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Information technology — Digitally recorded media for information interchange and storage — Data migration method for DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks

Technologies de l'information — Supports enregistrés numériquement pour échange et stockage d'information — Méthode de migration de données pour disques DVD-R, DVD-RW, DVD-RAM, +R, et +RW

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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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

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

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ISO/IEC 29121 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 23, *Digitally recorded media for information interchange and storage*.

This second edition cancels and replaces the first edition (ISO/IEC 29121:2009), of which has been technically revised.

Introduction

Many organizations now use optical disks for long-term storage of information. It is assumed that a disk selected for recording has already been qualified for that purpose. It is therefore important to be able to verify that data has been recorded correctly and remains readable for the required amount of time. Previous International Standards clearly defined requirements for interchange, but did not contain requirements for longevity.

Longevity is limited both by disk degradation and by technology obsolescence. Interchange shall be regularly verified to assure that information on existing recorded disks will continue to be recoverable. Users can have a maintenance policy that protects disks against unanticipated failure or use, such as by making one copy, another to function as a backup or master, and another for routine access. Hardware-support life cycles typically vary between five to ten years, and technology lifecycles usually end after 20 years. Consequently, recordings that require a longer lifecycle may have to be transferred to upgraded platforms every ten to thirty years.

Optical disks for long-term storage should be evaluated. Significant longevity differences can exist for disks from different manufacturers and even between disks from the same manufacturer. It is preferable that disks selected for long-term preservation should have a long estimated lifetime, which can be estimated according to ISO/IEC 16963.

Disks with initially poor quality do not offer sufficient headroom and can reach the unrecoverable-error threshold before the next scheduled inspection, which is to be avoided for long-term data storage. This means that a disk of high initial recorded quality that maintains this condition for life is expected to have superior longevity.

Because read data are corrected by an error-correction decoder, it is impossible to detect degradation without detecting the raw error rate or raw error number. The raw error can be detected with a standard test drive. The quality of the disk can be specified as the number of erroneous inner-parity detections with DVD-R, DVD-RW, +R, and +RW disks. The quality of a DVD-RAM disk is defined instead by its byte error rate. Deterioration can be monitored by checking the raw error numbers and shall continue to be monitored. Methods described in this International Standard define a quality-control policy that can non-destructively identify degradation, and thereby support timely and effective corrective action.

DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks are based on the technology now widely known as DVD in the market. This entails the use of red laser diodes, two 0,6-mm thick substrates bonded together by an adhesive layer to protect the recording layer from dust, write-once (DVD-R, +R) or phase-change recording layers (DVD-RW, DVD-RAM, +RW), and a 0,60 or 0,65 NA objective lens to ensure good spatial margins required for a professional data preservation. Disks having dual recording layers with a spacer between them are used in addition to those with a conventional single recording layer.

Information technology — Digitally recorded media for information interchange and storage — Data migration method for DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks

1 Scope

This International Standard specifies a data migration method for long-term data storage. According to the standard, manufacturers are able to construct storage systems that use DVD-R, DVD-RW, DVD-RAM, +R, or +RW disks for information storage. A user of the storage system can select disks with sufficient longevity potential, on the basis of an initial performance test, and can continuously monitor the potential for retrieving data from those disks on the basis of periodic performance test. These tests are to establish a practical estimate of the retrievability of the recorded data on a disk without producing uncorrectable errors, in response to time at controlled storage conditions to produce accelerated aging. Digital data can be migrated to a next new disk without loss from the present disk as long as data errors are completely corrected before and during the migration, and provided copying of the data is allowed.

The methodology for data migration is intended to be applied to disks with longer storage lifetime. It is recommended to use disks with estimated life time is given as a mean value and a standard deviation as specified in ISO/IEC 16963. If the estimated lifetime of the disks is known, users can determine a test interval according to the estimated lifetime. If the estimated lifetime is known as a mean value and a standard deviation, regardless of the test method for the estimation, it is recommended to carry out data migration based on this standard. If the estimated lifetime is unknown, the test interval should be three years or less. Considering the generational changeover of systems or applications, the user can determine a migration interval disregarding the estimated lifetime of the disks.

Disks with shorter estimated lifetimes have more rapid degradation and require more frequent periodic tests. In addition, degradation of recorded data occurs by complex failure mechanisms. Storage lifetime, therefore, varies depending not only on temperature and humidity but also on many other effects such as exposure to light, corrosive gases, contamination, handling, and variation in playback subsystems. Consequently, severe storage environments require more frequent periodic tests. The frequency of periodic testing also needs to be fixed based on the quality of the disks for storing data and the storage environment.

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 16963, *Information technology — Digitally recorded media for information interchange and storage — Test method for the estimation of lifetime of optical media for long-term data storage*

ISO/IEC 12862, *Information technology — 120 mm (8,54 Gbytes per side) and 80 mm (2,66 Gbytes per side) DVD recordable disk for dual layer (DVD-R for DL)*

ISO/IEC 13170, *Information technology — 120 mm (8,54 Gbytes per side) and 80 mm (2,66 Gbytes per side) DVD re-recordable disk for dual layer (DVD-RW for DL)*

ISO/IEC 16448, *Information technology — 120 mm DVD — Read-only disk*

ISO/IEC 17341, *Information technology — Data interchange on 120 mm and 80 mm optical disk using +RW format — Capacity: 4,7 Gbytes and 1,46 Gbytes per side (recording speed up to 4X)*

ISO/IEC 17342, *Information technology — 80 mm (1,46 Gbytes per side) and 120 mm (4,70 Gbytes per side) DVD re-recordable disk (DVD-RW)*

ISO/IEC 17344, *Information technology — Data interchange on 120 mm and 80 mm optical disk using +R format — Capacity: 4,7 Gbytes and 1,46 Gbytes per side (recording speed up to 16X)*

ISO/IEC 17592, *Information technology — 120 mm (4,7 Gbytes per side) and 80 mm (1,46 Gbytes per side) DVD rewritable disk (DVD-RAM)*

ISO/IEC 23912, *Information technology — 80 mm (1,46 Gbytes per side) and 120 mm (4,70 Gbytes per side) DVD Recordable Disk (DVD-R)*

ISO/IEC 25434, *Information technology — Data interchange on 120 mm and 80 mm optical disk using +R DL format — Capacity: 8,55 Gbytes and 2,66 Gbytes per side (recording speed up to 16X)*

ISO/IEC 26925, *Information technology — Data interchange on 120 mm and 80 mm optical disk using +RW HS format — Capacity: 4,7 Gbytes and 1,46 Gbytes per side (recording speed 8X)*

ISO/IEC 29642, *Information technology — Data interchange on 120 mm and 80 mm optical disk using +RW DL format — Capacity: 8,55 Gbytes and 2,66 Gbytes per side (recording speed 2,4X)*

3 Terms and definitions

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

3.1
BER max
maximum byte error rate at any consecutive 32 ECC blocks on a disk as measured in the first pass of the decoder before correction

Note 1 to entry: BER max is applied to DVD-RAM disks.

3.2
B_{mig} Life
lifetime for use of data migration and same as $B_{0,000\ 1}$ Life which is 0,000 001 quantile of the lifetime distribution (i.e. 0,000 1 % failure time) or 99,999 9 % survival lifetime (see Annex E)

3.3
B_5 Life
5 percentile of the lifetime distribution (i.e. 5 % failure time) or 95 % survival lifetime

3.4
$(B_5$ Life$)_L$
95 % lower confidence bound of B_5 Life

3.5
B_{50} Life
50 percentile of the lifetime distribution (i.e. 50 % failure time) or 50 % survival lifetime

3.6
data migration
process to copy data from one storage device or medium to another

3.7
Error Correction Code
ECC
mathematical computation yielding check bytes used for the detection and correction of errors in data

Note 1 to entry: For DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks, the Reed-Solomon product code defined in ISO/IEC 16448:2002 for DVD-ROM systems is applied.

3.8
error rate
rate of errors on the recorded disk measured before error correction is applied

3.9
initial performance test
test of the recording performance of data recorded on a disk before storing

3.10
lifetime
time that information is retrievable in a system

3.11
PI SUM 8 max
maximum inner-parity (PI) error count at any consecutive 8 ECC blocks on a disk as measured in the first pass of the decoder before correction

Note 1 to entry: See ISO/IEC 16448, ISO/IEC 23912, ISO/IEC 17341, ISO/IEC 17342, and ISO/IEC 17344.

3.12
periodic performance test
periodic test of the recording performance of data recorded on a disk during the storage

3.13
retrievability
ability to recover physical information as recorded

3.14
storage time
time that a disk is being stored since data is recorded on the disk

3.15
substrate
transparent layer of the disk, provided for mechanical support of the recording or recorded layer, through which the optical beam accesses the recordable/recorded layer

3.16
system
combination of hardware, software, storage medium, and documentation used to record, retrieve, and reproduce information

3.17
uncorrectable error
error in the playback data that could not be corrected by the error correcting decoders

3.18
X_{mig} Life
migration interval (year) which is determined by user

Note 1 to entry: See Annex F.

4 Test methods

4.1 Test parameters

For DVD-R disk defined in ISO/IEC 23912 and ISO/IEC 12862, DVD-RW disk defined in ISO/IEC 17342 and ISO/IEC 13170, +R disk defined in ISO/IEC 17344 and ISO/IEC 25434, and +RW disk defined in ISO/IEC 17341, ISO/IEC 26925 and ISO/IEC 29642, the maximum inner-parity error shall be measured at any consecutive 8 ECC blocks (PI SUM 8 max) in the first pass of the decoder before correction.

For a DVD-RAM disk defined in ISO/IEC 17592, the maximum Byte error rate (BER max) shall be measured (see Annex C).

4.2 Test Drive

The test drive shall comply with ISO/IEC 16448 for DVD-R, DVD-RW, +R, and +R disks and ISO/IEC 17592 for DVD-RAM disks. It shall have the capability to measure PI SUM 8 max for DVD-R, DVD-RW, +R, and +RW disks and BER max for a DVD-RAM disk, respectively.

4.2.1 Test drive calibration

The test drive shall be calibrated by using a calibration disk prepared by the test drive manufacturer based on the calibration procedure defined by the manufacturer. The calibration shall be done at the intervals recommended by the manufacturer.

4.2.2 Test preparation

Prior to conducting tests, the disks shall be visually examined to determine whether they contain dust, finger prints, or other contaminants. If appropriate, such contaminants shall be removed in accordance with the disk-manufacturer's recommendations. Certain options are contained in Annex A. Microscopic examination may reveal physical deterioration, such as delamination and porosity of the protective coating.

4.2.3 Test execution

Before testing disks, the test drive shall be verified by checking the calibration disk supplied with the test drive or publicly verified. If the drive passes the calibration check, the disk to be checked shall be tested by the test drive.

Test results shall be judged by the PI SUM 8 max for DVD-R, DVD-RW, +R, and +RW disks or the BER max for a DVD-RAM disk.

4.3 Test area

The entire recorded area of all the disks should be tested in order to confirm the readability of the data (see Annex G).

5 Test result evaluation

5.1 Initial performance test result evaluation

When data is recorded on disks, the initial recording performance on the whole recorded area shall be checked. The initial recording performance is categorized as Level 1, 2 and 3 by PI SUM 8 max for DVD-R, DVD-RW, +R, and +RW disks and BER max for DVD-RAM as shown in Table 1 (see Annex C).

At least, the initial recording performance shall be within Level 1. Disks showing the initial recording performance of Level 2 should not be used for long-term data storage, and those of Level 3 are out of the specification and shall not be used.

If the initial recording performance is worse than Level 1, the performance of the disk and drive used for recording the data should be verified because PI SUM 8 max and BER max depend on the performance of both disks and drives. If the drive is not good, the drive should be replaced. If the disk is not good, another lot of disks should be used.

Table 1 — Category of initial recording performance

Level	Status	DVD-R, DVD-RW, +R, +RW	DVD-RAM
1	Recommended	< 140	$< 5,0 \times 10^{-4}$
2	Should not be used	140 to 280	$5,0 \times 10^{-4}$ to $1,0 \times 10^{-3}$
3	Shall not be used	> 280	$> 1,0 \times 10^{-3}$
Recording performance indicator		PI SUM 8 max	BER max

5.2 Periodic performance test result evaluation

Disks used for storing data should be periodically checked with the test interval described in Clause 6. The recording performance at the periodic performance test is categorized in Level 4, 5 and 6 by PI SUM 8 max for DVD-R, DVD-RW, +R, and +RW disks and BER max for DVD-RAM as shown in Table 2 (see Annex C).

If the recording performance is within Level 4, the disk is good enough to continue to be used.

If the recording performance is within Level 5, the data stored on the disk shall be migrated to another disk as soon as possible.

If the recording performance is in Level 6, the data stored on the disk shall be copied to another disk immediately, as far as the data can be retrieved, Please note that PI SUM 8 max and BER max are high enough in Level 6 to disable retrieval the data without uncorrectable errors.

Data migration flow for the initial performance test and periodic performance test is shown in Figure 1.

Table 2 — Category of recording performance at periodic performance test

Level	Status	DVD-R, DVD-RW, +R, +RW	DVD-RAM
4	Use as it is	< 200	$< 7,1 \times 10^{-4}$
5	Migrate data as soon as possible	200 to 280	$7,1 \times 10^{-4}$ to $1,0 \times 10^{-3}$
6	Migrate data immediately	> 280	$> 1,0 \times 10^{-3}$
Recording performance indicator		PI SUM 8 max.	BER max.

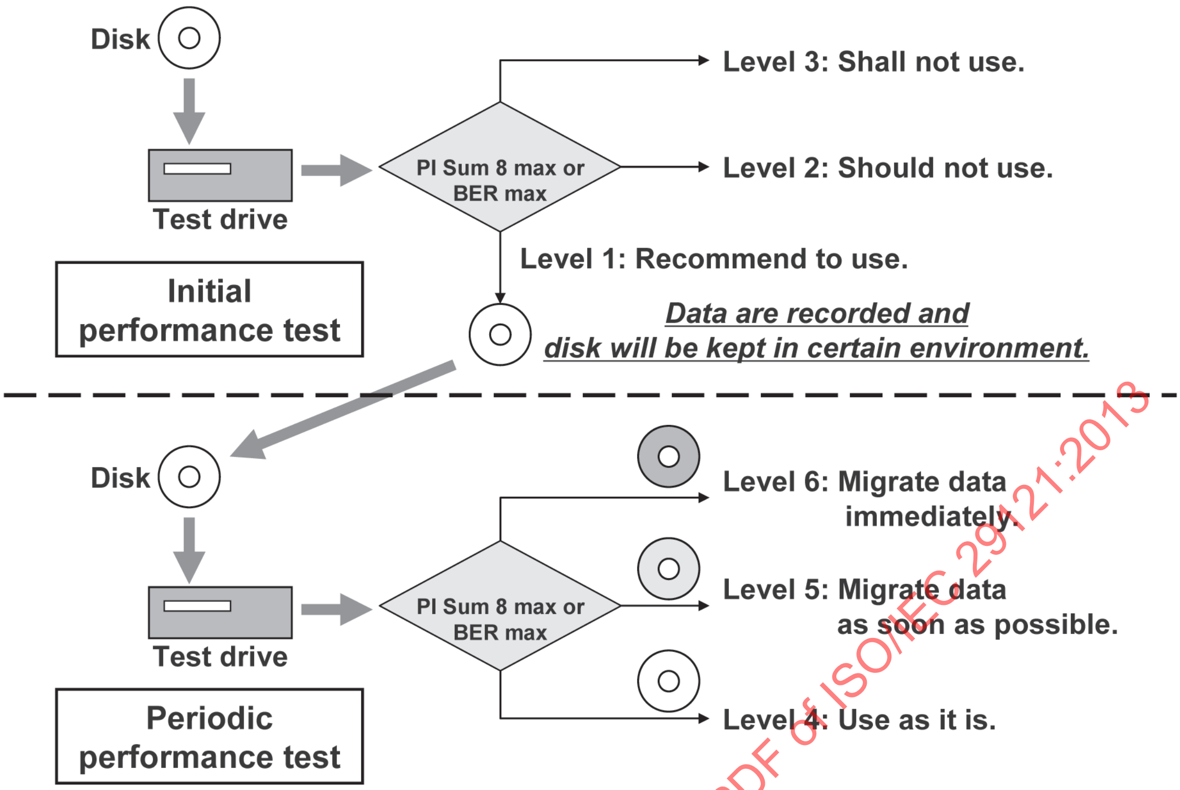

Figure 1 — Data migration flow for DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks

6 Test interval

If estimated lifetime of the disks is known, the test interval may be determined according to the estimated lifetime, otherwise the disks should be checked every three years or less.

If the estimated lifetime is given using ISO/IEC 16963, the disks should be checked according to Annex E and Annex F.

Disks having well defined characteristics that are stored under conditions described in Annex B, are carefully handled, and are read infrequently may require testing only every few years. A history of satisfactory longevity with similar disks would encourage longer intervals between testing.

The occurrence of retrievability problems or long read times may indicate a need for immediate testing.

When tests indicate deterioration of one disk, additional tests may be performed on other disks of the same type, age, or lot to ascertain their condition. Replacement of all similarly affected disks should be considered if such additional tests indicate significant problems.

7 Prevention of deterioration

Necessary precautions shall be taken to reduce the possibility of deterioration, in order to assure the integrity of the disks during their use, storage, handling, or transportation. Causes of deterioration and their effects are noted in Annex A. For long-term storage, the recommendations in Annex B should be implemented.

Disks intended for long-term storage should not be left in readers, nor remain exposed to light, dust, or to extremes of temperature or humidity.

Annex A
(informative)

Causes of deterioration for DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks

A.1 Deterioration

DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks are composed of a recording layer and a reflective layer. Deterioration of the recording and reflective layers may occur in the following environments;

— storage at high temperature and/or high humidity

— storage under sun light or UV light

— storage in a high density of corrosive gases (hydrogen sulfide, etc.)

— storage in fluctuating environments (temperature change, humidity change, etc.)

In addition, the laser incident surface may be damaged or contaminated during use.

This deterioration will increase the error rate of disks.

A.2 Disk structure

DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks comprise a recording substrate covered with recording and reflective layers bonded to a dummy substrate, for a single-sided disk, or another recording substrate for a double-sided disk. The angle between the two substrates is controlled to minimize distortions associated with changes in ambient conditions. The adhesive material selected for bonding of the two substrates is selected to minimize stresses resulting from the bonding process.

DVD-R and +R disks adopt organic dye recording layers, whereas DVD-RAM, DVD-RW and +RW disks adopt inorganic phase-change recording layers.

A.3 Causes of deterioration

Recording and reflective layers may deteriorate during long-term storage in an extreme environment, as indicated in A.1 above.

Recording layers may be degraded by corrosion, cracking, decomposition, etc. As a result, reflectivity and quality of recording signals are degraded. Recorded marks may be also deformed during long-term storage in such an extreme environment. In the case of phase-change disks, amorphous recorded marks may be partially crystallized at random, and then fluctuations of the rim and change of the reflectivity of each mark may occur. Those phenomena result in reduction of the signal modulation or increase in the jitter noise. In the case of dye-type disks, a recorded mark is formed with a change in refractive index of the dye material or with physical deformation of the substrate material. On receiving environmental stress, discoloring of the dye material or a relaxation of the physical deformation may occur. Those phenomena also result in the reduction of signal modulation or an increase in jitter noise.

Reflective layers may be degraded by corrosion, cracking, decomposition, etc. As a result, reflectivity and the quality of recording signals are degraded.

As with all optical disks, small defects are allowed at the time of manufacture. Over a long period of time, under extreme environmental exposure, these defects may grow. The growth of defects as well as the deterioration of recording and reflective layers as mentioned above can be shown to follow Arrhenius laws and this method can be used to confirm the predicted lifetime of DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks.

Storage in fluctuating environments may also degrade mechanical property, such as tilt, and axial or radial runout.

Damage or contamination on laser-incident surface can obscure the recording layer and create dropouts in the data. Additionally, particulate damage or contamination may cause transients in the servo signals used by the drive to maintain focus and tracking to the required accuracy. One of the most-frequent causes of uncontrolled contamination is casual cleaning of disks using unapproved materials and procedures. Cleaning of disks should only be carried out in accordance with the procedures contained in Annex B.

A.4 Nature of deterioration

The operating environment will determine the nature of the deterioration. In the case of disks used in a library this environment is well controlled, however, operation of disks in stand-alone drives will potentially subject the disks to a wider range of contamination and environmental extremes. In particular, disks left in uncontrolled storage may be subject to physical abuse or contamination in contravention of manufacturers' recommendations.

A.5 Effects of deterioration

The combination of beam obscuration and possible disturbance of the servo signals will be to generate a dropout in the data reaching the decoder. While the Error Correction Code has a very high burst correction capability (6 mm maximum), a large dust particle may cause this capability to be exceeded.

A.6 Unexpected deterioration

For protection from unexpected serious deterioration of the disks, it is recommended to have a backup system for the long-term data storage according to the characteristics and importance of the data.

Annex B
(informative)

Recommendations on handling, storage and cleaning conditions for DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks

B.1 Handling

The fragile protective coating on the label surface is vulnerable to damage and should be protected together with the readout surface. It is recommended to handle the disk carefully, touching only the outer edge and inner hole. It is strongly recommended not to touch the readout surface.

Disks should be protected from dust and debris. This is especially important for recordable and rewritable disks during the recording process. The use of a deionizing environment is recommended to neutralize static charges on the disk that can attract and retain loose contaminants.

B.2 Storage

For general storage such as in an office environment, it is recommended to limit the storage environment to the ranges given in Table B.1.

Table B.1 — Recommended conditions for general storage

Ambient Condition	Recommended Range
Temperature	5º C to 30º C
Relative humidity	15 % to 80 %
Absolute humidity	1 g/m³ to 24 g/m³
Atmospheric pressure	75 kPa to 106 kPa
Temperature gradient	10 °C per hour maximum
Relative humidity gradient	10 % per hour maximum

If long-term storage is desired, the storage conditions should be more tightly controlled and it is recommended to limit the storage environment to the ranges given in Table B.2.

Table B.2 — Recommended conditions for controlled storage

Ambient Condition	Recommended Range
Temperature	10º C to 25º C
Relative humidity	30 % to 50 %
Absolute humidity	3 g/m³ to 12 g/m³
Atmospheric pressure	75 kPa to 106 kPa
Temperature gradient	10 ºC per hour maximum
Relative humidity gradient	10 % per hour maximum

There should be no condensation of moisture on the disk. Cool and dry storage condition is preferred. To maintain the desirable temperature and humidity fluctuation tolerance levels, and to protect against high intensity light and pollutants, storage of DVD-R, DVD-RW, DVD-RAM, +R, and +RW disks in clean insulated records containers is suggested. Dust or debris in operational or storage locations should be minimized by appropriate maintenance and monitoring procedures, especially when recording disks.

B.3 Cleaning

Prior to performing cleaning operations of disks containing useful data, tests should be carried out on disks of the same type and from the same supplier that do not contain any useful data, in order to ensure that no adverse reaction will occur.

Loose contaminants may be removed by short, one second bursts of clean, dry air, avoiding expulsion of cold propellants. If the manufacturer has not supplied any cleaning information, organic polymer substrate disks can be cleaned using a lint-free cloth of a non-woven fabric and either clean or soapy water. It is recommended not to use detergents or solvents such as alcohol. All wiping actions should be in a radial direction, taking care not to exert isolated pressure or to scratch the disks. It is strongly recommended not to use abrasives. It is recommended not to use acrylic liquids, waxes, or other coatings on either surface.

Annex C
(informative)

Relation between BER and PI SUM 8

The byte error rate BER is the number of erroneous bytes divided by the total number of bytes. Because the length of one code word of the inner code is 182, the probability of an erroneous inner code word N_{pi} can be expressed as a binomial probability on the assumption that errors occur at random, and it is

$$N_{pi} = \sum_{i=1}^{182} {}_{182}C_i \times p^i \times (1-p)^{182-i} \quad \text{(C.1)}$$

where p denotes BER.

The number of PI errors in 8 ECC blocks N_{pis8} can be expressed by Formula (C.2) because the length of the outer code word is 208, as shown in Figure C.1.

$$N_{pis8} = 208 \times 8 \times N_{pi} \quad \text{(C.2)}$$

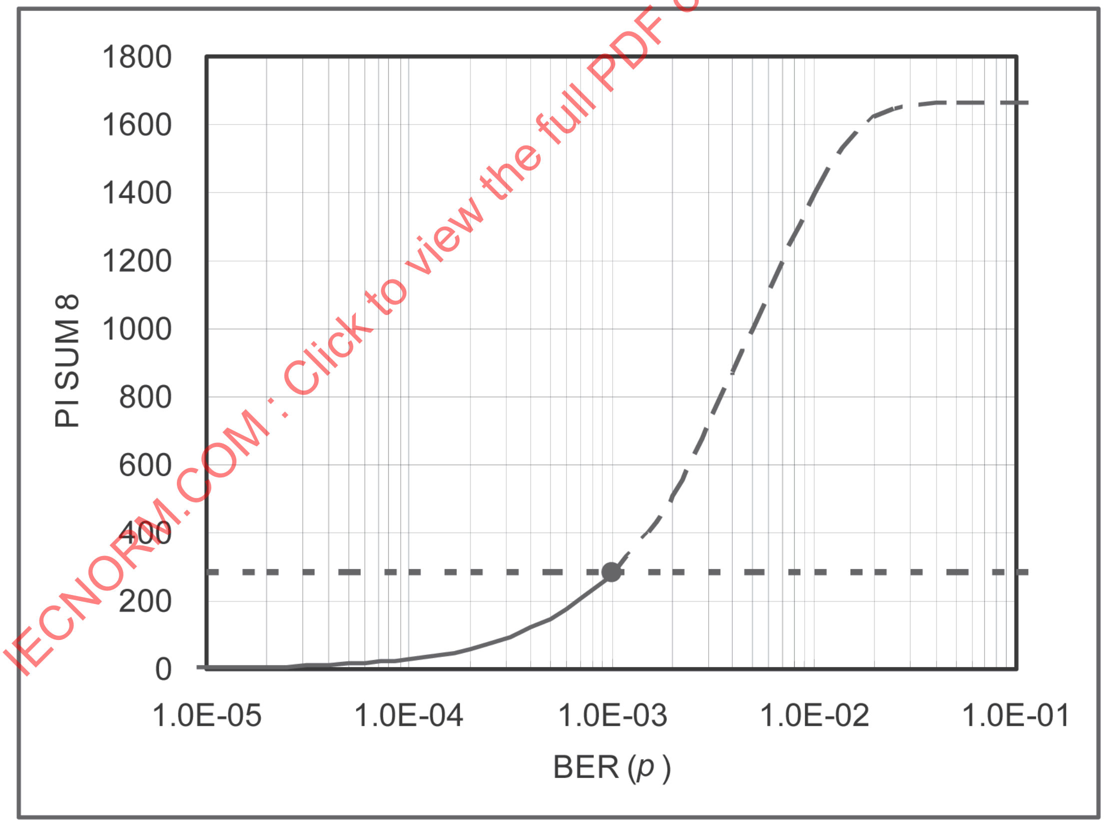

Figure C.1 — Relationship between BER (p) and PI SUM 8

Annex D
(informative)

Guideline for adjustment of the estimated lifetime to higher stress conditions

In actual storage conditions, the temperature and relative humidity may deviate from 25 °C/50 % RH, which changes the estimated lifetime. In this case, the estimated lifetime at 25 °C/50 % RH should be adjusted to the estimated lifetime at the actual storage conditions as described below.

According to ISO/IEC 16963, the estimated lifetime B_5 Life, based on Eyring Method, is derived as follows.

$$B_5 \text{ Life} = \exp\left(\hat{\beta}_0 + \hat{\beta}_1 X_{10} + \hat{\beta}_2 X_{20} - 1,64\hat{\sigma}\right) \quad \text{(D.1)}$$

where,

$\beta_0 = \ln A,\ \beta_1 = \Delta H/k,\ \beta_2 = B$

X_{10} and X_{20}	denote the temperature-dependent factor and the relative-humidity-dependent factor at the Controlled storage condition (25 °C / 50 % RH) respectively.
A	denotes the pre-exponential time constant
ΔH	denotes the activation energy per molecule
k	denotes the Boltzmann constant
B	denotes the RH exponential constant

If the storage temperature and humidity differ from 25 °C /50 % RH, B_5 Life is replaced with B_5 Life$_{(m,n)}$, which will be expressed by the following formula, where m and n denote numerals representing the temperature and the relative humidity respectively. X_{1m} and X_{2n} represent the temperature-dependent factor at temperature m and the relative-humidity-dependent factor at relative humidity n respectively in following equations. B_5 Life in the Eq. D.1 can be also described as B_5 Life$_{(0,0)}$ in this Annex D applying Eq. D.2.

$$B_5 \text{ Life}_{(m,n)} = \exp\left(\hat{\beta}_0 + \hat{\beta}_1 X_{1m} + \hat{\beta}_2 X_{2n} - 1,64\hat{\sigma}\right) \quad \text{(D.2)}$$

Then, the adjustment coefficients normalized by B_5 Life ($A_{d\,(m,n)} = B_5$ Life$_{(m,n)}$ / B_5 Life) are derived as follows.

$$A_{d(m,n)} = \exp\left(\hat{\beta}_0 + \hat{\beta}_1 X_{1m} + \hat{\beta}_2 X_{2n} - 1,64\hat{\sigma}\right) \Big/ \exp\left(\hat{\beta}_0 + \hat{\beta}_1 X_{10} + \hat{\beta}_2 X_{20} - 1,64\hat{\sigma}\right)$$

$$= \exp\left(\hat{\beta}_1\left(X_{1m} - X_{10}\right) + \hat{\beta}_2\left(X_{2n} - X_{20}\right)\right) \quad \text{(D.3)}$$

Corresponding to the ISO/IEC 16963, an example computation of the adjustment coefficients $A_{d\,(m,n)}$ for the estimated lifetime B_5 Life (Year) (B_5 Life/24/365) is shown in Table D.1. It is calculated by changing the temperature from 25 °C to 30 °C in unit of 1 °C and the humidity from 50 % to 80 % in units of 5 %, under the condition that B_{50} Life(Year) at the 25 °C/50 % RH is 1101 years and B_5 Life (Year) is 887 years.

Table D.1 shows that the estimated lifetime shortens abruptly when the storage conditions become more severe than 25 °C/50 % RH even in the recommended conditions for general storage shown in Table B.1. For example, the estimated lifetime at the storage conditions of 30 °C/80 % RH shortens by about 1/6 compared with that of 25 °C/50 % RH. Therefore, careful consideration should be given to the actual storage conditions.

In addition, in order to calculate the adjustment coefficients for a disk, the estimated lifetime of the population to which the disk belongs and the estimation values of the coefficients based on the Eyring method are needed. Except for the case where life estimation using ISO/IEC 16963 is performed, it is recommended to inquire of the disk manufacturer as to the adjustment coefficients of the disk.

Table D.1 — - Adjustment coefficients for the estimated lifetime (calculated by using the test data of Annex B of ISO/IEC 16963)

	n	0	1	2	3	4	5	6
m		50 % RH	55 % RH	60 % RH	65 % RH	70 % RH	75 % RH	80 % RH
0	25 °C	**1,00**	0,86	0,74	0,64	0,55	0,47	0,41
1	26 °C	0,84	0,72	0,62	0,54	0,46	0,40	0,34
2	27 °C	0,70	0,61	0,52	0,45	0,39	0,33	0,29
3	28 °C	0,59	0,51	0,44	0,38	0,33	0,28	0,24
4	29 °C	0,50	0,43	0,37	0,32	0,27	0,24	0,20
5	30 °C	0,42	0,36	0,31	0,27	0,23	0,20	**0,17**

Annex E
(informative)

Calculation for B_{mig} Life using B_{50} Life and B_5 Life

ISO/IEC 16963 defines the estimated lifetime of optical disks as B_{50} Life, B_5 Life and 95 % lower confidence bound of B_5 Life (= $(B_5 \text{ Life})_L$). The estimated lifetime of B_5 Life means 5 % of products reach failure. Therefore, from the viewpoint of reliability, it is not appropriate to use B_5 Life as the estimated lifetime, when determining a test interval and deciding on data migration, for long-term storage to retain the integrity of original data.

In the case of data migration, it is necessary to have low enough failure probability. Therefore, the time at which one millionth products reach their time to failure is used as the estimated lifetime to determine the test interval or migration interval in this standard. $B_{0,000\,1}$ Life is 0,000 001 quantile of the lifetime distribution (i.e. 0,000 1% failure time) and defined as B_{mig} Life in this standard. B_{mig} Life can be calculated using B_{50} Life and B_5 Life as follows:

According to ISO/IEC 16963, $\ln \hat{B}_p$ is given as Eq. (E.1)

$$\ln \hat{B}_p = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} + z_{p/100}\hat{\sigma} \tag{E.1}$$

Where, z denotes percentile of $N(0, \sigma^2)$ and $\{x_{10}, x_{20}\}$ denotes the Controlled storage condition (25 °C and 50 % RH)

Using Eq (E.1), $\ln \hat{B}_{0.0001}$ which is the estimated lifetime with the failure probability of one millionth is given by Eq. (E.2). The estimated lifetime with the failure probability of one millionth corresponds to 4,75 σ provided the distribution is normal.

$$\ln \hat{B}_{0.000\,1} = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 4.75\hat{\sigma} = \ln \hat{B}_{50} - 4,75\hat{\sigma} \tag{E.2}$$

On the other hand, $\ln \hat{B}_5$ is given by Eq. (E.3)

$$\ln \hat{B}_5 = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1,64\hat{\sigma} = \ln \hat{B}_{50} - 1,64\hat{\sigma} \tag{E.3}$$

Putting B_{50} Life and B_5 Life into Eq. (E.2) and Eq. (E.3)

$$B_{0.000\,1}\text{Life} = \exp\left(\ln \hat{B}_{50} - 4,75\hat{\sigma}\right) = \exp\left(\ln \hat{B}_{50} - 4,75\frac{\ln \hat{B}_{50} - \ln \hat{B}_5}{1,64}\right)$$

$$= \exp\left(2,9 \ln \hat{B}_5 - 1,9 \ln \hat{B}_{50}\right) \tag{E.4}$$

Thus

$$B_{mig}\text{Life} = B_{0,000\,1}\text{ Life} = \exp\left(2,9 \ln \hat{B}_5 - 1,9 \ln \hat{B}_{50}\right) \tag{E.5}$$

For example, Annex B of ISO/IEC 16963 gives the data of B_{50} Life and B_5 Life.

$$B_{50}\text{ Life} = 1\,101 \text{ years} (= 9\,648\,593 \text{ hours})$$

$\ln \hat{B}_{50} = \ln (9\ 648\ 593) = 16,082\ 3$

$B_5 \text{ Life} = 887 \text{ years} (= 7\ 770\ 875 \text{ hours})$

$\ln \hat{B}_5 = \ln (7\ 770\ 875) = 15,865\ 9$

B_{mig} Life is calculated by substituting these values to equation (E.5).

$B_{mig}\text{Life} = \exp (2,9 \ln \hat{B}_5 - 1,9 \ln \hat{B}_{50}) = \exp (2,9 \times 15,865\ 9 - 1,9 \times 16,082\ 3)$

$= 5\ 151\ 199 \text{ hours} = 588 \text{ years}$

Annex F
(informative)

Guideline of test interval and migration

This Annex describes guidelines for choosing the test interval and performing data migration both for disks whose lifetime is estimated and known and for disks whose lifetime is unknown.

According to this standard, optical disks are periodically tested and when disks errors exceed the specified values in Table 2, data migration is carried out. Therefore, if the estimated lifetime of disks is long enough, the migration interval of disks can also be increased.

However if generational changes of the system, including reading devices, and/or the file structures and/or applications, occur during the migration interval, the stored data may not be easily retrieved. Moreover, if the stored data has high value, the user might like to migrate after a shorter interval for safety. In consideration of these factors as stated above, the migration interval is defined as X_{mig} (years) and this value is determined by use of this standard.

The migration interval X_{mig} may be also applied even if the estimated lifetime of disks is unknown.

In Annex E, the estimated lifetime for test interval and data migration is defined as B_{mig} Life (=$B_{0.000\,1}$ Life: 0,000 1 % failure time). A half of B_{mig} (hereafter B_{mig} (years)) is set as the test interval, and the periodical performance test (PP test) is carried out. After two times of PP test, which means test intervals reach to B_{mig}, in case the test result is equal to Level 4 in Table 2, next test interval is set to three years or less. In this case the test is recommended to be limited twice.

If the test interval is long, it is recommended to carry out sampling check of the disks in appropriate timing.

F.1 Test interval and data migration

1) In case the initial performance test result is equal to Level 1 (Recommended) in Table 1. (Other than Level 1, should not be used or shall not be used)

   a) If X_{mig} - B_{mig} /2 is greater than 0, test interval of the first periodic performance test (PP test) should be set to B_{mig} /2.

   b) If X_{mig} - B_{mig} /2 is less than or equal to 0, test interval of the first PP test should be set to X_{mig}. Data migration should be carried out at the first PP test in spite of the test result.

2) In case the PP test result of a) is equal to Level 4 (Use as it is) in Table 2. (Other than Level 4, migrate data as soon as possible or migrate data immediately)

   c) If X_{mig} - 2×B_{mig} /2 is greater than 0, test interval of the second PP test should be set to B_{mig} /2.

   d) If X_{mig} - 2×B_{mig} /2 is less than or equal to 0, test interval of the second PP test should be set to X_{mig}. Data migration should be carried out at the second PP test in spite of the test result.

3) In case the test result of c) is equal to Level 4 (Use as it is) in Table 2. (Other than Level 4, migrate data as soon as possible or migrate data immediately)

   e) In case of X_{mig} - 2×B_{mig} /2 - 3 is greater than or equal to 0, the test interval of the third PP test should be set to three years.

