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Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections - Strategies and Alternatives

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Executive summary

Ever since their appearance on the market in the early 1990s, recordable compacts discs (CD-Rs), later recordable DVDs and now recordable blue laser discs formats have been used as storage media not only for private purposes, but also for the storage of digitised or born-digital documents in archives and libraries. The attraction to employ these recording media lies in their easy availability and, most importantly, in the low prices of media and recording/replay equipment.

The use of CD and DVD recordable discs in archives and libraries has soon raised concerns as to their reliability as storage media. Most of these concerns have focussed on the issue of life expectancy of the media themselves, concluding that different types of dyes, recording substrates, and reflective layers behave differently. The problem, however, is more complex. The quality of the recorded digital signal is an important factor of life expectancy. This quality, however, relies on the interaction of the individual burner, the medium, and the individual player. As burners and players are not standardised, the data quality and life expectancy is to some extent unpredictable. Unless the data quality is systematically tested using reliable professional testers the quality of the content is unknown and consequently at risk. Testing is possible; however, reliable testing is time consuming, dependant on manual systems and in need of expensive test equipment.

While recordable optical discs are viable tools in the access to and dissemination of digital information of all kinds, it is strongly recommended that professional data storage methods, as developed by the IT industry, should be used. All digital carriers are to some extent unreliable, however, data tape and hard disc systems are made reliable because technological testing, copying and management systems are implemented to support the data carrier and the quality of its content, maintain and manage the integrity of the data. These systems are feasible for storing critical data even under climatically and financially sub-optimal conditions. No viable automatic testing and management system exists to make optical disc reliable, and consequently any archival use of optical systems must depend on a manual approach using people and testing equipment as described in this publication.

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Preface

Ever since its introduction in the early 1990s the recordable CD (CD-R) - and later the recordable DVD - has been attractive to archivists, librarians and curators of museum collections as a digital preservation target media. This view was supported by optimistic claims from some optical disc manufactures about the longevity of their products. Relatively low prices for blank media and recorders made recordable optical discs a widely used target media not only in small but also in larger institutions world wide. CD-Rs were used in a great number of digitisation projects, not only for audio recordings, but also to keep image files of manuscripts and rare books, photographic collections and photographs of museum objects. No catastrophic failure of the technology was reported in those early days, which may have encouraged the further use in blind faith.

Around 2000, however, when the race to ever higher recording speeds was fully developed, sound archives started to take a more critical look at these media. For these archives, digitisation is an indispensable tool for the preservation of their highly endangered analogue originals. This is different to the use that CD-R is put by the many projects outside the sound archives' world. In these other areas, digitisation was aimed at supporting access to documents or objects which, generally, were not at risk and are still preserved in their original form. Concerns about the reliability of recordable CDs and DVDs were also supported by an increasing number of reports of discs failing at the time of their production.

The Memory of the World Sub-Committee on Technology joined forces with the IASA Technical Committee for the first time in June 2002 by inviting manufacturers of recordable CDs to the UNESCO headquarters in Paris to discuss the problems faced by archival users of their products. While the representatives of manufacturers expressed sympathy with the concerns of the archivists, and while several products have been marketed since which attempt to optimise their longevity, the principle problem remained unsolved. As this publication explains, the problem can only be resolved by the adoption of standards for blank media and writers which aim to optimise the reliability and longevity of the recorded media. It is possible, however, to use recordable optical discs as reliable storage media even before this agreement is reached. It requires the application of a stringent procedure of testing and selecting of both the blank discs and the recording devices. Such testing is time consuming and requires expensive test equipment.

This publication does not discourage the use of recordable optical media. It does explain, however, the complexity of the recording process and the risks associated with the use of the optical discs as the sole recording media for long-term preservation. These media will retain their indispensable role in the dissemination of and access to audiovisual and general data contents. By pointing to professional digital storage technology, which has already become affordable, even for the many grossly under-funded institutions, an alternative method for organising reliable long-term preservation of digital data is suggested to the many small institutions.

This publication could, on the other hand, trigger a development which, by means of co-operation between manufacturers of media and writers, bring about a set of standards which, when implemented, would render recordable optical discs a safe archival medium without the need for elaborate and costly test procedures. Perhaps the introduction of blue laser technology and of related recordable media would be an appropriate moment for such development.

The Sub-Committee on Technology will continue to monitor the issue and inform the archival community of new relevant development, as appropriate.

Though this publication contains much new material, it draws extensively on the advice given in IASA-TC 04, *Guidelines on the Production and Preservation of Digital Audio Objects*, K. Bradley (ed.) (2004) but renders it in a less audio-specific form that is more suitable for general data storage. In TC 04, the primary author for the section on CD as a target media - the main topic of this publication - was Lars Gaustad, Chair of the IASA Technical Committee, and for the replay of CD media the primary authors were Albrecht Häfner and Mathew Davies. Their contribution to this work is gratefully acknowledged. The draft text was critically reviewed by the IASA Technical Committee.

The Memory of the World Sub-Committee on Technology expresses its gratitude to the IASA Technical Committee and, in particular, to Kevin Bradley as author for the excellent co-operation in considerably advancing knowledge and advice in the field of digital preservation well beyond the boundaries of audiovisual archives.

June 2006

Dietrich Schüller
Chair, Sub-Committee on Technology

Introduction

The Compact Disc (CD) was initially developed as a device for the storage and replay of digitally encoded audio. However, not long after the music buying public had accepted the new format an additional, and eventually more extensive, role for the CD appeared. Computer software developers began writing larger computer applications that exceeded the storage capacity of the then commonly used floppy disc and CD became a standard exchange format. This requirement for a high capacity, commercially replicable carrier of data led to the enhancement of the capabilities of the audio CD so that it could be used to carry other types of data. The invention of recordable and rewritable CDs and later, DVDs[1], made a convenient format available in a recordable form, allowing users to store their own data and thereby democratising to some extent the process of writing, sharing and distributing data.

Though the CD and DVD are now only one of many types of more affordable and reliable storage technologies, the format remains popular for many reasons, amongst them their ease of use and common familiarity. The CD was initially marketed as the perfect permanent carrier, but this was soon shown not to be the case when many of the early discs failed. Even though subsequent technological development has improved on many of the early manufacturing faults no credible claim can be made to permanence. In fact, digital archiving experts commonly acknowledge that no carrier is permanent[2]. Instead, the processes of acquiring data, transferring to storage systems and managing and maintaining the data, and providing access and ensuring the integrity of the stored information, presents a new range of risks that must be managed to ensure that the benefits of digital preservation and archiving are realised. Failure to manage these risks appropriately may result in significant loss of data value and content.

Recordable CDs and DVDs are often chosen as archival carriers, however, the risk of failure of a storage system based on this type technology is high when compared to other approaches. An integrated digital mass storage system with suitable digital repository management software is recognised as the most appropriate for the long term sustainability of data. Such systems permit automatic checking of data integrity, refreshment, identification, retrieval and finally, migration with a minimum need for human intervention. Coupled with appropriate repository software, these systems provide direct management of the digital content and the associated metadata, including the structural, technical, descriptive, and preservation metadata necessary to the reliable retention of the digital content.

The low system complexity, easy availability of technology, and inexpensive hardware and media makes the recordable and rewritable CD and DVD a popular option with archives. The cost of a more reliable data storage system, however, could

[1]DVD was originally an acronym for Digital Video Disc, then Digital Versatile Disc but is now officially used without referring to a specific set of words.

[2] Most digital preservation experts recognise file format obsolescence as the major risk to gaining access to the meaning encoded in a file or dataset. However, unless the byte stream is retained on a reliable carrier, no content will available to be accessed. For this reason the concern with carriers is critical to the issue of sustainable digital storage. The UNESCO Guidelines for the Preservation of Digital Heritage (Webb) contain advice on the management of digital content.

be less even for quite small holdings, if averaged across the entire collection. There are, however, occasions where a collection manager may still choose to use a discrete optical media such as recordable CD or DVD. While recommending the use of a more reliable integrated digital storage system, this document provides guidance on managing data on recordable CD and DVD in digital library and archive collections.[3]

Purpose

The purpose of this document is to provide detailed guidance on managing the risks associated with storing archival data on recordable CD and DVD. This document addresses what appears to be a gap in the literature of archival data management; that is the identification of the risk of failure in recordable CD and DVD. It recommends a strategy to reduce that risk through error measurement and appropriate management. Some limited advice regarding storage and handling is also provided in this document.

This document also seeks to address the common misconception that recordable CD or DVD is a permanent media. No storage media is a permanent solution to the issue of digital preservation, and no technological development will ever provide the ultimate solution; rather they are a step in a process whereby institutions will be responsible for maintaining data through technological changes and developments, migrating data from the current system to next for as long as the data remains valuable. It is ultimately the archiving institution or individuals who are responsible for making digital information sustainable. The technology is merely a tool, a link in the chain that makes for sustainable digital preservation.

Though media failure is an issue for concern, the other major factor in this process of change and migration will be format obsolescence, where the manufacturers of equipment no longer support the technology, which as a consequence means the data can no longer be read and understood. This inevitable scenario will lead to a requirement that the data must be copied to a new carrier. This guidance document also provides advice on the accurate and efficient copying of CD and DVD optical disc media to other recordable discs or to more permanent storage systems when that becomes necessary.

To this end, the advice given in this guidance document is divided into three parts: the description of Recordable CD and DVD when used as target storage formats, advice on care, handling, testing and analysis, storage and copying procedures, and advice on duplicating CDs and DVDs. Developing or upcoming versions of recordable optical discs (double layer recordable DVD, Blu Ray etc) are not included in this publication.

While it is the aim of this publication to alert archivists on the risks related to the use of recordable optical disks, and to describe approaches that reduce that risk, it is recommended that more professional and reliable storage approaches be used if at all

[3] IASA-TC 04, *Guidelines on the Production and Preservation of Digital Audio Objects* K. Bradley ed (2004). provides information on audio archiving and other more generally applicable approaches to archival storage, and should be consulted. An order form for the Guidelines is available at the IASA web site http://www.iasa-web.org. Please note that meanwhile available or upcoming versions of recordable optical discs (double layer recordable DVD, Blu Ray etc) are not discussed in detail in either publication.

possible. Integrated digital mass storage systems are more reliable if good archival practice is applied to their installation and operation.

Recordable CD and DVD as Target Storage Formats

Since their introduction in 1982 the replicated optical disc family (CD-ROM, DVD-ROM) has become the dominant technology for distribution of published software, games and audio and video recordings. Recordable optical disc[4] formats were first made available in the late 1980s[5] and though other technologies continue to appear, they still play a significant role in the distribution and storage of digital data. In their recordable form, the easy availability and low set up costs have made them attractive to many small and not so small collections. However, the successful management of a digital archive on CD-R or DVD-/+R requires significant investment in knowledge and technology in order to garner reliable service from them, well beyond that which is required for producing the discs. As stated above, a recordable optical disc of any type is not a permanent solution. Carrier decay and format obsolescence will require that the content of the disc be migrated to another format in the near future.

Bearing in mind these constraints, it is possible to use recordable optical discs as reliable carriers for a limited period of time providing standards and guidelines such as those presented here are carefully adhered to.

The CD and DVD Family

The CD[6] family may include CD-ROM, CD-R, CD-RW, all characterised by a 780nm wavelength laser. DVD media is characterised by blue laser around 350 to 450nm for glass mastering and 635-650nm playback, DVD+R has a laser with a wavelength of 650nm both for authoring and playback and DVD-R has a laser with a wavelength of 635nm laser for authoring and 650nm for playback.

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[4] According to the Oxford English Dictionary, disc may be spelt correctly as either disk or disc. The IASA TC04 guidelines, in an effort to distinguish between an analogue disc, which is the source of much of its content, and the digital storage disk, which is the target, implemented the rather unorthodox approach of spelling the source carrier as disc and the target carrier as disk. However, as CD Compact Disc was patented with the "c" spelling, and this document's subject matter is the optical disc, of which CD is the most common example, disc is spelt with a "c" throughout.

[5] The first working CD-R system, Yamaha's PDS (Programmable Disc System), was launched in 1988

[6] With regards to various the suffixes of optical disc, this document follows the consistent terminology which has more recently developed and which has been adopted in ISO and other standards:
- ROM (read only memory) is used for discs mass replicated by injection moulding from metal master.
-R (or +R) is used for once-recordable media, which make use of organic dyes ("dye discs")
-RW (or +RW) and RAM is used for discs that can be recorded, erased and newly recorded, making use of an metallic alloy film whose structure can be repeatedly changed between amorphous and crystalline ("phase change")
All three types of disc may contain audio or video streams or general data in file formats of any kind. Originally, the replicated (injection moulded) audio CD, carrying an audio data stream, which is not a file format, was supplemented by replicated CDs which held general data in various file formats. These have been originally called CD-ROMs. With the advent of recordable CDs, this terminology became confusing

Recordability, rewritability, erasability and accessibility

CD and DVD manufactured discs are pre-recorded (pressed and moulded) read-only discs. They are neither recordable nor erasable. CD-R, DVD-R and DVD+R discs are dye-based recordable (write once) discs, but not erasable. CD-RW, DVD-RW and DVD+RW discs are phase-change based repeatedly rewritable discs permitting erasure of earlier data and recording of new data in the same location on the disc. DVD-RAM discs are phase-change rewritable discs formatted for random access, much like a computer hard disc.

Recordable CD and DVD Description

CD-Rs and DVD-/+Rs store data in line with microscopic grooves running in a spiral from the centre of the disc to its periphery. All CD/DVD drive types use laser beams to scan these grooves. They differ in the wavelength of the laser beam: DVDs use a narrower track pitch of 0.74µm, compared to 1.6µm on CDs. DVD also takes advantage of new modulation and error correction methods not available when the CD was specified.

The mechanical dimension of CDs and DVDs are equal: 120mm in diameter, and 1.2 mm thick. The DVD, however, is made up of two discs of 0.6mm thickness, which are bonded together.

CD-R and DVD+R consist of three layers: the clear polycarbonate substrate, the dye layer and the reflective layer. In CD-R the reflective layer is close to the label side of the disc and an additional protective lacquer surface layer covers the fragile surface. DVD-Rs reflective layer is situated in the middle of two polycarbonate layers.

In the recording process, a laser of much higher intensity than the reading laser "burns" the organic dye according to the coded signal, leaving a row of minuscule transparent and non transparent areas aligned along grooves in the disc.

All recordable CDs and DVDs contain a reflective layer that allows a reading laser to bounce off the CD/DVD and to be "read" by the pickup sensor in the CD or DVD replay device. Many metals are suitable for use as a reflective layer, although only two have been in widespread use on recordable CD and DVD, gold or silver. The combination of the recorded dye groove with the reflective layer modulates the reading laser in the same way as the injection moulded pits and lands and the reflective aluminium layer of a CD-ROM.

The three common organic dyes used in recordable discs are cyanine, phthalocyanine and azo. In a recordable CD each dye gives the media its distinctive look depending on which metal is used for the reflective layer; cyanine (blue) dye appears green on gold media and blue on silver media; phthalocyanine (clear light green) dye appears transparent on gold media, but light green on silver media; azo (deep blue) has developed into different shades of blue, the original being a deep blue, and the more recent Super Azo a brighter shade of blue. Because the dye layer is applied so thinly in recordable DVD the type of dye used on recordable DVDs is not easily distinguishable. However, manufacturers of recordable CD and DVD encode information about the type of dye in the polycarbonate layer. The CD and DVD burners use this information to calibrate laser power, and with suitable software the information can be read by users to more accurately describe aspects of the disc itself. The type of software available to read this data is described in Appendix 4.

Recently, recordable dual layer DVDs have become available.

Rewritable CDs and DVDs operate on an entirely different principle. Rewritable discs are erasable and can be rewritten, albeit a finite number of times. The recordable layer is made of germanium, antimony and tellurium. A laser is used to heat the surface to two set temperatures. The higher temperature is known as the melting point (approximately 600 degrees centigrade), while the lower level temperature (approximately 350 degrees centigrade) is described as the crystallisation temperature. Heating the disc, and controlling the cooling rate, produces a track of amorphous or crystalline areas. Due to their different reflectivities, these areas will be interpreted by the reading laser like the pit/land structure of a CD-ROM.

Earlier rewritable discs and drives could only be written at relatively low speeds and this was encoded and implemented in the first generation of drives and standards. More recent developments have provided a mechanism for burning data onto rewritable discs at a higher speed. Though the older drives will read a new high speed rewritable disc, only the latest generation of disc burners will write a disc of the latest formulation.

Standards

Adherence to standards is the mechanism by which discs are writable or playable on different manufacturers' machines. The manufacturers have the responsibility to make the disc in accordance with the particular standards. These standards, however, are not formulated with regard to longevity or reliability of the carrier, but only format interchange. Consequently, a disc recorded and playable on a particular machine may in fact be borderline, or even fail to meet the standard that applies. So, although the manufacturers are responsible for the formulation of a disc, the potential life of any information storage media will only be realised if end users take responsibility for producing a suitable digital copy that falls within the parameters set by those standards. Relying on the technology to meet the standards is not sufficient to ensure optimum disc life.

This requirement to ensure that the digital information stored on an optical disc is produced in accordance with the standards is exemplified by the issue of disc and burner compatibility. The standards apply to the recording media rather than the replay and recording technology. Philips warns manufacturers of disc burners that they “must implement a writing strategy giving acceptable results”. However, this can be interpreted in a number of ways, resulting in varying compliance. Philips/Sony attempted to address this issues with the MID (manufacturers identification code). The nature of the production of recordable media means, however, that the only information MID really records is the name of the manufacturer of the stampers that are used in the production of discs. Consequently, it has done little to resolve the issue of disc/burner interaction, which remains something of a problem.

Disc and Drive Compatibility

Compatibility between discs and drives may well be an issue when recording data on recordable and rewritable CDs and DVDs. Situations often occur where certain discs produced on a particular drive may produce very poor quality duplicates, or may be unreadable on other drives. Testing of this issue has revealed that this failure rate may be very high. An International Standards Organisation project- *ISO N178 Electronic imaging — Classification and verification of information stored on optical media*, may address the specific problem of drive compatibility.

The reason for poor performance may be related to a number of factors: Early drives do not have the laser power to calibrate on later types of discs; Drives designed for dye based discs cannot write, and often cannot read, rewritable discs; Software issues, aging parts, particularly lasers, and particular implementations may all produce inadequate results; The calibration information encoded into the polycarbonate substrate may not necessarily be precisely accurate. However, even taking these issues into account, a significant number of failures occur which are only explained as technical incompatibilities. The equipment manufacturers' slightly varied implementation of the disc read standard and the variation in the discs quality mean that a situation can occur where discs and drives are incompatible to the extent that the particular combination may produce failed discs on a particular brand, or batch, of discs.

In order to ensure that drives and discs are compatible, it is recommended that a range of brands of reliable and reputable discs are recorded on the selected drive, and these discs are tested to determine error levels. Each of these is discussed in the sections below.

Recording Reliable Data on a Recordable CD or DVD

Writing data to a recordable disc can produce very varied results. Each component in the chain, and the interaction between each of the components, can affect the outcome. The success or otherwise of recording data onto a CD or DVD can be decided objectively by measuring the resultant error level. Error measurement is a critical part of producing reliable data on a recordable disc. The fact that the data is able to be read, as assessed by "verification", is not sufficient indication on its own because a disc with a high level of errors can sometimes still be read, but is very likely to fail soon after.

The components in the chain for writing data to optical disc are, the blank disc, the computer and software, the disc burner and the testing equipment.

Disc Selection.

There are three basic types of dye used on write once recordable discs, phthalocyanine, cyanine, and azo. Manufacturers of phthalocyanine discs claim a longer life for their product than the competitors. Some, though not all initial testing supports this view. Some manufacturers use Azo dyes in discs that they claim are archival. Cyanine was the first dye type developed for optical disc recording, and is generally recognised by most manufacturers as having a shorter life expectancy (LE). Dye type, though significant, is only one of the factors determining the life of the media.

The variation in the amount of dye used in the dye layer, a result of the manufacturers' race for even higher recording speeds and higher density recording, is a contributing factor in the long term failure of recordable optical media. Recording speed has increased from X1 to X52 and is still rising, as the recording density has gone from 650MB to 800MB for CD-Rs. It should be noted that discs optimised for high speed recording use less dye, which may indicate a shorter life expectancy. DVD-R uses less dye as a matter of course, as the data rate when writing to a recordable DVD is much higher than for CD-R.

It is not, however, just a matter of reducing speed; if discs with a denser dye layer, optimised for writing at lower speeds, are written at higher speeds, they deliver a worse error rate. Though manufacturers indicate the maximum recording speed, writing at that maximum speed may not achieve adequate results. There is an optimum writing speed at which the disc produced obtains the best possible technical measurement for performance. Identifying this speed is best done by trial and error measurement using a reliable disc tester. Typically, the best results will be achieved on a dense dye layer disk written at around 8 times speed.

At best, the quality of blank recordable CD and DVD media can be described as variable. The recordable CD and DVD- manufacturing industry has become a market place driven by narrow profit margins and large quantities. Recordable CD and DVD manufacturing equipment has become smaller, cheaper and more self-contained. As a consequence, the production of reliable data carriers for the quality market has largely been replaced by manufacturers of recordable CD and DVD, producing recordable CD and DVD for the low cost market.

Many discs that appear to be reputable brands may turn out to have been manufactured by a second party and repackaged for sale. A recordable CD or DVD manufacturer can manipulate the dye, reflective layer and the now expensive polycarbonate components to reduce price or control quality.

As a general rule it has often been recommended that only reliable brand recordable CD and DVD are purchased, however, testing has revealed a range of compliance with agreed standards even amongst them. Instead, it is recommended that the responsible individual or institution insist on dealing with a supplier that is open about the importer or manufacturer they deal with, and who is able to provide contact with the relevant technical personnel in the manufacturing company. Discs that fail the standard specified below should be returned.

It is quite difficult to identify the best quality media without high level analysers (Slattery et al., 2004). In most practical circumstances discs must be recorded before they can be tested. Some very high quality CD and DVD testing equipment will analyse an unrecorded disc, but most testing is carried out by recording a test signal and analysing the result. ISO 18925:2002, AES 28-1997, or ANSI/NAPM IT9.21 is a standard test method to establish the life expectancy of compact discs, and ISO 18927:2002/AES 38-2000 is a standard for estimating method for estimating the life expectancy based on the effects of temperature and relative humidity for recordable compact disc systems. As temperature and humidity aging does not always produce clear results, other approaches have concerned themselves with the susceptibility of recordable dye based discs to light exposure with age, and some manufacturers have undertaken testing in this area. There is, however, no standard for this (Slattery et al., 2004).

Summary of Disc Selection

- *Purchase a range of best quality discs, based on market research. Purchase more than one of each type. (Though price is not necessarily an indicator, always remember that the cost of even the most expensive discs is small compared to the value of the data.)*
- *Under controlled conditions record some data on each of the discs.*
- *Test to see which discs perform best with regard to specification in this document. All discs must exceed the recommended quality standards recommended below (see Table 1, Maximum error levels in an archival CD-R).*
- *Test at a number of different writing speeds.*
- *Keep disc/burner compatibility in mind: different burners may yield different results.*
- *Choose the three best discs, from at least two dye types (phthalocyanine and azo).*
- *Record identical copies of the data on the three chosen discs.*
- *Ensure that delivered supplies of chosen discs are identical with tested sample discs*
- *Repeat tests each time a batch of discs are purchased*

Computer, Software and Recording Devices.

Almost all recent computer systems are capable of writing to a recordable DVD or CD. Most writing devices come bundled with appropriate software. As with all such purchases, choose reliable well known equipment using appropriate market research. Even allowing for variations in technology, there are many variables in the process of writing a disc.

The recording phase is the most important and sensitive part in the life cycle of a recordable CD/DVD. Anything that may influence the laser beam on its way to the dye layer may cause an error. So the need for a clean environment and cautious handling is essential. Even in a clean environment blank media should be blown clean with laboratory standard clean air prior to writing. Pressurised cans of clean air can be purchased for this purpose.

It is necessary to acclimatise the disc prior to recording so as to avoid an uncontrolled thermic calibration of the laser that may interrupt the dataflow. This calls for air-conditioning or reasonable airflow around the equipment. Discs, which may be stored in cool conditions to extend their life, should be left in the same environment as the recording equipment to acclimatise prior to writing. Computers and other equipment should be preferably installed under climate controlled conditions, or at least with adequate ventilation.

Interruptions in the dataflow (buffer underrun) can lead to failure in writing discs. Buffer underruns may be caused by factors such as fragmented file structure in which the data to be written to the recordable disc is located in a number of places on the hard disc. Automated computer background activities, such as screensavers, mail checks and the like, may also cause interruptions to the data flow. All programs that have the potential to cause interruptions to the data flow should be turned off.

As is strongly and constantly stated in this document, always test discs to ensure that recorded discs meet the required standards. Testing is a mandatory part of storing data on a recordable disc. However, it is possible to write a disc where the data is corrupted and yet the error levels do not indicate this loss of data integrity. This risk can be managed by verifying the discs on completion of the writing. Verification is the process by which the recorded file is compared to the original data from which it was taken. Data verification is a measure by which a successful write can be assessed. An error test will not necessarily reveal incomplete data, and verification will not reveal data and disc condition; both are necessary.

Multiple Copies of Optical Discs

It is necessary to create redundant copies of stored digital data. The integrity of all digital data is maintained by the production of what is termed redundant data, but which is clearly anything but redundant if the reliability of the data is important. At least three copies of each optical disc should be kept, one MASTER, stored under optimal conditions, one WORKING copy to be used for access purposes or copying, and one SAFETY copy to be stored at a different location. Providing suitable media is available, the MASTER and the SAFETY copy should be recorded on discs from two different producers. This is especially the case if CD-Rs or DVD-Rs are the target media, as these differ in reflective layer, dye formulation and other critical components. Such a strategy mitigates the risk associated with a particular formulation.

Summary of Writing Procedures

- *Defragment the hard disc – files scattered around your hard disc may cause buffer underrun.*
- *Make a dedicated partition on the hard disc for files to be recorded.*

- *Make an image of the catalogue to be recorded on the partition. Partition size will be dependent on whether CD-Rs or DVD-Rs are being used. This will reduce the need for defragmentation in between recording sessions.*
- *Make sure there is room for selected data on the carrier.*
- *Always use mono-session process (=Disc At Once – DAO).*
- *Close all other applications such as screensaver, autosave, mail check etc., and make sure the only active application running is the software needed for recording.*
- *Use burning software that verifies correct results.*
- *Test your newly recorded discs. If a CD test program is beyond budget, choose a different storage medium.*
- *Undertake the recording process three times to produce safety and master discs.*

Errors, Life Expectancy and Testing and Analysis

The only way to know the condition of a digital collection is constant and comprehensive testing. This cannot be stated too strongly; no collection using CD-R or DVD-R/+R as an archival carrier should be without a reliable tester. The error correction capability of most replay equipment will mask the effects of degradation until the errors are well into the uncorrectable region. When this point is reached, all subsequent copies are irreversibly flawed. On the other hand, a comprehensive testing regime allows for best possible planning of preservation strategies by acting on the known, objective and measurable parameters that digital archiving make possible. In the well-documented digital archive, metadata will record the history of all objects, including a record of error measurements and any significant corrections.

Life expectancy of CD-R or recordable DVD is a many varied topic. To most end users, a CD-R or DVD-R/+R reaches the end of its life when the drive no longer reproduces the data written on the disc, but because drives are not governed by standards, a CD/DVD that will not play on one drive may well play on another. There are innumerable examples of this. Alternately, some standards and suppliers specify an acceptable Block Error Rate (BLER). BLER is the number of erroneous blocks per second measured at the input of the C1 decoder (see ISO/IEC 60908) during playback at the standard (1x) data rate averaged over a 10 second measuring period.

Standards ISO/IEC 10149 and ANSI/NAPM IT9.21-1996, or Red Book standard, specify a maximum BLER rate of 220. The standard for recording general data on CD, otherwise known as Yellow Book standard, specify a BLER of 50. For data purposes this lower level is vital.

Studies have shown that BLER alone is not a very useful measure when determining LE, because defective discs may exhibit BLER well under 220, or indeed under 50. It is necessary to measure other test parameters, among them E22, E32 (uncorrectable errors), and frame burst errors (FBE, sometimes called Burst Error Length or BERL), which are valid end-of-life indicators. When these parameters exceed the limits specified below, it indicates a need for immediate duplication, assuming the disc containing archival information is still readable.

Errors in archival CD-Rs should not exceed that specified in the table below. These are maximum levels after which CD-Rs must be copied. In practice error levels much lower than this are achievable and preferable, and must be met in order for the disc to have any archival life before recopying becomes necessary. A BLER average of 1 and a peak level of less than 20 are easily achievable. Jitter is also a useful diagnostic indicator of the quality of the data recorded on a CD and should be measured after writing. The 3T jitter values should not exceed 35 nS (Fontaine and Poitevineau, 2005).

Frame burst errors FBE	< 6
Block error rate BLER average	< 10
Block error rate BLER peak	< 50
E 22 (correctable errors)	0
E 32 (uncorrectable errors)	0
3T Jitter	<35nS

Table 1, Maximum error levels in an archival CD-R

The construction of DVDs are significantly different to that of the CD, and though there are many aspects in common the criteria that applies to CDs does not necessarily apply to the DVD. Jitter in DVDs is customarily measured in percentages. Though measured differently, the actual jitter measurement is largely equivalent in the two disc types, the main error measurements, however, are quite different. The two main DVD error measurements are Parity Inner Errors (PIE) and Parity Outer Errors (POE). Industry standards state that the POE should be zero. Other types of error measurement are defined, but at the time of writing no agreed threshold for archival purposes has been developed. The DVD specification also states that any eight consecutive ECC blocks (PI Sum8) may have a maximum of 280 PI errors and jitter should not exceed 9%. However, with regard to the use of recordable CD, archival experience and testing has led to a recommendation in maximum error levels that is approximately 25% of the red book recommendations, An extrapolation on the DVD figures would lead to a recommendation of a maximum of 70 PI errors in any eight consecutive ECC blocks. It is important to recognise that a distributed range of tests on DVD recordable in archival situations has not been undertaken to assess the validity of these figures.

Initial investigations indicate that recordable CDs do not necessarily proceed to failure in a linear way and that as a consequence small change in initial error rates could have a greater effect on useful life of the disc. There are several tests that have indicated this to be the case (Trock, 2000), (Bradley, 2001), however, there has not been an extended examination of this proposition. A "longitudinal" examination of recordings over time coupled with artificial aging experiments might bring better information on the factors of disc stability. A factor which continues to add to the lack of consistent research is the lack of an agreed standard for the production of CD/DVD-drives.

Being a composite item containing, amongst other components, organic dyes or other chemical compounds, these optical carriers are bound to deteriorate due to slow chemical reactions. Choosing optical discs as the target medium entails the requirement to set up a monitoring program for the discs and a procedure for recopying discs that approach the limit of LE. The use of recordable and rewritable CD/DVDs as archival carriers cannot be advocated unless a strict testing and monitoring program is set up. It should be noted that testing and analysing, though absolutely necessary, will be time consuming, adding long-term costs to the archival solution. When planning an archival strategy, these costs should be included.

Logs of test results should be stored, and occasional testing, perhaps annually, can be carried out on statistically appropriate number of stored discs carrying archival information. When the error rate is shown to be increasing, a transfer to a new carrier can be undertaken of all the discs of that age or type.

Summary of Testing

- *Test all discs when writing.*
- *Reject any discs which fail to meet specification*
- *Store the relevant test records of all discs*
- *Undertake a regular testing of a statistically significant number of stored discs of each different batch of products.*
- *Undertake a recopying of discs when error rates increase.*

Testing of Existing Recorded Discs

If data on recordable CD or DVD was not tested at the time of creation, it is critical that tests are made of their current state. Discs must be subjected to rigorous error testing as their current error rates play a major part in determining their further life expectancy. If error rates are measured above the levels expressed in table 1, contents should be immediately transferred to new media.

Testing Equipment

Professional testing equipment with dedicated, or at least specified, drives is recommended for accurate testing DVDs and CDs. Such systems are more expensive but are necessary if accurate, reliable and repeatable error measurement are to be achieved. The testing should at least comply with *ISO 12142 Electronic imaging - Media error monitoring and reporting techniques for verification of stored data on optical digital data discs*. Such testing will not, however, address the problem of the lack of standardisation of optical disc drives. There is at the moment of writing, a standards project with the International Standards Organisation, *ISO N178 Electronic imaging — Classification and verification of information stored on optical media,* which may address the specific problem of drive compatibility.

Although there is test software available on the web as shareware, such software should be carefully evaluated before being relied on in an archival environment. Such software based systems depend on the accuracy of the non-standard computer drives. If a testing system based on computer drives is required, then a proprietary system supplied by the disc manufacturer stands a better chance of being useful. At least one CD/DVD burner company does provide software that allows their drive to be used for the purposes of testing. Appendix 3 contains information about commercial CD testing equipment. The results of any testing system that depends on the CD burning drive should be checked against a known, calibrated testing system to ensure adequate compliance.

Disc test equipment which accurately measures only the parameters specified in this guidance document are commercially available and of good standard. However, the figures provided by testing these parameters are suitable only for identifying problems. Analysis of problems probably requires access to a high analytical CD and DVD testing facility. It is useful to gain access to this type of equipment, by renting or borrowing, when solving problems, selecting blank media or calibrating in house testing facilities.

Kodak, in their web-document “Permanence and Handling of CDs” (Kodak 2002) claim that 95 % of their CD-Rs will maintain a data lifetime of a hundred years in an office environment. The results of these tests are often held to be suspect by archivists, and many have found it difficult to reproduce the tests and achieve the same results. This may be due to different interpretation of the figures and some argument about the validity of the method of estimating lifespan. Even if these tests proved to be true, and in the unlikely event that CD drives are still available 100 years hence, a 5% failure rate is unacceptable in an archive. This conclusion also supports the requirement of an error monitoring program.

Storage

Recordable or rewritable optical media should be stored under clean, dry, cool conditions. The process of decay is accelerated by high temperatures and humidity. The range of conditions given by manufacturers and experts for the storage of optical media is very broad. The NIST report (Byers, 2003) and *ISO 18925:2002, Imaging materials — Optical disc media — Storage practices* list them, and give advice on the care and handling of CDs and DVDs. Though very little testing has been done on storage most experts recognise that cool stable conditions are best.

Recordable optical media should be stored in a dark environment, as light with a high UV content will considerably increase the degradation rate of the recordable layer (Kunej, 2001). Dust and dirt have a significant effect on the error rate on the replay of optical media and if abrasive may cause permanent damage. Clean environments are important to longevity.

Reproduction of Optical Disc Media (CD and DVD)

It will eventually become necessary to copy data on CD and DVDs to another carrier. Under optimum conditions digital discs can produce an unaltered copy of the recorded signal, however any un-corrected errors in the replay process will be permanently recorded in the new copy, or unnecessary interpolations will be incorporated into the archived data, neither of which is desirable. Optimisation of the transfer process will ensure that the data transferred equates the information on the original carrier. By adhering to the testing procedures above and the reproduction techniques below, accurate and reliable data can be sustained on optical disc carriers for an extended, though finite, period of time.

Playback Compatibility

The variety of standards and the manner in which they may be encoded makes selection of the correct replay equipment necessary. The domestic freestanding CD player, for instance, will most likely only play CD-Audio and its variants, whereas the CD drive in a computer will play all the formats, though it requires the appropriate software to determine the content. DVDs will not play in CD drives or players, although many DVD drives are compatible with CDs.

The tables below lay out the compatibility between certain drives and their appropriate media.

Disc type	**CD-ROM drive**		**CD-RW**	**-R/RW drive,**	**CD-R Drive**	
	Read	Write	Read	Write	Read	Write
CD-ROM	Yes	No	Yes	No	Yes	No
CD-R	Yes	No	Yes	Yes	Yes	Yes
CD-RW	Yes	No	Yes	Yes	Yes	No

Table 2, Section 5.6: Compatibility; CD

Disc type	**Home DVD player Play only**	**DVD-ROM drive Play only (Computer)**	**DVD-R (G) drive Records General -R**	**DVD-R (A) drive Records Authoring -R**	**DVD-RW drive Records -RW, General -R**	**DVD+RW/ +R drive Records + RW, +R**	**DVD-RAM drive Records RAM**
DVD-ROM	No	No	No	No	No	No	No
DVD-R(A)	No	No	No	Yes	No	No	No
DVD-R(G)	No	No	Yes	No	Yes	No	No
DVD-RW	No	No	No	No	Yes	No	No
DVD+RW	No	No	No	No	No	Yes	No
DVD+R	No	No	No	No	No	Yes	No
DVD-RAM	No	No	No	No	No	No	Yes
CD-ROM	No	No	No	No	No	No	No
CD-R	No	No	Yes	No	Yes	Yes	No
CD-RW	No	No	No	No	Yes	Yes	No

Table 3: Compatibility; DVD (Write Mode).

Disc type	Home DVD player Play only	DVD drive Play only (Computer)	DVD-R (G) drive Records General -R	DVD-R (A) drive Records Authoring -R	DVD-RW drive Records -RW, General -R	DVD+RW/ +R drive Records +RW, +R	DVD-RAM drive Records RAM
DVD-ROM	Not Usually	Yes	Yes	Yes	Yes	Yes	Yes
DVD-R(A)	Mostly	Usually	Yes	Yes	Yes	Yes	Yes
DVD-R(G)	Mostly	Usually	Yes	Yes	Yes	Yes	Yes
DVD-RW DVD+RW	Partly Partly	Usually Usually	No Usually	Yes Usually	Yes Usually	Usually Yes	Usually Usually
DVD+R	Partly	Usually	Usually	Usually	Usually	Yes	Usually
DVD-RAM	Rarely	Rarely	No	No	No	No	Yes
CD-ROM	Depends	Yes	Yes	No	Yes	Yes	Usually
CD-R	Usually	Yes	Yes	No	Yes	Yes	Usually
CD-RW	Usually	Yes	Yes	No	Yes	Yes	Usually
DVD-Audio DVD-Video	All DVD drives should play DVD-Audio or DVD-Video if the computer has DVD-Audio or DVD-Video software installed. DVD-RAM drives are questionable.						

Table 4, Compatibility; DVD (Read Mode).

Cleaning, Carrier Restoration

CDs or DVDs do not require routine cleaning if carefully handled, but any surface contamination should be removed before replay or in preparation for storage. It is important when cleaning to avoid damaging the disc surface. Particulate contamination such as dust may scratch the disc surface when cleaning, or use of harsh solvents may dissolve or affect the transparency of the polycarbonate substrate.

Use an air puffer or compressed clean air to blow off dust, or for heavier contamination the disc may be rinsed with distilled water or water based lens cleaning solutions. Care should be taken as the label dyes in many recordable and rewritable discs are water soluble. Use a soft cotton or chamois cloth for a final wipe of the disc. Never wipe the disc around the circumference, only radially from the centre to the outside of the disc – this avoids the risk of a concentric scratch damaging long sections of sequential data. Avoid using paper cleaning products or abrasive cleaners on optical discs. For severe contamination isopropyl alcohol may be used if required.

It is preferable that no repairs or polishing is undertaken on archival optical discs as these processes irreversibly alter the disc itself. However, if the disc surface (reading side) shows scratches that produce high level errors, repairs which return the disc to a playable state may be allowed for the purposes of transfer. These may include wet polishing systems providing careful testing of the effect of these restoration systems have been undertaken before being applied to important carriers. This should be undertaken by testing an expendable disc, undertaking the restoration process, and retesting to determine the effect of restoration (for further details consult ISO 18925:2002, AES 28-1997, or ANSI/NAPM IT9.21 and ISO 18927:2002/AES 38-2000).

The Alternative: Professional approaches to digital data storage

Costs and Scale

The selection of CD-Rs as a storage technology is often made on economic grounds. The belief that CD-R is less expensive may, however, be fallacious for many types of archives. For example, a collection of digitised or born digital materials acquired at a rate of 500 Gigabytes (GB) over a 10 year period would amount to five terabytes (5TB) of data. Already today, this could be stored quite comfortably on medium sized hard disc arrays with data tape backup, redundant copies and an appropriate autoloader and software at a cost less than that of buying the necessary number of best quality recordable discs (including redundant copies) and technical infrastructure. With the added cost of necessary jukebox hardware and software and accurate testing equipment added, this would greatly increase the cost of using recordable optical discs. As reliable storage media continues to become less expensive with each year, this discrepancy will even become more obvious.

Larger scale data tape libraries become cheaper per Terabyte (TB) as the quantity of data to be stored increases, whereas CD-Jukeboxes do not provide equivalent significant savings when scaled up. In all but the very smallest collections professional and more reliable storage is probably more affordable, and third party storage solutions offer an option, providing they adhere to strict standards. Costs for large scale, reliable storage systems fall every year and the comparatively greater costs of CD becomes more each year.

Conclusion

Recordable CDs and more recently DVDs are very popular storage media. Because of the relative simplicity of their production, their easy availability and their financial affordability they have been very frequently used in projects to preserve and make accessible cultural and scientific documents of all kinds. As they were never intended for use as reliable media for long term preservation and have been developed primarily as a consumer product for the mass market their use in critical archival and preservation contexts constitutes a significant risk. As this publication demonstrates, elaborate measures are necessary to ensure reliable retrieval of data when using recordable CDs and DVDs as (the only) preservation media for digital materials. It also points out, that falling costs for hard disk drives and computer backup tapes as storage media have made professional digital storage technology a viable alternative even for small and often under financed institutions.

Appendix 1

Practical Aspects of Data Protection Strategies

Large scale computer based storage systems were once only found in the domain of government agencies, national libraries and archives, and large commercial data managers. Nowadays small scale storage systems are quite affordable and very accessible and used to store and manage smaller collections. A terabyte of disc storage can now be purchased from desktop computer suppliers, and while tape back-up is still the purview of professional computer industry, the costs are much lower.

A digital storage system ideally consists of the hard disc drive with tape backup, repository management software to manage data and metadata, and hierarchical storage management (HSM) software. The hardware is readily available, the repository software is readily available in open source (Wheatley, 2004), but hierarchical storage management remains expensive. However, manual back up management systems can be put in place to reduce the risk to data until such time as the HSM software market matures or funding becomes available.

A simple solution would be to set up a suitably protected disc storage system attached to the collection or encoding computer, with a regular back up of the entire data repository to tape at regular intervals. One approach would be to connect to a cluster of hard disk drives (HDDs) arranged in a RAID (Redundant Array of Inexpensive (or Independent) Disks). RAID increases the reliability of the hard disk system, and the overall access speed by treating the array of disks as one large hard disk. If a disk fails, it can be replaced and all the data on that disk can be reconstructed with data from the rest of the disks in the array. The level of failure the system will tolerate, and the speed of recovery from such failures is a product of the RAID levels. RAID is not designed as a data preservation array.

RAID level 1 is little more than two drives mirrored, keeping two copies of the data on different physical hardware; if one disk fails it is available on the other drive. Higher level RAID arrays (2 to 5) implement increasingly complex systems of data redundancy and parity checking that ensures the data integrity is maintained with more efficient use of storage space.[7]

Data on hard disc must also be duplicated on data tape. There are a number of data tape formats, however, a popular tape format is LTO Ultrium, which in 2005 is introducing its 3rd generation tape format with 400 GB native storage capacity. Like all digital data, redundant copies are mandatory. Data tape, though more reliable than optical disc, can nonetheless fail. As there is significant amounts of data on each tape, the effect of the failure could be very damaging, so multiple copies guard against this possibility.

[7] For a more detailed discussion of that approach see IASA-TC 04, 6.5. Being written for audio preservation, the content of the chapter can easily by restructured for other digital contents and their specific characters and access needs.

It is also critical to note that any current technology, data tape or otherwise, will require migration to a newer storage media in the next 5-10 years, otherwise the data tapes themselves will become inaccessible through either tape failure or format obsolescence. This is a principle of all digital storage and preservation practices. Professional data storage and management systems with appropriate tape back up are more reliable, efficient and accurate.

If access by a number of users at one time is required, a networked system of data storage and backup should be implemented. Such a networked system allows access to multiple users in accordance with the rules set down by the data management system. Small scale networks are relatively common and, with the right level of knowledge, easy and affordable to implement. Reasonable quantities of storage can be achieved with an enterprise level Network Attached Storage (NAS) device. Most low cost NAS devices exhibit reduced bandwidth when compared to the more expensive devices resulting in slower access times, or a lower number of allowable simultaneous access availability. Speed of access may not present a problem in many archival situations, especially as even the slowest NAS is quicker than a shelf of CDs.

In principle, small scale approaches can be designed for scalability, so that with growing amount of digitised materials, growing demand for access, and growing financial resources, a fluent transition from a simple fully manual start, over semi-automated systems to DMSS proper can be arranged.

Logical organisation of data and strict naming procedures are a necessity of small scale manual storage systems. Without Hierarchical Storage Management (HSM) software and well developed, integrated databases, there is an obligation to organise and structure data in order to ensure that the information remains accessible and locatable. Repository software helps support this task, as does suitable volume management software.

The risk with any such systems is the level of technical expertise required to run the system, and the dependence on staff and funding to maintain its integrity. Managers intending to implement such a system should seek professional technical advice, however such systems present a level of integrity and reliability that make them the most appropriate choice for most data storage situations.

Digital Mass Storage System Principles

For the sake of reliability and sustainability, in many, if not most situations it is preferable to store data on a digital Mass Storage System (DMSS). A DMSS may be a comprehensive, fully automated system designed to store, manage, maintain, distribute and preserve an array of complex digital heritage objects and their related metadata, or a straightforward storage and back up system for a single type of file format, its derivative copies and related metadata. The decision about an appropriate system will primarily be dependent on, amongst other things, collection size and type, the relation of the collection to a larger archive or library, the need for managed online access and the available budgetary resources.

The following information is based very closely on the practical aspects of Data Protection Strategies from the UNESCO Guidelines for the Preservation of Digital Heritage. It is modified only to reflect the possibility of systems that incorporate non-automated back up. The section is included with the kind permission of the author (Webb, 2003).

Allocation of responsibility: Someone must be given unambiguous responsibility for managing data storage and protection. This is a technical responsibility requiring a particular set of skills and knowledge as well as management expertise. For all collections, data storage and protection require dedicated resources, an appropriate plan and must be accountable for these strategies, and even very small collections must have access to the necessary expertise and a dedicated person responsible for that task.

Appropriate technical infrastructure to do the job: Data must be stored and managed with appropriate systems and on an appropriate carrier. There are digital asset management systems or digital object storage systems available that meet the requirements of digital preservation and sustainability programmes, some approaches to which are discussed below. Once requirements have been determined, they should be thoroughly discussed with potential suppliers. Different systems and carriers are suited to different needs and those chosen for preservation programmes must be fit for their purpose.

The overall system must have adequate capabilities including:

Sufficient storage capacity: Storage capacity can be build up over time, but the system must be able to manage the amount of data expected to be stored within its life cycle.

As a fundamental capability, the system must be able to **duplicate data** as required without loss, and transfer data to new or 'refreshed' carriers without loss.

Demonstrated reliability and technical support to deal with problems promptly.

The ability to map file names into a file-naming scheme suitable for its storage architecture. Storage systems are based around named objects. Different systems use different architectures to organise objects. This may impose constraints on how objects are named within storage; for example, disk systems may impose a hierarchical directory structure on existing file names, different from those that would be used on a tape system. The system must allow, or preferably carry out, a mapping of system-imposed file names and existing identifiers.

The ability to manage redundant storage. As digital media have a small, but significant failure rate, redundant copies of files at every stage are a necessity, especially the final storage phase.

Error checking. A level of automated error checking is normal in most computer storage. Because archival digital materials must be kept for long periods, often with very low human usage, the system must be able to detect changes or loss of data and take appropriate action. At the very least the strategies in place must alert collection managers to potential problems, with sufficient time to allow appropriate action.

Technical infrastructure must also include means of storing metadata and of reliably linking metadata to stored digital objects. Large operations often find they need to set up digital object management systems that are linked to, but separate from, their digital mass storage system, in order to cope with the range of processes involved, and to allow metadata and work interfaces to be changed without having to change the mass storage.

Appendix 2

Optical Disc Standards and Manufacturers Specification

Optical Discs general

ISO 18925:2002, Imaging materials — Optical disc media — Storage practices.

ISO/AWI 18938, Imaging materials — Optical discs — Care and handling practices for extended usage

Compact Disc

The standard for CD was originally a product of the companies Philips and Sony. The standards are named after a colour, the first being the Red Book. The colour book standards, subject to certain limitations, are may be ordered from the Philips web site at http://www.licensing.philips.com/. They are primarily intended for manufacturers.

The ISO standards are purchasable from International Standards Organisation (ISO) Central Secretariat http://www.iso.org/

Philips-Sony Red Book CD Digital Audio. Also includes CD Graphics, CD (Extended) Graphics, CD-TEXT, CD-MIDI, CD Single (8cm), CD Maxi-single (12cm) and CDV Single (12cm) .

IEC 908:1987, Compact Disc Digital Audio System (CD-DA)

(n.b. IEC 908:1987 and Philips-Sony Red Book are basically equivalent.)

ISO 9660:1988, Volume and File Structure (CD-ROM) (ECMA-119)

ISO/IEC 10149:1995, Read-Only 120 mm Optical Data Disks (CD-ROM) (ECMA-130)

Orange Book Part II: CD-R Volume 1 CD-WO (CD write once) also known as CD-R standard describing 1x, 2x and 4x nominal CD speed.

Orange Book Part II: CD-R Volume 2: Multi-Speed CD-R (CD Recordable) describing the speeds up to 48x nominal CD speed.

Orange Book Part III: CD-RW Volume 1 CD-RW (CD Rewritable) describing 1x, 2x and 4x nominal CD speed.

Orange Book Part III: CD-RW Volume 2: High Speed CD-RW (CD Rewritable) describing 4x and 10x nominal CD speed.

Orange Book Part III: CD-RW Volume 3: Ultra Speed CD-RW (CD Rewritable) describing 8x and 32x nominal CD speed.

Green Book. Compact Disc Interactive Full Functional Specification

White Book Video-CD Specification

There are also standards for other proprietary CD formats.

ANSI/NAPM IT9.21-1996 - Life Expectancy of Compact Discs (CD-ROM)-Method for Estimating Based on Effects of Temperature and Relative Humidity

DVD Optical Disc

There is an extensive range of ISO standards for DVD. However, similarly to CD, there are proprietary versions of the standards for DVD. These standards are referred to by an alphabetical appellation: DVD-ROM, the basic data standard, is specified in Book A, DVD video is described in Book B, DVD-Audio in Book C, DVD-R in Book D, and DVD-RW in Book E.

ISO 7779:1999/Amd 1:2003 Noise measurement specification for CD/DVD-ROM drives.

ISO/IEC 16448:2002 Information technology -- 120 mm DVD -- Read-only disk

ISO/IEC 16449:2002 Information technology -- 80 mm DVD -- Read-only disk

ISO/IEC 16824:1999 Information technology -- 120 mm DVD rewritable disk (DVD-RAM)

ISO/IEC 16825:1999 Information technology -- Case for 120 mm DVD-RAM disks

ISO/IEC 17341:2004 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 17342:2004 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 17592:2004 Information technology -- 120 mm (4,7 Gbytes per side) and 80 mm (1,46 Gbytes per side) DVD rewritable disk (DVD-RAM)

ISO/IEC 17594:2004 Information technology -- Cases for 120 mm and 80 mm DVD-RAM disks.

ISO/IEC 20563:2001 Information technology -- 80 mm (1,23 Gbytes per side) and 120 mm (3,95 Gbytes per side) DVD-recordable disk (DVD-R)

ISO/IEC 16969:1999 Information technology -- Data interchange on 120 mm optical disk cartridges using +RW format -- Capacity: 3,0 Gbytes and 6,0 Gbytes .

ISO/IEC DTR 18002 - DVD File System Specifications

ISO/IEC 13346, Recordable/Rewritable Volume and File Structure (ECMA-167)

Appendix 3

CD and DVD Testers

Standalone Commercial CD and DVD Testers

The testers listed below represent manufactures of reliable and accurate CD and DVD testing equipment.

Accurate, High Quality Production Testers

The cost of accurate, high quality production testers starts at around US$ 30,000 for the basic models and increases to over US$ 50,000 for many devices. The cost is incurred in the high quality reference drives which are a necessity for accurate and repeatable testing.

All testers are aimed at the market of optical disc manufacturers for production control purposes. Actual prices depend on the scale of measurable parameters, many of which are not relevant for testing recordable optical discs as to their archival reliability.

Currently, there are three producers of high quality testers: Audio Development (http://www.audiodev.com/), DaTARIUS (http://www.datarius.com/) and Expert Magnetic Corporation (http://www.expertmg.co.jp/).

Manufacturers and suppliers should be contacted for quotes.

Mid Range Quality Production Testers

The cost of these devices range from a US$ 3,000 to US$ 11,000 or more. These systems test all the required parameters using standard PC drives which have been specially selected and calibrated. It is recommended that before considering such mid priced testers, the prospective purchaser investigate thoroughly the types of drives and the accuracy of the device. It is also strongly recommended that all mid priced systems be regularly calibrated against a known standard.
Currently, a major manufacturer of such mid range testers is Clover Systems (http://www.cloversystems.com/)

Downloadable Testers

There are a number of downloadable testers available online which use a computer’s inbuilt CD/DVD drive to measure error in written CD and DVDs. However, due to the limitations of the software and inaccuracy of the drives, most, if not all, are unsuitable for archival purposes.

All information apply to the market situation as of spring 2006

Appendix 4

ISRC and ATIP Code Viewers

CD Media Code Identifier http://www.softpedia.com/get/CD-DVD-Tools/CD-DVD-Rip-Other-Tools/CDR-Media-Code-Identifier.shtml Freeware. Allows users to view information such as dye type, disc manufacturer, capacity, write speeds and media type. It appears to only work effectively with SCSI based optical drives.

ISRCView – www.cloversystems.com Freeware. This Windows program will display the Table of Contents, Control Codes, and ISRC codes on Audio, Mixed Mode, and Enhanced CD's. It is compatible with IDE and SCSI drives, however it provides much less manufacturer information than the CD Media Code Identifier products available.

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