INTERNATIONAL STANDARD

ISO/IEC 29121

Third edition
2018-03

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

Reference number
ISO/IEC 29121:2018(E)

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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.

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 ISO documents 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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

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

This third edition cancels and replaces the second edition (ISO/IEC 29121:2013), which has been technically revised.

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

— CD-R, CD-RW, BD-Recordable and BD Rewritable disks have been added as the optical disks for long-term data storage applicable in this document, and accordingly, the title of this document has been changed.

— Terminologies have been harmonized with those used in ISO/IEC 16963 and relevant updates in the latest version of ISO/IEC 16963 have been reflected.

— ISO/IEC 16963 has been moved from the Normative references clause to the Bibliography at publication stage in order to conform to the requirements from the ISO/IEC Directives Part 2.

— Minor editorial changes have been made to conform to the latest version of ISO/IEC Directives Part 2.

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 did not contain requirements for longevity.

Longevity is limited both by disk degradation 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 five to ten years, and technology life cycles usually end after 20 years. Consequently, recordings that require a longer life cycle may 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 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 continues to be monitored. Methods described in this document 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.

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, ISO/IEC JTC 1/SC 23 started work to include BD Recordable and Rewritable disks in this document and held joint discussions with Ecma International TC31. The BD data migration part of this work was standardized separately by Ecma International as ECMA-413, along with contributions from the Japanese national committee of SC 23. CD-R and CD-RW disks included in ISO/IEC 16963 are also incorporated.

ISO/IEC 16963 was initially listed as a normative reference in this document to introduce the lifetime estimation method. However, as the application of this method is strongly recommended as opposed to required, ISO/IEC 16963 was moved from the Normative references clause to the Bibliography for conformance with the ISO/IEC Directives Part 2.

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 as long as 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 including test parameters, test area, test drive, disk preparation and test execution;

— an initial performance test and a periodic performance test that check a readability of the data recorded on the disks with categorized Maximum Data Error tables; and

— a necessity of precaution to reduce the possibility of deterioration in order to assure the integrity of the disks during their use, storage, handling or transportation.

This document offers guidelines to use disks with estimated lifetime of B_{mig} ($B_{0{,}000\ 1}$) Life which is introduced using B_5 Life and B_{50} Life specified in ISO/IEC 16963.

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 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 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)*

ISO/IEC 30190:2016, *Information technology — Digitally recorded media for information interchange and storage — 120 mm Single Layer (25,0 Gbytes per disk) and Dual Layer (50,0 Gbytes per disk) BD Recordable disk*

ISO/IEC 30191:2015, *Information technology — Digitally recorded media for information interchange and storage — 120 mm Triple Layer (100,0 Gbytes single sided disk and 200,0 Gbytes double sided disk) and Quadruple Layer (128,0 Gbytes single sided disk) BD Recordable disk*

ISO/IEC 30192, *Information technology — Digitally recorded media for information interchange and storage — 120 mm Single Layer (25,0 Gbytes per disk) and Dual Layer (50,0 Gbytes per disk) BD Rewritable disk*

ISO/IEC 30193, *Information technology — Digitally recorded media for information interchange and storage — 120 mm Triple Layer (100,0 Gbytes per disk) BD Rewritable disk*

ECMA-394, *Recordable Compact Disc Systems CD-R Multi-Speed*

ECMA-395, *Recordable Compact Disc Systems CD-RW Ultra-Speed*

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 http://www.iso.org/obp

3.1
B_{mig} Life
B_{mig}
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

[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 on the recorded disk measured before error correction is applied

3.8
initial performance test
test of the recording performance of data recorded on a disk before storing

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

3.10
Max BER
maximum byte *error rate* (3.7) at any consecutive 32 *ECC* (3.6) blocks on a disk as measured in the first pass of the decoder before correction

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

3.11
Max C1 Ave 10
maximum number of C1 errors per second before error correction averaged over any 10 s

Note 1 to entry: See ISO/IEC 10149, ECMA-394 and ECMA-395.

3.12
Maximum Data Error
greatest level of data error measured 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
Max PI SUM 8
maximum Parity of Inner (PI) code error count at any consecutive 8 *ECC* (3.6) 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.

3.14
Max RSER
maximum Random Symbol Error Rate before error correction, 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 recording performance of data recorded on a disk during the storage

3.16
retrievability
ability to recover physical information as recorded

3.17
storage time
time that a disk is being stored since data are recorded on the disk

3.18
system
combination of hardware, software, storage medium and documentation used to record, retrieve and reproduce information

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

3.19
uncorrectable error
error in the playback data that could not be corrected by the error correcting decoders

3.20
X_{mig} Life
X_{mig}
migration interval (year) which is determined by the user

Note 1 to entry: See Annex F.

4 Test method

4.1 Test parameters

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 maximum inner-parity error shall be measured at any consecutive 8 ECC blocks (Max PI SUM 8) in the first pass of the decoder before correction.

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

For CD-R disk defined in ECMA-394 and CD-RW disk defined in ECMA-395, the maximum C1 Ave 10 (Max C1 Ave 10) 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, the maximum Random Symbol Error Rate (Max RSER) shall be measured (see Annex H).

4.2 Test area

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

The test area for the periodic performance test should be the whole recorded area of all disks (see Annex G).

4.3 Test drive

4.3.1 General

For DVD-R disks defined in ISO/IEC 12862 and ISO/IEC 23912, the test drive shall comply with each standard. For DVD-RW disks defined in ISO/IEC 13170 and ISO/IEC 17342, the test drive shall comply with each standard. For +R disks defined in ISO/IEC 17344 and ISO/IEC 25434, the test drive shall comply with each standard. For +RW disks defined in ISO/IEC 17341, ISO/IEC 26925 and ISO/IEC 29642, the test drive shall comply with each standard. The test drive shall have the capability to measure Max PI SUM 8.

For DVD-RAM disk, the test drive shall comply with ISO/IEC 17592. The test drive shall have the capability to measure Max BER.

For CD-R and CD-RW disks, the test drive shall comply with ECMA-394 and ECMA-395, respectively. The test drive shall have the capability to measure Max C1 Ave 10.

For BD Recordable disks defined in ISO/IEC 30190 and ISO/IEC 30191, the test drive shall comply with each standard. For BD Rewritable disks defined in ISO/IEC 30192 and ISO/IEC 30193, the test drive shall comply with each standard. The test drive shall have the capability to measure Max RSER.

NOTE The measuring circuit for RSER described in ISO/IEC 30191 and ISO/IEC 30193 is different from that of described in ISO/IEC 30190 and ISO/IEC 30192, especially in HF signal pre-processing circuit. See ISO/IEC 30190:2016, Annex H and ISO/IEC 30191:2015, Annex H.

4.3.2 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.

4.4 Disk preparation

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

4.5 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.

On testing disks, care handling of the disks shall be taken in order to avoid introducing unexpected defects. See Annex I.

Test results shall be judged by Maximum Data Error. Maximum Data Error is Max PI SUM 8 for DVD-R, DVD-RW, +R and +RW disks; Max BER for a DVD-RAM disk; Max C1 Ave 10 for CD-R and CD-RW disks and Max RSER for BD Recordable and BD Rewritable disks.

5 Test interval for periodic performance test

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.

In cases where the estimated lifetime is provided in accordance with 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.

6 Test result evaluation

6.1 General

The readability of the data recorded on the disks is checked by the initial performance test and the periodic performance test. When data are recorded on disks, the initial recording performance shall be checked by the initial recording performance test. Depending on the test result of the initial recording test, disks are selected to be used for the long-term data storage. The performance of the recorded data on those disks should be periodically checked in the storage duration with the periodic performance test. Depending on the test result of the periodic performance test, the necessity of the data migration is judged.

6.2 Initial performance test

The initial recording performance is categorized as Level 1, 2 and 3 by Maximum Data Error as shown in Table 1.

At least, the initial recording performance shall be within Level 1. Disks showing the initial recording performance of Level 2 should not be used. Disks showing the initial recording performance 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 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 initial recording performance

Level	Status	DVD_R, DVD-RW, +R, +RW	DVD-RAM	CD-R, CD-RW	BD Recordable, BD Rewritable
1	Recommended	<140	<5,0 × 10^{-4}	<110	<5,0 × 10^{-4}
2	Should not be used	140 to 280	5,0 × 10^{-4} to 1,0 × 10^{-3}	110 to 220	5,0 × 10^{-4} to 1,0 × 10^{-3}
3	Shall not be used	>280	>1,0 × 10^{-3}	>220	>1,0 × 10^{-3}
Maximum Data Error		Max PI SUM 8	Max BER	Max C1 Ave10	Max RSER

6.3 Periodic performance test

The recording performance at the periodic performance test is categorized in Level 4, 5 and 6 by Maximum Data Error as shown in Table 2.

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 Maximum Data Error is high enough in Level 6 to disable retrieval the data without uncorrectable errors.

Table 2 — Category of recording performance 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 it 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		Max PI SUM 8	Max BER	Max C1 Ave10	Max RSER

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

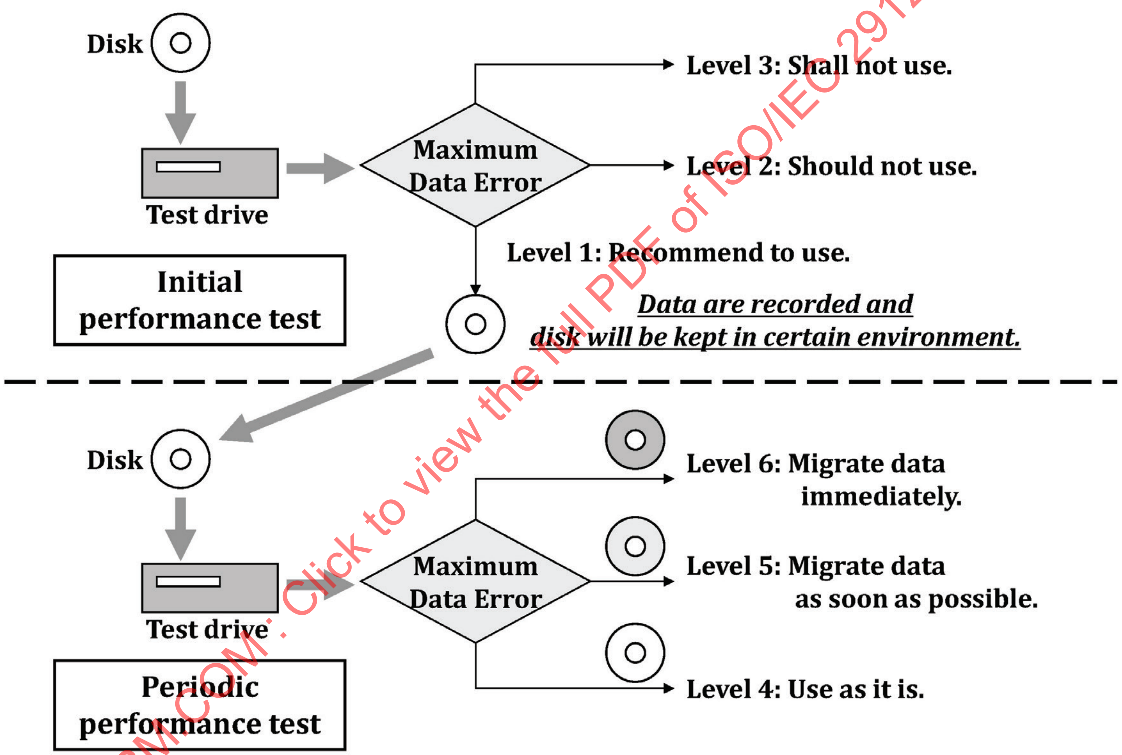

Figure 1 — Data migration flow for optical disks for long-term data storage

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 and Annex D 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 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 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 bonded to a dummy substrate for a single-sided disk, or 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 a long period of time, under extreme environmental exposure, 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 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 can 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, 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 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	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 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	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 will occur.

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 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, as shown in Formula (C.1):

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

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.

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

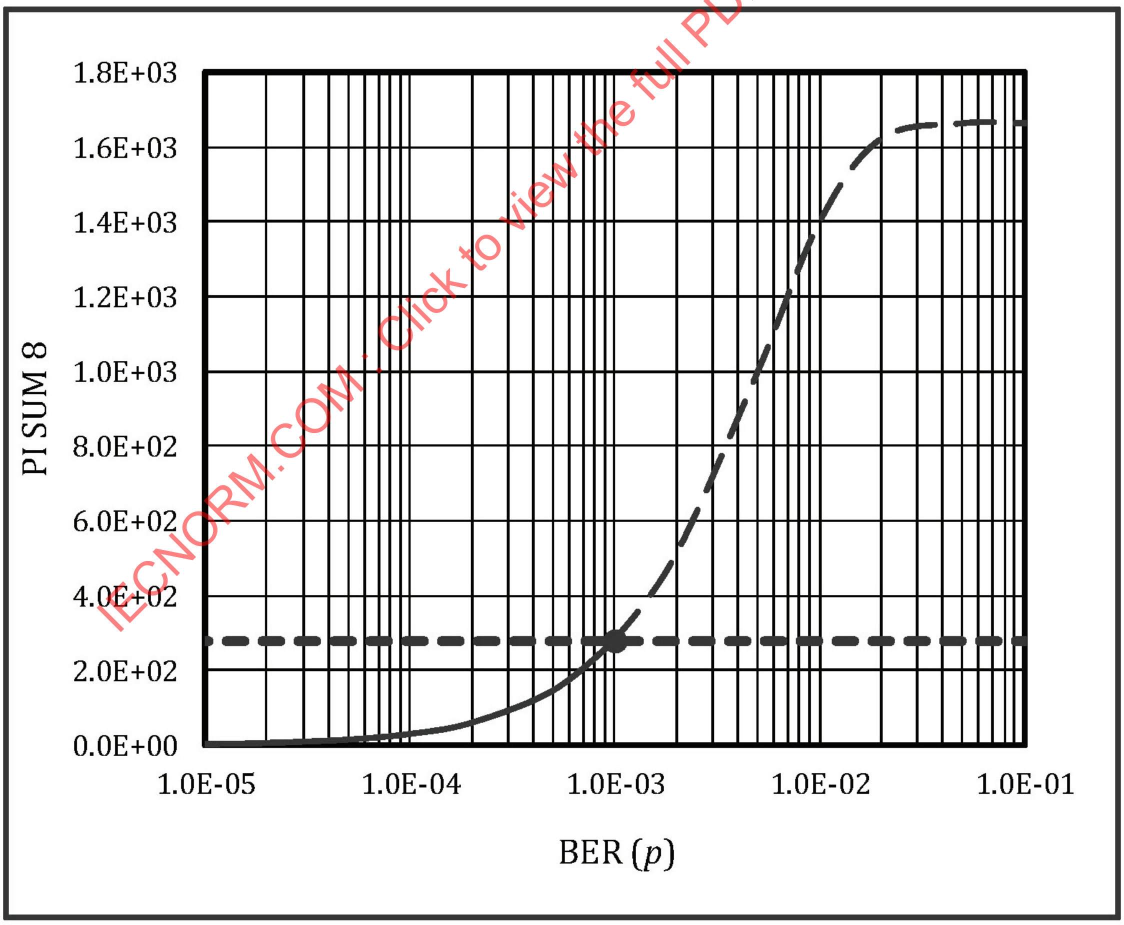

Figure C.1 — Relationship between BER (*p*) and PI SUM 8

Annex D
(informative)

Guideline for adjustment of the estimated lifetime to higher stress conditions

In actual storage conditions, the temperature and relative humidity 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 Eyring Method, is derived in Formula (D.1):

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

where

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

x_{10} and x_{20} are the temperature-dependent factor and the relative-humidity-dependent factor at the Controlled storage-condition (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 relative humidity exponential constant.

If the storage temperature and relative humidity differ from 25 °C/50 %, 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 formulae. B_5 Life in Formula (D.1) can be also described as B_5 Life$_{(0,0)}$ in Annex D, applying Formula (D.2):

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

Then, the adjustment coefficients normalized by B_5 Life ($A_{d\,(m,n)} = B_5$ Life$_{(m,n)}$/B_5 Life) are derived using Formula (D.3):

$$\begin{aligned} A_{d(m,n)} &= \exp\left(\hat{\beta}_0 + \hat{\beta}_1 x_{1m} + \hat{\beta}_2 x_{2n} - 1{,}64\hat{\sigma}\right) / \exp\left(\hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 1{,}64\hat{\sigma}\right) \\ &= \exp\left[\hat{\beta}_1\left(x_{1m} - x_{10}\right) + \hat{\beta}_2\left(x_{2n} - x_{20}\right)\right] \end{aligned} \tag{D.3}$$

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 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 the 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
(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 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, $\ln \hat{\beta}_p$ is given as Formula (E.1):

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

where, z denotes percentile of $N\left(0,\sigma^2\right)$ and $\left(x_{10}, x_{20}\right)$ denotes the temperature dependent factor and the relative-humidity factor at the Controlled storage-condition (25 °C and 50 % relative humidity), respectively.

Using Formula (E.1), $\ln B_{0,000\ 1}$ 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.

$$\ln \hat{B}_{0,000\ 1} = \hat{\beta}_0 + \hat{\beta}_1 x_{10} + \hat{\beta}_2 x_{20} - 4,75\hat{\sigma} = \ln \hat{B}_{50} - 4,75\hat{\sigma} \quad \text{(E.2)}$$

On the other hand, $\hat{\beta}_5$ is given by Formula (E.3):

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

Putting B_{50} Life and B_5 Life into Formula (E.2) and Formula (E.3) gives Formula (E.4):

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

Thus,

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

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

$$B_{50}\text{ Life} = 1\ \ 110\text{ years}\left(= 9\ 724\ 120\text{ hours}\right)$$

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

$$B_5\text{ Life} = 893\text{ years}\left(= 7\ 826\ 297\text{ hours}\right)$$

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

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

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

$$= 5\ \ 180\ 811\text{ hours} = 591\text{ years}$$

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-condition (30 °C /80 % relative humidity) introduced based on Arrhenius method.

$$B_{50}\text{ Life} = 1\ 62\text{ years}\left(= 1\ 417\ 280\text{ hours}\right)$$

$$\ln\hat{B}_{50} = \ln\left(1\ 417\ 280\right) = 14{,}164\ 25$$

$$B_5\text{ Life} = 124\text{ years}\left(= 1\ 087\ 462\text{ hours}\right)$$

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

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

$$B_{mig}\text{Life} = \exp\left(2{,}9\ \ln\hat{B}_5 - 1{,}9\ \ln\hat{B}_{50}\right) = \exp\left(2{,}9 \times 13{,}899\ 36 - 1{,}9 \times 14{,}164\ 25\right)$$

$$= 657\ 413\text{ hours} = 75\text{ years}$$

Annex F
(informative)

Guideline of 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 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 the user of this document.

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). 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.2 Test interval and data migration

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

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

4) If $X_{mig} - 2 \times B_{mig}/2$ is less than or equal to 0, test interval of the second PP test should be set to $X_{mig} - B_{mig}/2$. 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 $X_{mig} - 2 \times B_{mig}/2 - 3$ 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 $X_{mig} - 2 \times B_{mig}/2 - 3$ 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 it is) (other than Level 4, migrate data as soon as possible or migrate data immediately):

7) If $X_{mig} - 2 \times B_{mig}/2 - 2 \times 3$ 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 $X_{mig} - 2 \times B_{mig}/2 - 2 \times 3$ 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).

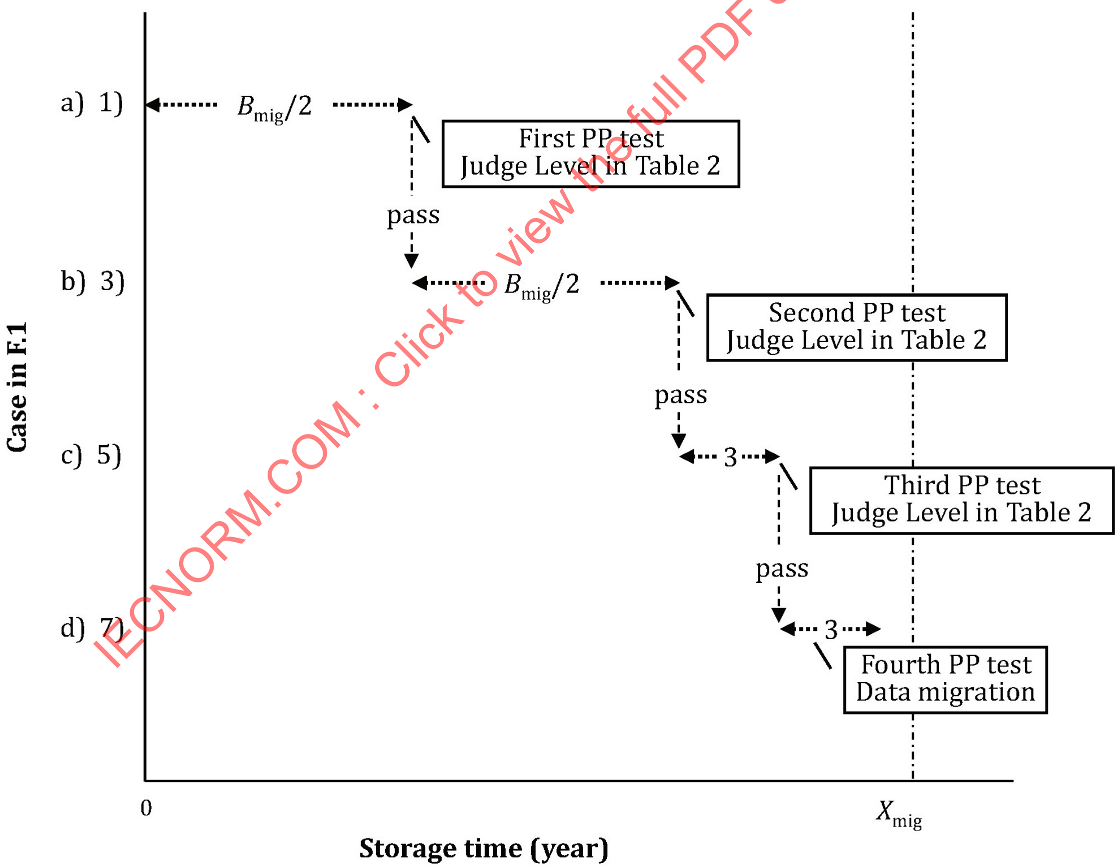

Figure F.1 — Timing for periodic performance (PP) test and data migration in case the estimated lifetime is relatively shorter than the user-defined migration period

