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Imaging materials — Recordable compact disc systems — Method for estimating the life expectancy based on the effects of temperature and relative humidity

Matériaux pour image — Systèmes de CD enregistrables — Méthode d'estimation de l'espérance de vie basée sur les effets de la température et de l'humidité relative

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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 18927 was prepared by Technical Committee ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO 18927:2002), of which it constitutes a minor revision.

The following changes have been made to the first edition:

— modification of definition 3.10 (life expectancy);

— modification of 5.2 on block error rate;

— updating of normative and bibliographical references;

— removal of the original Annex A.

Imaging materials — Recordable compact disc systems — 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 of information stored on recordable compact disc systems. Only the effects of temperature and relative humidity on the media are considered.

This International Standard does not cover the effects of light, air pollution, or time-dependent flow phenomena.

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)*

IEC 60908:1999, *Audio recording — Compact disc digital audio system*

Experimental statistics, U.S. National Bureau of Standards Handbook 91, 1963

3 Terms and definitions

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

3.1
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.

3.2
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)

1) Equivalent to ECMA 130.

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]

3.2.1
maximum block error rate
max BLER
maximum BLER measured anywhere on a disc

3.3
compact disc-recordable
CD-R
recordable optical disc in which information can be recorded to certain areas in compact disc format

NOTE 1 Information can be recorded once and read many times.

NOTE 2 The term "compact disc-write once" (CD-WO) has also been used to describe this type of disc.

3.4
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

3.4.1
lognormal cumulative distribution function
$F(t)$
cumulative distribution function in which the logarithm of the relevant parameter, in this International Standard the disc lifetime, has a normal distribution and is defined by the following equation:

$$F(t)=\frac{1}{\sqrt{2\pi}}\int_0^t \frac{1}{\sigma_l x} e^{-\frac{1}{2}\left(\frac{\ln(x)-\mu_l}{\sigma_l}\right)^2} dx$$

where

- t is the time;
- x is a variable representing disc lifetime;
- σ_l is the log standard deviation;
- μ_l is the log mean;
- $\ln(x)$ is the natural logarithm of x

NOTE When $t = e^{\mu_1}$, the lognormal cumulative distribution function evaluates to 0,5. In other words, the model predicts that half the samples have failed at that time.

3.5
disc-at-once recording
method of recording a CD-R disc whereby the entire CD is recorded in one pass without turning off the laser

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

3.7
extended-term storage conditions
storage conditions suitable for the preservation of recorded information having permanent value

3.8
glass transition
reversible change in an amorphous polymer from, or to, a viscous or rubber condition to, or from, a hard and relatively brittle one

3.8.1
glass transition temperature
T_g
approximate mid-point of the temperature range over which glass transition takes place

NOTE 1 T_g can be determined readily only by observing the temperature at which a significant change takes place in a specific electrical, mechanical, or other physical property.

NOTE 2 T_g can also be sensitive to the moisture content of the polymer.

3.9
information
signal or image recorded using the system

3.10
life expectancy
LE
length of time that information is predicted to be acceptable in a system after dark storage at 23 °C and 50 % relative humidity (RH)

3.10.1
standardized 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

3.11
retrievability
ability to access information as recorded

3.12
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.

3.13
survivor function
$R(t)$
probability that a random unit drawn from the population survives at least time t, or the fraction of all units in the population which survive at least time t

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

3.14
system
combination of material, hardware, software and documentation necessary for recording and/or retrieving information

3.15
test cell
device that controls the stress to which the specimen is exposed

3.16
track-at-once recording
method of recording a CD-R disc whereby each track is recorded individually with 150 empty sectors immediately preceding it and two run-out sectors immediately following

3.17
uncorrectable error
error in the playback data that is not correctable by the cross interleave Reed-Solomon code defined in IEC 60908 as implemented in a system

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 recordable compact disc systems. This methodology provides a technically and statistically sound procedure for obtaining and evaluating accelerated test data.

The methodology deals only with the effects of temperature and humidity on the retrievability of stored information. For this reason, this International Standard is primarily directed to those storage applications, e.g. libraries and archives, in which exposure to other influences potentially detrimental to information life expectancy, such as chemical agents, intense light sources and improper handling, is controlled and minimized.

4.2 Assumptions

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

— specimen life distribution is appropriately modelled by the lognormal distribution;

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

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

Publications by Hamada and Stinson provide data indicating that these assumptions are applicable to compact disc-recordable (CD-R) systems (see references [5] and [6] in the Bibliography).

5 Measurements

5.1 Summary

A sampling of 80 recorded discs shall be divided into five groups according to a specified plan. Each group of discs (test cell) shall be subjected to one of five test stresses, combinations of temperature and relative humidity. Periodically during the stress conditions, all discs from each stress group shall have their block error rate (BLER) measured. Data collected at each time interval for each individual disc are then used to determine a lifetime for that disc.

The disc lifetimes at each stress level are fitted to a lognormal distribution to determine a mean lifetime for the stress. The resulting five mean lifetimes are regressed against temperature and relative humidity according to an Eyring acceleration model. This model is then used to estimate the distribution of lifetimes at a usage condition.

5.2 Block error rate (BLER)

End-of-life is the occurrence of any loss of information. Ideally, each specimen is tested until the first loss of information occurs. Realistically, this is impractical. This International Standard considers max BLER to be a high-level estimate of the performance of the system. The objective of measuring BLER is to establish a practical estimation of the system's ability to read recorded data without uncorrectable errors. A change in max BLER in response to the time at an accelerated 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.

A BLER of 220 is an arbitrary level chosen as a predictor of the onset of uncorrectable errors and thereby end-of-life. A BLER of 220 corresponds to an upper limit for error correction. As a result, lower BLER discs are recommended to use for long-term storage.

5.3 Test equipment

5.3.1 General requirements

A compact disc player that conforms to ISO/IEC 10149 and software capable of producing a display of max BLER.

If it becomes necessary to replace the test equipment, the US National Bureau of Standards Handbook 91 shall be followed for correlating test equipment outputs.

The make, model and version of the test equipment (including software) shall be reported with the test results.

5.3.2 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 an accredited source.

In addition to the calibration disc, one control disc shall be maintained at ambient conditions and its max BLER measured before and after each data collection interval. A control chart shall be maintained for this control disc.

The mean and standard deviation of the control disc shall be established by collecting at least five measurements. Should any individual max BLER 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 remeasured.

5.4 Test specimen

5.4.1 General requirements

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

5.4.2 Specimen selection

All discs shall be nominally identical with regard to substrate groove structure, layer structure, coating composition, recording capacity, and age prior to test initiation. It is preferred that the CD-R media be chosen from different lots and production lines in order to be representative of normal process variations.

All discs shall be maintained in the manufacturer's transportation and storage conditions prior to recording.

The nominal disc capacity shall be reported with the test results.

5.4.3 Recording system

Specimen discs may be recorded in any appropriate recording device. Since the extrapolated lifetime is a function of the system including the CD-R media, all discs shall be recorded identically to the extent possible. Similar recording devices shall be used, as well as similar software and recording conditions. Discs recorded on different physical devices shall be distributed as equally as possible across the test cells.

The make and model of the recording device, the linear velocity employed during recording and the software used in the recording system shall be reported with the test results.

5.4.4 Ambient recording conditions

Ambient conditions during recording shall be within the following limits:

— temperature: 15 °C to 35 °C;

— relative humidity: 45 % to 75 %.

During recording, the recording system shall be isolated from external vibrations.

5.4.5 Recording method

It is strongly recommended that all discs be recorded using the "disc-at-once" method. If discs are recorded using the "track-at-once" method, all errors occurring at the gap between tracks shall be ignored for the purpose of this International Standard. Packet writing (in which several write events are allowed within a track) shall not be employed.

Independent of the writing method, the specimen discs shall be recorded as a single session and finalized.

6 Accelerated stress test plan

6.1 General

Information properly recorded in a CD-R system of good manufacture should have a life of 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 a test plan that will provide the information necessary to satisfactorily evaluate the particular system.

Many accelerated life test plans follow a rather traditional approach in specimen selection, 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-R 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 and 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-R 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. This is because, 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 condition 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 conditions that shall be used is shown in Table 1. Additional specimens and conditions may be used if desired for improved precision.

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	5
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 shall not be so high that plastic deformation occurs anywhere within the disc structure.

The typical substrate material for CD-R media is polycarbonate (glass transition temperature ~ 150 °C). The glass transition temperature of other layers may be lower. Experience with high-temperature testing of CD-R discs 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 for control 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. The 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 undergo a transition from the ambient conditions to stress conditions and back again a number of times during the course of testing. The transition (or 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 information-recording 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 curvature.

In order to minimize the effects of moisture-concentration gradients, the ramp profile outlined 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 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.

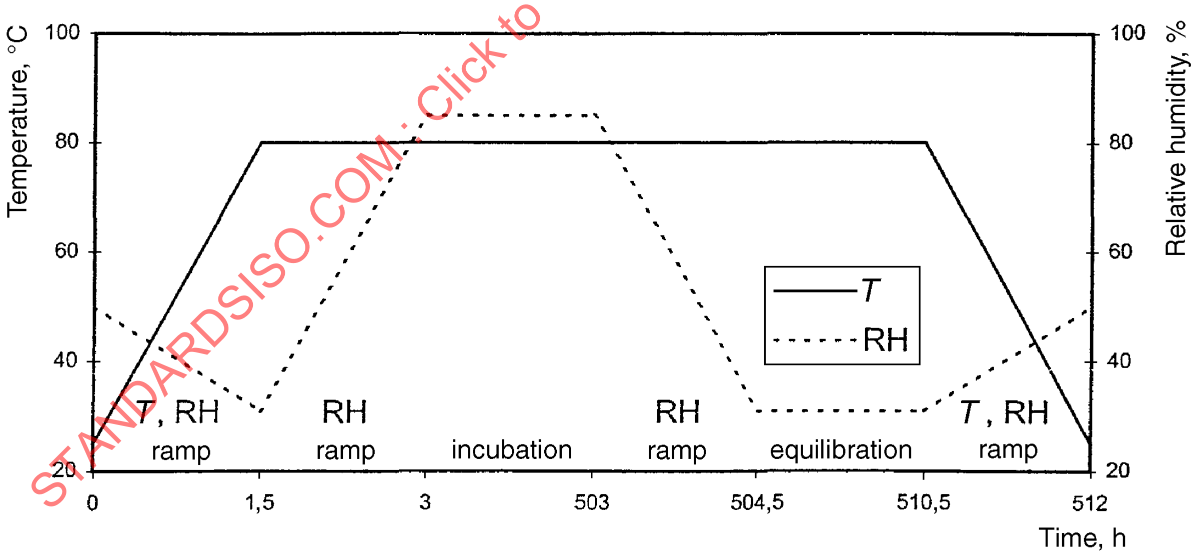

Figure 1 — Graph of nominal 80 °C/85 % RH transition (ramp) profile

6.2.6 Independent verification of chamber conditions

A system independent of the chamber control system shall be used to monitor temperature and relative 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. A space of at least 2 mm shall be maintained between discs.

6.2.8 Other influences

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

6.3 Accelerated test cell sample population

In order to estimate the log mean and log standard deviation of a lognormal 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 to 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 page 233 of Reference [7] in the Bibliography).

To compute the estimated failure time for each disc, it is necessary to first determine a transformation of max 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.

6.4 Time intervals

For data collection, measurement of max BLER shall occur at four time intervals for each disc. The baseline measurement (at test initiation) shall be an additional data point. Within a stress condition, the intervals shall be constant. At the milder stress conditions, the intervals are longer. The 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, time intervals, minimum total test 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 an allowed range of ± 2 °C; all relative humidities have an allowed range of ± 3 % RH.

The intermediate relative humidity, RH(int), in Table 1 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 following equation:

$$z_{\mathrm{RH(int)}} = \frac{0{,}24 + 0{,}003\,7\, y_{\mathrm{T(amb)}}}{0{,}24 + 0{,}003\,7\, y_{\mathrm{T(inc)}}} z_{\mathrm{RH(amb)}} \qquad (1)$$

where

$z_{\mathrm{RH(int)}}$ is the intermediate relative humidity, in %;

$y_{\mathrm{T(amb)}}$ is the ambient temperature, in °C;

$y_{T(inc)}$ is the incubation temperature, in °C;

$z_{RH(amb)}$ is the ambient relative humidity, %.

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 either max BLER or ln (max BLER) versus time, and to produce a satisfactory confidence level to make meaningful conclusions.

6.6 Measurement conditions

Between stress intervals, the specimens shall be maintained within the ambient recording conditions specified in 5.4.4. Any surface particulates that may accumulate shall be cleaned from the disc prior to testing by use of a pressurized stream of clean, dry air or nitrogen.

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 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. This distribution has also been found to be applicable to the analysis of failure data of CD-R media (see reference [6] in the Bibliography).

7.1.2 Model validity

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

The preferred method of testing log standard deviation 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 log standard deviation confidence intervals. If the 95 % confidence interval for the log standard deviation at one stress level overlaps the interval at other stress levels, statistically the parameters are not significantly different. The LR test is, however, more robust than the interval method.

If a software package is unavailable, log standard deviation equality can be tested subjectively by visual inspection of lognormal plots. If best-fit straight lines drawn through sets of failure data plotted on lognormal graph paper are reasonably parallel, then the data sets have equivalent estimated log standard deviations.

If a significant difference exists among the stress log standard deviations, examine the estimates and confidence limits for each log mean and determine how they differ. In the absence of testing error or human error, it may very well be that a different failure mechanism is operating at the different stress conditions. In that case, a life expectancy estimated by this method, or any method with similar assumptions, should be considered unreliable.

7.2 Eyring acceleration model

The Eyring model has found broad application and shall be the model for estimating life expectancies of CD-R systems (see Reference [8] 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.

$$t_{50\%} = AT^{a}\mathrm{e}^{\Delta H/kT}\mathrm{e}^{(B+C/T)\mathrm{RH}} \tag{2}$$

where

$t_{50\%}$ 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 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 Reference [9] in the Bibliography):

$$t_{50\%} = A\mathrm{e}^{\Delta H/kT}\mathrm{e}^{(B)\mathrm{RH}} \tag{3}$$

7.3 Acceleration factors

Once the log mean and log standard deviation have been determined for each acceleration stress, then the Eyring model shall be solved by a regression of temperature, relative humidity, and log mean to determine the estimated log mean at the storage or usage condition of interest (25 °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, such the acceleration factor is $\mathrm{e}^{\left[\mu_{\mathrm{l}}(\text{usage})-\mu_{\mathrm{l}}(\text{stress})\right]}$.

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

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".

7.5 Aids

A listing of computer packages, along with their key features, that may be useful for life expectancy data analysis is given by Nelson (see pages 237 to 239 of Reference [7] in the Bibliography). Equivalent software may be used.

Annex B shows an example of a CD-R media life expectancy calculation.

8 Disclaimer

Using this model, the standardized life expectancy (SLE) is defined 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 in a CD-R system 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) 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 (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 log mean and the log standard deviation at the usage conditions from this plot, or the combined data;

j) calculate 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 example, a hypothetical data set was generated in accordance with the assumptions of 4.2. The data set was assigned the following characteristics at 25 °C/50 % RH:

$$\mu_l = \ln(10 \times 365 \times 24\ \text{h}) = 11{,}38 \qquad \text{(B.1)}$$

where

$\sigma_l = 0{,}1$;

$A = 0{,}1^{-10}$ years;

$B = -0{,}01/\%\ \text{RH}$.

These values are not to be considered indicative of any actual media, system, or manufacturer. The data are offered solely as an example of the mathematical methodology used in this test procedure.

Step 1

Following the test plan in Clause 6, max BLER is measured for each specimen at the specified interval. Discs failing or censored during the test duration are not replaced.

For each specimen, a linear regression is performed with ln (max BLER) as the dependent variable and time as the independent variable. The failure time of the specimen is calculated from the slope and intercept of the regression as the time at which the specimen would have a max BLER of 220. Table B.1 is a summary, by stress, of the example max BLER data and the interpolated failure times of all the specimens.

Step 2

For each stress condition, specimens are ordered by increasing time-to-failure. Specimens that have not failed during the test duration are time censored unless less than ten failures are observed. In that case, the ten specimens with the shortest time to failure are retained.

NOTE While all example specimens from the 80 °C/85 % RH and the 80 °C/70 % RH stress conditions failed (i.e. > 220 max BLER) during the time of the test, only four failed at 80 °C/55 % RH, nine at 70 °C/85 % RH and none at 60 °C/85 % RH.

The median rank of the non-censored specimens is calculated using the estimate $(i–0{,}5)/n$, where i is the failure order and n is the total number of specimens at the stress condition. The resultant data for all the stress conditions are gathered in Table B.2.

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

Specimen number	Stress condition		Measured max BLER					Time to failure
	T °C	RH %	Initial	Interval 1	Interval 2	Interval 3	Interval 4	h
1	80	85	9	24	58	136	322	1,770
2	80	85	10	30	98	302		1,361
3	80	85	11	29	64	155	372	1,698
4	80	85	12	29	68	166	398	1,663
5	80	85	12	33	91	257		1,425
6	80	85	10	29	76	205	549	1,535
7	80	85	11	25	61	139	327	1,767
8	80	85	10	25	64	166	422	1,654
9	80	85	7	31	94	299		1,371
10	80	85	11	25	71	189	505	1,581
11	80	70	12	29	74	187	475	1,588
12	80	70	10	20	47	107	243	1,950
13	80	70	11	26	56	123	281	1,851
14	80	70	8	22	44	99	215	1,995
15	80	70	10	25	58	148	358	1,728
16	80	70	7	21	50	117	274	1,850
17	80	70	13	25	66	172	443	1,640
18	80	70	9	26	63	156	388	1,682
19	80	70	9	24	71	201	571	1,545
20	80	70	9	24	53	127	292	1,823
21	80	55	8	18	38	85	182	2,117
22	80	55	11	25	54	114	243	1,925
23	80	55	12	23	46	98	203	2,072
24	80	55	10	26	64	157	384	1,686
25	80	55	11	20	39	76	149	2,310
26	80	55	9	22	52	127	305	1,814
27	80	55	9	19	42	95	207	2,041
28	80	55	8	15	35	83	192	2,109
29	80	55	14	25	52	105	211	2,043
30	80	55	10	21	40	80	162	2,225
31	80	55	10	23	47	100	198	2,046
32	80	55	10	20	40	81	162	2,220
33	80	55	9	19	41	82	162	2,190
34	80	55	10	24	64	164	425	1,656
35	80	55	9	20	40	89	180	2,123
36	70	85	12	24	57	119	256	2,848
37	70	85	10	24	54	123	269	2,794
38	70	85	9	24	58	144	352	2,601
39	70	85	9	24	65	167	440	2,459
40	70	85	11	22	49	103	223	2,997

Table B.1 *(continued)*

Specimen number	Stress condition		Measured max BLER					Time to failure
	T °C	RH %	Initial	Interval 1	Interval 2	Interval 3	Interval 4	h
41	70	85	12	25	56	116	251	2,871
42	70	85	11	24	56	130	300	2,728
43	70	85	10	19	43	88	191	3,161
44	70	85	12	24	53	114	249	2,893
45	70	85	10	21	42	98	210	3,063
46	70	85	8	21	45	100	225	2,960
47	70	85	11	18	40	79	158	3,386
48	70	85	13	21	40	80	162	3,427
49	70	85	10	19	47	98	216	3,024
50	70	85	12	21	44	87	182	3,246
51	60	85	11	16	25	41	70	6,574
52	60	85	11	15	27	44	71	6,378
53	60	85	9	15	21	34	52	7,335
54	60	85	9	16	28	50	87	5,625
55	60	85	12	20	33	56	95	5,643
56	60	85	9	18	31	55	96	5,375
57	60	85	7	15	27	47	87	5,462
58	60	85	12	20	33	54	95	5,683
59	60	85	9	17	26	48	79	5,879
60	60	85	12	20	32	55	96	5,655
61	60	85	9	19	33	63	115	5,000
62	60	85	10	15	26	44	76	6,125
63	60	85	7	15	26	44	76	5,743
64	60	85	12	16	28	45	76	6,334
65	60	85	8	14	29	52	93	5,344
66	60	85	9	17	28	45	77	5,970
67	60	85	9	17	28	48	85	5,723
68	60	85	11	13	24	35	55	7,352
69	60	85	12	19	37	61	106	5,314
70	60	85	10	16	27	49	84	5,823
71	60	85	9	13	20	32	50	7,465
72	60	85	10	18	30	51	84	5,779
73	60	85	8	14	19	27	44	8,013
74	60	85	11	19	32	56	96	5,536
75	60	85	9	17	27	47	82	5,821
76	60	85	10	17	28	49	79	5,944
77	60	85	11	17	29	49	87	5,855
78	60	85	8	15	22	38	63	6,473
79	60	85	10	14	28	44	76	6,068
80	60	85	9	18	33	56	102	5,250

Table B.2 — Non-censored data for all the stress conditions

Stress	Failure order	1	2	3	4	5	6	7	8	9	10
80 °C	**Specimen no.**	2	9	5	6	10	8	4	3	7	1
85 % RH	**Failure time** (h)	1,361	1,371	1,425	1,535	1,581	1,654	1,663	1,698	1,767	1,770
$n = 10$	**Median rank**	0,050	0,150	0,250	0,350	0,450	0,550	0,650	0,750	0,850	0,950
80 °C	**Specimen no.**	19	11	17	18	15	20	16	13	12	14
70 % RH	**Failure time** (h)	1,545	1,588	1,640	1,682	1,728	1,823	1,850	1,851	1,950	1,995
$n = 10$	**Median rank**	0,050	0,150	0,250	0,350	0,450	0,550	0,650	0,750	0,850	0,950
80 °C	**Specimen no.**	34	24	26	22	27	29	31	23	28	21
55 % RH	**Failure time** (h)	1,656	1,686	1,814	1,925	2,041	2,043	2,046	2,072	2,109	2,117
$n = 15$	**Median rank**	0,033	0,100	0,167	0,233	0,300	0,367	0,433	0,500	0,567	0,633
70 °C	**Specimen no.**	39	38	42	37	36	41	44	46	40	49
85 % RH	**Failure time** (h)	2,459	2,601	2,728	2,794	2,848	2,871	2,893	2,960	2,997	3,024
$n = 15$	**Median rank**	0,033	0,100	0,167	0,233	0,300	0,367	0,433	0,500	0,567	0,633
60 °C	**Specimen no.**	61	80	69	65	56	57	74	54	55	60
85 % RH	**Failure time** (h)	5,000	5,250	5,314	5,344	5,375	5,462	5,536	5,625	5,643	5,655
$n = 30$	**Median rank**	0,017	0,050	0,083	0,117	0,150	0,183	0,217	0,250	0,283	0,317

The data of Table B.2 can be plotted in different ways. If lognormal graph paper is employed, the data is plotted with failure time on the abscissa and median rank on the ordinate (see Figure B.1).

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 failure time on the abscissa (see Figure B.2).

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

Step 3

Best fit straight lines are drawn through the plotted data. Since 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 (see Reference [2] in the Bibliography). First, for each stress, estimate the times corresponding to 16 %, 50 % and 84 % failure based on the best fit straight line through the failure data. The estimated log standard deviation is then calculated from the equation:

$$\sigma_l = \ln \frac{1}{2}\left(\frac{t_{50\%}}{t_{16\%}} + \frac{t_{84\%}}{t_{50\%}} \right) \tag{B.2}$$

Step 4

The log mean is the natural logarithm of the time at which 50 % failures occur. That time can be estimated from the best fit lines as the time corresponding to a median rank of 0,5 (or, equivalently, a critical value of zero).

The log mean and log standard deviation calculated for each stress from a least squares regression of the data are listed in Table B.3.

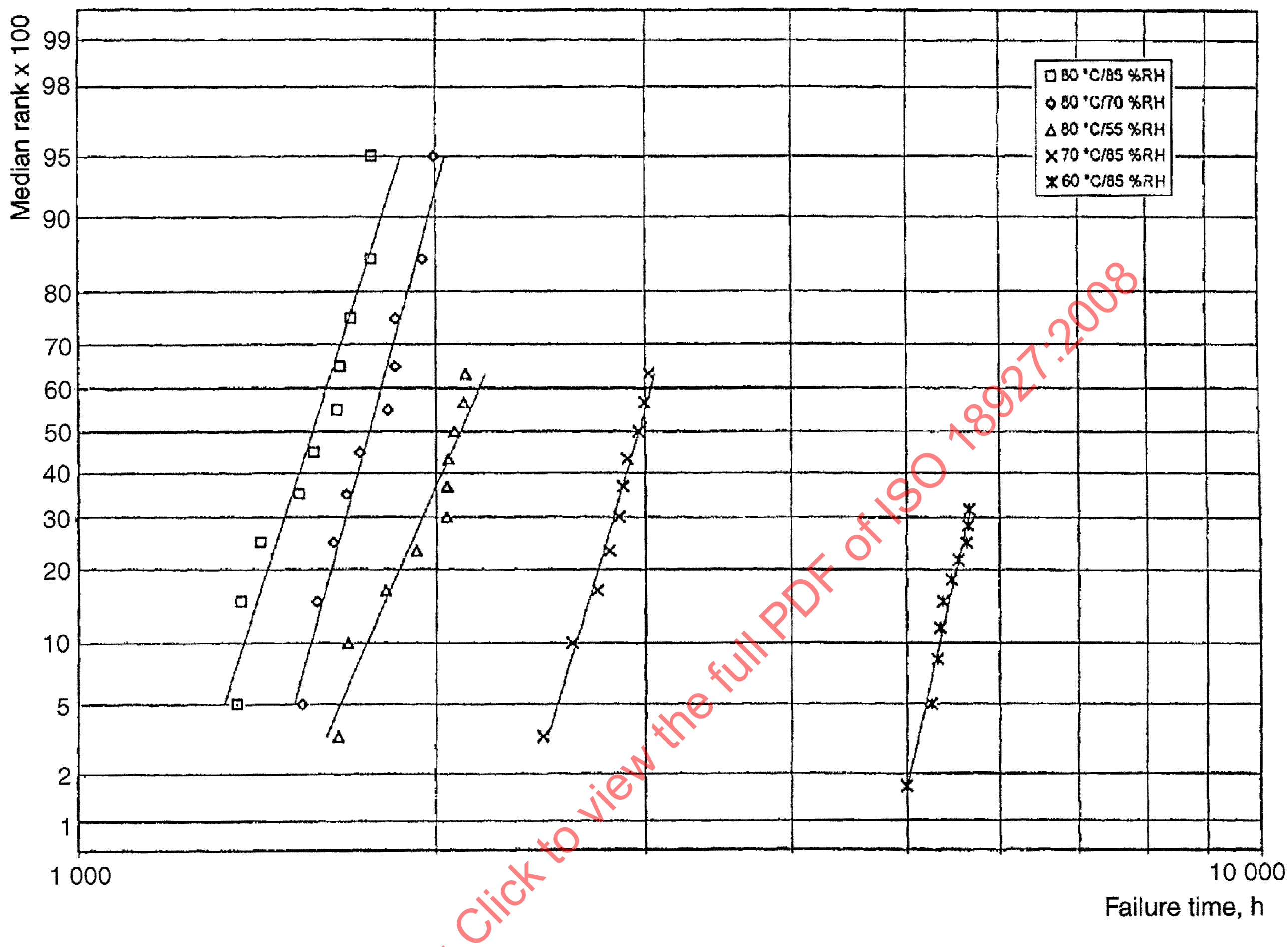

Figure B.1 — Lognormal plot of Table B.2 data

Step 5

The log mean values are now used, along with the temperature and relative humidity, to determine A, B, and $\Delta H / k$ by fitting to the reduced Eyring equation of 7.2. In practice, the regression is done using the equation that results from taking the logarithm of both sides of the reduced equation:

$$\ln\left(t_{50\%}\right) = \log\text{mean} = \ln(A) + \left(\frac{\Delta H}{k}\right) \times \left(\frac{1}{T}\right) + B \times \text{RH} \qquad \text{(B.3)}$$

The values are determined to be:

$A = 8{,}26 \times 10^{-7}$ h $= 9{,}43 \times 10^{-11}$ years;

$B = -9{,}72 \times 10^{-3}$ /% RH;

$\Delta H / k = 7{,}83 \times 10^{3}$ K;

$\Delta H = 10{,}8 \times 10^{-20}$ J/molecule.

The log mean at 25 °C/50 % RH is calculated from the reduced equation to be 11,77. The $t_{50\,\%}$ at 25 °C/50 % RH is then $e^{1,77}$ h, i.e. $1,29 \times 10^5$ h, or 14,7 years.

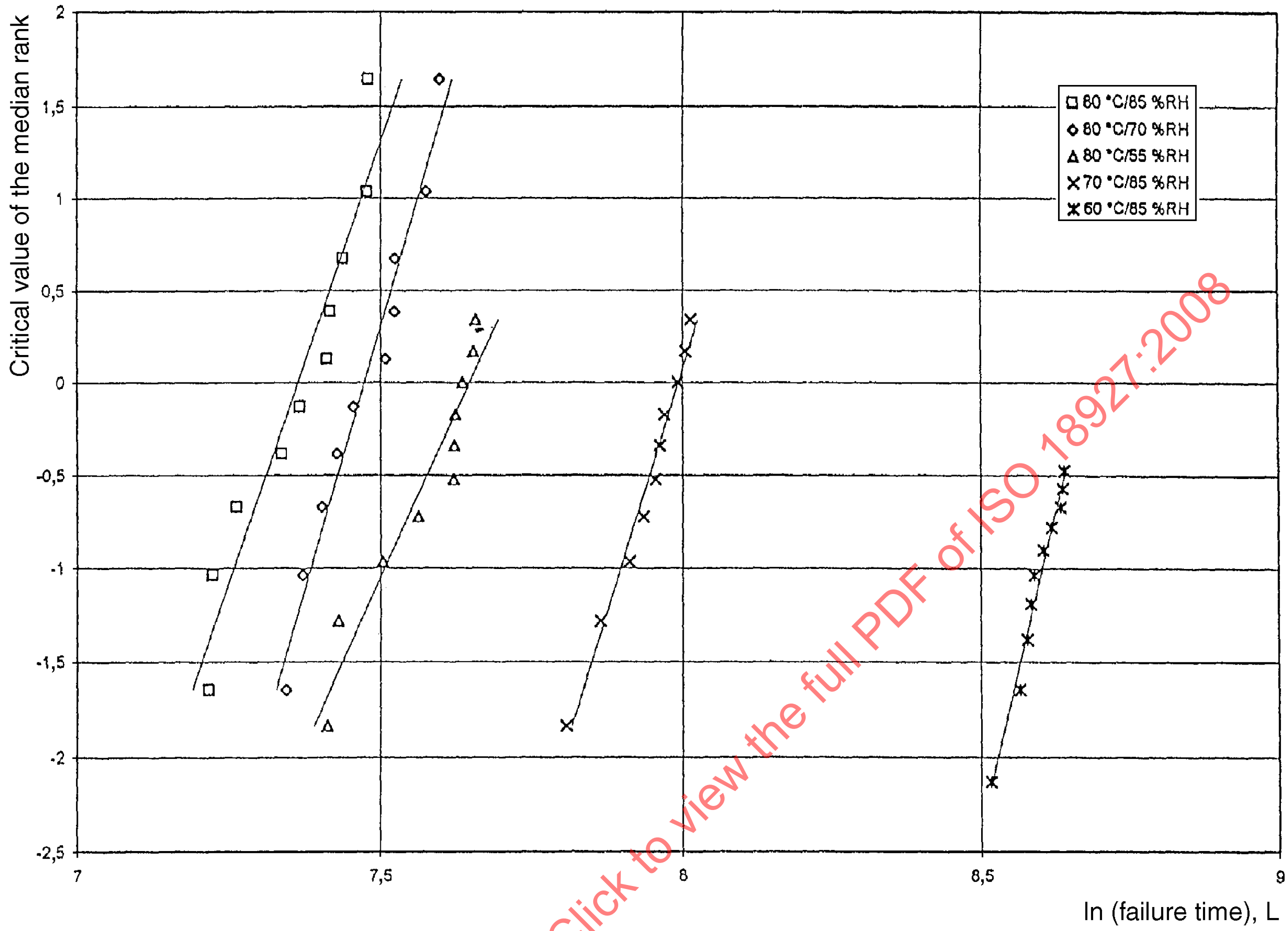

Figure B.2 — Linear plot of Table B.2 data

Table B.3 — Log mean and log standard deviation for each stress condition

Stress condition						
Stress condition	Temperature, °C	80	80	80	70	60
	Relative humidity, %	85	70	55	85	85
Log mean		7,36	7,47	7,65	7,99	8,68
Log standard deviation		0,105	0,089	0,141	0,097	0,076

Step 6

The acceleration factors are calculated from the difference between the estimated log mean at each stress condition and that at the usage condition via the equation provided in 7.3 and are listed in Table B.4.

Table B.4 — Acceleration factor for each stress condition

Stress condition	**Temperature**, °C	80	80	80	70	60
	Relative humidity, %	85	70	55	85	85
Acceleration factor		82,3	73,7	61,6	43,8	22,0

Step 7

The failure times of all the specimens at all the stress conditions are normalized to the usage condition by multiplying them by the acceleration factor for their stress condition.

Step 8

The normalized failure times of all the non-censored specimens are plotted on the same composite graph. This allows a graphical approach to obtain the log mean at 25 °C/50 % RH and should verify the mathematical treatment in step 5.

The median rank for each specimen in this composite plot is estimated in the following way. First, the non-censored specimens are ranked by normalized failure time. Then, the median rank estimate is calculated as $(i - 0{,}5)/n_i$, where i is the rank and n_i is calculated for each specimen as the total number of specimens minus the number of censored specimens with a smaller normalized time to failure (see Table B.5).