temperature and relative humidity".

8 Disclaimer

Using this model, the standardized life expectancy (SLE) of the discs is valid for discs maintained at 23 °C and 50 % RH. Discs exposed to other conditions of temperature and humidity are expected to have a different life expectancy.

The test plan documented in this International Standard does not attempt to model degradation due to exposure to sunlight or corrosive gases.

Annex A
(normative)

Ten-step analysis outline

The following is a brief outline of the steps required to estimate the life expectancy of information stored on a magneto-optical (MO) disc, as a function of temperature and relative humidity.

1) Determine the failure time for each specimen.
2) For each stress condition, determine the median rank of each specimen and plot the median rank versus failure time on a lognormal graph.
3) Verify that the plots for all stresses are reasonably parallel to one another. The log standard deviation for each stress may be calculated using standard techniques or estimated from straight lines drawn through the plots.
4) Calculate the log mean for each stress condition.
5) Regress the log mean, temperature and relative humidity for all stress conditions using the reduced Eyring equation in 7.2. Calculate the estimated log mean for the standardized temperature (23 °C) and relative humidity (50 %).
6) Determine the acceleration factor for each stress condition.
7) Normalize all of the failure times by multiplying each failure time by the acceleration factor for its stress condition.
8) Combine all normalized failure times and censored data into one data set. For the entire set, make one composite lognormal plot.
9) Estimate the log mean and the log standard deviation at the usage conditions from this plot or from the combined data.
10) Calculate confidence intervals for the survival function.

Annex B
(informative)

Example of a test plan and data analysis

The following is an example of the data analysis used for estimating the life expectancy of magneto-optical discs. It is based on a lognormal lifetime distribution and an Eyring acceleration model as required by this method.

The example follows the test plan and data analysis outlined in the ten steps given in Annex B. For this example, a purely hypothetical data set was generated. These data are not to be considered indicative of any actual media, system, manufacture or any other real situation. The data are offered solely as examples of the mathematical methodology used in this test procedure.

Step 1: Determine the failure time for each specimen

Following the test plan in Clause 5, the uncorrected BER was measured and recorded for each disc at each increment of time. Table B.1 shows hypothetical results for the ten discs subjected to stress 1 (80 °C/85 % RH). The asterisks indicate that testing was discontinued on those discs as they had far exceeded the defined end-of-life of BER $> 5 \times 10^{-4}$.

Table B.1 — Disc BER $\times 10^{-4}$ versus time at stress 1 (80 °C/85 % RH**)**

Disc	0 h	500 h	1 000 h	1 500 h	2 000 h
1	0,155	0,532	1,826	6,3	21,59
2	0,082	1,53	28,41	*	*
3	0,254	0,769	2,33	7,1	20
4	0,244	0,979	3,926	15,80	60
5	0,127	1,749	24,09	*	*
6	0,192	12,82	856,9	*	*
7	0,087	2,608	78,18	*	*
8	0,186	1,16	7,246	45,2	*
9	0,317	16,5	866	*	*
10	0,172	5,099	151,8	*	*

As it has been shown (see Reference [3]) that the change in ln(BER) for MO discs is linear over time, the disc BERs are transposed by taking the natural log of each value. The results of this transformation for disc 1, stress 1, are shown in Table B.2.

Table B.2 — Transformed BER data for disc 1, stress 1

Time h	BER	ln(BER)
0	$0{,}155 \times 10^{-4}$	– 11,074 7
500	$0{,}532 \times 10^{-4}$	– 9,841 4
1 000	$1{,}826 \times 10^{-4}$	– 8,608 0
1 500	$6{,}300 \times 10^{-4}$	– 7,374 7
2 000	$21{,}59 \times 10^{-4}$	– 6,141 4

A linear regression performed on disc 1 data, with ln(BER) as the dependent variable and time, t, (in hours) as the independent variable, yields the equation $\ln(\text{BER}) = -\,11{,}075 + (0{,}002\,467 \times t)$. As the natural logarithm for 5×10^{-4} is –7,600 9 then this equation results in $7{,}600\,9 = -\,11{,}075 + (0{,}002\,467\ t)$.

Solving this expression for t shows that the time for disc 1 to reach a BER of 5×10^{-4} is 1 408,2 h. Therefore, the estimated lifetime of disc 1, stress 1 is 1 408,2 h. A graphical representation of ln(BER) versus time in hours at 80 °C/85 % RH for disc 1 is shown in Figure B.1.

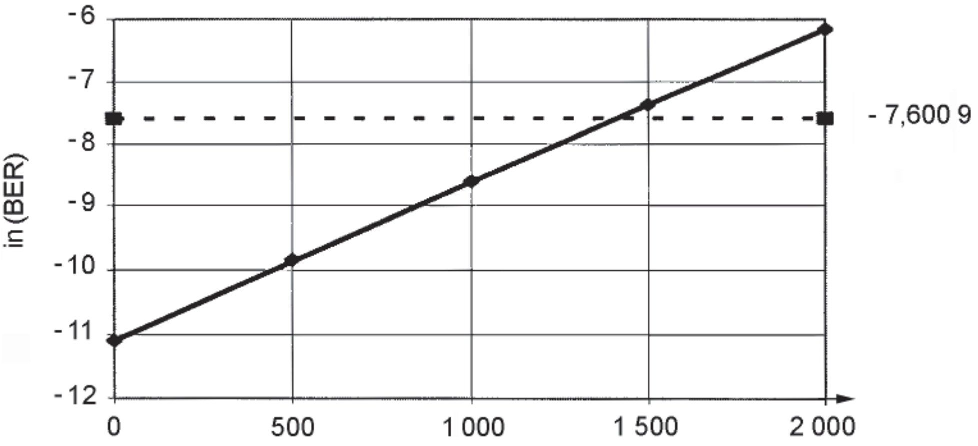


Figure B.1 — Disc 1 ln(BER) versus time in hours at 80 °C/85 % RH

Following the same procedure, the times-to-failure were estimated for each disc. Discs failing during the test duration were not replaced. Those surviving the test duration were censored on test completion. Table B.3 is a summary of the estimated failure times for each disc, sorted in ascending order, within each accelerated stress condition. For the purpose of this example, failure occurs when the BER reaches a value of 5×10^{-4}.

Table B.3 — Estimated time-to-failure (in hours) for example data

Failure order	Stress 1	Stress 2	Stress 3	Stress 4	Stress 5
	80 °C/85 % RH	80 °C/70 % RH	80 °C/55 % RH	70 °C/85 % RH	60 °C/85 % RH
1	349	384	461	1 026	2 200
2	388	526	650	1 270	2 486
3	497	707	700	1 374	2 587
4	596	780	857	1 592	2 675
5	700	863	885	1 650	2 998
6	703	952	998	1 740	3 121
7	899	1 009	1 076	2 010	3 268
8	1 087	1 387	1 247	2 083	3 507
9	1 345	1 487	1 300	2 106	3 791
10	1 408	1 885	1 453	2 425	3 995
11			1 640	2 750	Discs 11 to 30 censored
12			1 654	2 996	
13			1 902	Discs 13 to 15 censored	
14			Discs 14 and 15 censored		
15					

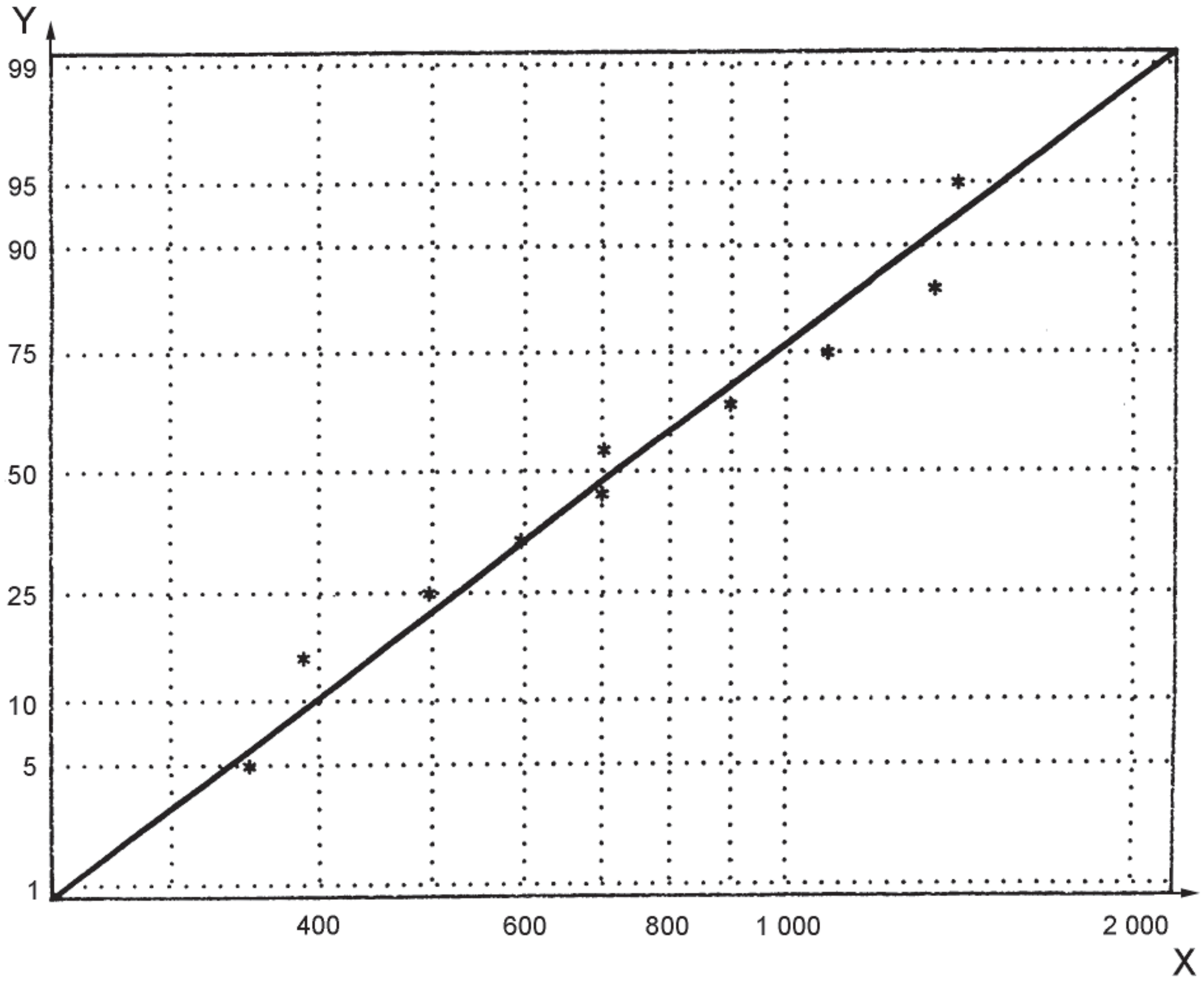
Step 2: For those specimens within each stress, plot the mean rank versus the failure time on a lognormal graph

Calculate the mean rank for each specimen using the estimated mean rank $(i - 0{,}5)/n$, where i is the failure order and n is the total number of specimens at the stress condition. The results for stress 1 are shown in Table B.4.

Table B.4 — Mean rank for stress 1

Failure order i	**Mean rank**	**Hours to failure** t
1	0,050	349
2	0,150	388
3	0,250	497
4	0,350	596
5	0,450	700
6	0,550	703
7	0,650	899
8	0,750	1 087
9	0,850	1 345
10	0,950	1 408

A plot of this stress 1 data, using the mean rank on the ordinate (Y axis) and hours-to-failure on the abscissa (X axis) is shown in Figure B.2. Note that the actual ordinate scale is the probability of failure. The mean rank value was converted to probability by multiplying the value by 100.



Key

X hours to reach BER = 5×10^{-4}

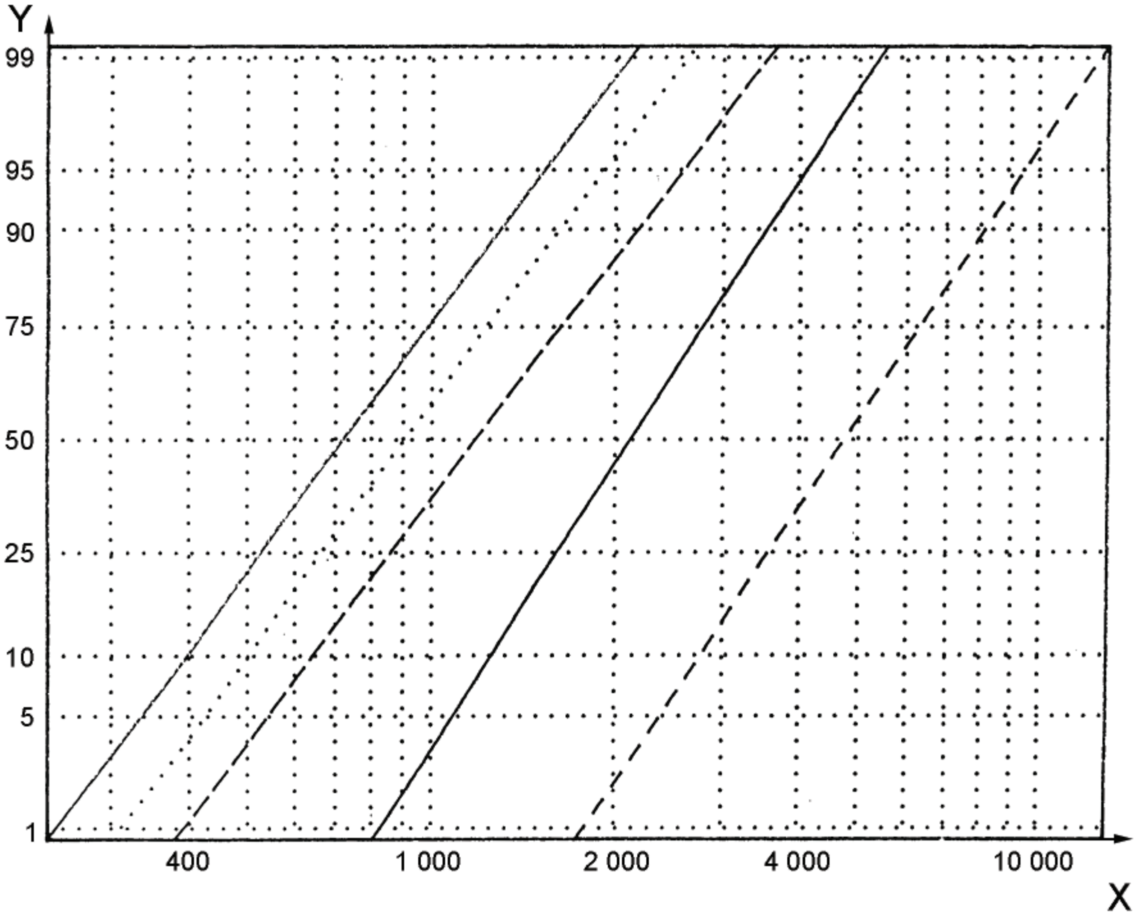
Y probability of failure

Figure B.2 — Lognormal plot for disc lifetimes at stress 1

T(50) = 718,09 h, shape = 4 628

Step 3: Determine that the plots for each stress are reasonably parallel

For each stress, plot the mean rank versus the failure time on a single lognormal graph. Construct a straight line through each set of plotted data. A lognormal plot for each stress is shown as Figure B.3. For the sake of clarity, the data points are not shown.



Key

X hours to reach BER = 5×10^{-4}

Y percentile

Figure B.3 — Multiple lognormal plots from stress 1 to stress 5

Step 4: Calculate the log mean for each stress

The log mean is the time at which the line crosses the 50 % probability of failure. The calculated log mean and log standard deviation factor for each stress are listed in Table B.5. These times can be estimated from the graphical treatment of the data.

Table B.5 — Log mean and log standard deviation for each stress condition

	Stress 1	Stress 2	Stress 3	Stress 4	Stress 5
Log mean	718,09	902,43	1 190,3	2 115,8	4 755,1
Log standard deviation	0,462 8	0,458 2	0,485 4	0,404 5	0,421 5

Step 5: Calculate the log mean for the standardized temperature (23 °C) and relative humidity (50 %)

Using the Eyring model, the log mean values were regressed along with the temperature and relative humidity values to produce a solution to the reduced equation shown in 7.2 [$t_\mathrm{c} = A\mathrm{e}^{\Delta H/kT}\mathrm{e}^{(B)RH}$]. By taking logarithms of both sides of this equation, the expression becomes linear as shown below

$$\ln(t_\mathrm{c}) = \ln(A) + \frac{\Delta H}{k} \times \frac{1}{T} + (B \times \mathrm{RH}) \tag{B.1}$$

The solution produced the following parameters:

$A = 4{,}861\,9 \times 10^{-11}$ h

$\Delta H = 0{,}961\,6$ eV

$B = -1{,}429/\%$ RH

By substituting the temperature and relative humidity for the standardized life expectancy, [23 °C (296,1 K) and 50 % RH], the log mean at that condition was calculated to be $4{,}268\,5 \times 10^5$ h. The log mean for each of the accelerated stresses was also calculated according to the regression equation. The calculated values are compared to the experimental values in Table B.6.

Table B.6 — Experimental versus calculated log mean

	Stress 1	**Stress 2**	**Stress 3**	**Stress 4**	**Stress 5**
Experimental log mean	718,09	902,43	1 190,3	2 115,8	4 755,1
Calculated log mean	761,5	943,5	1 169,2	1 912,2	5 074,9

Step 6: Determine the acceleration factor for each stress

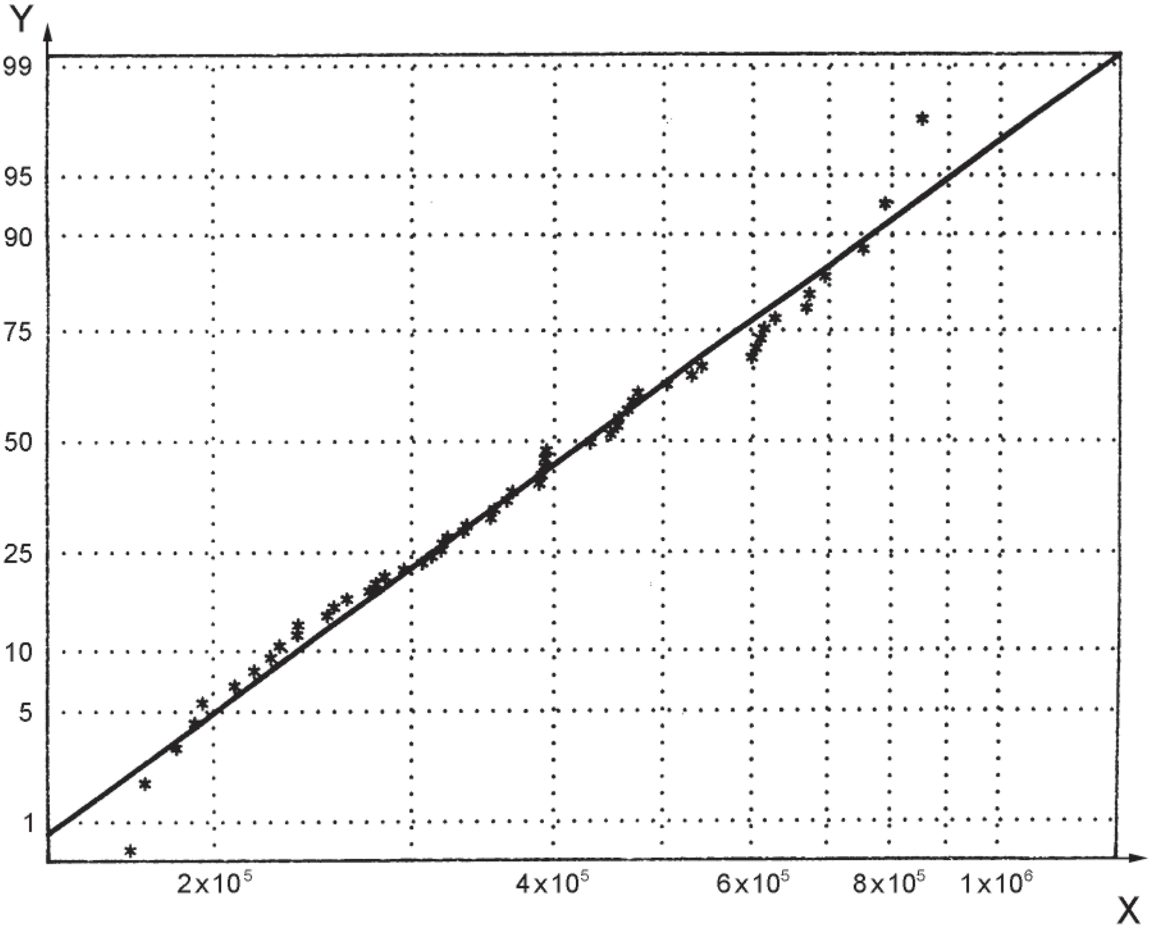
These acceleration factors will be applied to the accelerated data, normalizing it to the usage condition. For example, the acceleration factor for stress 1 relative to the usage condition is: (log mean of 80 °C/85 % RH) ÷ (log mean of 23 °C/50 % RH) which becomes $4{,}268\,5 \times 10^5/761{,}46 = 560{,}5$.

Step 7: Normalize all of the failure times to the standardized life expectancy condition

Normalize the estimated times-to-failure measured at 80 °C/85 % RH (stress 1) to the usage condition (23 °C/50 % RH) by multiplying each failure time in stress 1 by 560,5. The failure times at the other stress conditions are likewise normalized by multiplying them by the respective acceleration factors.

Step 8: Combine all of the normalized failure times in one lognormal plot

Plot all of the normalized failure times on the same composite lognormal graph. This allows a graphical approach to obtain the log mean at 23 °C and 50 % RH and should verify the mathematical treatment of step 5. Figure B.4 shows the results of plotting all of the normalized example data on a single composite lognormal graph.



Key

X hours to reach BER = 5 × 10^{-4}

Y percentile

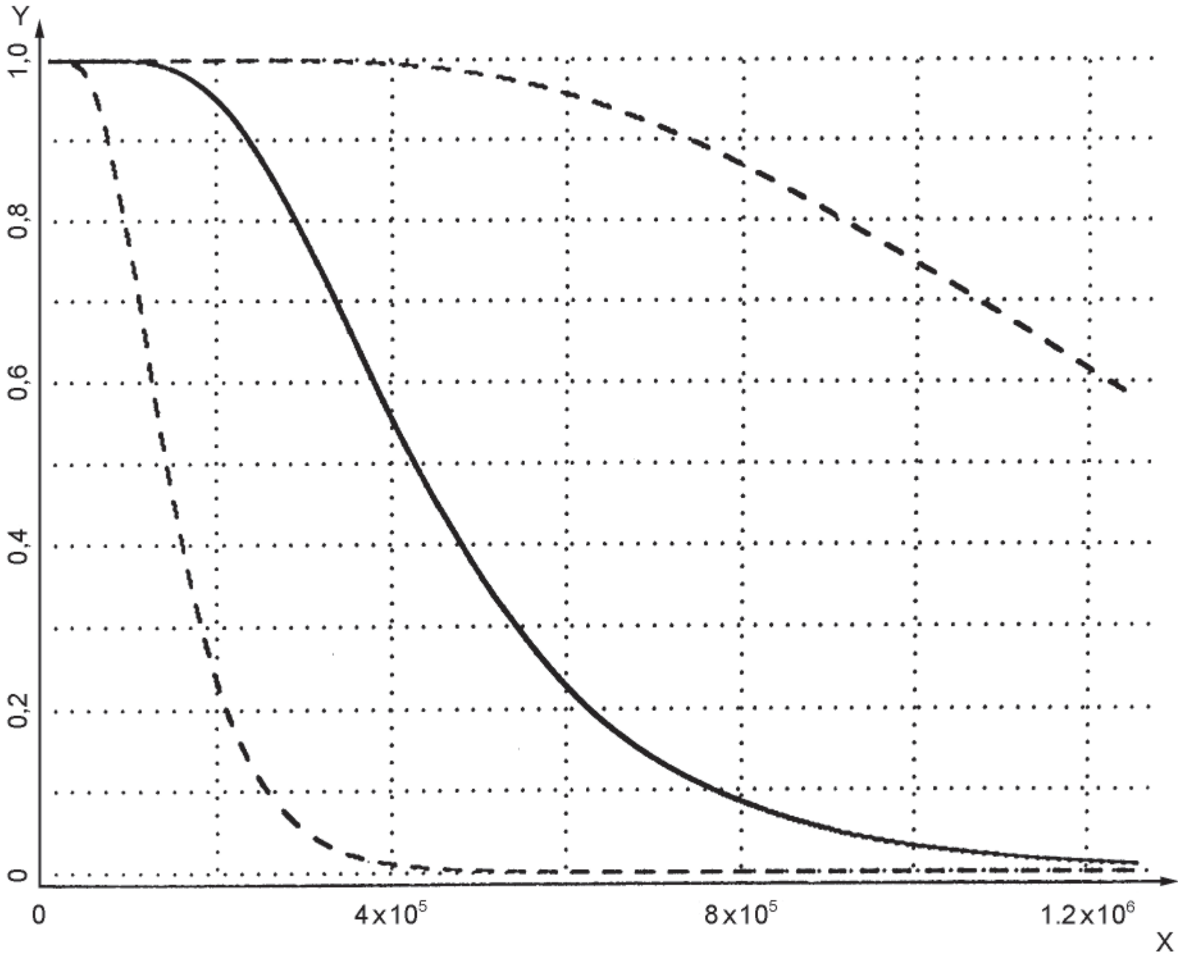
Figure B.4 — Time scale adjusted to 23 °C/50 % RH
Lognormal plot, multiple censoring

Step 9: Estimate the log mean and log standard deviation at the standardized life expectancy conditions

This graph can be used to estimate the time for a given percentage of the discs to fail (i.e. log mean). For the example data, the estimated time for 50 % of the discs to fail is 4,3 × 10^5 h, which is a good agreement with the calculated log mean value of 4,268 × 10^5 h. The graphical solution not only serves as another method for checking the calculated log mean, but also would show the presence of any outliers. The log standard deviation is calculated from the individual normalized life estimates.

Step 10: Calculate the survival function and confidence limits

Plot the survivor probability (1 - the failure probability) versus time for each disc on ordinary graph paper. Figure B.4 shows the survivor probability for our example data, along with the 90 % asymptotic normal confidence intervals. Figure B.5 shows the expanded survivor probability, zooming in on the 0,95 to 1,00 product compliance fraction.



Key

X hours to reach BER = 5 × 10^{-4}

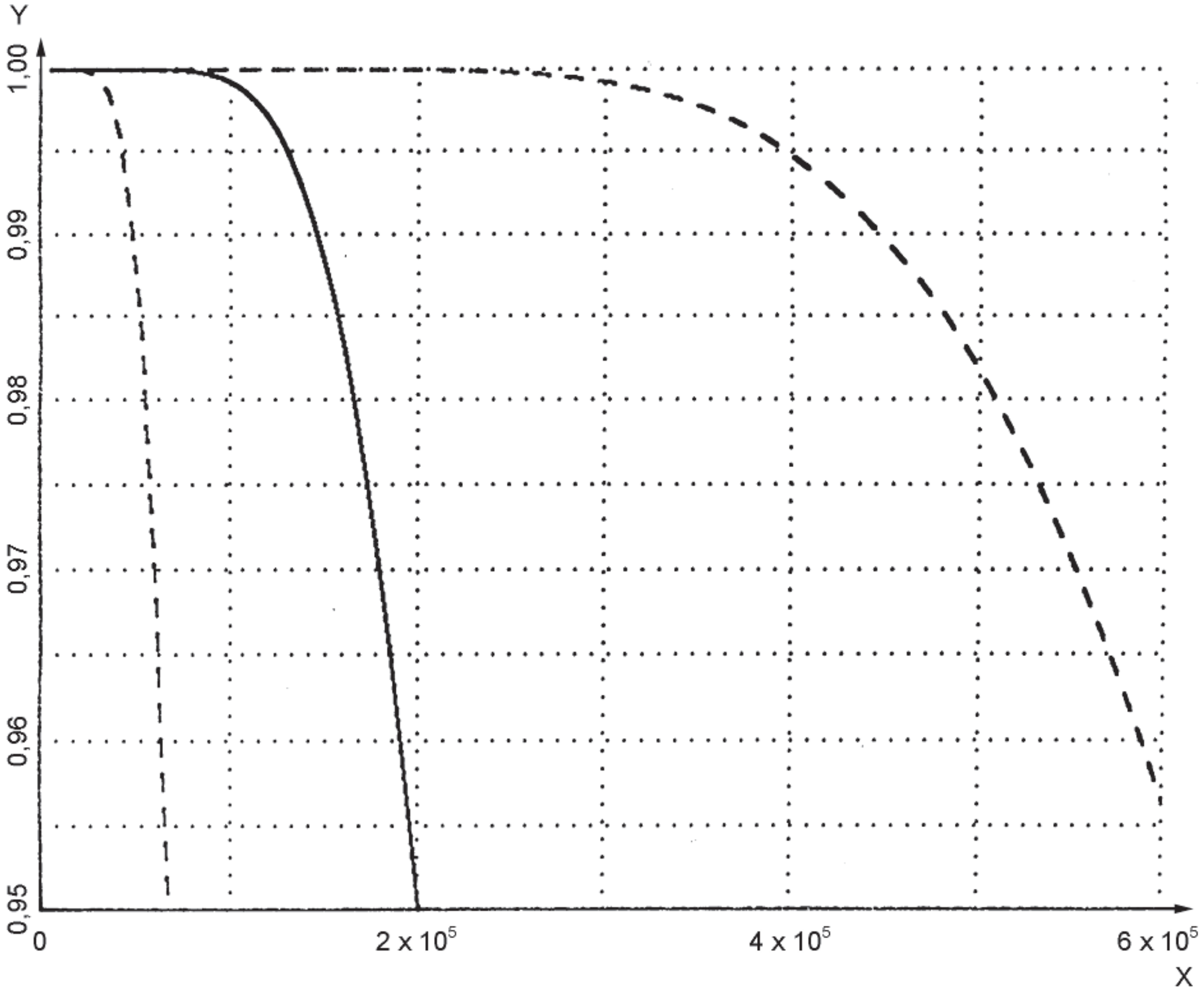
Y fraction surviving

Figure B.5 — Time scale adjusted to 23 °C/50 % RH
Survival function for example data

Nelson (see Reference [2]) provides a comprehensive discussion on the calculations of confidence intervals when an accelerated model and a life distribution are combined. In addition, all of the computer packages referenced in his book are capable of performing such calculations.

Determine where the intersection of the confidence interval intersects the 0,95 probability of survival line. The time on the X-axis corresponding to this point is the time that, with 95 % confidence, 95 % of the population represented by these example discs will survive. This point on Figure B.5 is 6,76 × 10^4 h, (7,7 years) at 23 °C and 50 % RH before reaching an uncorrected BER of 5 × 10^{-4}. This coincides with the standardized life expectancy defined in 3.7.1. Therefore, the standardized life expectancy of these example discs, considering only the effects of temperature and relative humidity, is 7,7 years.

Figure B.6 is an expanded version of Figure B.5.



Key

X hours to reach BER = 5 × 10^{-4}

Y fraction surviving

Figure B.6 — Time scale adjusted to 23 °C/50 % RH
Survival function for example data

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