PRESERVATION, DETERIORATION AND RESTORATION OF RECORDING TAPE

by Steven Smolian

Deterioration of the paper used in books was recently publicized in "Slow Fires," an hour long PBS TV program shown this past year. However, the program barely touched on the aging of recording tape, a crisis which is a less widely recognized but equally imminent.

Recording studios use tape as a medium to record, edit and hold sound until it is either played back or converted to a mass-marketable format. The more quickly the master tape is transformed into a salable product, the sooner the money-generating process can begin. A commercial recording is a business investment. No one can foretell how a session will turn out beforehand, much less what the future will consider either a desert island disc or so much musical flotsam. Exploiting older recordings well after their costs have been amortized has proven enormously profitable each time home playback technology has changed. Understanding the forces which enhance preservation of the recorded master and applying that understanding to everyday studio processes are signs of far-sighted management. Producers and engineers market their product as quickly and cheaply as possible. Anything which delays delivery or adds expense gets small consideration while the clock ticks and other projects await.

Most tape recordings are used most intensely in the earliest part of their lives. The sound archivist turns this process on its head. The value of what he preserves, or produces to be preserved, increases with the passage of time. Manufacturers make price-competitive, high-quality tapes for the mass market; specifications for these tapes include somewhat nebulous lifespan projections. Future shelf survival seems an incidental consideration for most users, at least at first.

A study entitled "Prediction of the Long Term Stability of Polyester-Based Recording Media" was recently completed for the National Archives by a working group headed by Dr. Leslie Smith of the Polymers Division of the National Bureau of Standards. (It is scheduled to be published in January, 1989, though a preliminary version appeared in June, 1986). Dr. Smith presented some of the group's findings in the fall of 1988 to a National Archives committee concerned with video preservation issues.

Not all tapes stored together will fail at once. A random portion will begin to develop a variety of problems toward the end of its atmospherically determined lifespan; this portion increases as time passes. To avoid the expense of premature copying, a process is needed that would anticipate the point at which a specific tape's failure in storage occurs. This process does not exist yet. From the data in the NBS report it seems the most prudent archival policy would be to copy tape every twenty years. Ultimately, the ideal system would preserve the signal in a non-alterable, non-deteriorating medium. Technology and equipment to convert the signal back to sound should be widely available in perpetuity. No such system is offered at present.

The archivist's responsibility is to preserve everything selected for the archive, working within budgetary limits. He should maximize the use of cheaper procedures (storing tape properly) in order to postpone the time when expensive, labor and material intensive methods of copying become necessary. A copy is defined as an "unimproved" clone of the original, or as close to one as is possible with present technology.

Material preserved in a sound archive is not fodder for experimentation. Hardware and software should be selected which utilize a proven recording system with physical components that seem assured of technological survival and repairability well into the future. Consistency is essential. Changes in the basic recording system leave a confusing hodge-podge of artifacts. Learning to operate properly each system would provide an increasingly complex legacy to succeeding generations of technicians. Introducing exotic recording devices whose inner workings are proprietary would leave future archivists with unserviceable systems after the device is discontinued or the manufacturers go out of business.

It is tempting to spec in the "latest" at grant proposal time. The lab can be first on its block to have new toys to play with, to allow the engineer to learn a technology with which he can enhance his resume, and perhaps to serve as a key to easier subsequent funding. Reduced overhead might even be obtained: one 1/2" videotape is cheaper than four 10" reels and occupies less storage space. These are risky options, however.

Tape lifespan is, in great part, determined by the care taken with the tape before, during and, particularly, after its encounter with the recorder. Assuming that the tape has been designed and manufactured properly, most problems leading to premature failure result from poor engineering practice (dirt, uneven tension, bent reels, poorly maintained machines) and the effects of temperature and humidity on the tape binder and backing, either of which can alter tape's integrity, signal and ability to make proper head contact.

Tape should be handled as infrequently as possible. Transfer of body oils to tape surfaces has a long-term chemical effect and will attract other contaminates. Smoking in the studio and other working areas should be prohibited-- particulates carried by smoke are not healthy for tape, nor are some of the by-products of perfumes, food, and other quickly degradable products. Are deodorants chemically benign? Has anyone looked into the effects of negative ionizers in the studio?

Recording tape is a strip of iron oxide or other magnetizable particles affixed to a backing by a binder. Plasticizer, not necessarily a plastic chemically, is added to keep materials supple, a property tape requires in order to assure complete head contact.

A report about the effects of stray magnetic fields on tape was published in the July, 1980 issue of the Journal of the International Association of Sound Archives. In this report, Erhard Aschinger concluded that, "In practice, special care must be taken with cases housing tape recorders, recorded tapes, dynamic microphones, and dynamic headphones adjacent to each other. On the other hand, loudspeakers (except those in miniature enclosures) are not nearly as dangerous as thought up to now. Also, the AC and DC stray fields found in the path of tape recorders can be considered harmless..." In this regard, it is important to note that airport security systems use passive and active devices, and the active ones will reduce the amplitude of a tape signal. The best idea is to hand the tape around, not through the doorway to the security person.

There are three types of tape backing. Paper, used in the earliest years of the tape recorder in the U.S., say 1947 through 1950, is replete with special problems, though little work has been devoted to their analyzing. Paper-backed tape differs so widely from later tape products as to be almost an alien tape-form. Discussion of paper-backed tape must await the accumulation of more data.

Acetate entered general use in the United States in about 1949. Acetate tape snaps under stress and can be identified by holding the reel up to a strong light which should be visible through it. As it ages, acetate tape turns quite brittle.

Polyester tape was marketed here about 1960. Under stress it will stretch before breaking. It contains no plasticizer and is transparent before coating. Binder components make it appear opaque when the wound reel is held to the light. It is the most stable backing yet offered.

Acetate and polyester are different species. A product or procedure which works with one may give different results when applied to another. Acetate-backed tape is eight times more sensitive to moisture in the air than polyester. With an increase of 60% in the relative humidity, a 2400 foot long polyester-backed tape 1.5 mils in thickness, recorded at 7 1/2 ips and playing for 60 minutes on the standard 10.5 inch reel, will lengthen by about a foot, thus increasing the playing time by about 1-1/3 seconds. Acetate-based tape of the same length will be about 14 feet longer and increase running time by 23 seconds.

The thicker the tape, the greater the tensile strength and the lower the print-through. Thinner tapes stretch more easily and are more subject to edge damage. Worst is the half-mil tape on which many U. S. symphony orchestra programs were distributed in the late 1960s.

The binder holds the iron oxide onto the backing. Chemicals are added to introduce or enhance desirable properties such as adhesion, flexibility, lubrication, stability of the mix and reduction of static. Formulations are proprietary with each tape manufacturer and may be subtly altered over the product's catalog life. An entire tape line usually results when a new binder system is introduced.

Most tape today uses several lubricants in the same coating, enabling it to glide smoothly over the non-moving surfaces in its path. Poor lubricant application, evaporation, or chemical alteration may result in squealing and jerking and cause premature head wear. As raw materials become unavailable or emission rules for manufacturing are altered, changes in formulation or processing are made which sometimes work and sometimes create new problems.

The NBS report cited above found that polyester-urethane binder system tape kept at 65-70 degrees farenheit and 35-40% relative humidity will last perhaps fifty years, provided it is used, moved and stored under these near-utopian conditions. Allowing relative humidity to fluctuate will substantially shorten this period. Tape kept under casual storage conditions in a northeastern U.S. city may find its lifespan reduced by half or greater. Although there is no similar look at acetate-based tape, personal observation shows it even more susceptible to problems resulting from water in the atmosphere.

Print-through is the unintentional magnetic transfer of the recording on one layer of tape to adjacent layers. According to a paper by Bertram, Stafford and Mills, "The Print-Through Phenomenon," in the October, 1980 issue of the Journal of the Audio Engineering Society, it is a natural consequence of proper recording, occurring most intensely immediately after recording with accumulation diminishing substantially after the first hour. Levels which saturate the tape, and increased molecular activity, a consequence of exposure to elevated temperatures, will intensify the problem. Rewinding a few times before playing dissipates the greatest part of it.

Some sources recommend winding tape annually in the fast forward mode, then slowly playing it back to its stage position; this practice not only lowers the level and permanence of the printed signal but also reduces the tendency of tape layers to adhere to each other and to cause blocking and delamination problems. Not doing this so frequently, however, may have other positive effects which offset the virtues of yearly tape shunting. Winding retightens the tape-pack and this freshly accumulated tension restarts the tape stretching cycle anew. Thus ritual rewinding may cause more ills that it cures. A closer study of these issues is required.

The AES paper mentions methods to reduce print-through by retaining the signal affixed to tape with bias current and removing that which lacks it. No device designed for this purpose seems to have been marketed since the paper was published, but there is little doubt that tape studios would welcome such a tool.

Imprecise slitting during manufacture causes edge curl and width variations which exceed the recorder's guides tolerances The resulting edge crimping causes tape to ripple. Editing becomes difficult since tape will pop or fall out of a standard-width splicing block.

Dust on or around the heads or on a cue-tip used to clean the heads after running a reel may mean trouble. The cause can be dried-out tape. Evaporation of the lubricant may indicate not only that the ribbon has become stiffer and rougher, making for poorer head contact, but that what is passing the heads is wearing them--a sandpaper effect. Tape debris can also cause frequency loss by blocking the head-gap and may record a high-frequency whistle if the erase head becomes clogged. Dirt may be drawn into the storage pack to form bumps around which the tape reconforms. Dust should be removed before playing by running the tape through a cleaning mechanism. Analysis of this dust may offer clues to the tape's health.

The few high-speed cleaning machines now being marketed are designed for computer applications and cost about $7,000 each. I have seen no data about how they deal with tape which contains splices or is shedding. Adapting a regular recorder running at a more reasonable speed should be tried. The heads can be removed and the tape path rerouted to accommodate 3M's pellon tape-cleaning fabric. Prudence suggests that cleaning be preceded by playing the tape through at slow speed and checking for splice and tape integrity.

Dust may also indicate more serious problems unique to that formulation which emerge during aging, a matter of specific tape chemistry. Write or call the manufacturer: if it's a generic problem, he's undoubtedly heard about it from others already and may have a solution. Bear in mind that since the formulation of tape varies, a treatment effective on one may have a completely different result on another. And just because distressed tape acts one way at the beginning of a reel does not mean things won't change as the tape unwinds.

Sometimes the spoor of the maintenance process has unwanted after-effects. Chemicals used to clean recorders may leave a residue on the tape or be absorbed into the pinch-roller where it later leaches out and interacts with the tape. Additional problems are caused by using drugstore-grade isopropyl alcohol which is about 10% water that remains after the alcohol evaporates. Water in the tape path can cause considerable difficulty.

Tape manufacturers do their best to give the industry the finest possible product. Accelerated aging under laboratory conditions is a useful tool for weeding out defective tape designs before they are marketed. It is also advisable for products which are still in commercial distribution. Many problems emerge only after time passes. Symptoms include tape turning powdery, dry and brittle, gooey or actually loosing portions of the oxide and, when backed, backing. Skewing and squealing often result. Backcoated polyester tape has been identified as the villain in Scott Kent's article in the July, 1988 issue of Recording Engineer/Producer, but closer inspection reveals that the problems occur on most formulations, polyester and acetate. Most professional quality tapes since the mid-1960's have been back-coated, and as this period is the one most heavily drawn upon for CD reissues, engineers have a great awareness of problem tapes, problems blamed on back-coating.

I discussed this issue with technical representatives from Ampex, Agfa and 3M at the November, 1988 Audio Engineering Society meeting. They suggested a slow recurring process which temporarily rehydrolyzes and rebonds the tape. Most treated tape quickly reverts to its deteriorated state--some within 30 to 60 days, some in a day or so. The safest procedure is to copy the tape the same day the recurring process is completed. In many cases it is necessary to clean and remake splices before copying, so a considerable amount of consecutive studio time is needed. Freshly restored tape is particularly vulnerable to deformation and disintegration caused by worn heads and rough tape guides.

Acetate tape should be treated so the water which it lost can be absorbed back into it evenly. If wound tightly on the reel, it has to be loosely rewound before treatment as there has to be enough slack to enable each layer to expand as hydrolysis occurs. If the tape is somewhat loose when first treated, it might be advisable to run a short cycle, to allow the tape to stabilize slowly to studio temperature and humidity, then to wind it loosely and treat it for the balance of the required time. This would give severely deteriorated and fragile tape a chance to acquire some tensile strength and to partially recure before subjecting it to slow winding.

Acetate tape on its reel should be placed in an environmental chamber with precise temperature and humidity controls set to 105 degrees (plus or minus 5 degrees) for 8 to 12 hours at 80 percent relative humidity (plus or minus 5%). This oven should be dedicated to tape restoration and not have been used previously for cooking, as any residual fat may well ruin the tape. After completion of the heating cycle, the tape should be wound at normal tension in both directions and left in the tails-out position if it is not to be copied immediately.

Polyester based tape calls for similar treatment, but at 130 degrees fahrenheit (plus or minus 5 degrees) for 8 to 12 hours at 10% relative humidity. The technical staff at AGFA use a rapid, labor-intensive industrial process with critical parameters which involves use of a microwave oven to prepare certain flawed tapes for immediate copying, though they strongly advise this not be performed by those without special training. They also suggest that the slower method above will be effective in most cases;

their microwave procedure was developed so that large quantities of tape could be copied in a short time. The oven should be allowed to slowly return to room conditions before tape is removed. This avoids thermal shock and condensation.

Recuring mimics part of the tape manufacturing process. An environmental chamber offers temperature and humidity devices which control the process at the necessary, close tolerances; a professional convection oven may be nearly as good, and a new one of either type costs $ 3,000 and up. It is far more difficult to manage water than temperature in an oven's atmosphere, especially over a long cycle, so even a temperature-precise dry oven is inadequate without proper humidity control.

Tape should be brought from storage to the studio at least a day before use so it can stabilize under its new environmental conditions. If it has been subjected to a hot-wet environment, store it in a cool-dry place for a few days and slow-wind it there first. An attendant should not only be present, but have his attention focused on the slowly moving tape. Usually physical deformation is most severe along the edges. I once rescued a mono, full-track tape which was deckle-edged and had oxide chipping off by playing it back on a four-track, 1/4" head with all channels working, dubbing to a four-track, 1/2" copy which was then played down, track by track, the appropriate good portions noted in the score, matched for levels and mixed. I assume that a half-track head positioned down the center of a full-track tape would minimize distortion caused by poor head contact at the tape edges.

Splicing is a necessary evil when editing sound recordings. Since most splices age badly, they must be cleaned and remade before copying tapes. Old splicing tape must be removed, residual adhesive cleaned off the splice area and any adjacent layers to which it may have bled, and new splicing tape applied. Time for splice-cleaning should be included in budget estimates. At elevated temperatures, 3M's splicing tape #67 adhesive cures rather than becomes softer and more stringy and is one of the few splicing tapes which work on back-coated tape as well.

Products used in studios for splice cleaning have been reported as including Ronson lighter fluid, mineral spirits, and isopropyl alcohol diluted with distilled water, all applied with a cue-tip, and talcum powder. None of these have been lab tested. Empirical observation discloses that mineral spirits, though it dries more slowly, leaves less color on a cue-tip, seemingly having the least chemical effect on the master tape. LAST has just marketed a lubricant and restorative for polyester tape. It is too new to have been proven as yet, but it is being tested.

Uneven tape wind causes air pockets within the pack. Tape will corrugate and crease within it and will result in variable head contact. These folds are also prime locations for uneven evaporation of binder materials and for moisture to enter the tape system. Tape should be slow or library wound with even tension throughout and should not move at the center of the pack when the outside layer is pulled. Isolate recorders which cause improper wind and do not use them until they have been properly readjusted.

Reels must not interfere with tape motion; those with bent flanges should be discarded. Tape scrapes the reel edges as the pancake feeds, causing uneven motion and, in extreme cases, a sharp, jerky snap which makes the tape bounce as the heads are passed. A bent flange makes even more trouble when it is on the take-up side, since the tape enters the pack at different heights, creating uneven feed tension during each wrap. Tape stretches over time to equalize these tensions which then cause pitch drops and warped tape. Wind tape onto reels slowly; if the recorder is operating well enough to produce a flat tape pack surface on the take-up reel, use the library wind, a slightly faster than normal tape speed (which also avoids head contact) that is available on some recorders.

Scatter wind results from incomplete rewinding, poor tape guide adjustment or worn guides. Edges of random portions of the tape will stick up where it is prone to being folded over or, worse, stretched along the exposed edge. It also allows unprotected edges to interact with the atmosphere more quickly than the balance of the tape. Always run tape to the end, then rewind completely. If playing only a portion of the tape, wind it back to the head and then slow or library wind it. DO NOT FAST FORWARD OR FAST REWIND TAPE AS THE LAST STEP BEFORE STORAGE.

Plastic reels deform, break, (mostly) use slitted hubs, and are made by accessory manufacturers as well as tape suppliers, with consequent wide variations in standards. They should be avoided. Hubs with threading slots make a place over which the tape will dimple when winding, causing spoke pressure lines and later tape deformation over them. The preferable solution is to use unslotted reel hubs; next-best is to wind unrecorded tape for about a half-inch at the reel center, a "pad." The new 10" precision reel, now supplied with some 3M and AGFA tapes and available separately, has truer mounting surfaces on the reels which allow the flanges to fit over extensions on the hub rather than to be slapped on the top and bottom of it, creating a more rigid reel. The hub is machined and six screws rather than three affix the flanges into, not onto it. The improvement achieved by winding tape onto precision reels and storing it properly is a simple and productive method of extending tape life.

Since precision reels are a minimum of 10-1/2" in diameter, tape on smaller reels should be run onto the larger ones. This requires shelving adjustments to take the larger reels and copying the documentation written on the 7" box, but it is necessary work if tape longevity is your goal.

Skewing hinders tape from making full and even contact with the playback head. If this occurs after tape recuring, a device should be employed to hold the tape gently against the head. Older recorders used pressure pads but introduced friction which caused head wear, sometimes slowed the reels, and caused brittle tape to flake or break. It has been many years since I've seen a professional machine with pressure pads, but the concept is an avenue worth investigation. I've had a machine shop build a bearing-seated pressure roller with adjustable tension for my playback machine. If tension is carefully adjusted and monitored, splices pass easily and a steadier signal results.

The introduction of phasing problems caused by damaged tape is a field which also requires investigation. Skewed tape means one edge arrives at the playback head ahead of the other. A broadcast product called the "Phase-Chaser" could well be effective on stereo tapes but is untested. The loose tape end should be affixed to the reel with an adhesive backed hold-down tape which does not create dust as the drying adhesive ages. 3M makes two products, # 83 and # 8125, for this purpose.

Playback speed should equal that of recording. Beware of pitch drop from torque variations between feed and take-up reel during recorder operation, a habit of older Ampexes in the 300, 350 and 440 series as well as some other reel-to-reel and cassette recorders. Pitch should be checked at the beginning and end of music on each reel. Assuming the tape playback machine has a continuously variable pitch-adjustment control, the tape-counter and pitch-correction facility can be used to plot where to make speed adjustments to the original before making dubs.

When making copies, record and playback machines with the lowest possible tape motion variation should be employed so as to limit wow and flutter build-up. Wow and flutter is always greater at lower recording and playback speeds. I make all archival tapes which contain music at 15 ips. The lower the tape speed of the original, the more important it is to run high-speed copies to preserve what quality is present on the master. Compensation for the loss of any low frequencies introduced by this process may be adjusted when making the subjective master. Wow and flutter build-up during the copying process erodes musical integrity more than very high or very low frequency loss.

The playback head should be adjusted to be in a position identical to that of the recording head at the time the original recording occurred. Standard engineering practice requires each tape to contain high-frequency set-up test-tones which guide later operators in manipulation of the playback head to achieve this goal. Most U.S. archives do not do this even now. Adequate techniques have yet to be developed to replicate this head position when, as is so often the case, there are no set-up tones on the source. Normally this problem is solved by elevating the high end of the audio spectrum via an equalizer, and rocking the head until the high frequencies peak, as determined by ear or meter.

An archival master contains all the original sound, made with the reciprocal of the original recording equalization. Nothing should be altered by the engineer which is a reflection of his judgment except speed correction. All signals must be retained in the event a future enhancement system is developed which would require the original sound information. Thus, even even those portions of the audio spectrum which may make the original uncomfortable to listen to should be preserved in order to obtain an objective master copy. A sonically adjusted listening master, subjectively equalized, can be run, often simultaneously, from which service copies can be drawn. My procedure is to make two identical archival masters, placing one in normal use, the other off-site in a storage vault. A pair of listening masters is also made and distributed in the same way. I also save the original in the off-site facility.

Hiss at low levels is inherent in the analog tape recording process. Each time a tape is dubbed, this noise in the master is added to that of the copy. Considerable background noise thus accumulates on tapes many generations down the line. Dubbing at high recording levels reduces hiss somewhat but may increase print-thru. Overrecording will introduce distortion.

Dynamic noise reduction systems have been developed which compress the signal's louder and quieter portions so that they can be recorded at higher levels, then expand the material in playback to its original dynamic range. Though sharply reducing generational hiss build-up, most noise reduction systems leave an aural fingerprint, however slight. A subjective comparison of four professional noise reduction systems can be found in the July, 1988 issue of Recording Engineer/Producer. There has been no unbiased, laboratory generated study so far analyzing how well each system cancels the aural effects introduced by the compression-triggering mechanism when it reverses itself in the expansion mode.

When dubbing archival tape copies, then, a choice must be made between hiss build-up and the possible introduction of sonic problems from using a noise reduction systems. This policy decision should be made by each archive. If a noise reduction system is chosen, however, other users of this material such as the station broadcasting a given orchestra should be equipped to decode tapes from that orchestra's archive.

Archival storage of tape with leader should be avoided. Paper leader has no static but absorbs moisture easily. I know of no testing done for the acidity of paper leader but I have observed it changing shade and becoming brittle. If leader must be used when tape is being prepared for storage, paper should be replaced by plastic. Some plastic leader absorbs and generates static. Static discharge creates tape and head magnetization difficulties. 3M's Leader Tape #61 and #62 have a proprietary anti-static coating on them to prevent this. To separate portions of a tape in storage, the best method is to replace all leader in the master with similar lengths of the recording tape itself. Archival copies should contain no leader at all as this violates the tape's integrity.

Boxes should be stored on edge in order to prevent pack shifting, uneven stress and consequent physical tape distortion. The tape box should be of low acidity products throughout. There must be an insert which allows the reel to be supported by the hub so that, when shelved vertically, the flanges do not bear the reel's weight. The box spine should be clear of logos or advertising so that written ID can run from top to bottom. This enables rapid scanning of boxes on the shelf without the eye having to "climb stairs." Hinges and glues should conform to long-life and chemically neutral requirements. Boxes should be hinged along the inside seam as well as outside since they are required to hold together for 25 to 50 years and this, the box's moving part, is very prone to failure.

The Library of Congress has developed its own tape and film storage box made of polypropolene, a non-deteriorating plastic, with an added fire retardant. The cover is not hinged to the box but fits over it, secured by Velcro. To be studio-useful, a labeling surface which takes ball-point ink will have to be affixed to the back. Cost is roughly $ 3.00 per box plus label, in quantity.

The damage suffered by tape from box products is discussed in Jean-Marc Fontaine's report, "Degradation de l'Enregistrement Magnetique Audio." His test results show that the effects of melted plastic harms tape more than charred cardboard.

The recording should be placed in a closed plastic bag with a non-magnetic, non-corrosive metallic foil layer. Some say that placing the foil facing the tape avoids plastic migration or decomposition products affecting the stored item, though others consider it overkill. The bag not only protects tape from what is outside the box but also captures evaporated material in a limited space which prevents more chemicals from exuding. Tape should be bagged and sealed under climate controlled conditions, preferably 25% relative humidity. It should be placed in the open bag and put over a jig which conforms to the hub insert and its support, then sealed. This assures enough slack in the sealed bag so the reel will fit over the hub within the box well enough to remain suspended when in vertical storage.

Aging tape generates acids. Acid scavengers might be added to the plastic bag material, a concept just being considered. Decomposing paper creates gasses. If a written or printed item must accompany the tape, it should be xeroxed onto non-acidic paper. If labels are to be affixed to the box outside, they should not come off during the recording tape's lifetime, leaving a box with no identification. The film archive at the Library of Congress has uncovered a suitable adhesive made by 3M, their product #7110. The Nopper Beckett Corp., in Lionville, Pa., supplies labels using this adhesive.

The NBS study, cited above, found that when continual access to tape is required, the preferred temperature for adjoining studio and storage areas is 68 degrees fahrenheit (plus or minus 3 degrees) at between 35-40% relative humidity. Long-term storage at 50 degrees fahrenheit (plus or minus 3 degrees) is better for the tape but uncomfortable for humans. Storing tape significantly below this temperature creates problems. Rules for using items placed in long-term vaults should be provided when tapes are brought to a studio, and at least 24 hours allowed for each item to stabilize at the new atmospheric conditions before being used.

The recording surface, binder and backing expand and contract at different rates. Rapid environmental changes cause flexing which weakens the unit even as bending a piece of metal back-and-forth would do; hence the importance of stabilizing tape in the playback environment before using it. Tape is most vulnerable to atmospheric damage when being moved between environments. Proper temperature and humidity maintenance at the warehouse and in the studio are ineffective if the vehicle transporting tape between them achieves a cargo compartment temperature of more than 140 degrees fahrenheit, inducing thermal shock twice--during loading and unloading. Tape should be moved in a vehicle with a functioning temperature control system which should be left on should the driver stop for food or sleep. During winter, an electric blanket can be effective. Marlow Industries of Dallas is developing a transporter which can be loaded into a truck. It has a built-in temperature and humidity control system with a time lock which is programmable to adjust the interior atmosphere from that under which it was loaded to that of the destination. It looks as if it depends on an external power source and may thus need an extra auto battery.

Operation in tropical environments presents special problems. The mechanics of moving a tape across stationary surfaces at precisely uniform speeds comes into play. High temperatures which can soften the oxide coating and the high relative humidities which can change the surface friction (thus lubrication needs) are extremely difficult to handle in tape designs. Formulations have improved over the years which allow tapes to withstand humid environments better. This, however, is little consolation to someone who has a recording on an old tape which has seen extended tropical storage conditions. A tape preservation and restoration facility should not be located in a tropical environment unless the studio is protected by perpetual temperature and humidity controls with appropriate power backup.

Fluorescent light should be avoided or, if this is totally impractical, ultra-violet filters should be used since UV causes decomposition of plastics. A carbon dioxide or halon type fire extinguisher should be available since they cause no damage to the tape.

Videotape is basically the same as that used for audio but is more fragile since it is thinner. The cassette format, audio as well as video, creates additional stress on tape, both in handling and in the storage environment.

We all have hopes and expectations of digital recording easing the sound archivist's burden, but some issues require resolution before this technology can be considered fulfilling archival requirements. There are two elements within the digital question. Digital recording, a technology, should not be confused with the various media to hold the encoded digital signal--DAT, compact discs, etc. The present digital system, when considered from an archival standpoint, is limited by the 44.1 sampling rate through the loss of hall resonance and other quiet noises during conversion. This violates the principle of reversibility--something is lost in recording which cannot then be accurately restored. The latest version of the Sony 1630 system presumably deals with this problem, but there has been no opportunity to test it. Should this, in fact, be the case, then digital manipulation of those sound elements which interfere with a clear signal--clicks, pitch fluctuation, etc.--may enable us to make a copy whose aural result should be a significant improvement over what we can now accomplish through even the most advanced analog methods. This ability has already proven effective on material where intelligibility was considered more important than tonal and ambiential accuracy.

But what then? How does one store the finished results? A digital signal on magnetic tape cannot be preserved with any assurance that it will meet even a twenty-year minimum archival preservation goal. Tape is wound under tension. It cannot be loosely wound without creating other problems which shorten storage life. Over time, these forces redistribute themselves throughout the storage reel, stretching the tape in the process. During recent testing at the NBS, tape creep, developing over a relatively short storage period, caused dimensional changes in the tape which seem to have created misalignment of portions of the signal exceeding the error-correcting coding's tolerances. The problem is exacerbated when using the 1/2" video cassette format for digital encoding and storage. The tape is thin--1 mil or less--with consequent lower tensile strength. At the NBS a digital signal on a BETA cassette was recorded and played back immediately with total success, only to find that some of it was beyond recovery some short time later. A new signal was recorded over the old one which then reproduced flawlessly. The only variable element in the equation was storage time, and the only meaningful change which could occur during storage was tape stretch. Accelerated aging also caused the interior mechanism of some video cassettes to experience dimensional changes before the tape did and may prove more troublesome than tape failure. Unexplained loss of a digital signal is a phenomenon known to the engineering departments of most record companies and this experiment seems to indicate at least one cause.

Even using manufactured CD's for storage is risky. We really don't know how well they stand up to time, and the variations in making them--sealing or not sealing edges, the inks used to print identification data on the disc, etc.--make all longevity data specific to individual manufacturing processes. This issue was raised in the British press this past summer.

We cannot put an unproven medium into service. Even were a digital restoration process to emerge which fulfills archival requirements, there is no twenty-year or greater storage medium reliable enough to hold the code. This is analogous to the universal solvent: there's nothing reliable enough to store it in. If preservation is the goal, digitally processed signals should be converted to analog tape recordings.

Home remedies are used in studios to deal with many of the problems I've mentioned, but systematic study must replace folklore. We need to:

1. Establish standards for the minimum life expected of a of a sound archival medium, to be no less than that of audio tape;

2. Design specifications for a recording tape specifically for use in archives so that we can petition the tape manufacturers to develop such a product;

3. Measure existing tape against these specifications. Tapes should be ranked and the results published so that archives can decide what tape to adopt;

3a. An independent lab should perform these tests and have new tape formulations submitted as they are marketed;

4. Establish standards for materials: reels, including the precision reel, the 7" and smaller reel, hubs, boxes, labels, splicing tape, etc.;

5. Establish engineering standards for archives. This would include tape speed for copies, for acceptable signal-to-noise levels, for wow, flutter, documentation, etc.;

6. Create standards for signals to be placed on archival copies. These should identify the copying method used (analog, digital), the head azimuth position, level, noise compression system employed, etc.;

7. Investigate possible uses of other technologies to encode tape engineering and content data so that, should a tape be separated from its package and reel, it does not have to be played to be identified;

8. Have guidelines for equipment for use in archives;

8a. common sense inspection, including explanations of manufacturer's specifications;

8b. basic procedures with common tools- test tapes, for instance;

8c. laboratory testing;

9. Rank commercial products which are contemplated and marketed for use in the archive. Consumer's Reports furnishes a fine model;

10. Establish standards for the development of a new archival sound-storage system. It should be unerasable and be capable of having the signal extracted without the losses caused by conversion from one medium to another;

11. Identify the general problems and those unique to each tape backing type as affects use and storage requirements. Establish appropriate storage and studio handling procedures;

12. Design a reasonably priced tape cleaning machine for audio rather than computer purposes;

13. Study methods traditionally used to clean splices and their effects on tape lifespan;

14. Have procedures for dealing with tape which is shedding or bleeding oxide;

15. Develop ways to work with skewed and other deformed tape;

16. Investigate the effects of storing tape in video and audio cassettes. Look into the possibility of removing archivally useful tape from cassettes so they can be placed on reels;

17. Study all sound-carriers including film and the various video formats to deal with any special problems they present in storage or playback;

18. Have as much information as possible about all tapes which have been commercially available worldwide. This includes:

18a. Descriptions--type of backing, thickness, if backcoated, years available, sizes available, markets for which intended, color, etc.;

18b. An anecdotal file of engineering experience with each tape;

18c. Data to deal with changes in the make-up of tapes which use the same product number but are altered chemically or in the method of manufacture over time;

19. Devise a method to identify tapes which lack printing, e.g., spectroscopic?

20. Identify the time when tape is about to fail and should be copied. Since tape generates acid as it ages, some way of measuring this output may prove a useful indicator. Perhaps heat changes within the tape-pack may also be useful in this regard;

21. Study oxide dust shed during playback, and what it may indicate about the tape's condition;

22. Look at the effects of climate, particularly in tropical environments, on tape and on recorders;

23. Investigate the methods used to deal with aging acetate-based film and their possible application to acetate-based recording tape;

24. Design and test devices to reduce print-through;

25. Study the effects of rewinding tape periodically on print-through and on tape stretching;

26. Follow-up on the Library of Congress Preservation Lab in-progress study of LAST's newly marketed tape restorative system;

27. Devise ways to deal with tapes lacking test tones;

28. Find techniques to correct problems of phasing, etc. resulting from skewed tape for mono as well as stereo signals;

29. Investigate methods for assuring better contact of warped tape with playback heads;

30. Develop ways to compensate for changes in tape speed during recording when playing tape back on a constant-speed machine. Computer technology looks promising here;

31. Design a machine for playback only which will include various devices to enhance the sound of older tapes;

32. Test the effects of various noise reduction systems;

33. Keep abreast of changes in digital technology which may affect sound archive processes;

34. Investigate the materials, methods, and effectiveness of bagging and sealing tape;

35. Study the effects on tape of smoking, foods, perfumes, etc.;

36. Study the effects of negative ionizers on tape;

37. Consider the effects of dealing with the above problems upon archives:

37a. in locations with different general and technical education;

37b. in locations without consistent electrical service;

37c. where solutions are tiered to different levels of funding;

38. Look at the copyright requirements and ethical concerns generated by the tape preservation processes;

39. Investigate the accelerated aging testing methodology, and determine what it can and cannot be relied upon to tell us. With back-coated tape some part of the process has obviously failed. Accelerated aging is used in studies of many materials and should have generated a fair-sized literature;

40. Educate recording engineers to the archival consequences of their work;

41. Prepare guidelines from this and later studies to better inform foundations and archival administrators as they consider grant applications and project funding. When framing these studies, it is extremely important to determine not only when problems begin but how quickly they advance and when they become tape-disabling. Each time-sensitive component of the tape deterioration cycle might then be used as a compass to point at those cases in the archive requiring the most immediate attention. Some of these issues are also raised in the ARSC-AAA Preservation Committee Report for the National Endowment for the

Humanities. Let us hope that the research phase of their project is funded so that we can move to a more complete understanding of what we have done, are doing and need to do in order to preserve the bulk of our recorded legacy over the last 40 years, for there is a vast amount of it on tape, more than on disc, more than we have time to save.

The paper people are faced with the same crisis and the same calendar. I have no doubt competition for preservation and restoration funds during the 1990's will be fierce, both with them and amongst ourselves. Why, when we have the technology, should we convey to the 21st century anecdotal evidence of our sound culture when for the first time in history we have the opportunity to do so by passing on the sound itself?

Acknowledgments

A wide variety of sources was consulted: publications and personnel of tape manufacturers, NASA, the National Bureau of Standards, National Archives, Library of Congress, the Preservation Committee of the Audio Engineering Society, etc. This paper was originally delivered in May, 1988, at the ARSC national conference in Toronto, and was later presented to a joint meeting of the Washington, D.C. ARSC chapter and the local Audio Engineering Society chapter; various versions of this manuscript have been circulated. Issues raised in subsequent discussions have generated a chain of revisions of which this publication is the latest. I deeply appreciate the help from all concerned. Thoughtful responses were received from, but by no means limited to, Richard Burns, Delos Eilers, Jean-Marc Fontaine, John French, Scott Kent, Jim Mallinson, John Matarazzo, Skip Pizzi, Dietrich Schuller, Warren Simmons, Gordon Skene, Leslie Smith, William Storm, and Jim Wheeler.

Errors, misunderstandings and just plain confusion are the responsibility of the author. The ARSC AAA Committee is working on a handbook for sound archives, into which the foregoing article and helpful responses to it will feed.