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Imaging materials — Compact discs (CD-ROM) — Method for estimating the life expectancy based on the effects of temperature and relative humidity

Matériaux pour l'image — Disques compacts (CD-ROM) — 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 18921 was prepared by Technical Committee ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO 18921:2002), of which it constitutes a minor revision.

The following changes have been made to the first edition:

— modification of definition 3.8 (life expectancy);

— modification of 5.1 on block error rate;

— correction of Equations (1) and (2) in 7.1;

— updating of normative and bibliographical references;

— removal of the original Annex A.

Imaging materials — Compact discs (CD-ROM) — 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 compact disc (CD-ROM) media, including CD audio, but excluding recordable media. Only the effects of temperature and relative humidity on the media are considered.

2 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 10149[1)], *Information technology — Data interchange on read-only 120 mm optical data disks (CD-ROM)*

3 Terms and definitions

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

3.1
cumulative distribution function
$F(t)$
probability that a random unit drawn from the population fails by time t, or the fraction of all units in the population which fails by time t

3.2
survivor function
$R(t)$
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 $R(t) = 1 - F(t)$.

3.3
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.

1) Equivalent to ECMA 130.

3.4
block error rate
BLER
ratio of erroneous blocks to total blocks measured at the input of the first (C1) decoder (before any error correction is applied)

NOTE The more commonly reported value for BLER is the number of erroneous blocks per second measured at the input of the C1-decoder during playback at the standard (1X) data rate.

[IEC 60908:1999]

3.5
CD-ROM
compact disc-read only medium

3.6
end-of-life
occurrence of any loss of information

3.7
information
signal or image recorded using the system

3.8
life expectancy
LE
length of time that information is predicted to be retrieved in a system at 23 °C and 50 % relative humidity (RH)

3.8.1
standard life expectancy
SLE
minimum life span, predicted with 95 % confidence, of 95 % of the product stored at a temperature not exceeding 25 °C and a relative humidity (RH) not exceeding 50 % RH

3.9
retrievability
ability to access information as recorded

3.10
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.

3.11
system
combination of recording medium, hardware, software and documentation necessary to retrieve information

3.12
test cell
device that controls the stress to which the specimen is exposed

3.13
test pattern
distribution of the characters I and 0 within a block and the block-to-block variation

4 Purpose and assumptions

4.1 Purpose

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

4.2 Assumptions

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

— the dominant failure mechanism acting at the usage condition is the same as at the accelerated conditions;

— the dominant failure mechanism is appropriately modelled by an Eyring acceleration model;

— life expectancy is appropriately modelled by the two parameter Weibull distribution (see [1] in the Bibliography). The shape parameter of the Weibull distribution is assumed to be independent of the stress level.

5 Measurements

5.1 Block error rate (BLER)

The objective of measuring the block error rate (BLER) is to establish a practical estimation of the system's ability to read the pre-recorded bits using a standard drive. This International Standard considers BLER to be a high level estimate of the performance of the system. A change in BLER in response to the time at an elevated temperature and humidity is the principal quality parameter.

IEC 60908 states that the BLER averaged over any 10 s shall be less than 3×10^{-2}. At the standard (1X) data rate, the total number of blocks per second entering the C1-decoder is 7 350. Thus, an equivalent limit on BLER is 220 blocks per second.

For the purposes of this International Standard, recorded data are considered to have reached end-of-life when the BLER, measured as erroneous blocks per second, exceeds 220 anywhere on the disc, i.e. when the maximum BLER exceeds 220. It is recognized that the correlation between actual loss of information and maximum BLER is very system dependent. A BLER of 220 is an arbitrary level chosen as a predictor of the onset of uncorrectable errors and thereby end-of-life.

5.2 Test equipment

5.2.1 Compact disc test system

Any compact disc test system (tester) that is in accordance with ISO/IEC 10149 may be used. The make, model and version of the test equipment (including software) shall be reported with the test results.

5.2.2 Calibration and repeatability

Calibration according to the tester manufacturer's procedure shall be performed prior to any measurement data being collected. A calibration disc shall be available from the tester manufacturer.

In addition to the calibration disc, one control disc shall be maintained at ambient conditions and its maximum BLER measured before and after each data collection interval. A control chart shall be maintained for this control disc with ± 3 σ action limits. The mean and standard deviation of the control disc shall be established by collecting at least five measurements. Should any individual maximum BLER reading exceed the action limit, 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 tester, a method shall be followed for correlating tester outputs (see [2] in the Bibliography).

5.3 Test specimen

A test specimen is any disc that meets ISO/IEC 10149 specifications and contains representative data extending to within 2 mm of the maximum recording diameter.

6 Accelerated stress test plan

6.1 General

A CD-ROM of good manufacture should last several years or even decades. Consequently, it is necessary to conduct accelerated ageing studies in order to develop a life expectancy estimate. The key is conducting and evaluating a test plan that will provide the information necessary to satisfactorily evaluate the particular product.

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

a) the total number of specimens is evenly divided amongst all the accelerated stresses;

b) each stress is evaluated at the same time increments;

c) the Arrhenius relationship is used as the acceleration model;

d) the least squares method is used for all regressions;

e) the calculated life expectancy is for the mean or median life rather than for the first few failure percentiles.

On the other hand, “optimum test plans” have been proposed which differ in significant aspects from traditional plans. These plans have the following characteristics:

— two and only two acceleration levels for each stress;

— a large number of specimens distributed mostly in 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 CD-ROM system has 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”. Modifications of this plan will be required to design the best plan for other applications. The methodology shall be applicable to all CD-ROM media assessments.

6.2 Stress conditions

6.2.1 Levels

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 is 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.

6.2.2 Conditions

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. For improved precision, additional specimens and conditions may be used if desired.

Table 1 — Summary of stress conditions

Test cell number	Test stress T(inc)[a] °C	Test stress RH(inc)[a] %	Number of specimens	Incubation duration h	Minimum total time h	Intermediate RH RH(int)[b] %	Minimum equilibrium duration h
1	80	85	10	500	2 000	31	6
2	80	70	10	500	2 000	31	8
3	80	55	15	500	2 000	31	4
4	70	85	15	750	3 000	33	8
5	60	85	30	1 000	4 000	36	11

[a] T(inc) and RH(inc) are the stress incubation temperature and relative humidity.

[b] RH(int) is the intermediate relative humidity that at T(inc) supports the same equilibrium moisture absorption in polycarbonate as that supported at room ambient temperature and relative humidity.

6.2.3 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 level shall not be so high that plastic deformation occurs.

The typical substrate material for CD-ROMs is polycarbonate (glass transition temperature ~ 150 °C). The glass transition temperature of other layers may be lower. Experience with high temperature testing of CD-ROMs indicates that an upper limit of 80 °C is practical for most applications.

6.2.4 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, e.g. 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.

6.2.5 Rate of stress change

The process described in this International Standard requires that discs be ramped from the test conditions to 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 reflecting layer. 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 produce, at the end of the specified profile, a disc that is sufficiently equilibrated to proceed directly to testing without delay.

The profile accomplishes this by varying the moisture content of the disc 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 2 — Temperature and relative humidity transition (ramp) profile

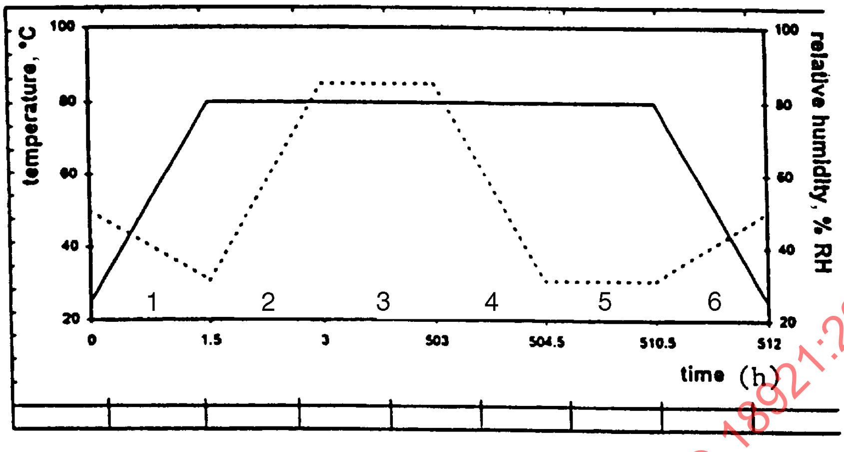
Process step	Temperature T °C	Relative humidity RH %	Duration h
Start	at T(amb)[a]	at RH(amb)[a]	—
T, RH ramp	to T(inc)[b]	to RH(int)[c]	1,5 ± 0,5
RH ramp	at T(inc)	to RH(inc)[b]	1,5 ± 0,5
Incubation	at T(inc)	at RH(inc)	See Table 1
RH ramp	at T(inc)	to RH(int)	1,5 ± 0,5
Equilibration	at T(inc)	at RH(int)	See Table 1
T, RH ramp	to T(amb)	to RH(amb)	1,5 ± 0,5
End	at T(amb)	at RH(amb)	—
Transitions should not deviate from a linear change over the chosen duration by more than ± 2 °C and ± 3 % RH. Ramp transitions may be controlled automatically or manually.			

[a] T(amb) and RH(amb) are room ambient temperature and relative humidity.

[b] T(inc) and RH(inc) are the stress incubation temperature and relative humidity.

[c] RH(int) is the intermediate relative humidity that at T(inc) supports the same equilibrium moisture absorption in polycarbonate as that supported at T(amb) and RH(amb) (see Table 1).

Figure 1 graphically portrays the temperature and relative humidity changes that would occur during one cycle of incubation at 80 °C and 85 % RH, as specified in Tables 1 and 2.



Key

____	temperature (T)
....	relative humidity (RH)

1 T, RH ramp
2 RH ramp
3 incubation
4 RH ramp
5 equilibration
6 T, RH ramp

Figure 1 — Graph of nominal 80 °C/85 % RH transition (ramp) profile

6.2.6 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

6.2.7 Specimen placement

Disc specimens 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, and a space of at least 2 mm shall be maintained between them.

6.2.8 Other influences

During the course of the test, the discs shall be shielded from excessive illumination and potentially corrosive fumes, gases and liquids.

6.3 Accelerated test cell specimen population

In order to estimate the shape and scale parameters of a Weibull distribution, at least ten failures shall be observed. Observing at least ten failures is generally not 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 at the lower 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 [3] in the Bibliography).

To compute the estimated failure time for each disc, it is necessary to first determine a transformation of the maximum BLER, such as ln (max BLER), 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 using each disc's regression equation.

If ten failures are not observed by the end of the test duration, then failures may be estimated by extrapolation using the above technique.

6.4 Time intervals

For a test plan where the "exact time to failure" is to be the result of extrapolated rate data, five time intervals for data collection shall be used for each disc. The baseline measurement (at $t = 0$) is one of these data points. Within a stress condition, the intervals shall be constant.

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

6.5 Test plan

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

All temperatures have an allowed range of ± 2 °C; all relative humidities have an allowed 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 7.1), to demonstrate linearity of either maximum BLER or the ln (max BLER) versus time and to produce a satisfactory confidence level to make meaningful conclusions.

6.6 Measurement conditions

Between stress intervals, the specimen shall be maintained at the test condition specified in ISO/IEC 10149. Foreign surface contaminants shall be cleaned from the disc prior to testing.

7 Data evaluation

7.1 Eyring acceleration model

The Eyring model has found broad application and shall be the model for estimating the life expectancies (LEs) of compact discs (see [4] in the Bibliography).

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

$$t_c = AT^a e^{\Delta H / kT} e^{(B + C/T)\mathrm{RH}} \quad (1)$$

where

t is the time;

t_c is the characteristic life, also called the scale parameter;

A is the pre-exponential time constant;

T^a is the pre-exponential temperature factor;

ΔH is the activation energy per molecule;

k is the Boltzmann's constant;

T is the Kelvin temperature;

B, C are the relative humidity exponential constants;

RH is the relative humidity.

For the temperature range used in this International Standard, it is common practice to set "a" and "C" to zero. The Eyring model equation then reduces to the following (see [5] in the Bibliography):

$$t_{\text{c}} = A\text{e}^{\Delta H / kT}\text{e}^{(B)\text{RH}} \quad (2)$$

7.2 Failure distribution model

The Weibull distribution model shall be used for determining the CD-ROM life distribution. The Weibull cumulative failure equation is:

$$F(t) = 1 - \text{e}^{-(t/t_{\text{c}})m} \quad (3)$$

where

m is the shape parameter;

t_{c} is the scale parameter (or characteristic life).

NOTE When $t = t_{\text{c}}$, the Weibull equation becomes $[F(t) = 1 - \text{e}^{-1}]$ and equals 0,632. Therefore at t_{c}, 63,2 % of the product has failed.

The Weibull distribution 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 fit where the failure mechanism is one where failure is due to one of many competing sites for failure. A simple example of this might be a chain, where the chain fails when the first link breaks, regardless of the condition of the other links. It has been shown to be applicable to the life expectancy of compact discs (see [4] in the Bibliography).

7.3 Acceleration factors

Once the Weibull scale parameters have been determined for each acceleration stress, then the Eyring model shall be solved by a maximum likelihood regression of the temperature, relative humidity and the scale parameter to determine the estimated scale parameter at the storage or usage condition of interest, i.e. 25 °C/50 % RH.

A ratio of the usage scale parameter to the accelerated scale parameter produces the "acceleration factor" for that stress relative to the usage condition. For example, the acceleration factor 80 °C/85 % RH relative to 25 °C/50 % RH is equal to the estimated scale parameter at 25 °C/50 % RH divided by the scale parameter at 80 °C/85 % RH.

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

The accuracy of life estimates and confidence limits depends on how well a model fulfils a few basic assumptions. One important assumption for the Weibull model is that the shape parameter, m, has the same value at all stress levels. It is important to verify this assumption.

The preferred method of testing shape parameter equality is by "likelihood ratio" (LR) tests. Many software packages offer a significance level for this LR test.

An alternative procedure, the "interval method", is a comparison of shape parameter confidence intervals. If the confidence interval for the shape parameter at one stress level overlaps the interval at other stress levels, statistically the parameters are not significantly different. The LR test is more robust than the interval method. If a software package is unavailable, shape parameter equality can be tested subjectively by visual inspection of Weibull plots. Groups with equivalent shape parameters are parallel shifts of each other.

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

A listing of computer packages, along with their key features, that may be useful for life expectancy data analysis is given by Nelson (see [3] in the Bibliography). Equivalent software may be used. Annex B shows an example of CD-ROM lifetime calculations.

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 its 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 specimens tested. The confidence intervals of the survivor fraction 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 indicate the caveat that only the effects of temperature and humidity are included. For a standardized life expectancy (SLE), this would read: "At a storage condition of 25 °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 25 °C and 50 % RH. Discs exposed to more severe conditions of temperature and humidity are expected to experience a shorter life.

The test method specified in this International Standard does not attempt to model degradation due to exposure to light, corrosive gases, contaminants, mishandling and variations in the playback system.

Annex A
(informative)

Step analysis outline

The following is a brief outline of the steps required to estimate the life expectancy of information stored on CD-ROM media as a function of temperature and relative humidity:

a) determine the failure time for each specimen;

b) for each stress condition, determine the median rank for each specimen and plot the median rank versus failure time on a lognormal graph;

c) verify that the plots for all stress conditions are reasonably parallel to one another; the log standard deviation for each stress condition may be calculated using standard techniques or estimated from straight lines drawn through the plots;

d) calculate the scale parameter for each stress condition;

e) using the reduced Eyring equation in 7.1, regress the temperature, relative humidity, and the scale parameter; calculate the scale parameter at the standardized temperature (25 °C) and relative humidity (50 % RH);

f) determine the acceleration factor for each stress condition;

g) normalize all the failure times by multiplying each failure time by the acceleration factor for its stress condition;

h) combine all normalized failure times and censored data into one data set; for this entire set, make one composite lognormal plot;

i) estimate the shape and scale of CD-ROM life expectancy at the usage conditions from this plot or from the combined data;

j) compute the maximum likelihood confidence intervals for the survival function.

Annex B
(informative)

Example of test plan and data analysis

An example of a test plan and data analysis that follows this procedure and uses the ten steps from Annex A is given below. For this model, a purely hypothetical data set was generated. These values were completely fabricated for this assumption and are not to be considered indicative of any actual media, system, manufacture or any other real situation. The data is offered solely as an example of the mathematical methodology used in this test procedure.

Step 1

Following the test plan in Clause 6, the exact times to failure were interpolated for each disc. Discs failing or censored during the test length were not replaced. Those surviving the test duration were censored as of the test completion.

Table B.1 is a summary, by stress, of the failure times obtained (or interpolated) at each accelerated condition. For the purpose of this example, failure is a maximum BLER of 220.

Table B.1 — Estimated time to failure (in hours) for example data

Failure order	Stress 1	Stress 2	Stress 3	Stress 4	Stress 5
1	223	117	497	503	1 046
2	231	239	538	1 089	1 219
3	379	514	575	1 317	1 246
4	473	666	576	1 457	1 419
5	535	700	645	1 573	1 629
6	564	755	672	1 614	2 005
7	691	770	693	1 751	2 323
8	800	808	722	1 843	2 629
9	903	1 138	781	1 871	3 183
10	903	1 383	790	1 954	3 236
11	—	—	862	2 303	3 399
12	—	—	1 390	2 538	3 621
13	—	—	1 566	2 864	3 963
14	—	—	1 798	Disc 14-15 censored	Disc 14-15 censored
15	—	—	1 962		

Step 2

From this hypothetical data, a Weibull scale parameter for each stress was calculated as shown below. The failure times were plotted along the abscissa (x-axis) and the sample median rank was plotted along the ordinate (y-axis) of the Weibull graph paper. For determining median rank, the estimate $(i-0{,}5)/n$ is used. The failure order is represented by i, and the total number of samples is represented by n. The results for “stress 1” are shown in Table B.2.

Table B.2 — Median rank for stress 1

Failure order i	Median rank	Hours to failure h
1	0,050	223
2	0,150	231
3	0,250	379
4	0,350	473
5	0,450	535
6	0,550	564
7	0,650	691
8	0,750	800
9	0,850	903
10	0,950	1 704

Step 3

A Weibull plot for these data is shown as Figure B.1. The ordinate, probability of failure, is the median rank multiplied by 100.

Step 4

The scale parameter (t_c) is the time by which 63,2 % failures will have occurred.

The shape parameter (m) can be estimated from a graphical treatment of the failure data. First, the time corresponding to a 99 % cumulative failure (t_{99}) is estimated from the "best fit" straight line through the failure data. The estimated shape parameter is then calculated from the equation:

$$m = \frac{\ln(4,6)}{\ln(t_{99}/t_c)} \quad \text{(B.1)}$$

which is derived from the Weibull cumulative failure equation in 7.2.

The calculated shape parameter and scale parameter for all test stresses are listed in Table B.3. The plots for the different stresses are nearly parallel.

Table B.3 — Shape and scale parameters for all test stresses

	Stress 1	Stress 2	Stress 3	Stress 4	Stress 5
Shape parameter	1,72	2,05	2,15	2,60	1,86
Scale parameter	735	797	1 067	2 217	5 384

Step 5

Using the Eyring model, the scale parameters were regressed along with the temperature and relative humidity values to produce a solution to the reduced equation shown in 7.1 [$t_c = A e^{\Delta H / kT} e^{(B)\text{RH}}$]

The values were determined to be:

$A = 1{,}241\ 6 \times 10^{-11}$ h;

$\Delta H = 0{,}164\,3$ eV/molecule $= 2{,}632 \times 10^{-20}$ J/molecule;

$B = -8{,}888 \times 10^{-3}$ /% RH.

The scale parameter at 25 °C/50 % RH was calculated to be $4{,}29 \times 10^5$ h.

Step 6

This permits the acceleration factors to be calculated and applied to the accelerated data, normalizing it to the usage conditions. For example, the acceleration factor for stress 1 is $4{,}29 \times 10^5$/735, which equals 584.

Step 7

To normalize the estimated times to failure at stress 1 to the usage condition, multiply each stress 1 failure time by 584, all the failure times at stress 2 by its own acceleration factor, etc., until all the stress times at all five stresses have been multiplied by their respective acceleration factors.

Step 8

Plot all the normalized failure times on the same composite Weibull graph. This step is a graphical approach to obtain the scale parameter at 25 °C and 50 % RH and should verify the mathematical treatment in step 5.

Figure B.2 shows the results of plotting all the normalized example data on a single composite graph.

Step 9

From the plot or data analysis, estimate the shape parameter and scale parameter of the composite Weibull distribution. The scale parameter is the time at which 63,2 % of the product will fail (see 7.2) and agrees with the $4{,}29 \times 10^5$ h calculated in step 5.

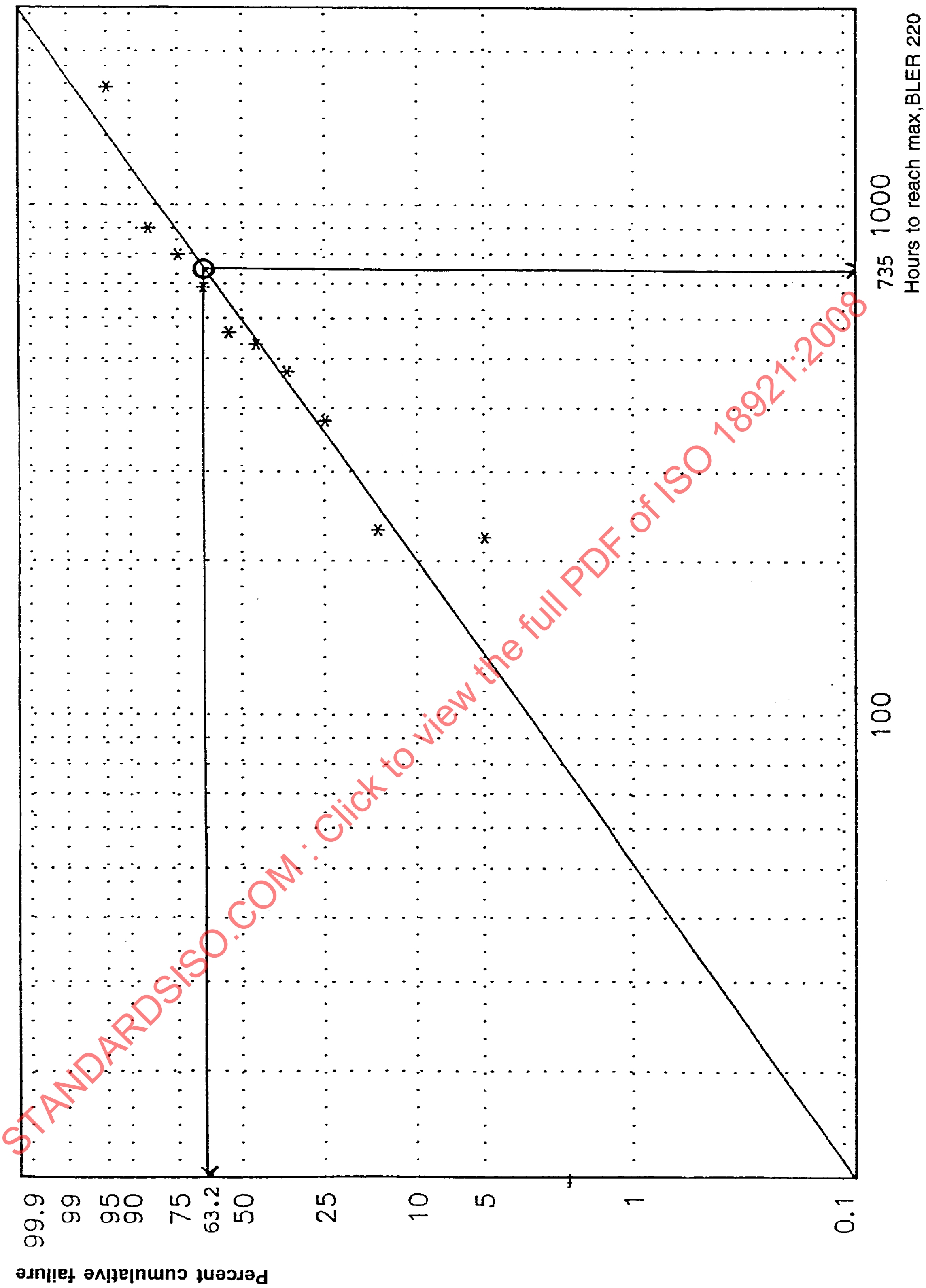
Step 10

Figure B.3 shows the "survivor function" $[R_{(t)} = 1 - F_{(t)}]$ along with the 90 % confidence intervals of the best estimate. With 95 % confidence, the true survivor function does not fall below the lower dotted line of these figures.

Figure B.4 shows the "expanded survivor function", zooming in on the 0,95 to 1,0 product compliance fraction.

The graphical results show that, with 95 % confidence, 95 % of the population represented by these example discs will survive $3{,}2 \times 10^4$ h (3,65 years) at 25 °C and 50 % RH before reaching a maximum BLER of 220. This coincides with the standard life expectancy (SLE) defined in 3.8.1.

Therefore, the SLE of these example discs, considering only the effects of temperature and relative humidity, is 3,65 years.



NOTE Weibull probability plot, $N = 10$; multiple censoring, $R = 10$.

Figure B.1 — Stress 1, 80 °C/85 % RH