INTERNATIONAL STANDARD

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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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# Contents

Page

# 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 third edition cancels and replaces the second edition (ISO 18927:2008), of which it constitutes a minor revision.

The following change has been made to the second edition:

— An update of the bibliographical references.

# 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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, *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 1 to entry: 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)

Note 1 to entry: 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]

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

1) Equivalent to ECMA 130.

**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 to entry: Information can be recorded once and read many times.

Note 2 to entry: 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;



$\sigma_l$ is the log standard deviation;

$\mu_l$ is the log mean;

$\ln(x)$ is the natural logarithm of $x$

Note 1 to entry: When $t = e^{\mu_l}$, 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 to entry: $T_g$ 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 to entry: $T_g$ 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 1 to entry: 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 1 to entry: $R(t) = 1 - F(t)$.

**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 $3 \times 10^{-2}$. 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 re-measured.

## 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 | | Number of specimens | Incubation duration h | Minimum total time h | Intermediate RH RH(int)[b] % | Minimum equilibrium duration h |
|---|---|---|---|---|---|---|---|
| | T(inc)[a] °C | RH(inc)[a] % | | | | | |
| 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 approximately 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, and

— 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**<br>T<br>°C | **Relative humidity**<br>RH<br>% | **Duration**<br>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.