Strategies and preservation policies for safeguarding audio documents

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Abstract

Audio documents are stored on many types of physical carriers in the form of cylinders, wires, discs and tapes. Each carrier requires specific machines to replay the sounds, so the obsolescence of technology is as great a threat to recordings as the process of carrier decay. Carriers should be conserved for as long as possible but copying the content to new carriers is essential. Digital copying and storage remain the only viable preservation option, but well-tested standards and policies now mean that audio preservation in the digital domain has matured into a trusted procedure. This paper outlines the various strategies and best practises for the conservation and long term preservation of sound recordings.

Introduction

"Nothing endures but change" Heraclitus (540-475 BC)

Sound documents have been stored on many different media over the past 130 years. The very first recording, of Edison reciting "Mary had a little Lamb" on a fragile tinfoil phonograph cylinder in 1877, has not survived, although he re-recorded those immortal words again 50 years later in a commemorative newsreel. But an experimental talking clock recorded onto a lead cylinder by inventor Frank Lambert still survives, apparently recorded as early as 1878[1]. By the end of the 1880s, wax cylinders and the early Berliner disc formats were being mass-produced. Some of these historic late 19th century recordings still exist. As recording technology has progressed onto other formats, more and more examples of our spoken and musical culture have been captured and kept for posterity. It was estimated that in 1990 there were more than 45 million hours of audio recordings worldwide held in archives, growing at rate of 5-10% per year.[2]

The significance of this immense quantity of audio recordings and the challenges presented by the need to safeguard them has been summarised in the context of all kinds of audiovisual documents as follows[3]:

"Audiovisual media in all its formats – films, radio and television programs, audio and video recordings, 'new media' – are the documents most characteristic of the 20th and 21st centuries. Their cultural influence and informational content is immense, and rapidly increasing. Transcending language and cultural boundaries, appealing immediately to the eye and the ear, to the literate and illiterate alike, they have transformed society by becoming a permanent complement to the traditional written

[1] The "world's oldest playable sound recording" is available at: www.tinfoil.com/cm-0101.htm although some argue that this recording is more recent than 1878 (ARSC Journal, Spring 2002, pp. 77-84, and ARSC Journal, Autumn 2002, pp. 237-242). [Note: all online documents in this paper accessed 8 August 2006.]

[2] Schüller, Dietrich (1994). Strategies for the Safeguarding of Audio and Video Materials in the Long Term. IASA Bulletin 4, 58-65.

[3] UNESCO Instrument for the Safeguarding and Preservation of the Audiovisual Heritage: CCAAA Issues Paper, 2005. Available from www.ccaaa.org/paper_heritage.shtml

record. Their content cannot be reduced to written form, and its integrity is closely tied to the format of its carrier – be it film, magnetic or optical media.

Most audiovisual media are inherently fragile. Since they are not human-readable, both their survival and accessibility are also vulnerable to rapid technological change. Preservation needs to be guided by specialised skills and structures, supported by appropriate national legislation.

Much of the world's audiovisual heritage has been irrevocably lost through neglect, destruction, decay and the lack of resources, skills, and structures, impoverishing the memory of mankind. Much more will be lost if stronger and concerted international action is lacking."

The primary activities of an audio archive are the acquisition, description, access and preservation of audio documents[4]. All these activities are totally dependent on technology. In safeguarding an audio document, audio archivists have to consider not just the medium on which it is held, but the equipment required to bring the recording to life and a significant time factor. In common with all moving media, the content - in this case the audio - does not "exist" except with the passage of time: there is no predetermined time required to view a still image such as photograph, whereas experiencing a sound recording is intimately connected with its duration. Nor can an audio document exist until it is rendered through a playback machine: audio recordings are not directly readable by humans. These properties have far-reaching consequences for the audio archivist, not least because recording and playback machinery has changed so much over the years; and because the dimensions of time are of course unavoidable in all aspects of audio preservation, or indeed in the preservation of any time-based media, in a very practical sense: listening to, assessing and copying sound recordings can be very time-consuming.

Principles of safeguarding audio documents

Preservation may be defined as "the totality of things necessary to ensure the permanent accessibility – forever – of an audiovisual document with the maximum integrity"[5]. There are several key considerations when planning audio preservation. These are summarised below, with some points examined in more detail later on.

- Preservation must take precedence over exploitation[6]. While recordings in an audio collection are preserved so that that they can be used, current demands on use should not compromise future uses. For example, it is accepted a recommended archival policy that the handling of vulnerable carriers should be restricted to trained staff; users requesting to listen to such items should instead listen to copies specially made for that purpose.
- Preserve the integrity of the audio in the long-term. Preservation and conservation actions should ensure that the original fidelity and structure of recordings are maintained in the long-term, including in any archival transfers made from original recordings. Thus long duration recordings ideally should not be split into shorter

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4 See: Ray Edmondson (2004). Audiovisual Archiving: Philosophy and Principles. Paris: UNESCO. Available online www.ccaaa.org/paper_archiving.shtml ; International Association of Sound and Audiovisual Archives. The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy (IASA TC-03), Version 2, 2001. web version: www.iasa-web.org./iasa0013.htm

5 Edmondson (2004). Audiovisual Archiving: Philosophy and Principles, op cit; see also Ray Edmondson (2004b) Arxius Audiovisuals: filosofia, principis i ètica. Imatge i Recerca, 8es, pp 73-102. Jornades Antoni Varés, Girona.

6 Harrison, Helen P (1990) Curriculum development for the training of personnel in moving image and recorded sound archives. Paris: UNESCO. Available from www.unesco.org/webworld/ramp/html/r9009e/r9009e00.htm

extracts, and subjective engineering treatments such as noise reduction and other corrective treatments must not be applied to master archival versions of recordings, only to copies and only when this is deemed necessary. Data reduction of archival digital files, while saving storage space and transfer times in digital archives, should be avoided as this permanently reduces fidelity.

- Fully document, ideally in a computerised format, the conditions and content of the collection and the stages involved in the preservation of each item.
- Determine the archives' principal goals and its collecting and preservation priorities in the context of other institutional collections, regionally, nationally and internationally. This will help to focus priorities and aid in the identification of those items for which the archive has special responsibility.
- Formulate a written long-term preservation policy statement, including a disaster recovery plan.
- Identify the resources required to carry out preservation: the staff, studio and storage accommodation, equipment, training and finances.
- Prioritise individual recordings and collections for preservation, by value, vulnerability, obsolescence, etc.
- Implement a regular plan of conservation work including routine assessments of carrier conditions.
- Formulate and implement a written handling and storage policy, and a policy on the security of and access to the collection material.
- Continually monitor the ever-changing technological developments in the audio industries. Include forward planning of the equipment required to reproduce and copy from obsolete carriers, and maintain awareness of changing preservation practices.
- Choose an appropriate strategy for preservation and conservation. It is now a widely held view that in the long-term audio preservation may only be achieved by digitisation from analogue and then migration or "reformatting" in the digital domain (the accurate cloning of the contents from one digital medium to another) as and when required. The approaches are described more fully in the next section.

Conservation or preservation?

Since policies for safeguarding recordings will have far-reaching, long-term impacts on all other archival activities, they must be determined before formalising other institutional policies. Perhaps the aspect that has changed most significantly over the past few years is the strategy for preservation. One method, often referred to as technology conservation or the 'museum approach', is to conserve both a carrier and the specific machines needed to play it. The conservation of the machines requires stockpiling spare parts and service manuals and sustaining the engineering skills to maintain and repair machines long after a manufacturer ceases production of that particular model. In the case of modern digital systems that require computer programs to run, the machinery to be preserved will include both hardware and software. Conservation of the original recording held by an archive can be aided by proper handling and storage procedures to reduce the risk of damage, as discussed later. Note that "original" in this context may not always mean the true original recording; if this is not held by an archive, a transfer may be treated as an 'original' for the purpose of preservation.

Technology conservation was the approach taken by many sound archives until the 1980s. With the development and proliferation of new technologies and ever accelerating rates of obsolescence, this approach has become untenable. The alternative preservation method now favoured and recommended by the major sound institutions and audio-visual advisory bodies is the migration of the sonic content in an audio document from an obsolete carrier to a new digital one, while conserving the original carriers for as long as possible[7].

Carrier conservation and technology obsolescence

Sound recordings exist on a wide variety of carriers, from analogue grooved cylinders and disks, analogue magnetic tape and metal wire formats, to digital magnetic tapes and optical or magneto-optical disks (summarised in Table 1).

Table 1. Principle audio carriers[8]:

Analogue audio - groove carriers		
Cylinder, recordable	1876-1950s	Obsolete
Cylinder, replicated	1902-1929	Obsolete
Coarse groove disc (78 rpm and similar)	1888-c.1960	Obsolete
Transcription disc (pressed)	1930s-1950s	Obsolete
Instantaneous lacquer disc	1930s-1960s	Obsolete
Vinyl microgroove disc	1948-present	Obsolescent
Analogue audio - magnetic carriers		
Wire	1930s-late 1950s	Obsolete
Magnetic reel-to-reel tape	1935-present	Obsolescent
Compact cassette tape	1960s-present	Obsolescent
Cartridge tape	1960-present	Obsolete
Audio - digital carriers		
Compact disc, replicated (CD-DA)	1980-present	Current
Betamax and VHS F1	1982-1995	Obsolete
Compact disc, recordable (CD-R)	1992-present	Current
Digital Audio Tape (DAT)	1987-present	Obsolescent
Mini-Disc (MD)	1992-present	Current
Digital Versatile Disc **(**DVD)	1996-present	Current

Certain carriers are particularly susceptible to degradation over time, including cylinders, lacquer and other instantaneous (also known as direct-cut or so called “acetate”) discs. Also susceptible are acetate tapes, magnetic audiocassettes and the thinner types of open-spool tapes, and any other carriers showing signs of decay[9]. Sound archive preservation managers should highlight the carriers in their care that are most at risk of degradation. This is a first step towards taking remedial action, both to delay the process of decay as far as possible and to plan migration projects for the most vulnerable carriers. However, carrier degradation cannot be considered in isolation from technological obsolescence. Each category of carrier requires a specific type of machine for recording and playback. There are some audio carriers that, while relatively stable, may not be playable merely because the machinery is no longer in production. Examples include early digital audio recordings made on Betamax videocassette tapes using Sony's F1 digital processor. The Betamax F1 format was used by a number of institutions between 1982 and 1987 as the only viable means of recording digital audio before recordable compact disc was invented. The Betamax videotapes are relatively stable, but as the players are no

[7] IASA TC-03 op cit
[8] modified after Edmondson (2004). Audiovisual Archiving: Philosophy and Principles.
[9] IASA TC-03 op cit

longer manufactured, recordings on this format must be transferred to current formats at the earliest opportunity using the remaining stock of old Betamax players. The helical scanning playback heads have a limited playing life of around 1,500 hours, so backup machines are needed. Drive belts and other rubber components in the players soon deteriorate, so a contingency for breakdowns must be also planned in any conversion project to rescue a Betamax collection.

It is prudent to compile an "alert list" of carriers in an archive that are at risk due to carrier degradation or fragility, or due to technology obsolescence (e.g. Table 2). These carriers are not necessarily the oldest. Coarse groove discs are obsolete, and although brittle they are hard wearing. The technology needed to replay them is simple and still available. Furthermore, they were mass-produced and, at least for some recordings, many copies still exist. For these reasons, they are not currently at risk. Instantaneous discs by contrast are the most at risk, due to the decomposition of the lacquer layer, compounded by the fact that the majority of such discs are unique recordings [10].

Table 2. The principal carriers 'at risk' which urgently require migration

Carrier	**Main threat**
Cylinders	Vulnerable
Instantaneous discs	Vulnerable
Acetate tapes	Vulnerable
Double-play and triple-play quarter-inch tapes	Vulnerable
All other quarter-inch tapes	Obsolescent
Digital Audio Tapes (DAT)	Obsolescent
Microcassette tapes	Obsolescent
Digital Compact Cassettes	Obsolete
Dictabelts	Obsolete
Laserdiscs	Obsolete
Betamax tapes	Obsolete
Cartridge tapes	Obsolete
Elcaset tapes	Obsolete
DASH digital tapes	Obsolete

Storage, care and handling

There are number of useful documents available that detail the recommended practices for the care and handling of audio recordings [11]. These can be consulted

[10] George Boston (2003) Survey of Endangered Audiovisual Carriers. UNESCO, Paris

[11] see for example: Bradley, K. (ed), 2004 IASA TC-04 op cit; Ward, A (1988). *A Manual of Sound Archive Administration,* APPENDIX I. Gower Publishing. ISBN 0566055716; Magnetic Tape Storage and Handling - A Guide for Libraries and Archives. John Van Bogart. National Media Laboratory. 1995. Available from http://www.clir.org/PUBS/reports/pub54/ ; Byers, F.R. (2003) Care and handling of CDs and DVDs: a guide for librarians and archivists CLIR report; 121 Washington DC Council on Library and Information Resources /National Institute of Standards and Technology; Gilles St-Laurent, The care and handling of recorded sound materials (1996). Available from http://palimpsest.stanford.edu/byauth/st-laurent/care.html; Navale, V.: (2005) Predicting the Life Expectancy of Modern Tape and Optical Media RLG DigiNews, Volume 9, Number 4, 2005; AES22-1997 (2003): AES recommended practice for audio preservation and restoration -- Storage and handling -- Storage of polyester-base magnetic tape. www.aes.org/publications/standards/ ; AES49-2005: AES standard for audio preservation and restoration - Magnetic tape - Care and handling

for fuller information to allow an audio archive to formulate a written policy on care and handling, which should include the following key points:

- Only trained staff should handle vulnerable carriers.
- Recorded surfaces of any audio recording should not be touched.
- All grooved media (analogue cylinders, vinyl and coarse groove disks) are very susceptible to damage from mechanical scratches.
- An optical disc (CD, DVD) should only ever be placed on a disc player tray or in its storage case; the playing surface should never be placed on a table or other flat surface where there is a risk of scratching.
- Recordings must only be played on properly serviced equipment, by staff trained in its use. Recordings should not be left on machines after use.
- Where there is a risk that repeated replaying of a recording may damage it, a playback copy should be made expressly for future listening[12].
- Food, liquids, dust and smoke particles must not be allowed near recordings.
- Damage due to mishandling, accident, wear or ageing should be remedied when possible to prevent further damage. Tape recordings may require resplicing, or cleaning with a soft cloth, or slow re-spooling on a well-maintained tape deck. Discs may be cleaned using appropriate equipment such as a Keith Monks record cleaner or an ultrasonic bath, or by washing using demineralised water. Warped discs can sometimes be treated by carefully pressing between hardened glass in a laboratory oven at successively higher temperatures until the disc is flattened.[13] Repair and cleaning procedures are usually carried out immediately prior to copying as part of a migration programme.
- Proper storage prolongs the life of carriers. Recordings must always be kept away from sources of heat and direct sunlight. Different carrier types and sizes are usually shelved separately, and only in approved archival containers.
- All disc formats should be stored vertically on rigid shelving with dividers to provide sufficient lateral support to prevent warping. Published CD and DVD discs sold in card sleeves or other non-standard cases should be re-housed in approved jewel cases or other containers, and the original sleeves shelved separately. Analogue discs may need to be re-sleeved in archival standard paper sleeves.
- The data layers in recordable CD and DVD discs are dye-based and susceptible to damage from prolonged exposure to light. The discs must be stored after use in plastic jewel cases and the cases stored in card boxes with lids to exclude light. Discs may be labelled with thermal image printers but labelling should be kept to a minimum.
- Magnetic tapes should of course be kept away from sources of strong magnetic fields including loudspeakers. Tapes should be stored on reels with the tape wound 'tail out'.
- The stores should be maintained at a low relative humidity of 40% +/- 5% and a temperature of 20 ºC +/- 2 ºC. Optimal conditions may be expensive to maintain in tropical climates[14]. Lower temperatures, down to 5 ºC, and RH levels of 30% or

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practices for extended usage. Available from www.aes.org/publications/standards/ ; Gibson, Gerald D. (1994). Emergency preparedness and disaster recovery in audiovisual collections. In: IASA Journal, no. 4. pp. 13-1 8.

[12] For example, the micro-groove on a vinyl disk is easily deformed by the movement of the stylus in the groove during playback, even when using a correctly weighted and aligned tone arm and stylus. At the British Library Sound Archive, each playback of a vinyl disc is logged. Discs are played a maximum of three times. Subsequent listens of the same disc are only permitted on playback copies made from the disc.

[13] Bradley, K. (ed), 2004 IASA TC-04 op cit

[14] Schüller, Dietrich. (1996). Preservation of audio and video materials in tropical countries. IASA Journal, No. 7, pp. 35-45. web version: www.unesco.org/webworld/audiovis/reader/7_5.htm

lower, have been recommended for very long-term storage [15]. In practice, microclimate differences between storage and operational areas can do more harm to the recordings than storage at sub-optimum levels of humidity and temperature, so storage areas for regularly used materials are often kept at normal operational conditions.

- Access to storage areas should be restricted to approved staff. Recordings should be kept in stores when not in use, with a procedure for logging their removal and return.

Migration of content

In recent years, the idea of preservation of the *content* of audio recordings, rather than the original carriers, has become far more prevalent. That is not to say that an original carriers should not be conserved, as it may have value as an artefact in its own right. Original field recordings and mass-produced commercially-issued recordings, whether on audiocassette, analogue disc and cylinders or digital discs, frequently have associated visual and textual information that is of considerable cultural and documentary interest. There may also be additional technical and documentary information on the original carrier that cannot easily be transferred to a different audio carrier. Examples include the matrix numbers, labels and other important discographical information on the surface of analogue discs. Another reason to conserve the original carriers, regardless of the existence of any digital surrogates, is in the event that future digitisations can improve on current technologies to extract a better signal than is currently possible. Nevertheless, it is recognised that care of original recordings only delays their inevitable decay and obsolescence, so copying recordings is an inescapable obligation.

For preservation reasons, it is common practice for sound archives to preserve two or more examples of the same mass-reproduced recording. Where more than one exists, the best example should be chosen for migration copying. In the case of analogue discs, for instance, this may require close visual inspection to compare the general condition and extent of wear and damage.[16]

While copying recordings is standard practise in audio preservation, copyright legislation governing what is permissible can be complex and varies from one country to another. Under USA law for instance, "a qualifying library or archives may make up to three copies of an unpublished work in its collection for preservation and security or for deposit and research use at another library. A library may also make up to three copies of a published work to replace one that is damaged, deteriorating, lost, or stolen, or whose format has become obsolete, if the library determines, after “reasonable effort,” that an unused original cannot be obtained at a fair price. The copies may be in digital form, but a digital copy made pursuant to these provisions may not be made available outside the library premises." [17]

Optimising signal extraction

Migrating recordings can be both expensive and time-consuming. For this reason the activity must be regarded as a one-off process, one that may never be repeated on the same recording. Therefore it is vital that the copying is undertaken with the best equipment available, with the aim of recovering the optimum signal from the

[15] Magnetic Tape Storage and Handling - A Guide for Libraries and Archives. John Van Bogart. National Media Laboratory. 1995. Available from www.clir.org/pubs/reports/pub54/

[16] See Bradley, K. (ed), 2004 IASA TC-04 op cit on selection of best copy.

[17] Besek, June M., (2005): Copyright Issues Relevant to Digital Preservation and Dissemination of Pre-1972 Commercial Sound Recordings by Libraries and Archives. USA: Council on Library and Information Resources / Library of Congress. Available from www.clir.org/pubs/reports/pub135/contents.html

original carrier. The extraction of a signal from an analogue grooved disc for example should be undertaken with the greatest care to select the most appropriate stylus size and shape, tone arm tracking weight, replay equalisation curve, and playing speed. The disc must be if necessary cleaned to remove surface dust and dirt particles before copying[18]. The processes require specialist engineering skills, discographical knowledge and a good understanding of historical audio engineering techniques.

Similarly, copying from quarter-inch analogue tape requires specialist knowledge, skills and equipment to ensure optimal signal extraction. As with disc copying, the process starts with a visual inspection to determine condition and to identify the tape composition. Next, preview the beginning of a tape to check for the correct playing speed and azimuth. A high standard of technical proficiency is required to select the correct width replay heads, replay equalisation and the mechanical alignment relative to the tape path (azimuth and pitch), and to ensure high standards of cleanliness of the tape heads and guides. The tape may also require repair of broken splices, slow respooling to reduce damage, or baking to temporarily reduce the tape binder hydrolysis that leads to sticky tape syndrome.

An important principle is to ensure that any copy does not reduce the "power-bandwidth" product of the original signal. The power bandwidth product is the combination of both the dynamic range and the frequency range throughout the original signal. To ensure a faithful copy, all components including the copying equipment and the destination format, should have specifications that exceed the power-bandwidth product of the original signal. Most audio equipment is designed to handle signals within human hearing range. Certain non-human biological sounds may require special approaches. Sounds of dolphins extend well into the ultrasonic range, as high as 250 kHz, requiring specialised equipment to capture, copy and preserve the full range of sounds accurately.

Digitisation as a preservation strategy

For many years, the proliferation of digital formats and the lack of standards deterred archivists from regarding digital transfer as a reliable means to safeguard audio documents. This position has changed since the 1990s, when European broadcast libraries started using mass digitisation archiving to preserve their collections.[19] Since then, the audio industry has moved completely away from analogue recording and reproduction. It is now widely accepted that digitisation is not only a reliable audio preservation strategy, but the *only* one in the long term, given the rapid pace of technological change and the conversion to digital systems throughout the audio industry.

Prior to the invention of digital recording, audio archivists used standard-play analogue quarter-inch tape at a playing speed of 19 or 38 cm/s for archival preservation. Today, so few manufacturers of blank tape remain (in North America, the largest commercial supplier, Quantegy, ceased production in late 2005) that this format cannot be used any more.

Digitisation has many advantages. Digital recordings may be accurately cloned, and automatically checked. Far more precise copying is possible than with analogue formats. Analogue copying adds noise to every recording generation. Even

[18] A useful introductory guide to signal extraction from all kinds of audio carriers is in: Bradley, K. (ed), 2004 IASA TC-04 op cit.; See also**:** Capturing Analog Sound for Digital Preservation: Report of a Roundtable Discussion of Best Practices for Transferring Analog Discs and Tapes: (2006) National Recording Preservation Board. Library of Congress, Washington, D.C. Available from: www.clir.org/PUBS/abstract/pub137abst.html

[19] Schüller, Dietrich (2000) "Personal" Digital Mass Storage Systems - Viable Solutions for Small Institutions and Developing Countries. IASA Journal 16, 2000, 52-55. From www.unesco.org/webworld/points_of_views/schuller.shtml

the best-maintained professional analogue tape machines add noise to every generation of analogue copy; over several generations, the cumulative effects become noticeable. Digital recordings, on the other hand, may be copied again and again without deterioration. In the form of files, digital sounds can more efficiently and economically searched for and accessed using computers. Digitisation enables more efficient management of an audio collection, as digital files are amenable to automated backup, retrieval, content searching etc.

There is however little point in attempting to conserve the digital carriers forever. "There is no permanent carrier" is a familiar warning among the archiving and library communities. Therefore at the outset of any preservation strategy it is important to consider how the contents of any digital store will be migrated to a new system as and when the current technology becomes obsolete. Clearly, one disadvantage of 'going digital' is the ongoing cost of migration every few years. The lifespan of audio technologies are dependent on commercial considerations driven largely by broadcasters and music publishers. The commercial life of modern digital formats has been far shorter than analogue formats, and there is every sign that rapid obsolescence of upcoming formats will continue.

There are several important technical principles that should be born in mind in all audio digitisation projects:

- use the highest sample rate appropriate to the material being digitised. For most audio signals including music and speech, the minimum recommended sample rate is 96 kHz[20]. Although this sample rate permits signals containing frequencies up to almost 48 kHz to be preserved, more than an octave above the highest frequency audible to humans (as a rule, the maximum frequency recordable is just under half the sampling rate), it has been argued that it is important to accurately capture not just the signal but also as much of the unwanted noise unavoidably present in the transfer. This is so that current (and future) noise reduction algorithms have as much information about the unwanted noise as possible: the better the characteristics of the noise are recorded, the easier it is to remove it. Since the spectral and dynamic ranges of noise on original analogue recordings, particularly on mechanical grooved media, may be far higher than the signal, the higher sample rate appears warranted. Indeed there may be cases where even higher rates (192 kHz) are beneficial. For special signals obtained for scientific analysis, still higher sample rates may be required: high specification data acquisition boards are used to capture dolphin and bat sonar clicks at sample rates up to 500 kHz.
- The use of a bit depth ("word length") of 24-bits. The 16-bits resolution as used on the common CD audio format is now regarded as insufficient to capture the full information in a digital sample.
- Use of the uncompressed, 'linear' (or PCM – Pulse Code Modulation) version of the Windows .wav audio file, or of its Mac alternative, the AIFF (Audio Interchange File Format). The WAV format has become a *de facto* standard for audio. Alternatively, its modified version the Broadcast Wave Format (BWF) may be used. Both file types have the file name extension .WAV, but the BWF file, developed by the European Broadcasting Union, allows for extra metadata in the file header. Audio may instead be stored on CD as audio tracks (the CD-DA format), but the data file format such as WAV is preferred[21].
- Data reduction (or 'lossy compression') should not be used at any stage in preparing an archival digital file. Lossless compression file formats such as FLAC may be used but in practice the relatively modest reductions in file sizes (around

[20] Bradley, K. (ed), 2004 IASA TC-04 op cit
[21] Bradley, K. (ed), 2004 IASA TC-04 op cit

50%) are no longer a great advantage considering the ever decreasing costs of data storage.

- Selection of the highest quality analogue to digital (A-D) converters. Recommended technical specifications are given in IASA TC-04[22].
- The digitisation should be performed so that the transfer is as accurate a conversion from the original as possible. This digital file may be termed the Master file - a direct, unmodified copy of the analogue original, including any undesired artefacts arising from damage to the original. No attempts should be made to remove artefacts from the Master file, as this could compromise the potential for improved methods of restoration in future. Different versions of files derived from the Master file may then be created for access and restoration; one such scheme is described here. A Playback copy is generated at the highest quality in the digital domain from the Master file, but with noise reduction, normalisation, editing and other subjective treatments applied. Other defects such as wow and flutter may be corrected. Playback copies are intended for permanent retention but are only produced when it is desired to make the recording more listenable, or to correct for artefacts in the Master. The production of Master and Playback files should be undertaken by trained professionals using the best equipment available, and the process can be time consuming. Service ('Access') copies may be generated from the Master version or from the Playback version if available. Service copies are usually compressed files intended for previewing, web delivery and other uses, but not for permanent preservation. Their smaller file sizes are optimised for network distribution and cheaper storage. Service copies can be generated at lower production standards using time-saving batch processing software. Specifications for the different versions of the files are given in Table 3. Note that a single recording may exist in as many as four versions in an archive (original analogue recording, plus digital copies as Master, Playback and Service files), with backup copies of each digital file for added security.
- Born-digital originals may be transferred to digital Master files and (if needed) Playback files without changing the original bit depth or sample rate, but they should be converted if necessary to the standard WAV file format. Born-compressed digital audio files, for example MP3 or AAC files, should be archived in their original format, however it is prudent to convert a copy into an uncompressed standard WAV file in order to ensure their future compatibility.
- For large-scale digitisation projects, semi-automated batch digitisation may be used to speed up the work. Commercial systems made by Quadriga and NOA Audio Solutions use multiple ingest streams from several analogue sources with semi-automated monitoring. These tools are only cost effective for large and fairly uniform collections of several hundred items or more, and the process still requires careful monitoring to ensure that the conversions are satisfactory. Quality control should be undertaken by experienced technicians by listening to sample recordings in tandem with machine reporting.
- New methods for digitising analogue materials are emerging and likely to become important for certain carriers. There are several research projects worldwide currently in progress developing replay methods for analogue grooved media (cylinders and flat discs) using optical scanning or laser playback rather than mechanical means of following the groove. One such project, a collaboration between the Lawrence Berkeley National Laboratory in USA, Southampton University's School of Engineering in England, the British Library and the US Library of Congress, is using 3-D surface scanning to record high detail images of the groove modulations and then convert these to audio[23]. Although still under

[22] Bradley, K. (ed), 2004 IASA TC-04 op cit

[23] See the Archive Sound Project www.mech.soton.ac.uk/archivesound/Home.html. Other European projects include The Institut National de l'Audiovisuel (INA) in France which has a prototype optical

development, these non-contact methods are likely to be useful particularly for the non-invasive playback of damaged and broken materials that cannot otherwise easily be played by traditional methods, or where optical scanning yields better signal extraction than can be obtained with contact methods. It is hoped that further developments will offer the possibility of the virtual reconstruction and playback from restored images of "unplayable" recordings that are extremely deformed or broken into separate pieces (this is one reason why archivists should keep unique but unplayable recordings and fragments).

Table 3
Specifications for digital versions of audio files prepared from analogue originals

File version	Function	Data reduction	File type	Resolution	Source
Master	Archival file for permanent retention, unmodified transfer from original	Uncompressed (no data reduction)	PCM wav or bwf, mono or stereo	24-bit, 48 or 96 kHz,	Original
Playback	Archival file optionally created for permanent retention, modified to increase audibility	As Master file	As Master file	As Master file	Master file
Service	Access file not for permanent retention, optionally created for quick access and preview	Compressed	e.g. MP3, AAC, WMA	According to use, e.g. 128 or 256 kbps bitrates for web	Master or Playbac k file

Preferred target digital carriers for preservation

The first recordable digital format for archiving used Betamax or VHS videocassettes via the Sony F1 PCM processor, now an obsolete method. Digital AudioTape (DAT) was used from the mid 1980s but is now also obsolete. Minidiscs use data reduction so cannot be considered for archival purposes. The new Hi-MD variant does permit uncompressed recording but as the format has only achieved relatively small market penetration it cannot be considered a viable format in a long-term preservation plan.

Many sound archives store digital audio on recordable CDs. The discs and accompanying hardware are cheap and have a very wide user base worldwide, however, their longevity has been the subject of much discussion in recent years. Experiments on the life expectancy of optical discs predict that they may last several decades if kept under good storage conditions, although the results from different tests have varied greatly, indicating archival lives ranging from over a hundred 100 years to just three years[24]. It is likely that in some cases poor results are due to using

disc player. See also: Ottar Johnsen, Frédéric Bapst, Christoph Sudan, Sylvain Stotzer, Stefano S. Cavaglieri, Pio Pellizzari. (2003). VisualAudio: An Optical Technique to Save the Sound of Phonographic Records. *IASA Journal* 21: 38-47, a technique from Switzerland using scans from high resolution analogue photographs..

[24] Examples of studies on CD-R and DVD-R longevity include: Kunej, Drago, Instability and Vulnerability of CD-R Carriers to Sunlight. In: Proceedings of the AES 20th International Conference

low quality blank discs, resulting in high digital error rates. But there are now few producers of high quality blank discs, and only one still produces discs with a gold reflective layer, thought to be more stable than the silver layer used in most CD-Rs. “The early CD-Rs were carefully made and expensive to buy. The reliability was high. As the manufacture and use of blank CD-Rs has rapidly increased and the price has dropped considerably, the reliability has deteriorated. Discs made to a higher standard are available from a few manufacturers and offer greater security, but at an increased price. Even these higher standard discs should, however, be subject to a regular programme of checking changes in error rate to detect problems before they become catastrophic” [25]. Similar concerns are raised over recordable DVDs. The higher data densities on recorded DVDs further increases the risk of data loss. These concerns have led some bodies[26] to discourage against using CD-Rs and DVD-Rs for middle or long term preservation. To reduce the risks, use the highest quality blank discs, use a professional disc writer that ‘burns’ at a relatively low recording speed, and set up a programme of testing discs for errors. Many of the larger sound archives have initiated their own disc testing programmes, testing discs before and after recording.

At least two copies should be made of every disc and the two copies stored at different locations. At the British Library Sound Archive, the blank CD-R and DVD disks are sourced from different manufacturers, and the brand and batch number of each disc is stored in the Archive’s database. Periodic monitoring of samples of discs using an optical disc tester allows engineers to monitor any degradation in the performance of the discs and the integrity of the content overtime. Should any deterioration in one disc be discovered, the entire batch may be retrieved for further testing and any remedial action, including cloning from the undamaged pairs.

Storage of large quantities of digital audio on optical discs on shelves constitutes an ‘off-line’ archive - a relatively simple, and established method for digital archiving that is cheap to implement. However ensuring the reliability of discs by continual validation and integrity testing is an added cost. Other disadvantages are the handling time and risk of damage during use, the need to manually replicate backup copies for added security, and the inoperability compared with on-line systems. The alternative is to store on hard disk drives (HDD) or digital tapes in a digital mass storage system (DMSS), a method pioneered by large radio archives in Europe in the 1990s, starting with the German broadcasting station Südwestfunk. The DMSS uses a combination of on-line hard disk drives that are permanently connected to the system (‘on-line’), and ‘near-line’ tape drives that are accessed through a robotic library for storage of less-used documents. It has been argued that with the rapid decrease in costs of hard disk drives this is now a cheaper method than storage on optical discs[27]. CDs in particular have limited capacity – just 20 minutes if storing WAV files at the recommended 24-bit 96 kHz resolution. While CD and DVD are very cheap, the labour costs associated with preparation, handling, shelving and checking are far higher than the costs of running a DMSS. Although a

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Archiving Restoration, and New Methods of Archiving, Budapest, 5-7 October 2001, AES New York 2001, 18-25; Psohlavec, Stanislav, Practical Experience with Long-Term CD-R Archiving. In: Proceedings of the AES 20th International Conference Archiving Restoration, and New Methods of Archiving, Budapest, 5-7 October 2001, AES New York 2001, 15-17; Slattery, O., Lu, R., Zheng, J., Byers, F.R., Tang, X., 2004 Stability comparison of recordable optical discs: a study of error rates in harsh conditions in: Journal of research of the National Institute of Standards and Technology Gaithersburg, Md. National Institute of Standards and Technology / vol. 109, no. 5; J. Iraci (2005). The Relative Stabilities of Optical Disc Formats. Restaurator (International Journal for the Preservation of Library and Archival Material) 26: 134–150.

[25] George Boston (2003). op cit.

[26] For example, the International Association of Sound and Audiovisual Archives (IASA TC-04).

[27] Nicolas Hans & Johan De Koster (2004) A pragmatic strategy to digitizing production archives. Available from www.broadcastpapers.com/whitepapers/DaletDigitProdArchives.pdf

DMSS must be custom built and requires a high initial investment and careful planning, it supports automatic error checking, refreshment of data onto new drives, easier migration to new systems as technology evolves, and redundancy to prevent loss of data in the event of a drive failure.

On a cost per Gigabyte basis, hard disk drives are currently more expensive than magnetic tape media (LTO, DLT or AIT tapes), but are falling in price and may be considered alongside or even in place of tape media, usually configured as a RAID (Redundant Array of Independent Disks). Whichever storage type is used, it is vital that data in a DMSS is replicated on different drives, ideally of different brands and that a backup set is stored securely off-site in a different location to the main store, at least 50 km distant to allow for major disasters[28]. Small scale or 'personal' DMSS are becoming affordable even for smaller archival institutions[29]. One recent study estimated the costs per Gigabyte of raw storage between £2-£15 (€1.3-€10), plus 20% per GB for the network infrastructure[30]. The management of a DMSS requires well thought out, practical strategies to ensure the principle of data, rather than carrier, preservation:[31]

- The assignment of responsibility within the institution for data management
- Appropriate technical systems to do the job
- Sufficient storage capacity
- Ability to losslessly duplicate data
- Technical support to handle problems
- Mapping of file names according to the DMSS architecture
- Backing up and redundancy of storage
- Error checking and reporting
- Storage of and/or ability to link the audio files to their metadata

Preservation metadata and file identifiers

Proper documentation of information about digital assets is essential. In addition to descriptive and administrative metadata, preservation metadata for audio should include information about the original recording, the technical equipment, parameters and processes used in the transfer to a digital format, and any subsequent processing. Although metadata may be embedded in the file header of a BWF audio file, more commonly the data are stored in a separate database from where they may be easily retrieved and updated.[32] There are a number of schemes for structuring metadata and defining its individual elements. Among the best known among the library world is Dublin Core, which is widely used for bibliographic data, but cannot describe the complexities of audiovisual data in sufficient detail.

The Metadata Encoding and Transmission Standard (METS), expressed through XML, is one of the various schemes now being in audio archives for wrapping metadata with digital objects and facilitating the interchange of data between archives [33]. It allows links between different objects and is useful for preserving relationships between sets of complex digital objects: multi-part musical works such as movements in a performance of a classical symphony, or different kinds of digital objects sharing a common origin. For example, audio files may be

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[28] Bradley, K. (ed), 2004 IASA TC-04 op cit.
[29] Schüller, Dietrich (2000) "Personal" Digital Mass Storage - op cit.
[30] Jonathan Mathiesen (2006). A Survey of Digital Formats for Storage. PrestoSpace. Available from www.prestospace.org/project/deliverables/D12-6.pdf
[31] Bradley, K. (ed), 2004 IASA TC-04 op cit
[32] Bradley, K. (ed), 2004 IASA TC-04 op cit
[33] For more information on METS, see: www.loc.gov/standards/mets

linked in METS to image files scanned from disc labels and sleeves, or to text files containing transcripts of oral history interviews.

Digital files should be named using unique identifiers. In the context of the availability of audio files over the internet in the long-term, the use of persistent identifiers that are globally unique should be explored.[34]

Planning audio preservation digitisation projects

Managers of collections with many carrier types will already have identified high-risk carriers based on an 'alert list' highlighting vulnerability or obsolescence. Such items may be selected first for digitisation migration programmes regardless of other selection criteria. In planning the preservation of a collection with mixed carriers the first step is to sort the material into carrier types. Within these carrier categories, further prioritisation might be required based on some or all of the following criteria[35]:

- sub-type of carrier: e.g. particular tape track configurations, or tape recordings at very low or non-standard playing speed.
- relevance to the sound archive's collecting policy
- originals before replicas
- significance or value of the recording
- interest in the subject matter
- uniqueness of the recording
- need for improved access
- completeness of the metadata

The next steps are to estimate quantities and the conditions of the items, identify resources needed, the staff, studio, equipment and materials.[36] From this information is will be possible to estimate costs of a migration project. The PrestoSpace Project in Europe, which has championed a 'preservation factory' approach to audiovisual digitisation with the aim to reduce costs, has a basic web-based calculator[37].

While many sound archives have yet to embark on full digitisation programmes, there are now well established digital archives, principally among broadcast libraries, that provide useful case studies [38]. Experience reveals that the time taken to copy recordings can be a significant factor. To copy good condition

[34] Persistent Identification Systems. National Library of Australia. www.nla.gov.au/initiatives/persistence/PIcontents.html

[35] See: Breen, Majella , Flam, Gila, Giannattasio, Isabelle, Holst, Per, Pellizzari, Pio, Schüller, D. (2003) IASA Task Force on Selection. Task Force to establish selection criteria of analogue and digital audio contents for transfer to data formats for preservation purposes. IASA - International Association of Sound and Audiovisual Archives; a decision tree for selecting items for digitisation is in: Neil Beagrie and Maggie Jones (2001) Preservation Management of Digital Materials - The Handbook. London: The British Library. Available from www.dpconline.org/graphics/handbook/

[36] See the PrestoSpace project in Europe website for an introduction on digitisation planning. http://www.prestospace.org/

[37] Preservation Project Calculator. http://prestospace-sam.ssl.co.uk/hosted/d13.2/newcalc.php

[38] The National Library of Australia has published its experiences in requisitioning a DMSS : Request for Tender - Digital Collection Management System. www.nla.gov.au/dsp/rft/. A useful pointer to other examples and management principles for managing digital media in general is: Neil Beagrie & Maggie Jones (2001) Preservation Management of Digital Materials - The Handbook. London: The British Library. Available from www.dpconline.org/graphics/handbook/. Other case studies are from Finnish Radio Archives: The YLE Digital Sound Archive. J. Frilander, P. Gronow, P. Home, M. Petäjä, P. Salosaari, L. Vihonen. Digicult.info - A Newsletter on Digital Culture, Issue 4 pp 23-28 (2003), and from Denver University's Collaborative Digitization Program (2005). Digital Audio Best Practices**.** Colorado, USA. www.cdpheritage.org/index.cfm

standard tapes can take about three times the playing time, a ratio of 3:1[39], although this may be speeded up by using multiple ingest methods. More difficult fragile carriers such as cylinders lacquer discs can easily take 45 minutes or more for three minutes of sound – a ratio of 15:1[40]. Reformatting times for the transfer of digital audio from one medium to another medium will vary greatly according to the carrier. Digital audio extraction from audio CDs can be achieved using ripping stations with multiple drives, so that dozens of discs can be copied in minutes. In such cases, the documentation of the process and of each digital file will take many times longer than the reformatting itself.

In practice, due to the costs of digitisation, many audio archives manage their collections by digitising the highest priority materials first, while continuing to manage the conservation of lower risk analogue carriers. The preservation of digital objects requires a continual investment in maintenance and refreshment and migration. The ‘life cycle’ concept provides a framework for understanding the key processes and interdependencies involved in the whole life of a digital object beginning with its acquisition, and may be used to estimate the total costs of archiving digital audio. The LIFE project, run by The British Library and UCL Library Services [41] to study the life cycle costs of digital assets, uses this simple formula for the total life cycle cost L, over time T:

$$L_T = Aq + I_T + M_T + Ac_T + S_T + P_T$$

where the costs components are acquisition (Aq), ingest (I), metadata (M), access (Ac), storage (S), and preservation (P). Although the model was developed for electronic journals and websites, it could equally be applied to digital audio documents.

There are other potentially useful models and standards being developed from professional digital library organisations. The Digital Preservation Coalition in the UK, the Digital Curation Centre based in Scotland, and the Digital Library Federation (an international association of libraries) are all examples of organisations developing standards and best practices in digital archiving. The Reference Model for an Open Archival Information System (OAIS) [42], an ISO standard developed by the Consultative Committee for Space Data Systems, provides conceptual models and terminologies now used in planning the design and installation of many different kinds of digital repositories. The concept of 'trusted repositories' was refined by the Research Libraries Group and the US National Archives and Records Administration, to define the requirements and responsibilities for institutions to gain accreditation as reliable digital information repositories. Those requisites may be too stringent and costly for some audio archives. While large audio archives with collections of more than a million items will normally have resources in-house for implementing a digitisation programme, smaller institutions with less resources may look to co-operation with larger facilities. The skills and knowledge required to digitise particularly from the oldest analogue formats require continuing investment in training. For archives without the technical staff and facilities, outsourcing of digitisation work, and outsourcing the actual storage of the audio assets, may be options. There are many commercial audio preservation services, particularly in the USA.

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[39] Breen, Majella , et al.. (2003) IASA Task Force, op cit.

[40] Bradley, K. (ed), 2004 IASA TC-04 op cit

[41] McLeod, R., Wheatley, P. & Ayris, P. (2006) *Lifecycle information for e-literature: full report from the LIFE project.* Research report. UCL/The British Library, London. Available from: http://eprints.ucl.ac.uk/archive/00001854/

[42] See http://ssdoo.gsfc.nasa.gov/nost/wwwclassic/documents/pdf/CCSDS-650.0-B-1.pdf

In recognition of the need to increase the skills base in audiovisual archiving, there are many short practical training courses and workshops. There are, however, few in-depth, regularly scheduled courses leading to formal qualifications:[43] Charles Sturt University with ScreenSound Australia offers a Graduate Certificate in Audiovisual Archiving through distance learning over the Internet. Project TAPE (Training for Audiovisual Preservation in Europe), funded by the European Commission on Preservation and Access, promotes awareness of the need to preserve audiovisual collections, and provides training for professionals involved in preservation and digitisation of audiovisual materials, especially for audiovisual collections that do not constitute the core of an institution's holdings.

In recent years audiovisual archiving has matured as an academic discipline and an established profession[44]. Members of The Audio Engineering Society's technical and standards committees include professional audio archivists who research and publish standards on audio format longevity, care and handling. The main professional organisations representing audio archiving are co-ordinated under the auspices of an umbrella body, the Co-ordinating Council of Audiovisual Archives Associations (CCAAA), of which the International Association of Sound and Audiovisual Archives (IASA), the Association for Recorded Sound Collections (ARSC) and Southeast Asia-Pacific Audiovisual Archive Association (SEAPAVAA) are the most important to the audiovisual archivist. The ARSC and IASA newsletters and listservs are invaluable for keeping abreast of audiovisual developments, while IASA's recent publications *The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy* (TC-03) and *Guidelines on the production and preservation of digital audio objects* (TC-04) are key documents which formed the background to this paper.

Concluding remarks

It is all too easy to underestimate both the urgency needed and the costs and time required to digitise a collection of audio documents. In a survey of 31 audiovisual archives, PrestoSpace estimated that their annual investment in preservation amounting to 30 million Euros, would preserve just 1.5% of their holdings. For tape-based audio and video holdings, with an expected average 20-year life expectancy, this would result in the loss of 40% of existing material by the year 2045 in the best case scenario, and the loss of 70% by 2025 in the worse case. Yet acquisition rates were exceeding preservation work by a ratio of four to one [45]. Alarming though these predictions are, the requirements for safeguarding audio documents are far less demanding than they are for moving image documents. For audio, there are now well established digitising procedures, accepted standards for target formats for digital preservation, and tried and tested programmes for the migration onto digital mass storage systems. The real challenges that lie ahead are to raise awareness of the risks involved if not enough is done now to migrate the large legacies of analogue audio collections onto digital stores, and to lobby for funding to take action. Given adequate investment, there is no excuse if we fail to save our audio heritage for future generations.

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[43] H. P Harrison (ed) (1990). Curriculum development for the training of personnel in moving image and recorded sound archives. Paris: UNESCO. From: www.unesco.org/webworld/ramp/html/r9009e/r9009e00.htm. In 2007 the British Library will launch an audiovisual archiving internship training programme specialising in A-D transfers.

[44] Edmondson (2004). Audiovisual Archiving: Philosophy and Principles, op cit

[45] Addis, M. J., Choi, F. and Miller, A. (2005) Planning the digitisation, storage and access of large scale audiovisual archives. In *Proceedings of Ensuring Long-term Preservation and Adding Value to Scientific and Technical data (PV 2005)*, The Royal Society, Edinburgh. Available from: http://eprints.ecs.soton.ac.uk/12231/