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Information technology — Digitally recorded media for information interchange and storage — Data migration method for optical disks for long-term data storage

Technologies de l'information — Supports enregistrés numériquement pour échange et stockage d'information — Méthode de migration de données pour disques optiques pour le stockage à long terme

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Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 23, *Digitally Recorded Media for Information Interchange and Storage*.

This fourth edition cancels and replaces the third edition (ISO/IEC 29121:2018), which has been technically revised.

The main changes compared to the previous edition are as follows:

— ISO/IEC 16963 has been identified as the referee test method for the lifetime estimation;

— the ambient conditions for the measurement of maximum data error have been added;

— the requirements for test drives have been changed considering the use condition of users;

— the requirements for the estimated lifetime have been defined more clearly;

— the requirements for the periodic performance test have been defined more clearly.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 have been recorded correctly and remains readable for the required amount of time. Previous International Standards clearly defined requirements for interchange, but they did not contain requirements for longevity.

Longevity is limited both by disk deterioration and by technology obsolescence. Interchange is 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 5 and 10 years, and technology life cycles usually end after 20 years. Consequently, recordings that require a longer life cycle can have to be transferred to upgraded platforms every 10 to 30 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 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 deterioration without detecting the raw error rate or raw error number. The error rate measured before error correction is applied, which represents the raw error rate, 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 error rate and continues to be monitored. Methods described in this document define a quality-control policy that can non-destructively identify deterioration, 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.

After the issuance of the previous edition of this document, ISO/IEC standards for the physical format of BD recordable and rewritable disks were published in 2013. ISO/IEC 16963 was also updated to include testing of BD recordable and rewritable disks in 2015. Accordingly, work started to include BD recordable and rewritable disks in this document. The BD data migration part of this work was standardized separately as ECMA-413. CD-R and CD-RW disks included in ISO/IEC 16963 are also incorporated. The error rate measured before error-correction is applied is also defined in each International Standard of CD-R, CD-RW, BD recordable and BD rewritable disk.

Information technology — Digitally recorded media for information interchange and storage — Data migration method for optical disks for long-term data storage

1 Scope

This document specifies the data migration method for DVD-R, DVD-RW, DVD-RAM, +R, +RW, CD-R, CD-RW, BD Recordable and BD Rewritable disks for long-term data storage. By applying this document for information storage, digital data can be migrated to a next new disk without loss from the present disk if data errors are completely corrected before and during the migration and provided copying of the data is allowed.

This document specifies:

— a data migration method for long-term data storage;

— test methods for measuring maximum data error, including ambient condition, test area, test drive, disk preparation and test execution;

— an initial performance test and a periodic performance test that check an error rate of data recorded on the disks with categorized maximum data error tables;

— precautions to reduce the possibility of deterioration in order to assure the integrity of the disks during their use, storage, handling or transportation; and

— the estimated lifetime of B_{mig} ($B_{0,000\ 1}$) life to determine the test interval for the periodic performance test.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 16963, *Information technology — Digitally recorded media for information interchange and storage — Test method for the estimation of lifetime of optical disks for long-term data storage*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
B_{mig} life
lifetime (3.9) for use of *data migration* (3.5) and identical to $B_{0,000\ 1}$ life which is 0,000 001 quantile of the lifetime distribution (i.e. 0,000 1 % failure time) or 99,999 9 % survival lifetime

Note 1 to entry: See Annex E.

3.2
***B_5* life**
5 percentile of the *lifetime* (3.9) distribution (i.e. 5 % failure time) or 95 % survival lifetime

[SOURCE: ISO/IEC 16963:2017, 3.4]

3.3
(B_5 life)$_L$
95 % lower confidence bound of B_5 *life* (3.2)

[SOURCE: ISO/IEC 16963:2017, 3.5]

3.4
***B_{50}* life**
50 percentile of the *lifetime* (3.9) distribution (i.e. 50 % failure time) or 50 % survival lifetime

[SOURCE: ISO/IEC 16963:2017, 3.6]

3.5
data migration
process to copy data from one storage device or medium to another

3.6
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 for DVD-ROM systems is applied. For BD recordable and BD rewritable disks, the long-distance code (LDC) + burst-indicating subcode (BIS) defined in ISO/IEC 30190, ISO/IEC 30191, ISO/IEC 30192 and ISO/IEC 30193 is applied. For CD-R and CD-RW disks, the cross interleaved Reed-Solomon code (CIRC) and the Reed-Solomon Product-like Code (RSPC) defined in ISO/IEC 10149 are applied.

3.7
error rate
rate of errors or error count measured on the signal at the input of error-correction decoder, which represents raw-error rate of data recorded on a disk

3.8
initial performance test
first test of the *error rate* (3.7) of data recorded on a disk before storing

3.9
lifetime
time that information is retrievable in a *system* (3.18)

3.10
maximum byte-error rate
BER_{max}
greatest level of byte-error rate at any consecutive 32 *error correction code* (3.6) blocks in one of the relevant area 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.

3.11
maximum C1 average 10
$C1_{ave\ 10,max}$
greatest level of C1 errors per second at the standard (1x) data transfer rate in one of the relevant area on a disk measured on the signal at the input of error correction decoder averaged over any 10 s

Note 1 to entry: See ISO/IEC 16963.

3.12
maximum data error
greatest level of *error rate* (3.7) anywhere in one of the relevant areas on the disk

[SOURCE: ISO/IEC 16963:2017, 3.13, modified — Note 1 to entry has been deleted.]

3.13
maximum parity inner sum 8
$PI_{sum\ 8,max}$
greatest revel of parity (of the) inner code error count at any consecutive 8 *error correction code* (3.6) blocks in one of the relevant area 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.

3.14
maximum random symbol error rate
$RSER_{max}$
greatest level of random symbol error rate measured on the signal in one of the relevant area on a disk at the input of error-correction decoder, which excludes burst errors of length greater than or equal to 40 bytes

Note 1 to entry: See ISO/IEC 30190, ISO/IEC 30191, ISO/IEC 30192, ISO/IEC 30193 and ISO/IEC 16963.

3.15
periodic performance test
periodic test of the *error rate* (3.7) of data recorded on a disk during the storage

3.16
retrievability
ability to recover information as recorded

[SOURCE: ISO/IEC 16963:2017, 3.14]

3.17
system
combination of hardware, software, storage medium and documentation used to record, retrieve and reproduce information

[SOURCE: ISO/IEC 16963:2017, 3.20]

3.18
uncorrectable error
error in the read-out data that cannot be corrected by the error-correction decoders

3.19
X_{mig} interval
migration interval (year) which is determined by the user

Note 1 to entry: See Annex F.

4 General

Information is physically recorded on a disk as digital data. Although it is inevitable to cause errors in the physical recording process, error correction technologies can retrieve the physically recorded information completely from the read-out raw data with acceptable errors. If the errors in the read-out raw data exceed the error correcting capability, some of information is lost and the original information cannot be retrieved. The main cause of the errors is the physical deterioration of a disk. The deterioration can be measured by monitoring the error rate, and the original information can be migrated to a new disk in advance of an appearance of uncorrectable errors. Using the data migration method described in this document, the physically recorded information can be stored without loss of the original information, then the retrievability is maintained for a long time.

In order to check the error rate of data recorded on a disk, the maximum data error is measured using a test drive.

When data are recorded on a disk, the error rate shall be checked with the initial performance test. Depending on the test result of the initial performance test, the disk is judged to be used for long-term data storage.

The error rate of data recorded on those disks shall be periodically checked in the storage duration with the periodic performance test unless the data are migrated to the new disk before the first periodic performance test. Depending on the test result of the periodic performance test, the necessity of the data migration is judged.

In order to determine the test interval for the periodic performance test, B_{mig} life: (see Clause 6 for detailed definition) is used. ISO/IEC 16963 specifies an accelerated aging test method for estimating the lifetime of the retrievability of information stored on recordable or rewritable optical disks. ISO/IEC 16963 offers B_{50} life and B_5 life, and B_{mig} life is introduced using B_{50} life and B_5 life (see Annex E for detailed definitions). ISO/IEC 16963 shall be the referee test method for the lifetime estimation of disks and alternative test methods with equivalent statistical accuracy may also be applied, such as ISO/IEC 10995 for DVD disks or ISO 18927 for CD disks.

ISO/IEC 16963, ISO/IEC 10995 and ISO 18927 specifies the details of the accelerated test method. In case that the test conditions such as the acceleration conditions and/or the sample numbers are different from those specified in the standard, the estimated lifetime may be used on the condition that the statistical accuracy is maintained. Users of this document can determine the migration interval (X_{mig}) (Annex F for detailed specifications) with no relation to the estimated lifetime of the disk. In case the X_{mig} is introduced, follow the procedure defined in Annex F.

5 Test method for measuring maximum data error

5.1 Maximum data error for each disk

The maximum data error to be measured for a disk defined in each international standard is as follows:

For DVD-R disk defined in ISO/IEC 12862 and ISO/IEC 23912, DVD-RW disk defined in ISO/IEC 13170 and ISO/IEC 17342, +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 each maximum parity inner sum 8 ($PI_{sum\ 8,max}$) shall be measured.

For DVD-RAM disk defined in ISO/IEC 17592, the maximum byte-error rate (BER_{max}) shall be measured (see Annex C for additional information).

For CD-R disk defined in ECMA-394 and CD-RW disk defined in ECMA-395, each maximum C1 average 10 ($C1_{ave\ 10\ ,max}$) shall be measured.

For BD recordable disk defined in ISO/IEC 30190 and ISO/IEC 30191 and BD rewritable disk defined in ISO/IEC 30192 and ISO/IEC 30193, each maximum random symbol error rate ($RSER_{max}$) shall be measured (see Annex H for additional information).

5.2 Ambient condition of maximum data error measurement

The ambient condition is the surrounding condition in a room where a test drive is located. The ambient conditions for the maximum data error measurement are as follows:

— temperature: 15 °C to 30 °C;

— relative humidity: 20 % to 75 %.

5.3 Test area and sample disk

The test area is the recorded area to be tested in a disk.

The whole recorded area of all disks shall be tested for the initial performance test.

The whole recorded area of all disks should be tested for the periodic performance test. Although the integrity of the data becomes lower, the user may reduce the test area and/or the number of sample disks based on a certain sampling method, considering the value of information (see Annex G for additional information). For the reduction of test area, see ISO/IEC 16963:2017, 7.5, for additional information. The number of sample disks should be enough to guarantee statistical effectiveness. If the sample disks have different attributes such as disk standards, recording conditions or storage conditions, the disks should be divided into groups of disks considering the attributes so that the sampling can be applied on each group with the statistical effectiveness.

5.4 Test drive

5.4.1 General

For DVD-R and DVD-RW disks, +R and +RW disks, the test drive shall have capability to measure $PI_{sum\ 8,max}$.

For DVD-RAM disk, the test drive shall have capability to measure BER_{max}.

For CD-R and CD-RW disks, the test drive shall have capability to measure $C1_{ave\ 10,max}$.

For BD recordable disks and BD rewritable disks, the test drive shall have capability to measure $RSER_{max}$.

The test drive shall have the capability to evaluate the error rate level specified in the initial performance test and the periodic performance test.

There are two cases of the test drive. One is that the drive serves both as a test drive and a recorder which records the data on the disk. The other is that the test drive is different from the recorder. For both cases, the data recorded on the disk by the recorder shall fulfil the error rate level specified in the initial performance test and the periodic performance test.

NOTE The measuring circuit for RSER described in ISO/IEC 30191 and ISO/IEC 30193 is different from that described in ISO/IEC 30190 and ISO/IEC 30192, especially in HF signal pre-processing circuit. See ISO/IEC 30190:2021, Annex H, and ISO/IEC 30191:2021, Annex H, for additional information.

5.4.2 Test drive check

The test drive shall be checked by using a reference disk prepared by the test drive manufacturer or the disk prepared by the user, so that it fulfils the requirements in 5.4.1. When using the reference disk prepared by the test drive manufacturer, the check of the test drive shall be done at the intervals recommended by the manufacturer. When using the disk prepared by the user, it is recommended for the user to set an appropriate interval and to check the test drive at the interval.

5.5 Disk preparation

Prior to conducting tests, the disks shall be checked that there is no dust, fingerprints or other contaminants on them. If there is dust, fingerprints or other contaminants, such contaminants shall be removed in accordance with the procedure recommended by the disk-manufacturer. Certain options are contained in Annex B. Microscopic examination can reveal physical deterioration, such as delamination and porosity of the protective coating.

5.6 Test execution

Before testing disks, the test drive shall be verified by the procedure defined in 5.4.2. If the drive does not pass the verification, the test drive shall not be used for the test.

On testing disks, care handling of the disks shall be taken in order to avoid introducing unexpected defects (see Annex I for additional information).

6 Test interval for periodic performance test

In order to determine the test interval for the periodic performance test, B_{mig} life is used.

B_{mig} life shall be calculated according to Annex E, and B_{50} life and B_5 life or B_{50} life and standard deviation, σ, shall be provided (see Clause 4). The test interval shall be determined according to Annex F.

In case B_{mig} life is not available as shown below, the test interval should be three years or less. Relaxation of the test interval causes the risk of data loss and failure in the data migration. In case such a risk is unacceptable, the test interval of three years or less is strongly recommended.

— The estimated lifetime data is not provided.

— The estimated lifetime data is provided but lacks the statistical accuracy.

The ambient storage-condition for the lifetime estimation should be controlled storage condition (temperature, T = 25 °C and relative humidity R_H= 50 %) or harsh storage condition (T = 30 °C and R_H = 80 %). The estimated lifetime is affected by the storage condition. If the actual storage condition is far from the controlled storage condition or harsh storage condition, the estimated lifetime may be adjusted (see Annex D for additional information).

The occurrence of retrievability problems can indicate a need for immediate testing.

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

7 Test result evaluation

7.1 Initial performance test

The initial error rate is categorized as Level 1, 2 or 3 according to the maximum data error as shown in Table 1.

At least, the initial error rate shall be within Level 1. Disks showing a Level 2 initial error rate should not be used. Disks showing a Level 3 initial error rate are out of the specification and shall not be used.

If the initial error rate is worse than Level 1, the performance of the disk and drive used for recording the data should be verified because the maximum data error depends 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 error rate at initial performance test

Level	Status	DVD-R, DVD-RW, +R, +RW	DVD-RAM	CD-R, CD-RW	BD recordable, BD rewritable
1	Recommended	<140	$<5,0 \times 10^{-4}$	<110	$<5,0 \times 10^{-4}$
2	Should not be used	140 to 280	$5,0 \times 10^{-4}$ to $1,0 \times 10^{-3}$	110 to 220	$5,0 \times 10^{-4}$ to $1,0 \times 10^{-3}$
3	Shall not be used	>280	$>1,0 \times 10^{-3}$	>220	$>1,0 \times 10^{-3}$
Maximum data error		$PI_{sum\ 8,max}$	BER_{max}	$C1_{ave\ 10,max}$	$RSER_{max}$

7.2 Periodic performance test

The error rate at the periodic performance test is categorized as Level 4, 5 or 6 according to the maximum data error as shown in Table 2.

If the error rate is within Level 4, the disk is good enough to continue to be used.

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

If the error rate 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 the maximum data error is high enough in Level 6 to disable retrieval the data without uncorrectable errors.

Table 2 — Category of error rate at periodic performance test

Level	Status	DVD-R, DVD-RW, +R, +RW	DVD-RAM	CD-R, CD-RW	BD recordable, BD rewritable
4	Use as is	<200	$<7,1 \times 10^{-4}$	<160	$<7,1\times 10^{-4}$
5	Migrate data as soon as possible	200 to 280	$7,1 \times 10^{-4}$ to $1,0 \times 10^{-3}$	160 to 220	$7,1 \times 10^{-4}$ to $1,0 \times 10^{-3}$
6	Migrate data immediately	>280	$>1,0 \times 10^{-3}$	>220	$>1,0 \times 10^{-3}$
Maximum data error		$PI_{sum\ 8,max}$	BER_{max}	$C1_{ave\ 10,max}$	$RSER_{max}$

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

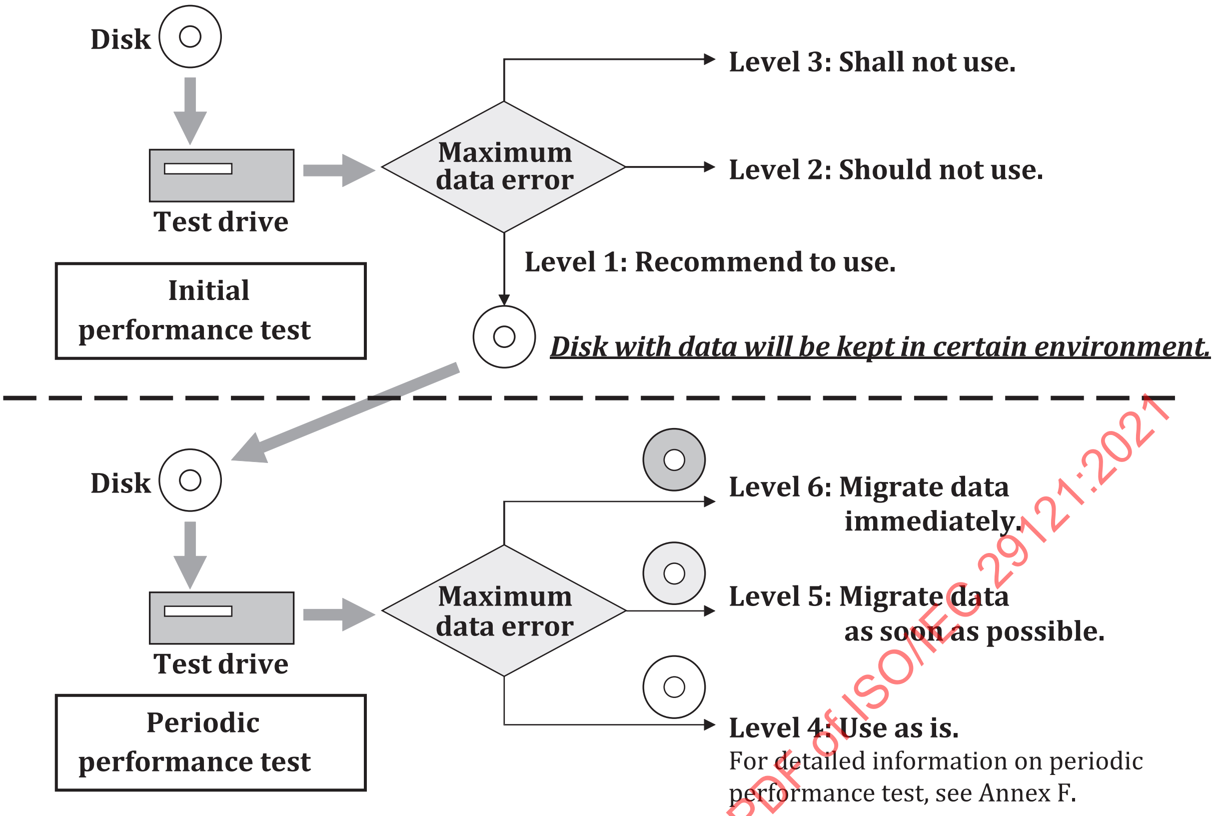


Figure 1 — Data migration flow for optical disks for long-term data storage

8 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 drives, nor remain exposed to light, dust or extreme temperatures or humidity.

Annex A
(informative)

Causes of deterioration for optical disks for long-term data storage

A.1 Deterioration

Optical disks for long-term data storage are composed of recording layers and reflective layers. Deterioration of the recording and reflective layers can 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 sulphide, etc.);

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

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

This deterioration increases the error rate of disks.

A.2 Disk structure

DVD-R, DVD-RW, DVD-RAM, +R and +RW disks comprise a recording substrate bonded to a dummy substrate for a single-sided disk, or they comprise two recording substrates bonded with each other for a double-sided disk. The recording substrate is covered with recording and reflective layers. 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.

CD-R and CD-RW disks comprise a recording substrate covered with recording, reflective and over-coating resin layers.

CD-R disks adopt an organic dye recording layer, whereas CD-RW disks adopt an inorganic phase change recording layer.

BD recordable and BD rewritable disks except the BD recordable triple layer double-sided disk comprise a recording substrate. BD recordable triple layer double-sided disk comprise two recording substrates bonded with each other. The recording substrate is covered with recording, reflective and over-coating resin layers.

BD recordable and BD rewritable disks adopt an inorganic phase change recording layer. For some types of BD recordable disks, an organic dye recording layer is also used instead of an inorganic phase change recording layer.

A.3 Causes of deterioration

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

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

Reflective layers can 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 time, under extreme environmental conditions, these defects can 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 optical disks for long term data storage.

Storage in fluctuating environments can 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 can 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 the 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 determines 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 potentially subjects the disks to a wider range of contamination and environmental extremes. In particular, disks left in uncontrolled storage can be subject to physical abuse or contamination that goes against the manufacturers' recommendations.

A.5 Effects of deterioration

The combination of beam obscuration and possible disturbance of the servo signals is to generate a dropout in the data reaching the error-correction decoder. While the error correction code has a very high burst correction capability, a large dust particle can 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 optical disks for long-term data storage

B.1 Handling

The fragile protective coating on the label surface is vulnerable to damage and should be protected together with the read-out 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 read-out 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	5 °C to 30 °C
Relative humidity	15 % to 80 %
Absolute humidity	1 g/m^3 to 24 g/m^3
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 controlled more tightly, 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	10 °C to 25 °C
Relative humidity	30 % to 50 %
Absolute humidity	3 g/m^3 to 12 g/m^3
Atmospheric pressure	75 kPa to 106 kPa
Temperature gradient	10 °C 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 optical disks for long-term data storage 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 occurs.

Loose contaminants can be removed by short, one-second bursts of clean, dry air, avoiding expulsion of cold propellants. Even if the manufacturer has not supplied any cleaning information, organic polymer substrate disks can be cleaned using a lint-free cloth of non-woven fabric and either clear 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, $N_{p,i}$, can be expressed as a binomial probability on the assumption that errors occur at random, as shown in Formula (C.1):

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

where p is the byte error rate.

$PI_{sum\ 8}$ is the PI errors in 8 ECC blocks.

N_{pis8} is the variable for the number of $PI_{sum\ 8}$. It can be expressed by Formula (C.2) because the length of the outer code word is 208, as shown in Figure C.1.

$$N_{pis8} = 208 \times 8 \times N_{p,i} \tag{C.2}$$

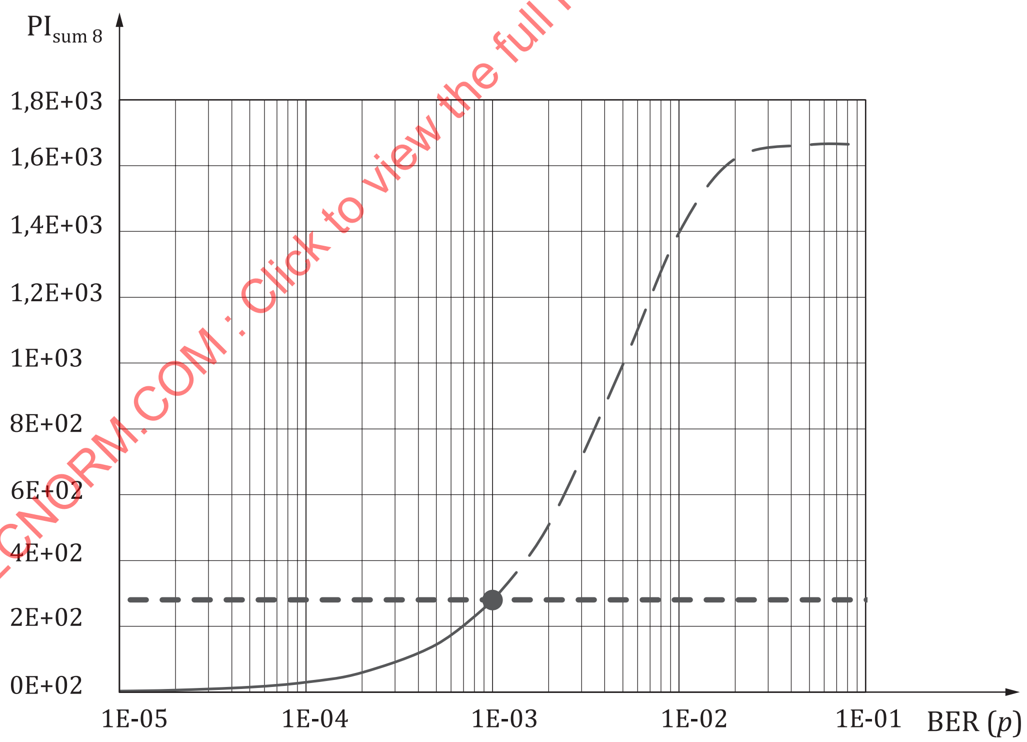


Figure C.1 — Relationship between BER (p) and $PI_{sum\ 8}$

Annex D
(informative)

Guideline for adjustment of the estimated lifetime to higher stress conditions

In actual storage conditions, the temperature and relative humidity can deviate from 25 °C/50 %, which changes the estimated lifetime. In this case, the estimated lifetime at 25 °C/50 % 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 the Eyring method, is derived in Formula (D.1):

$$B_{5\ \text{life}} = \exp(\ln\hat{B}_5) = \exp\left(\hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1{,}64\hat{\sigma}\right) \quad \text{(D.1)}$$

where

$\hat{B}_5$ is estimated value of B_5;

$B_{5\ \text{life}}$ is the variable for B_5life;

$\beta_0 = \ln A$;

$\beta_1 = \Delta H/k$;

$\beta_2 = B$;

x_{10} and x_{20} are the temperature-dependent factor and the relative-humidity–dependent factor at the controlled storage conditions (25 °C/50 % relative humidity) respectively;

A is the pre-exponential time constant;

ΔH is the activation energy per molecule;

k is the Boltzmann constant;

B is the constant of relative humidity exponential.

If the storage temperature and relative humidity differ from 25 °C/50 %, B_5 life is replaced with B_5 life$_{(m,n)}$, whose variable is expressed by Formula (D.2), 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 Formulae (D.2) and (D.3).

$B_{5\ \text{life}}$ in Formula (D.1) can be also described as $B_{5\ \text{life},(0,0)}$ in this annex, applying Formula (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 ($A_{\text{d}\ (m,n)} = B_{5\ \text{life},(m,n)}/B_{5\ \text{life}}$) are derived using Formula (D.3):

$$A_{\text{d}(m,n)} = \frac{\exp\left(\hat{\beta}_0 + \hat{\beta}_1 x_{1m} + \hat{\beta}_2 x_{2n} - 1{,}64\hat{\sigma}\right)}{\exp\left(\hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1{,}64\hat{\sigma}\right)} = \exp\left[\hat{\beta}_1\left(x_{1m} - x_{10}\right) + \hat{\beta}_2\left(x_{2n} - x_{20}\right)\right] \quad \text{(D.3)}$$

Corresponding to ISO/IEC 16963, an example computation of the adjustment coefficients, $A_{\text{d}\ (m,n)}$, 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 relative humidity from 50 % to 80 % in units of 5 %, under the condition that B_{50} life (Year) at the 25 °C/50 % is 1 110 years and B_5 life (Year) is 893 years.

Table D.1 shows that the estimated lifetime shortens abruptly when the storage conditions of temperature and relative humidity become more severe than 25 °C/50 % even in the recommended conditions for general storage shown in Table B.1. For example, the estimated lifetime at storage conditions, the temperature and relative humidity of 30 °C/80 % shortens by about 1/6 compared with that of 25 °C/50 %. 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

			Relative humidity (*n*)						
		n	0	1	2	3	4	5	6
	m		50 %	55 %	60 %	65 %	70 %	75 %	80 %
Temperature (*m*)	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**
NOTE This is an example calculated by using the test data of ISO/IEC 16963:2017, Annex B.									

Annex E
(normative)

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 to 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 shall define the estimated lifetime to determine the test interval or migration interval in this document. $B_{0,000\ 1}$ 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 document. 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 Formula (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 is the percentile of $\mathrm{N}\left(0,\sigma^2\right)$;

(x_{10}, x_{20}) are the temperature-dependent factor and the relative humidity factor at the controlled storage conditions (25 °C and 50 % relative humidity), respectively.

Using Formula (E.1), $\ln\hat{B}_{0,000\ 1}$ which is the estimated lifetime with the failure probability of one millionth is given by Formula (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 Formula (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 $\hat{B}_{50}$ and $\hat{B}_5$ into Formula (E.2) and Formula (E.3) gives Formulae (E.4) and (E.5):

$$\begin{aligned} B_{0,000\ 1\ \text{life}} &= \exp\left(\ln\hat{B}_{50} - 4,75\hat{\sigma}\right) = \exp\left(\ln\hat{B}_{50} - 4,75\frac{\ln\hat{B}_{50} - \ln\hat{B}_5}{1,64}\right) \\ &= \exp\left(2,9\ln\hat{B}_5 - 1,9\ln\hat{B}_{50}\right) \end{aligned} \tag{E.4}$$

where $B_{0,000\ 1\ \text{life}}$ is the variable for $B_{0,000\ 1}$ life.

Thus,

$$B_{\text{mig life}} \times 24 \times 365 = B_{0{,}000\ 1\ \text{life}} = \exp\left(2{,}9 \ln \hat{B}_5 - 1{,}9 \ln \hat{B}_{50}\right) \quad \text{(E.5)}$$

where $B_{\text{mig life}}$ is the variable for B_{mig} life in years.

For example, ISO/IEC 16963:2017, Annex B, gives the data of B_{50} life and B_5 life at the controlled storage conditions (25 °C/50 % relative humidity) introduced based on the Eyring method.

$B_{50\ \text{life}}$= 9 724 120 h (1 110 years) ($B_{50\ \text{life}}$ is the variable for B_{50} Life)

$$\ln \hat{B}_{50} = \ln\ (9\,724\ 120) = 16{,}090\,12$$

$B_{5\ \text{life}}$ =7 826 297 h (893 years)

$$\ln \hat{B}_5 = \ln\ (7\ 826\ 297) = 15{,}873\ 00$$

B_{mig} life is calculated by substituting these values to Formula (E.5):

$$B_{\text{mig life}} = \frac{\exp\left(2{,}9\ \ln \hat{B}_5 - 1{,}9\ \ln \hat{B}_{50}\right)}{24 \times 365} = \frac{\exp\left(2{,}9 \times 15{,}873\ 00 - 1{,}9 \times 16{,}090\ 12\right)}{24 \times 365}$$

$$= \frac{5\ 180\ 811\ \text{h}}{24 \times 365} = 591\ \text{years}$$

For the other example, ISO/IEC 16963:2017, Annex C, gives the data of B_{50} life and B_5 life at the harsh storage conditions (30 °C /80 % relative humidity) introduced based on the Arrhenius method.

$B_{50\ \text{life}}$ =1 417 280 h (162 years)

$$\ln \hat{B}_{50} = \ln\ (1\ 417\ 280) = 164{,}164\ 25$$

$B_{5\ \text{life}}$ =1 087 462 h (124 years)

$$\ln \hat{B}_5 = \ln\ (1\ 087\ 462) = 13{,}899\ 36$$

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

$$B_{\text{mig life}} = \frac{\exp\left(2{,}9\ \ln \hat{B}_5 - 1{,}9\ \ln \hat{B}_{50}\right)}{24 \times 365} = \frac{\exp\left(2{,}9 \times 15{,}873\ 00 - 1{,}9 \times 16{,}090\ 12\right)}{24 \times 365}$$

$$= \frac{5\ 180\ 811\ \text{h}}{24 \times 365} = 591\ \text{years}$$

Annex F
(normative)

Guidelines for test interval and migration

F.1 General

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 document, 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, there is a possibility that the stored data are not easily retrieved. Moreover, if the stored data have high value, the user can prefer to migrate after a shorter interval for safety. In consideration of these factors as stated above, the migration interval is defined as X_{mig} interval (years) and this value is determined by the user of this document.

In Annex E, the estimated lifetime for test interval and data migration is defined as B_{mig} life (equals $B_{0,000\ 1,\ life}$: 0,000 1 % failure time). Half of B_{mig} life or less shall be set as the test interval and the periodical performance test (PP test) is carried out. After two occurrences of PP tests, which means test intervals reach B_{mig} life, in case the test result is equal to Level 4 in Table 2, the next test interval shall be set to three years or less. In this case, it is recommended to limit the test to twice.

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

F.2 Test interval and data migration

Hereafter, X_{mig} is the variable for X_{mig} interval and $B_{mig\ life}$ is the variable for B_{mig} life in years.

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

   1) If $X_{mig} - B_{mig\ life}/2$ is greater than 0, test interval of the first periodic performance test (PP test) should be set to $B_{mig\ life}/2$ (see Figure F.1).

   2) If $X_{mig} - B_{mig\ life}/2$ 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 (see Figure F.2).

b) In case the PP test result of 1) 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):

   3) If $X_{mig} - 2 \times B_{mig\ life}/2$ is greater than 0, test interval of the second PP test should be set to $B_{mig\ life}/2$ (see Figure F.1).

4) If $X_{mig} - 2 \times B_{mig\ life}/2$ is less than or equal to 0, test interval of the second PP test should be set to $X_{mig} - B_{mig\ life}/2$. Data migration should be carried out at the second PP test in spite of the test result (see Figure F.2).

c) In case the test result of 3) 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.):

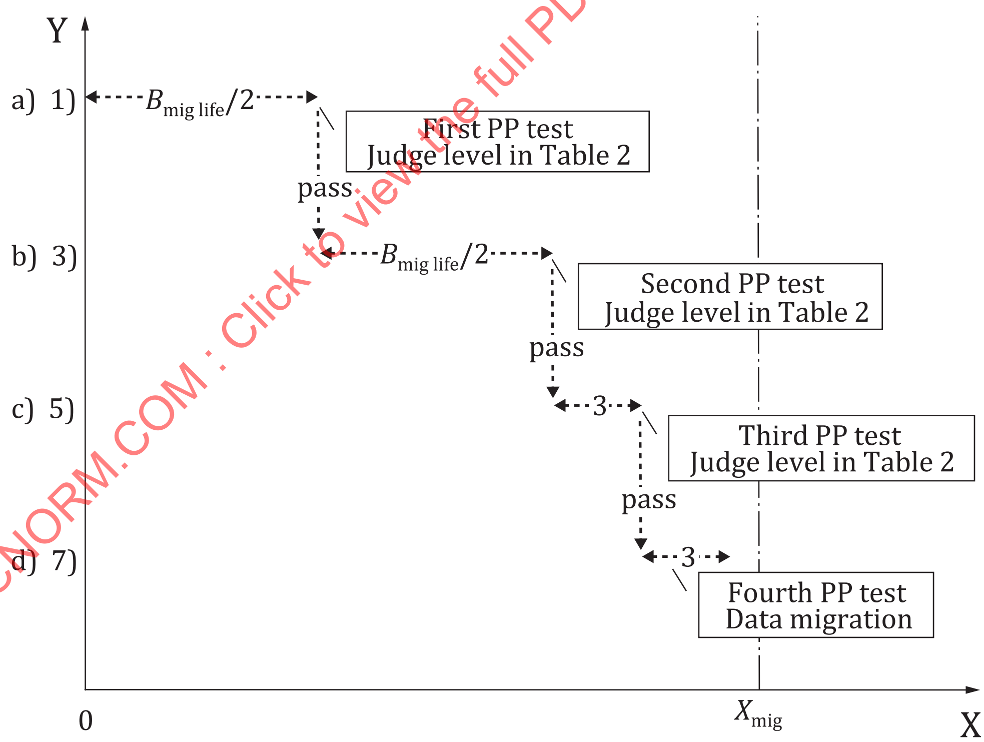
5) In case of $X_{mig} - 2 \times B_{mig\ life}/2 - 3$ is greater than or equal to 0, the test interval of the third PP test should be set to three years (see Figure F.1).

6) If $X_{mig} - 2 \times B_{mig\ life}/2 - 3$ is equal to −2 or −1, then the test interval of the third PP test should be set to one year and two years, respectively. Data migration should be carried out at the third PP test in spite of the test result (see Figure F.2).

d) In case the test result of 5) is equal to Level 4 in Table 2 (Use as is) (other than Level 4, migrate data as soon as possible or migrate data immediately):

7) If $X_{mig} - 2 \times B_{mig\ life}/2 - 2 \times 3$ is greater than or equal to 0, the test interval of the fourth PP test should be set to three years. Data migration should be carried out at the fourth PP test in spite of the test result (see Figure F.1).

8) If $X_{mig} - 2 \times B_{mig\ life}/2 - 2 \times 3$ is equal to −2 or −1, then the test interval of the fourth PP test is set to one year and two years, respectively. Data migration should be carried out at the fourth PP test regardless of the test result (see Figure F.2).

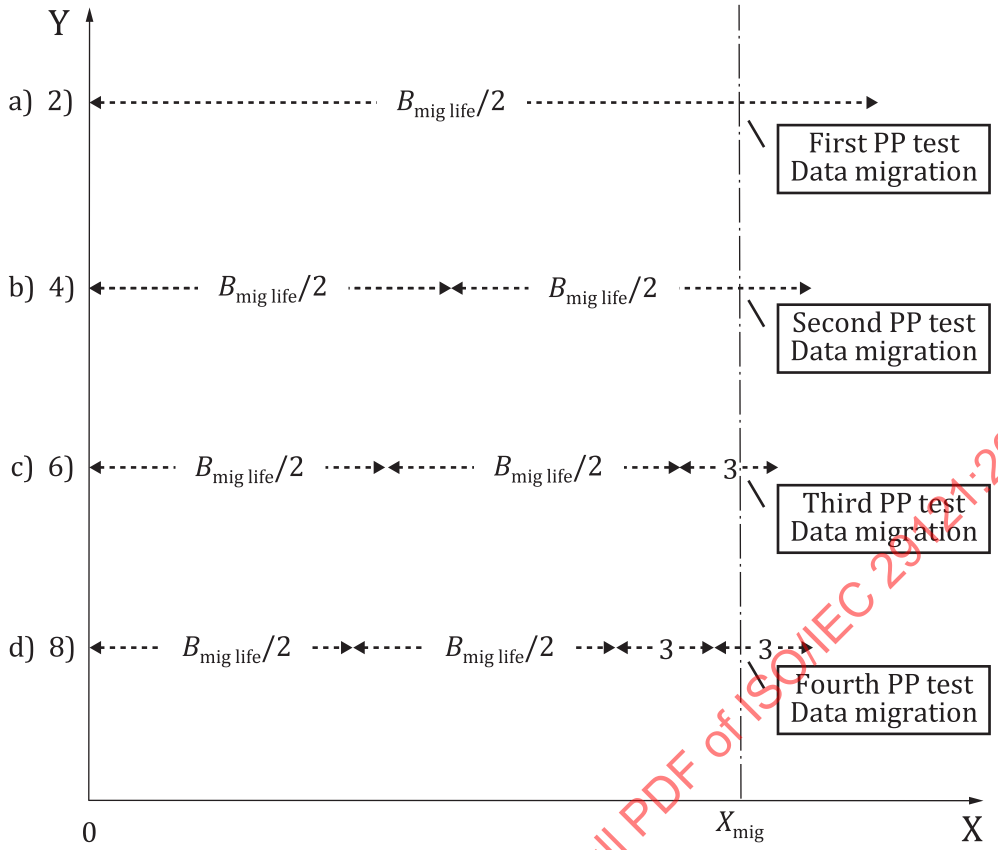


Key

X storage time (year)

Y case in F.2

Figure F.1 — Timing for periodic performance (PP) test and data migration in case the estimated lifetime is relatively shorter than the user-defined migration period



Key

X storage time (year)

Y case in F.2

Figure F.2 — Timing for periodic performance (PP) test and data migration in case the estimated lifetime is relatively longer than the user defined migration period

F.3 Specific calculation examples

Case 1

In case the B_{mig} life of the disk is equal to 20 years, migration interval X_{mig} interval is set to 25 years and initial performance test result equal to Level 1.

According to a), $X_{mig} - B_{mig\ life}/2 = 25 - 10 = 15$ is greater than 0, so the test interval of the first PP test should be 10 years. Suppose the test result of the first PP test is Level 4.

According to b), $X_{mig} - 2 \times B_{mig\ life}/2 = 25 - 2 \times 10 = 5$ is greater than 0, so the test interval of the second PP test should be 10 years. Suppose the test result of the second PP test is Level 4.

According to c), $X_{mig} - 2 \times B_{mig\ life}/2 - 3 = 25 - 2 \times 10 - 3 = 2$ is greater than 0, so the test interval of the third PP test should be three years. Suppose the test result of the third PP test is Level 4.

According to d), $X_{mig} - 2 \times B_{mig\ life}/2 - 2 \times 3 = -1$ is less than 0, so the test interval of the fourth PP test is two years. Data migration should be carried out at the fourth PP test in spite of the test result.

Case 2

In case the B_{mig} life of the disk is equal to 50 years, migration interval X_{mig} interval is set to 20 years and initial performance test result equal to Level 1.

According to a), $X_{mig} - B_{mig\ life}/2 = 20 - 25 = -5$ is less than 0, so the test interval of the first PP test should be 20 years. Data migration should be carried out at the first PP test in spite of the test result.