TECHNICAL REPORT

ISO/TR 17797

First edition
2014-10-01

Electronic archiving — Selection of digital storage media for long term preservation

Archivage électronique — Sélection d'un support de stockage numérique pour une préservation à long terme

Reference number
ISO/TR 17797:2014(E)

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Published in Switzerland

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Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 171, *Document management applications*, Subcommittee SC 1, *Quality*.

Introduction

A significant proportion of digital information generated by different human activities will need to be stored for a long period of time and in some cases for as long as it is possible. Where ‘long-term’ is used in this Technical Report, a storage period of not less than the anticipated life of the storage media is assumed.

The media currently used to store digital information for the long-term have not been analysed and manufactured for this purpose but mainly developed to maximize transfer rates, density recording, and access time. All these parameters have to be taken in perspective when long-term preservation is the requirement, not just simple backup purposes.

In general, current information management systems might not be conducive to the satisfactory achievement of long-term preservation. For long-term preservation, there needs to be the development of special resources and complex procedures with often increased costs when compared with ‘normal’ information management systems (duplication of files, refreshing storage, equipment redundancy, monitoring systems, heavy maintenance, frequent and risky migration, high energy consumption, etc.).

Even when a system is designed for long-term preservation, the day-to-day requirements for access and management of the stored digital information needs to be taken into consideration.

When designing systems for long-term preservation, it is necessary to have specific pathways with the objective of providing qualified storage media on criteria such as reliability and stability; this would ensure that the sustainability of digital information leads to optimize the solution for both long-term preservation and access to digital information.

The context of the requirement for long-term digital preservation needs to establish conditions and recommendations for media that is specially manufactured with a guaranteed potential of stability and reliability.

The main criteria involved in the long-term preservation of digital information can be summarized as follows:

a) intrinsic stability of storage media;

b) stability of physical and/or chemical modifications of media produced by record processing;

c) quality and reliability of recording process;

d) preservation of access path to information and metadata;

e) preservation of access tools (i.e. any special software needed to use digital items that have not been migrated to a long-term or standardized format);

f) quality of information;

   — compliance with format specification;

   — data integrity.

Only the first three criteria from the list above are considered as part of this Technical Report.

It is noted that the objective is not to make rules or specifications for use on information management systems as several International Standards, such as ISO 14641-1, ISO 15489-1, and ISO/TR 15489-2, fill this role.

Electronic archiving — Selection of digital storage media for long term preservation

1 Scope

This Technical Report gives guidelines on a selection of the most appropriate storage media for use in long-term electronic storage solutions. It includes a discussion on magnetic, optical, and electronic storage.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12651-1, *Electronic document management — Vocabulary — Part 1: Electronic document imaging*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12651-1 and the following apply.

3.1
refreshment
data migration where the media is replaced with equivalent media such that all storage hardware and software functionality is unchanged

Note 1 to entry: Refreshment cycles are based on the predicted life span of the medium.

[SOURCE: ISO 13008:2012]

3.2
migration
process of moving digital information, including their existing characteristics, from one hardware or software configuration to another without changing the format

Note 1 to entry: Migration can also include converting to a more current computing environment, involving changes to hardware/software configurations.

[SOURCE: adapted from ISO 13008]

3.3
storage medium
device on which digital information can be recorded

Note 1 to entry: Device can designate a support, a combined support and media player, or a set recorder.

4 Methodology

The characteristics required for storage media should be clearly established regarding the following criteria:

— reliability;

- anticipated longevity;
- sensitivity to environment (operating or storage), internal and external conditions;
- obsolescence of hardware and software.

A part of this Technical Report describes methods or guidelines which lead to the identification of appropriate media based on criteria specified, such as the following:

- control strategies;
- media evaluation process (procedures, monitoring devices);
- tools for monitoring characteristics (ECC, data verification, etc.);
- defining acceptance criteria level;
- analysis of means (existing or desired) for detecting trends.

On this basis, this Technical Report is structured around the following points:

- requirements for the long-term storage media;
- capability of different types of technologies to store digital information in the long term, including aspects of quality, reliability, and durability;
- definition of criteria considered;
- diagnostic elements to be used.

5 Choice of storage system/media

This clause lists some of the issues related to the different types of media that can be used for the storage of digital information. The choice of media should support the long-term preservation strategy and the architecture of the information management system.

All media/recording systems are at risk of a sudden loss of access to digital information, regardless of the technology, so an information management system should be designed to mitigate this risk of loss of this information.

There are various reasons for loss of access, but the most common is the physical failure of media/drivers. This can be the cause in up to 70 % of cases (30 % drive read instability, 38 % drive failure).

The choice of storage system/media is complex because of their often unpredictable behaviour during their life. Reliability models used by manufacturers can provide estimates that are often not achieved in the operational environment. The reliability of storage media is often given by manufacturers in terms of failure rate or in terms of lifespan; for example, the rated lifetime of a particular media type might range from 10 years to several centuries. However, in practical applications it can be found that the actual lifespan can range from a few months to 20 years, as it can be shown that operational life depends upon the operating environment. This disparity needs to be taken into consideration when deciding between different types of media or different models of the same type of media.

A further factor that should be taken into consideration when choosing storage solutions is the issue of obsolescence. Recent developments in storage systems have resulted in a very rapid increase in functional performance, but this has also lead to the rapid obsolescence of implemented solutions. Moreover, reliability and lifespan are typically not transferable from old systems to newer replacements. With each new advance in technology, much of the knowledge gained by tests or various statistical studies on existing systems will need to be replaced by trials and other methods of estimating the reliability of the new systems. This requirement is not supported by research on media degradation processes which makes it very difficult to establish a model for estimating storage media life (see Bibliography).

Storage solutions should be chosen taking into consideration the following:

— results of acceptance tests;

— traceability of the manufacturing processes;

— quality testing by sampling processes;

— longitudinal monitoring of media/drivers;

— environmental conditions of operational use and storage;

— continuous monitoring on the evolution of supply (hardware and software) in relation to the risk of withdrawal of commercial products.

6 Hard disk drive

6.1 General

Hard disk drive (HDD) technology is well established, and over the past 50 years there have been substantial improvements in data transfer rates and capacity along with a marked decrease in product price.

Hard disk drives are electromechanical devices containing generally aluminium platters that are layered with magnetic recording material. Data are written to and read from the disk by moveable read/write heads which float over the surface of the disk.

Two main risks are associated with the use of hard disk drives as physical carriers.

— They have a short life expectancy and should be replaced every five years.

— This technology is also susceptible to data loss from extended use, powering the disk on or off, physical damage of the drive itself, and sudden disk failure, etc.

Configurations

HDD can be used in information management systems under different configurations: either removable or external drives or integrated systems using redundancy and error correction codes to improve performance and reliability.

— **On-line:** the system configuration maintains a continuous or intermittent solicitation through a permanent connection;

— **Off-line:** not under control of processing unit, physically removed or disconnected and can't be accessed without human intervention:

— idle or inactive;

— RHDD removable hard disk drive;

— iVDR versatile hard disk;

— external HDD, etc.

6.2 Reasons for failure

Storage systems, and in particular those that have moving parts, are prone to mechanical failure. Failure can occur through a number of factors.

6.2.1 Mechanical failures:

— Heads: contamination, disk contact (crash);

— Arm: resonance, damping;

— Platters: scratch, wear, local defect, warping, magnetic layer defect;

— Motor: spindle motor, bearing, defective rotation, lubricant;

— Exploitation processing; data swap.

6.2.2 Electronic failures (motor driver, controller, buffer, connectors, interface, etc.):

— Main causes: power spikes, electrical surge, static electricity;

— Damaged to integrated components;

— Fail connection (power unit, driver, bus, etc.);

— Servo, memory chips.

6.2.3 External factors:

— Magnetic fields;

— Temperature and humidity;

— Water contact;

— Shocks, vibrations.

6.2.4 Disks off-line, the potential factors identified are

— Magnetic thermal decay of recorded bits;

— Media corrosion;

— Media lubricant oil evaporation;

— Fluid dynamic bearing oil evaporation or degradation;

— Electronic corrosion and degradation.

These archival life factors are all functions of temperature and humidity.

See Reference [54].

6.3 Quality indicators

6.3.1 General

Due to the incredibly precise nature of the technology used in hard disks and the fact that mechanical components are used, it is impossible to guarantee the reliability of even the highest quality disks for more than a few years. The failure rate of hard disks follows the so-called bathtub curve model of failures (see Figure 1): they have a relatively high rate of "premature failure" (or early failure), a period of very low failures for several years, and then a gradual reduction in reliability as they reach the end of their useful life

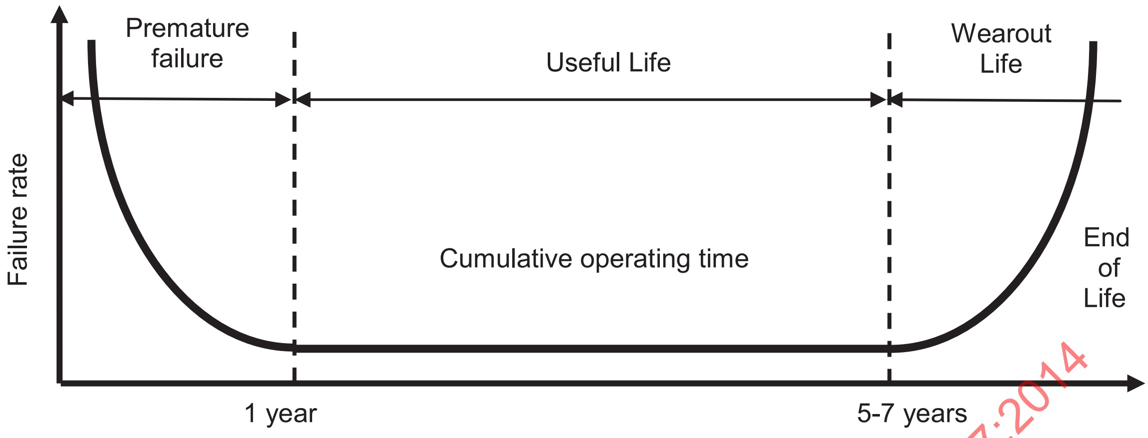

Figure 1 — Failure evolution: the bathtub curve

Most of the time, these are statistics based on systems in operation. However, these results do not give any indication about the new generations because technical similarities do not allow extrapolations. The rapid evolution of hardware provides backward compatibility but cannot predict their behaviour (although we have a good idea of the stability of the supports when they are replaced by the next generation).

6.3.2 Reliability terms

6.3.2.1 General

The disparity of units and values in the specifications provided by the manufacturers concerning the characteristics of reliability should be noted. Examples are:

— MTBF (Mean time before failure);

— MTTF (Mean time to failure);

— AFR (Annualized failure rate);

— MTBDL (Mean time between data loss);

— MTTR (Mean time to repair);

— Useful/Service life.

In addition, reliability data are rarely accompanied by a statement of conditions used for the development of the data.

6.3.2.2 Mean time before failure (MTBF) or Mean time to failure (MTTF)

MTBF is a statistical calculation that projects the average life expectancy of a typical disk in a large population of drives. MTBF does not indicate how long a disk drive will run before it fails, just the probability of failure.

To be interpreted properly, the MTBF figure is intended to be used in conjunction with the useful **service life** of the drive, the typical amount of time before the drive enters the period where failures due to component wear-out increase. MTBF only applies to the aggregate analysis of large numbers of drives; it says nothing about a particular unit.

If MTBF of a model is 500 000 hours and the service life is five years, this means that a drive of that type is supposed to last for five years, and that of a large group of drives operating within this timeframe, on average they will accumulate 500 000 hours of total run time (amongst all the drives) before the first failure of any drive.

There are in fact two different types of MTBF figures:

— ***Theoretical MTBF*** figure for a new drive based primarily upon analysis of historical data of other drives similar to the new one;

— ***Operational MTBF*** derived by analysing field return and comparing them to the installed base.

6.3.2.3 Annualized failure rate (AFR)

Annualized failure rate (AFR) gives the failure probability for a device or component during a full year of use. It is in relation with MTBF.

AFR is calculated from the device failure rate over time observed. Disk resellers are particularly sensitive to this issue since this statistic influences their spare parts strategy.

6.3.2.4 Mean time between data loss (MTBDL)

MTBDL is a statistical figure that attempts to predict how long an array group will operate before suffering a catastrophic failure and data loss. For example data loss occurs when information is written to the failed disk array subsequent to its last backup. RAID technology allows some disk array groups to survive the failure of one or more disks making MTBF less significant. MTBDL is a more meaningful measure of reliability than MTBF or AFR since it considers the performance of the array, not just a sub-component.

6.3.2.5 Mean time to repair (MTTR)

MTTR is the time it takes to repair a failed part. MTTR figures assume that no time elapses between the failure and the beginning of repair operations. That is to say, the appropriate person becomes aware of a bad component the instant it fails, has the necessary replacement parts available, and begins the repair process immediately. Unfortunately, this is not usually a valid assumption. As disk capacity increases, the time to complete the rebuild process grows in importance since it extends the time that the total array is vulnerable to a catastrophic failure.

See Reference [52].

6.3.2.6 Useful/Service life

It is the expected operation time of the HDD given by the manufacturer. This time corresponds to the ending period when failure rate becomes weak and constant. The “probability of survival” R of a HDD model and for a defined Useful life is given by Formula (1):

$$R = e^{-\text{Useful life}/\text{MTBF}} \quad (1)$$

where

R is the probability of survival, assuming constant failure rate model.

For example, for a model of HDD with a MTBF of 500 000 hours and a useful/service life of five years, the probability of survival of this HDD model is equal to 92 %. If this model is used 10 years the probability of survival decreases to 84 %.

6.3.3 Discussion on quality indicators

According to several publications, quality indicators given by manufacturers can overestimate the lifetimes (replacement rate) significantly. For five to eight year old drives, field replacement rates were a factor of 30 × higher than what the datasheet MTTF suggested.

See Reference [29].

Vendor-published failure-prediction metrics such as MTTF have been criticized by the research community. It is important to know how these metrics are derived. The aim in detailing accelerated life tests methodology to predict storage media reliability is to help storage system designers. Because disks are already reliable, meaningful data about actual performance is available only by studying very large populations of drives over very long periods. Furthermore disk technology changes so rapidly, information about current products will inevitably be established from accelerated life tests, not experience. Prediction will inevitably be based on models of how environmental factors affect performance.

See References [51] and [53].

Some causes of failure are different depending on whether the HDD are on-line or off-line.

See Reference [54].

6.4 Technical arrangements

6.4.1 General

To be compatible with long-term preservation, disks require full redundancy to address, among other things, early failure (see 6.3).

6.4.2 HDD on-line

6.4.2.1 General

For HDD on-line, literature shows that lifetime and reliability constraints are incompatible with long-term preservation. Without completely forgetting the risk of failure, the main corrective solution adopted is to rely on systems using data redundancy, but at the cost of operational complexity (tracking software for regular checks, for example), which should be precisely measured and regularly assessed.

6.4.2.2 Redundant arrays of independent disks (RAID)

The term RAID is applied to a collection of techniques that store data on a group of logically and physically bound disks in order to provide high throughput and, in most cases, parity protection for high reliability (see Annex A).

Recommendation
For high security, minimum redundancy desirable is RAID 6 type (despite the complexity of data reconstruction and the time required for restoration of incidents).

6.4.2.3 Additional procedures of RAID

6.4.2.3.1 Use of a spare HDD “hot swap” or “hot spare”

Disk capacity has become so important that the reconstruction of data in case of failure of one or two disks leave the system with a degraded protection for several hours.

Recommendation
To reduce the reconstruction time, it is recommended to use a rescue disk that will be used in “hot swap” or “hot spare” mode.

6.4.2.3.2 Use a backup system

No storage system, not even an advance RAID unit, can completely eliminate the danger of data loss. User error and accidental file deletion still account for most problems. For these and other reasons (virus attack, natural disasters) frequent backups and periodic archiving are essential. By combining conservative operational procedures with disk array technology, a storage strategy can be built in order to offer the best defence against catastrophic disk failures.

Recommendation
From experience it is highly recommended to use a backup (preferably different from those used by RAID system).

6.4.3 HDD off-line

For HDD off-line, a study made by a manufacturer and university advocates the use of accelerated aging methods (temperature-humidity relationship) to select RHDD. According to this study and the specifications given by the “RDX Storage Alliance”, the failure rate is only 1 % for 30 years.

Analysis of data from an accelerated life test predicts that, if data are written on 160 GB RDX removable hard drive cartridges based on 2,5 in laptop disk technology, and if cartridges are then stored in realistic conditions for 30 years, more than 99 % of the drives will then read their entire content with no errors. A small sample of 3,5 in CSS drives included in the test demonstrated much lower data retention.

See Reference [54].

Recommendation
In case of HDD off line, in addition to the necessary redundancy, it will first select the candidates with structurally a potentially longest life (by using accelerated aging tests) and also to organize a test periodic (at least annual) consisting of read access. An effective archival protection strategy should address these attributes including the following: — Multiple replicas of archived data; more replicas will mean greater protection; — Periodic start up and exercise of mostly non-operating hard disk drives to redistribute mechanical lubricants; — Periodic migration of data to current media and systems to prevent bit rot and system obsolescence; — Storage of archival media in controlled temperature and humidity environments to minimize bit rot and disk corrosion.

6.5 Control tools

6.5.1 Self-monitoring analysis and reporting technology (SMART)

This system is installed on HDDs to get information on mechanical and electrical components. The fundamental principle behind SMART is that many problems with hard disks don’t occur suddenly. They result from a slow degradation of various mechanical or electronic components. SMART evolved from a technology developed by IBM called Predictive Failure Analysis or PFA. PFA divides failures into two categories: those that can be predicted and those that cannot. The exact characteristics monitored depend on the particular manufacturer and model (see Annex B).

6.5.2 RAID monitoring tools

For a discussion, see A.3.

7 Magnetic tape

7.1 General

Recording technologies	Media width
Linear	¼ in
Linear	½ in
Linear	8 mm
Helical-scan	4 mm
Helical-scan	8 mm

NOTE The most widely used is ½ in linear tape.

7.2 Reasons for failure

7.2.1 Physical media degradation

7.2.1.1 General

The components of magnetic tape which affect the stability of the media include a substrate layer, magnetic particles, binder layer (which can contain a lubricant), and possibly backcoat layer.

7.2.1.2 Substrate layer

Very thin layer of polyester with mechanical weakness.

7.2.1.3 Magnetic particles or pigments

Magnetic tapes can fail when there is a decrease in magnetic remanence or coercivity.

7.2.1.4 Binder layer

Binder deterioration is the most common cause of tape failure. The binder layer functions are to protect and hold magnetic particles in place.

Users note a continuous reduction of magnetic particles size (nano particles) and the extreme thinness of this ultra-thin layer thus more vulnerable to mechanical aggressions.

Binder systems are based on polyester polyurethanes. These polymers can be degraded by a process known as hydrolysis, where polyester linkage is broken by a reaction with water. One of the by-products of this degradation is organic acids which accelerate the rate of hydrolytic decomposition. Furthermore, the acids can attack and degrade the magnetic particles.

The degree of hydrolysis of a tape binder system is a critical property that can determine the lifetime of a magnetic tape.

7.2.2 Media playback obsolescence

Each generation of tape drives and media can be viable for four years to six years, after which it is essential to migrate the data.

7.2.3 Blocking

This is the sticking together or adhesion of successive windings in a tape pack. Blocking can result from binder deterioration when tape reels are stored at high temperature and humidity, and/or excessive tape pack stresses.

7.2.4 Curvature error

Changes in track shape that result in a bowed or S-shaped track. This becomes a problem if the playback head is not able to follow the track closely enough to capture the information.

See Reference [55].

7.3 Quality indicators

Example quality indicators are the following:

— mechanical properties (headers, web tension);

— tribological properties of tape;

— features magnetic tapes;

— signal/noise and waveform (record, play);

— error rate (N.B. cycles record/read).

7.4 Technical arrangements

7.4.1 Storage and handling

ISO 18923 and ISO 18933 address the issues of physical integrity of the medium necessary to preserve access to the recorded data (information). Included are recommendations for handling procedures to maximize the effective life of tapes. Faulty handling, packing, and transporting techniques and methods often cause physical damage to the tapes and to the content recorded there on.

7.4.2 Removal of magnetic tapes from archival storage

Tapes cannot be removed from storage and immediately played on a recorder. Time shall be allowed for tapes and recorder in order to equilibrate temperature and humidity environment prior playback processing.

7.4.3 Refreshing of tapes

In order to maximize their useful life, tapes can require periodic refreshing.

Refreshing should not be confused with restoration. It is a preventative maintenance procedure.

Recommendation
The International Association of Sound and Audiovisual Archives recommend a refreshment cycle of three to five years for magnetic tape media and drive replacement every one to five years.

7.4.4 Cleanliness

Cleanliness is important because minute debris can cause loss of reproduced signal by disturbing the intimate contact necessary between the tape surface and the reproducing head.

7.4.5 Periodic rewinding

For long-term storage, it is helpful to rewind tapes at an interval of not more than three years.

7.4.6 Estimation of magnetic tape life expectancies (LEs)

There is no recent study about lifespan of current tapes (LTO, T10000, etc.). However, if one takes into account the contributions of the study, magnetic tapes can be selected using a method in accelerated aging in temperature and humidity.[56]

The test conditions have to be determined with manufacturers.

7.5 Control tools

Reporting software on backup process have been developed, but these programs focus more on the analysis of backup process ensuring compliance. Devoted to quality, software has also been developed using two different approaches.

— Monitoring "In-Band": Analysis made during the use of the tape with diagnostic equipment (drivers and software) installed on reader/recorder device.

— Approach "Out of Band" used by some manufacturers: Analysis from readings collected during use of the tape and transmitted to the cartridge memory (memory chip). A device (cartridge memory analyser) can then collects and upload data on the system in order to establish a diagnosis of driver, tape and data.

8 Solid state drive (SDD), flash memory

8.1 General

Flash memory is non-volatile memory that can be erased and reprogrammed in units of memory called blocks. Flash memory chips store data in a large array of "*floating gate metal–oxide–semiconductor (MOS) transistors*" Silicon wafers are manufactured with microscopic transistor dimension, now approaching 40 nanometers.

Solid state drive is a term that refers to electronic circuitry built entirely out of semiconductors. The primary storage medium is through semiconductors. Solid state drives do not contain moving parts and retain data in non-volatile memory chips.

NOR and NAND technologies dominate today's flash memory market.

— NOR is cost effective in low-capacity data storage, and delivers high read performance. A feature of NOR is eXecute In Place (XIP), which allows an application to be run directly from flash instead of reading the application code into system RAM.

— NAND is an ideal solution for high-capacity data storage. Its architecture competes by offering extremely high cell densities that translate to high storage capacity, combined with fast write and erase rates. The block cell size of NAND flash is almost half the size of a NOR block cell.

Flash memory is susceptible to wear due to repeated program and erased cycles. Constantly programming and erasing to the same memory location eventually wears that portion of memory out and makes it invalid. To prevent it, special algorithms are deployed within the SSD called Wear Levelling.

8.2 Reasons for failure

Flash memory reliability

Major reliability concerns for flash memory technologies are endurance, data retention, bit flipping, and bad block handling. The reliability of flash memory decreases during use. The wear phenomenon occurs for a finite number of entries: 10^4 to 10^5, it depends upon the following:

— quality of the oxide;

— cell size;

— cell type: 1 bit (SLC) or more (MLC);

— cycle number of erasures and rewrites;

— number of readings.

The system includes a flash memory [Flash translation layer (FTL)] which aims to optimize endurance and speed: it manages the physical addresses (areas), the deletes, wear levelling, and the treatment of defective areas.

8.3 Quality indicators

8.3.1 Long-term data endurance (LDE)

To the end user, the SSD is a system. What is needed is an endurance specification for the system as a whole, a single, simple "indicator" that everyone can use. The goal of the endurance test is to find the right mix of workloads and then run it against different devices to measure their overall endurance.

Manufacturer proposes to define "Long-term data endurance (LDE)" as based on the total number of GBs written over an SSD's "nominal" lifetime.

See Reference [57].

Recommendation
LDE can be considered as a part of specifications which necessarily communicate with the concerned product.

Service Life time Estimation for the SLC NAND flash, P/E cycle endurance is approximately 100 000 cycles, as opposed to MLC which is only 10 000 cycles.

See Reference [42].

8.3.2 Highly accelerated stress screening (HASS)

Typically, these tests stress the under test with application of vibration, heat, cold, and temperature gradients.

Recommendation
At a minimum, test results data retention and HASS should be accessible to users and have to be associated with the identification of manufacturing.

8.4 Technical arrangements

8.4.1 Wear levelling

This is a technique used for prolonging the service life of some kind of flash memory systems. It involves the writing of data to different flash memory locations to evenly distribute the wear on the cells to ensure durability and consistent performance.

There are two levels of wear levelling, dynamic and static.

— Distribution of writings on all blocks (dynamic phase);

— Balancing the case of use of the blocks (static phase).

8.4.2 Sparing

Spare blocks are provided to replace blocks that have failed, extending the life of a SSD.

8.4.3 Over-provisioning

To create a new block that can accept new writes, one or more old blocks are selected for erasure. However, before a selected block can be erased, any valid data that it holds should first be read, combined with valid data from other selected blocks, and then written elsewhere (garbage collection).

8.4.4 Write caching

By storing write data in non-flash cache memory, many flash writes can be eliminated.

8.4.5 Bad block management

This can take a number of forms:

— A program to search bad blocks on a device;

— A program to test storage devices for bad blocks (on HDD: bad sector);

— An algorithm that monitors and maintains bad blocks within the NAND device. The controller maintains tables of known bad blocks and can replace them with spare blocks reserved for use.

The system includes a flash memory [flash translation layer (FTL)] which aims to optimize endurance and speed: it manages the physical addresses (areas), the deletes, wear levelling, and the treatment of defective areas.

8.4.6 Data retention

Several manufacturers use a method of accelerated aging temperature and Arrhenius relationship to estimate SSD's lifetime. A typical resulting value is 10 years to 20 years.

See Reference [58].

NOTE Some solid state drives have been found to exhibit spontaneous irreversible data erasure.

See Reference [60].

8.5 Control tools

Manufacturer specification and device qualification review.

Test and validate device specification:

— Write endurance;

— Write and read disturb;

— Data retention;

— MTBF prediction;

— HASS, highly accelerated stress screening;

— Accelerated life test.

See Reference [59].

9 Optical discs (recordable and rewritable)

9.1 General

In the category of optical discs, there are write-once-recordable types and rewritable types for CD, DVD, and BD. WORM technology (write-once-read-many) is a write-once-recordable type disc and is critical to ensure the authenticity of the information and is the primary solution for archiving. These products also avoid accidental alteration.

Generally, a technology obsolescence of playback equipment precedes the physical degradation of the storage media itself. Optical disc technology, however, has not followed this trend, as they are the formats standardized by the international standards (CD-R: ISO/IEC 10149, DVD-R: ISO/IEC 23912:2005, DVD+R ISO/IEC 17344:2006). CD-R and its drive were developed more than 20 years ago and the playback infrastructure has widely spread.

Significant longevity variations exist from different manufacturers and can exists between production lots at the same manufacturer. Disc manufacturers carry out acceleration aging tests to estimate longevity. Manufactures claim that the lifetime of CD-R/DVD±R will be 70 years to 300 years based on these tests, however, some users encounter read-back problems in the shorter period.

In order to avoid this contradiction on archiving, this report suggests users to understand the failure sources and the measurements as well as to follow the relevant International Standards.

9.2 Reasons for failure

9.2.1 Failure phenomena in actual usage

A part of or all data files cannot be opened.

The drive tries reading many times and taking longer time to open files.

9.2.2 Environment failure sources

The data signals on the optical disc might be deteriorated or deformed due to humidity and temperature during long-term storage in such an extreme environment. Due to these, the error values were increased and reached to unrecoverable error threshold that the error correction decoder could not correct.

Due to mechanical or physical damages, scratches or dirt on the disc, or distortions of the tilt, laser beam during playback might not be accurately irradiated on to the disk and failed to focus tracking the signals.

9.3 Quality indicators

9.3.1 General

Optical discs are widely accepted and used by consumers. Errors caused by fine scratches or dirt on the recorded surface could be corrected by “error correction function” of the drives or players. This error correction function becomes more powerful as the capacity of disk becomes higher from CD to DVD or from DVD to BD.

Periodical checking of error rates is recommended for long-term preservation. The error rate of discs represents their conditions (=deterioration over time). The properly accepted safe level of the error rate is defined in ISO/IEC 29121.

9.3.2 Measurement parameters

The longevity of the recorded disc is mainly evaluated using block error rate of the disc.

Main error parameters for CD-R are called C1 (BLER) and Cu (E32); for DVD±R are PI SUM8 and POF; and for BD-R are RSER 10k, BEC, and UnCorr.

9.3.3 Measurement of longevity

9.3.3.1 CD

C1 (BLER) stands for block error rate, a measure of the average number of raw channel errors when reading or writing CD-type media. BLER is a measure of the number of data blocks per second that contain detectable errors at the input of the C1 decoder. BLER < 220

9.3.3.2 DVD

PIE stands for parity inner error. The number of error corrections made on incoming rows of data in the first pass of the decoder using the inner parity correction code. A row of an ECC Block that has at least 1 byte in error constitutes a PI error. PIE is measured over 8 ECC blocks.

In any 8 consecutive ECC Blocks the total number of PI errors before correction shall not exceed 280, also called as PI Sum 8 or PI8.

9.3.3.3 BD

RSER 10k stands for random symbol error rate. After burst errors elimination (when the length of consecutive erroneous bytes is ≥40 in a LDC block), is defined as number of erroneous average over 10 000 LDC blocks divided by the total number of bytes in those blocks.

BEC or BC stands for burst error count. Designate the number of burst errors (at least 40 bytes long) in each physical cluster. The number of burst error with length ≥bytes shall be less than 8.

9.3.4 Parameters for playback

9.3.4.1 CD

Cu (E32) stands for Error 32. This error is not correctable. E32 is number of errors that were not corrected at the third error correction circuit.

9.3.4.2 DVD

POF stands for parity outer fail. The decoder was unable to correct the data using the outer parity codes. It is measured over 1 ECC block.

9.3.4.3 BD

UnCorr stands for uncorrectable LDC code words. Indicate if there are any uncorrectable LDC code words in one physical cluster. Total number of uncorrectable code words shall be ≤0.

9.4 Technical arrangements

9.4.1 Storage and handling

The storage of discs used for long-term preservation should be under conditions (temperature and humidity) that are well controlled. ISO/IEC 29121:2013, Annex B specifies the recommended conditions for storage.

9.4.2 Actions to retrieve the information (playback)

Wipe away in radial direction when the disc contracted dirt or dust.

Use one player which is well-tuned and maintenance.

9.4.3 Actions to prevent future playback problems

It is ideal to use discs properly designed for long-term preservation, which are tested based on the test method of ISO/IEC 10995 and ISO/IEC 16963[1)], as well as the use of the well-tuned drive for the lowest occurrence of initial error rate possible.

9.4.4 Life time expectancy of optical discs

ISO/IEC 10995 and ISO/IEC 16963[1)] define the test method to estimate the life expectancy for the rateability of information stored on recordable or rewritable optical discs at ambient conditions. These International Standards set the accelerated aging test method at several stress conditions and calculation methodology to estimate the life expectancy of the disc at ambient condition.

9.5 Control tools

Initial recoding performance is the key to the discs with long-term storage. The initial recording characteristic is decided by the discs and drives used.

To use the disc that is designated to use well-selected raw materials for long-term storage and produced with consideration of minimizing the quality fluctuation in manufacturing and inspection process. The disc's longevity can be estimated by the method set by ISO/IEC 10995 and ISO/IEC 16963.

Use the drive that applies the best matched laser irradiation program to the disc. The drive has to be well maintained before the use.

The quality of information stored in the disc can be monitored by evaluating error rates after the initial recording and at periodic inspection.

ISO/IEC 29121 set the method of migration of information storage of DVDs. It defines parameters of initial recording performance and periodical performance test to evaluate the stage of aging and classify the capability of preservation of the disc.

The quality of optical disc can be evaluated by using an optical disc analyser. This device can check mechanical, optical, signal/marking, and data (error rate) properties.

9.5.1 Parameters of digital errors

— Random errors describing a distributed degradation: C1 (CD), PI8 (DVD), and RSER (BD)

— Incorrigible errors: Cu (CD), POF (DVD), and UnCorr (BD)

9.5.2 Parameters of HF signal

— Range and contrast pit/land

— Asymmetry

— Jitter

Two levels of control can be used: at least error rate and for further analysis parameters including jitter and servo HF are required.

1) To be published.

10 General requirements for long-term preservation

10.1 General

During a long-term retention (which is generally understood to be more than 50 years), storage media can be stressed by a number of factors that determine their reliability. It is also important to know the physical and electrical environment they are in.

Usually, four categories of stress can be listed.

— Climate environment (T° and H % variations and level)

— Shocks and vibrations

— Magnetics fields (for HDD and magnetic tape)

— Various radiations

Modelling failures are very difficult to develop because they are not independent and they originate from complex media that induce a combination of risks induced by the number, quality, and various use of components.

10.2 Media traceability

It is important to focus on media whose traceability is based on proven and contractual information. This can be in the form of individual identification number identifying the manufacturer (MID) and giving the manufacturer the ability to determine the place of manufacture, batch, and date of production.

This traceability needs to be guaranteed by the media manufacturer.

10.3 Optimal storage identification

The various factors that need to be taken into consideration when choosing storage solutions include the following:

— data access frequency;

— volume of data;

— frequency of data updates;

— required transfer rate;

— required access time.

10.4 Duplication of storage

Whatever medium is used, its durability and reliability are typically insufficient to avoid a redundancy of information. It is therefore recommended to duplicate information using different technologies (hardware and software) and use different storage locations.

Duplicate (often mirrored) storage solutions can also support business continuity arrangements, by enabling an alternate data store to be used when the main (primary) store is subject to failure.

10.5 Media stocktaking

In preparation for an incident, take stock the physical storage of a medium periodically. This stocktaking is useful for a check and the early recovery from the damaged situation regardless of analogue and digital.

10.6 Periodic inspection

It is important to implement periodic inspection of storage media, in order to identify trends and one-off incidents that can indicate the approaching end of life of storage media. Such inspections should include the following:

— continuous monitoring of the operation (e.g. alert if modifications of transfer speed or access time);

— testing of each new batch of media under the conditions of use, prior to live implementation;

— sampling of individual batches of storage media;

— assessment of alternate storage media;

— quality tests involve loading the media and checking the values of selected parameters.

The frequency of testing should be based on results obtained. Generally, annual testing can be considered for both media in use and unused media.

11 Selection of media

11.1 General

When selecting storage media for long-term preservation, in addition to the technology components already documented, these factors should be considered.

— Volume of information

— Size of individual items

— Retention period of the information

— Capacity of the media

— Technology already in use within the organization

— Retrieval and accessibility requirements

— Exposure to threats to media

— Costs

— Records management, regulatory, and discovery

— Technology refresh cycle/software migration

— Industry acceptance and maturity

11.2 Volume of information

Overall volume requirements can have a significant effect on chosen storage media. Small volumes can be stored on exchangeable media (typically optical media) whereas larger volumes can require magnetic tapes or fixed media (such as hard disk systems).

11.3 Size of individual items

Some documents, particularly where video content is involved, will create large digital files. Storage media should be chosen that will prevent individual items spanning multiple media.

Where this is not possible, then software that will enable multiple media spanning will need to be used.

11.4 Retention period of the information

Wherever possible, storage media should be chosen which has an operational life in excess of the retention period of the information that is to be stored. If this is not possible, then media migration projects will need to be implemented prior to the end of the life of the storage media.

Some media operates in a 'WORM' mode, such that individual documents cannot be deleted from the media. In such cases, it is important to store documents with the same retention period on each item of media.

When assessing the life of storage media, the limiting factor can often be the availability of suitable media read/write hardware and software. Even if some media can keep the digital data for a very long period check periodically the obsolescence risk of hardware and software.

Some storage media systems, particularly those based on hard disk technology, have facilities to exchange media (sometimes in a 'hot' mode) without the loss of stored content. Such systems effectively extend the life of the storage media and reduce the need for media migration processes to be implemented.

11.5 Capacity of the media

This factor should be linked to the volume of information to be stored. In order to limit the initial and operating costs of storage media systems, excessive storage capacity should be avoided.

Separately, sufficient capacity for the information to be stored, including anticipated additional information, should be provided.

11.6 Technology already in use within the organization

Unless there is a specific requirement for the use of new storage media systems, existing systems that have, or can be expanded to have, sufficient capacity should be used. Support for new media storage systems require additional expertise to be available, either within the organization or externally by the use of sub-contractors.

11.7 Retrieval and accessibility requirements

Storage media systems are available in three major types.

a) On-line

These systems store information on media that is immediately accessible to the IT system. For example, hard disk storage systems can retrieve information without human or mechanical intervention.

b) Near-line

These systems hold storage media in automated access systems. For example, individual optical discs can be held in a juke-box and magnetic tapes can be accessed automatically using robotics by the IT system.

c) Off-line

These systems require manual intervention to 'load' storage media onto the IT system. For example, optical disc media and USB storage devices are in this category.

The requirements for speed of access should dictate which of the storage systems is chosen for a particular application. Typically, on-line storage is used for current information, high volume requirements are managed using near-line systems (which are typically less expensive than on-line storage) and archival systems use off-line storage.

11.8 Exposure to threats to media

Storage media should be chosen, bearing in mind the existing climatic conditions, handling conditions, and storage facilities. Some types of storage media require a computer room environment in order to operate. Other types can be used in a variety of environments, ranging from general office to harsh conditions found in, for example, heavy engineering, chemical manufacturing, and transportation locations.

Where harsh environmental conditions will be encountered, special hardware is often available to ensure reliable access to information.

Where removable storage media is used, storage conditions advised by the manufacturers should be used where possible.

Where appropriate, storage media should be stored in fireproof containers.

11.9 Costs

The costs (usually expressed as cost per MB) associated with the procurement and management of the storage media should be taken into account. Where possible, costs should be estimated over the whole storage life of the information concerned.

When estimating cost of storage, both initial and running costs should be taken into account. So, for example, hard disk technology can be cost effective in terms of capital cost, but running costs (e.g. electricity to spin the disks, cooling requirements, and routine replacements) can be high when compared to other storage technology.

11.10 Records management, regulatory, and discovery

The majority of the information stored will be subject to legislative, regulatory, and/or business requirements in terms of retention periods and the amount and type of information stored. These requirements should be considered when deciding upon storage media requirements.

As an example of this requirement, some information stored by an organization will have significant value to that organization. It can be appropriate to store this information on storage media that can be used in a system that can demonstrate that the authenticity of the stored information has not been compromised (see ISO/TR 15801). While such systems might not be the most cost effective to operate, the potential cost of e-discovery and litigation should the information be required as evidence could result in a better solution.

11.11 Technology refresh cycle/software migration

Organizations should have a policy for refreshing storage technology and operational software prior to the respective end of life. Such a policy will reduce the risk of system failure due to the use of old systems that are no longer supported.

When sourcing new storage solutions, an overall review of corporate requirements should be undertaken prior to a decision being taken. Such a review should include a risk assessment based on cost, reliability and longevity of the chosen and alternate solutions.

11.12 Industry acceptance and maturity

When researching storage systems, care should be taken with technology that does not have a proven track record. While new systems can be attractive in terms of speed and efficiency, cost, and reliability can be uncertain.

Annex A
(informative)

RAID

A.1 RAID = Redundant Array of Independent Disks

Table A.1 — RAID level comparison

Features	RAID 0	RAID 1	RAID 1E	RAID 5	RAID 5EE	RAID 6	RAID 10	RAID 50	RAID 60
Minimum number of drives	2	2	3	3	4	4	4	6	8
Data protection	No protection	One-drive failure	One-drive failure	One-drive failure	One-drive failure	Two-drive failure	Up to one-disk failure in each sub-array	Up to one-disk failure in each sub-array	Up to two-disk failure in each sub-array
Read performance	High	High	High	High	High	High	High	High	High
Write performance	High	Medium	Medium	Low	Low	Low	Medium	Medium	Medium
Read performance (degraded)	N/A	Medium	High	Low	Low	Low	High	Medium	Medium
Write performance (degraded)	N/A	High	High	Low	Low	Low	High	Medium	Low
Capacity utilization	100 %	50 %	50 %	67 % to 94 %	50 % to 88 %	50 % to 88 %	50 %	67 % to 94 %	50 % to 88 %
Typical application	High-end worksta-tions, data log-ging, real-time rendering, very transitory data	Operating system, transac-tion data-bases	Operating system, transac-tion data-bases	Data ware-house, Web serving, archiving	Data ware-house, Web serving, archiving	Data archive, backup-to-disk high-avail-ability solutions	Fast databases, applica-tion serv-ers	Large databases, file serv-ers, appli-cation servers	Data archive, backup-to-disk, high-avail-ability solutions,
Note: Source — ADAPTEC.									

A.2 RAID selection

Hard drives are available today with capacities far greater than when RAID concept was invented. Despite the increase of capacity, disk reliability has not improved, and what is more important, the probability of a bit error is increased in equal proportion to the capacity of the media. These three factors decrease the capability of a RAID to protect data.

RAID cannot protect data beyond the redundancy of different stacks of disks (for example: one failed disk for RAID-1, RAID-10 and RAID-5 and two failed disks for a RAID-6 stack).