ARCHIVING THE AUDIO-VISUAL HERITAGE

THIRD JOINT TECHNICAL SYMPOSIUM



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Editor's note:

The debate that followed many of the presentations at the Symposium appears, in slightly abridged form, adjacent to the text.

Money is no problem, finding the money is the problem.

Carlos Arnaldo, Unesco

Preface

George Boston

This Joint Technical Symposium was the third organized by the international federations for audio-visual archives. The first, held in Stockholm in 1983, dealt primarily with film and video. The papers reflected the concerns of the day: the handling of film and video tape, the preservation of nitrate stock, and the impact of new technologies such as optical discs.

By the time of the second JTS in Berlin in 1987, the first public worries about the chemical decay of safety film and magnetic tape stocks were being voiced. In addition, with the assistance of the United Nations Educational, Scientific and Cultural Organization (Unesco), a dialogue was started with the manufacturing community, and a Consultation on Curriculum Development – training for audio-visual archivists – was held.

At the Third Joint Technical Symposium, concerns about the chemical stability of carriers were beginning to dominate the thoughts of many archivists. Delegates were discussing the need to copy images and sound stored on carriers previously thought to be indestructible, and the usefulness of digital recording techniques for this purpose. The future use of computerized work stations was a logical development of the move to digital formats, and papers were presented on this subject.

Speakers from many different countries came to the Symposium: from Czechoslovakia, Thailand, Kenya, Australia, Brazil, St Lucia, Canada, the United States, Belgium, France, Japan, Austria, Denmark and Germany. The inclusion of the debates in this Report underlines the interactive role of symposia such as this; they are events for the exchange of information. The comments of speakers from the floor are as important as the formal papers in advancing the spread of knowledge and in increasing the awareness of the problems facing technicians in sound and moving image archives. Different solutions to problems are being tried in different parts of the globe. The only way to achieve the best solution is for the practitioners to exchange and discuss ideas. Without this interchange, an increasingly important part of the world's cultural heritage will literally crumble away.

Unesco is greatly concerned with the survival of the sounds and images stored on the material held in audio-visual archives around the world. As the great variety and richness of the human cultural heritage is increasingly eroded into one universal culture by the impact of modern communications technologies, enlightened governments and organizations around the world are making use of these same technologies to try to preserve for future generations the aural and visual impact of these cultural riches. The Organizing Committee would like to put on record its thanks for the help received from Unesco in arranging this Symposium, which is part of a much larger drive to preserve the films, the tapes and the discs used to store the sounds and images of the cultures of yesterday and

today for the peoples of tomorrow. Without the financial support of Unesco, the cost of attending the Symposium would have been prohibitive to all but the richest archives. Unesco also funded the air fares and accommodation costs for a number of representatives from archives in developing countries.

The Organizing Committee would also like to thank George MacDonald, Director of the Canadian Museum of Civilization, for providing the venue for the Symposium. The facilities offered were excellent, the surroundings spectacular. The staff of the Museum made us very welcome, and with great cheerfulness and energy coped with all the demands placed upon them. At all times, they made us feel that we were doing them a favour by invading their institution. Space permits me to mention a few names only: Frederick Granger, Manager of Interactive Technology at the Museum, organized all the facilities for the Symposium in Ottawa; Pierre Filion and his colleagues of the Museum's Security Department kept a helpful, but watchful, eye on the activities of the delegates; the ladies and gentlemen of the Audio-Visual Department bore with great humour and fortitude all the trials of liaising with speakers about their slides, tape inserts, films, etc; and the catering staff, it seemed, provided a constant supply of coffee and light refreshments for the Symposium delegates from dawn to dusk each day.

Milton Keynes, March 1992

Introduction

Madame Breda Pavlic

It is indeed a great pleasure for me to greet you today on behalf of Unesco and the Director General of Unesco, Mr Federico Mayor. I'm particularly glad that this meeting is taking place here in Ottawa, which the Director General visited on his recent official visit. I must say it was a wonderful visit, a very, very productive one, and we're glad that Canada is so supportive of all Unesco's programmes.

What you're discussing here – the increasing problem of chemical and biological decay of the films, tapes and discs used to store sounds and images – is of great importance to Unesco. Not only is it important in terms of the further development of scientific knowledge in this particular area and the enhancement of international cooperation among specialists and scientists focusing on these problems, but it also of great importance for Unesco in at least two other aspects. The first aspect is Unesco's endeavours to preserve and promote the world's cultural heritage: a great task indeed, and a very noble one. The second aspect is the organization's concern to enhance creativity in all its forms, and what you're discussing here enters this in many ways. In both cases audio-visual archives are extremely important instruments for the preservation of cultural values and society's collective memory and, indeed, as a means of communication across time between generations and across space between different cultures. Your daily efforts, ladies and gentlemen, are therefore very precious to Unesco's own endeavours in the areas of education, culture, science and communication. It is the result of your work, your knowledge, as well as those of other NGOs in other areas of our concern that make Unesco a worthwhile national organization. May I repeat what Mr Mayor, Unesco's Director General, never tires of saying: Unesco's real wealth and strength, not to say power, are the thousands of scientists, educators, artists, researchers, technicians in various disciplines, architects, and so on. Unesco is what these men and women (and this includes all those present at this meeting) contribute intellectually and practically to resolving the enormous problems and challenges that the world community faces.

On the basis of this meeting, and with your permission, the message that I would like to convey in turn to the Director General and through him to the member states, members of Unesco and the secretariate of Unesco is the following:

This meeting, like your previous meetings, manifests clearly your high professional competence, your genuine concern for the preservation of audio-visual archives, and your dedication to finding solutions that could help us all to save the frequently endangered cultural heritage. I am convinced that you will succeed in finding the answers to the many questions that you meet with in your research and which you have the opportunity in these three days to share and discuss with researchers from 22 countries present at this meeting. It is good to know that Unesco has helped, albeit in a very financially modest way, the materialization of such a gathering. Let

George Boston, Chairman, Technical Coordinating Committee: *One of the major supporters of the work of the Technical Coordinating Committee and of all the archive organizations that are helping to organize this event has been Unesco. We are relatively small organizations with limited funds, and Unesco has been very supportive, very encouraging, in helping us to do the work that we're trying to do. As we have delved in to the work, the boundaries are becoming ever wider and, for that reason, I'm very pleased to be able to welcome Madame Breda Pavlic, the Unesco representative in Canada.*

me conclude by reassuring you that Unesco will continue to support wholeheartedly your endeavours within the limits of its possibilities. We look forward to the results of your work, as individuals and of the meeting as a whole. We hope that you will continue to develop your cooperation through future joint technical symposia such as this one. Once again, congratulations, and thank you for giving me the floor.

Ottawa, May 1990

Session 1

Problems Facing Archives and Long-Term Stores of Audio-Visual Material in Countries with Adverse Conditions

Chairman: Harald Brandes

Breakdown of Sound and Image Carriers in the Caribbean

Embert Charles

Harald Brandes:
Our first speaker is Embert Charles, the Director of the Folk Research Centre in Castries on the Caribbean island of St Lucia.

Introduction

My presentation will deal with the breakdown of sound and image carriers in the Caribbean. As I was asked not to be too technical, I will give you what we consider to be a preliminary report, and answer any questions in the discussion at the end.

One of the main features of the Caribbean culture is the tradition that embodies a rich technology, forms of communication and creative expression. Likewise, because of the absence of a scribal tradition, cultural information has, in the past, been passed on orally from generation to generation. The production and preservation of cultural traditions on audio-visual media, particularly audio and video tape, became critical because of threats to the survival of Caribbean culture as a result of new patterns of socialization influenced largely by new communication technologies.

The use of magnetic tape to record sound and images has not been without problems, as with most technologies developed for use in temperate conditions and used in tropical climatic environments. This is a preliminary survey of the use of magnetic tape for the documentation of the audio-visual heritage in the Caribbean, the problems encountered, and the responses to these problems.

The Caribbean climate

The Caribbean region totals a land area of 257,662 square kilometres, and staggers in small islands and land masses between North and South America. Two major bodies of water wash the shores of these territories: the Caribbean Sea, noted for its gentle breeze at an average of 16–20 mph, and the Atlantic Ocean which has given birth to and nurtured numerous tropical storms and hurricanes with high winds and fluctuating levels of humidity.

The mean annual humidity in the Caribbean region varies from 73 to 80%. The humidity can fall to 68% in our traditional dry period from April to July when rainfall is usually low. High humidity occurs in the hurricane seasons and in what we call our cold period – September to February – with the humidity rising to over 80%. It is not uncommon to register humidity levels of 100% during this period. We took some readings during January this year which showed the following pattern of humidity: between 1am and 6am an average of 85%, from 10am to 2pm an average of 75%, and from 8pm to 11pm, 80%. The humidity is usually higher during showers.

High temperatures are another significant climatic feature. The annual mean temperature is about 28–30°C with highs of 32°C or above in the dry season, and with lows of 23°C during the latter part of the year. There are also some significant correlations. Average

wind speeds of about 16mph occur during the dry season, making the transmission of dust from the region, and in some cases from the North African deserts, a hazard to both man and technology. These figures are averages and, during field work covering events such as carnival festivals and most of the traditional festivals, conditions can be worse.

Tapes and technology

The Caribbean climatic conditions are not generous to the tapes and technology used in audio-visual documentation of our cultural heritage. A wide variety of formats has been used in the past, varying from open reel tape to micro super 8 cassettes for video. Usage has, however, stabilized over the past ten years in favour of the following formats:

- *audio recordings and playback*
  - open reel
  - cassettes – 60, 90, 120 minutes
- *video recording and playback*
  - U-matic ¾" cassettes – low and high band, industrial and broadcast
  - VHS – domestic and super VHS
  - Betamax – domestic and BetaCAM

The equipment used in documentation, like the tapes, varies from domestic quality to high band industrial quality. The occasions where broadcast quality is used are restricted to the major television and radio stations and the major commercial production houses. The archives do not have the financial resources of the broadcasters, and this restricts the range of equipment available to them.

The problems

The problems encountered in the use of magnetic audio-visual tape in tropical countries result from both usage and storage. I will look briefly at both of these factors.

Usage

More than 95% of heritage recording takes place outside the controlled studio conditions in areas where temperature varies from 20–34°C, and winds reach 22mph on average with peaks of 26mph.

The frequent insertion of tapes into audio and video machines exposes the recorders and tapes to dust from the surroundings. Dust settles on tapes and into the machines and, inevitably, gets moist when the articles are moved from the air-conditioned surroundings of the archive into the hot, humid outside environment. It has been mentioned before that, when transporting tapes and recorders in vehicles in regions of the world like the Caribbean, the temperature inside the vehicles can rise to over 70°C, and sometimes to 100°C.

The Folk Research Centre of St Lucia, whose principle objective is to document the audio-visual heritage, has discovered that scattered showers in periods of high temperature can result in humidity levels of 75–80%, causing dust deposits to moisten and then quickly dry when showers end.

At the Caribbean Institute of Mass Communication (CARIMAC) in Jamaica, which is the premier training institute for media specialists, we have also found that excessive dust deposits is a major problem on tapes and equipment used out of doors.

The tropical heat has its own destructive and testing features. Warm tapes, particularly ones of inferior quality with poor plastic backing, are more likely to kink and stretch when in use. Tapes have been known to crease and stretch, particularly if there are faulty mechanics in recorders. CARIMAC and the engineering departments of some radio stations have noted that machine tensions have to be constantly adjusted, and recorders get bounced around during transportation on the tropical terrain. The exposure of tapes and machines to high temperatures during transportation in closed warm vehicles is not uncommon.

We have another problem in the Caribbean. Because most of the villages are close to the sea, sea spray can fall on both tapes and equipment, resulting in salt deposits as the water evaporates.

Agencies such as government information departments have also noted that constant re-use of tapes without bulk erasing results in loss of quality of recordings and dirty tape heads.

Storage

In the past fifteen years, all major agencies involved in the documentation of the audio-visual heritage, particularly television and radio stations, have stored tapes in air-conditioned rooms. However, the air-conditioning units tend to get shut down because of interruptions to the power supplies. It is, therefore, difficult to achieve optimum humidity control in the Caribbean in these storage facilities. As tapes get older, the effects of these conditions become more serious. Some of the results of these conditions include:

- oxide shed from the tape backing, particularly on open-reel audio tapes,
- dry rot, resulting in breakage and separation of spliced joints,
- print-through, due to tape layers getting stuck together as a result of moisture and overloading of reels,
- fungus build up on all formats, including U-matic and VHS (those stored in plastic cases); the fungus is particularly prevalent on old tapes,
- another problem arises from stretched tapes, particularly in cases where too much tape is stored on to a spool.

Prevention and cure

All the problems associated with the use and storage of magnetic tape in the Caribbean are a result of lack of resources to provide near to ideal conditions. However, the frequency of cases where tapes are not able to withstand normal temperatures suggests that tropical climatic conditions should be taken into account when deciding on specifications for tapes. The vast amount of heritage still unrecorded in tropical countries, particularly in the Caribbean, means the demand for special tapes for use in conditions of high temperatures and high humidity is well founded and well established. In view of the absence of readily available and inexpensive tapes for tropical countries, the institutions that use magnetic tapes take preventive measures – very creative preventive measures – to ensure the longevity of these tapes and their recorded sounds and images:

- institutions such as CARIMAC and the large television stations perform routine maintenance on the equipment, including head cleaning and regular de-magnetization;

- smaller agencies such as the Folk Centre and small television units such as HTS St Lucia and GIS (St Lucia) do regular, but not routine, maintenance;

- in all cases, tapes are stored under cooled conditions whenever possible, but back-up power supplies are not always available;

- the Folk Research Centre, in a pilot exercise, has been able to lodge selected recordings in a sound archive in Austria where ideal conditions exist. Copies of the same materials are also available in St Lucia;

- tapes are occasionally rewound to counteract print-through.

The measures for prevention and cure must always be implemented against a background of the non-availability of resources in Caribbean countries. Some central storage facilities need to be developed to ensure that the vast majority of recorded material is properly preserved. Tapes with high heat and humidity resistant qualities must also be developed and made available to these agencies.

In conclusion, I wish to note that the problems encountered in storage result directly from the lack of adequate resources. There has to be creative intervention to ensure that these tapes last and that the sounds and images recorded on them last for a long time. We would like to propose the need for some kind of collaboration within, at least, the Caribbean and some other tropical countries to ensure that these materials that are recorded on magnetic tape remain in a good, usable condition for a long time.

Preservation of Audio-Visual Archives in Eastern Africa

Musila Musembi

Harald Brandes:
Our next paper is from Mr Musila Musembi, Chief Archivist of the Kenya National Archives in Nairobi. Mr Musembi cannot be present and his paper will, therefore, be read by Lloyd Stickells from the National Sound Archives in the United Kingdom.

Introduction

The infrastructure for the management of audio-visual archives in Eastern Africa is not well developed. In almost all cases, the countries have yet to evolve well programmed and effectively coordinated systems for the acquisition of, and access to, the audio-visual archives. As a result, very limited attention continued to be given to the preservation of these materials. There are several factors that have led to this unsatisfactory situation.

Firstly, the preservation of audio-visual archives in Eastern Africa did not really pose any serious problems until recently. More significantly, their accumulation was very slow. However, the establishment of television stations in the 1970s in most of the countries in the region and the introduction of video libraries and facilities changed this situation. At the moment audio-visual records are increasingly being created locally, while access to foreign produced materials is now much easier. The problems of appraisal and selection will soon become real.

Secondly, while the audio-visual archives were quite insignificant in terms of quantity, all the countries in Eastern Africa needed to take very urgent measures to collect and preserve their valuable paper-based records. This was particularly so after Independence. Therefore, whatever resources were available had first to be directed at solving this urgent problem. With the exception of Somalia and Uganda, archives services in the region are now fairly well developed and there is no reason why greater attention and resources should not be given to the preservation of audio-visual archives.

Perhaps the most significant factor that has led to the present unsatisfactory situation with regard to the preservation of audio-visual archives in Eastern Africa is the attitude demonstrated by the archivists and librarians. They seem to have given very low priority to the preservation of these 'new' materials, although audio-visual records may have been included in the respective Public Archive Acts. In Kenya, for example, Section 4 (1)(g) of the Public Archives Act specifically states that the Chief Archivist shall 'make arrangements for the separate housing of films and other records which require to be kept under special conditions.' Although the Act was enacted in 1965, no serious consideration was made for the acquisition and preservation of these materials. What this means is that, while requests for funds were made for general records and archive management programmes, no specific requests were made for the preservation of audio-visual archives. I have no doubt at all that in the case of the Kenya National Archives, greater financial resources could have been committed to the preservation of these 'new' archives. The same is true for several other countries in the region. In my view, therefore, the lack of interest on the part of

Steven Smolian:
When you were discussing print-through due to moisture, were you speaking about the migration of the adhesive in the splices from one layer to the next, or are you actually speaking about the carrying of a signal from one layer of the tape to the next? Until now, I wasn't aware that there was an actual print-through problem caused by moisture.

Embert Charles:
It has to do more with the adhesives.

Steven Smolian:
An idea about the actual building of sound archives: I don't know that this would work well the Caribbean, but I assume in Africa it certainly could. What about underground storage as a basic beginning point?

Embert Charles:
I wish I could answer that question. I think that with underground storage you'd be getting into a new area because, even in basic infrastructure-design terms, underground storage hasn't been considered for anything yet. So probably it's a new area which we may want to consider. In a lot of the areas, many of the buildings are built on fairly waterlogged re-claimed land, so it's very difficult to go down even further. In some cases you may have to drive piles to get your false floor, so there are some constraints to that suggestion.

Lloyd Stickells:
I suspect that, as far as Africa goes, you've got the same problem. It's a lot more expensive to dig a big hole than it is to put a few bricks on a rock, especially if the

archivists and librarians in the region has probably been the greatest cause of the present poor infrastructure development for the preservation of audio-visual archives.

Challenges ahead

The Eastern African countries, like most other developing countries, have a long way to go before they can develop appropriate storage facilities and systems for the preservation of audio-visual archives. This is particularly so when account is given to the financial requirement for physical facilities and equipment. The following areas will continue to be major constraints in the development of the audio-visual archives in the region.

Establishing distinct units for preserving audio-visual archives

There is no doubt at all that one of the greatest challenges in the development of audio-visual archives in each Eastern African country is to establish one central unit or agency that will concern itself with the acquisition, preservation, and access to audio-visual archives. We would definitely miss the point if this function were to be left to a television broadcasting station or other similar institution. This view was probably stated more clearly by a participant from Mozambique during the First African Seminar on Developing Audio-Visual Archives held in Maputo 2–7 June, 1986. He observed that films were being mutilated or erased to produce other documentary films, and stated that:

> This usage is quite often to the detriment of preserving the original document. Handling is under the worst conditions and already on various occasions unique parts of archives were mutilated to meet immediate needs. We think there will be no change in this situation so long as there is nobody responsible for pressing the preservation of this part of our heritage.

The establishment of an effective unit or agency for the preservation of audio-visual archives is, in many developing countries, easier said than done. This is particularly so when account is taken of the present economic status of these countries. As a matter of fact, the mutilation and erasing of tapes is the result of these adverse economic conditions and the under-capitalization of television stations. Be that as it may, it is possible to make a start by establishing a division within the national archives, or any other appropriate body, to specifically concern itself with these 'new' archives.

Storage facilities and equipment

The preservation of audio-visual archives requires specialist storage conditions and equipment, without which a lot of materials could ultimately go to waste. Television stations in Kenya and Zanzibar do not have storage facilities and equipment that meet the accepted standards for film preservation, and nor does the Audio-Visual Institute of Tanzania. This means that audio-visual archives are not kept under controlled temperature and relative humidity levels. Similarly, the national archives in the region do not have facilities that meet the recommended storage conditions for audio-visual archives. However, the problem has been recognized, and the

situation will be improved with time. In the case of the film library of the Kenya Institute of Mass Communication, for example, measures are now being taken to improve these facilities.

The Audio-Visual Institute of Tanzania preserves its materials at 20°C and a relative humidity of 65–70%. Colour and black-and-white materials are kept together under the same conditions. In Zanzibar, the storage conditions are similar.

The long-term solution to the storage problem is the provision of proper facilities and equipment. This can be quite expensive, and it will obviously take several years before the necessary resources can be found. However, we need not wait for that long. In the meantime, remedial measures can be taken, especially in improving the storage conditions. The experience of the Kenya National Archives is that it should be possible, at least to some extent.

Acquisition

Now, and in the future, the acquisition of motion pictures and other audio-visual materials for preservation is likely to be a big problem. Unlike the conventional archive materials, the acquisition of audio-visual archives needs a substantial amount of money. In most developing countries, East African countries included, funds are very limited. Furthermore, most of the motion pictures are made by foreign companies who are normally not prepared to deposit copies with the national agency involved in the preservation of audio-visual archives. Poor storage conditions in the would-be recipient institutions do not help in reducing this reluctance. This means that the Eastern African countries will have to spend large sums of money to retrieve from overseas countries the audio-visual archives that were created even after Independence. Kenya's experience is that this can be a frustrating exercise and, as if this were not enough financial burden, they will also need to retrieve a lot of other audio-visual archives that were produced during the colonial period and that are no longer available in Eastern Africa. There is no doubt that this will place a severe financial burden on the already under-capitalized institutions involved in the preservation of audio-visual archives.

Training

In Eastern Africa, there is a severe scarcity of persons qualified in the management of audio-visual archives. This was confirmed in a Unesco Workshop on the Preservation of Moving Images, which was held in Nairobi in Kenya in 1985, and the First African Seminar on Developing Audio-Visual Archives, which was held in Maputo in Mozambique in 1986. It is necessary to have audio-visual archives that are managed by qualified persons – especially in the areas of cataloguing and classification, as well as in restoration techniques. In my view, this problem can be solved if greater national and international efforts could be mobilized to train audio-visual archivists. It is also important to note that, if archives and library schools had a significant component on audio-visual archives in their curriculum, this problem would be much less – not only in Eastern Africa but also in other countries.

hole needs to be dug into rock, and a lot of Africa is rock.

Steven Smolian:
Wouldn't the investment be worthwhile if it resulted in lower running costs and better storage facilities? This would be the most economic solution in the long term.

Lloyd Stickells:
I think most of the problem of the developing countries is purely lack of financial resource immediately, no matter what it might save in the long term. If you can't expend it in the first place, you have to live with it.

Harald Brandes:
And there is another problem: these buildings have to be strictly waterproof and, if this works only for some decades, this is really a problem.

Alan Lewis:
I had occasion to visit with Mr Musembi in Nairobi some months ago and, if I remember our conversation correctly, he is beginning to deal with the cataloguing problem with the collection in Kenya by placing one of his people at the television station to begin to do cataloguing of the material when it is still resident at the TV network. So, presumably, further down the line when those materials flow in to the National Archives, they will already have been catalogued to some extent.

Helen Harrison:
I was very interested in the lack of training in Kenya and, in fact, anywhere around the world, in management and technical aspects of audio-visual archives. I'd like to draw the attention of the conference to a report that has just been completed by a

working party consisting of members of FIAF, FIAT, IASA, ICA and IFLA (the Federation of Library Associations). The report was done for Unesco and will be published later this year by Unesco. We looked into curriculum development of all the management aspects of audio-visual archives. We also did a survey of existing courses – of which there are none! – and we developed a draft curriculum for the teaching of a two-year, fairly high level, course in training and this we hope will be taken up by all these countries who actually require the material and require the training programmes. In addition, we were also hoping that the Technical Coordinating Committee, which is running this particular conference, would be able to input technical aspects and develop training courses for technical people. The report will be available from Unesco later this year.

Legal base

The establishment and development of audio-visual archives require the existence of comprehensive policies – whether legal or administrative. It is true that some countries in the region, such as Kenya and Tanzania, do have some policies on the preservation of these 'new' archives. However, in the case of Kenya, they are not comprehensive enough. Elsewhere the situation may be much less satisfactory. There is, therefore, a lot of room for improvement. In particular, deposit legislation in Eastern Africa will need to be reviewed in order to expand the catchment area of those audio-visual archives that have historical importance. It is hoped that the already expressed need to establish efficient audio-visual archives in the Eastern African countries will, in the near future, be accompanied by the provision of solid legal bases on which these services can be developed and coordinated.

Conclusion

The need to preserve audio-visual archives has been firmly recognized by most East African countries. We have, however, a long way to go before these services are fully developed. Solutions to complex problems related to finance, storage facilities, equipment and training have yet to be found. At the moment, there is adequate evidence to indicate that the relevant national authorities in some of the countries are willing to commit more resources to the development of the audio-visual archives. This, indeed, is as it should be. However, their wish to effectively preserve these fragile materials will continue to be greatly hampered by inadequate funds. It is for this reason that we welcome any technical assistance in the development of audio-visual archives in Eastern Africa.

Problems of Film Preservation

Penpan Jarernporn

The National Film Archive of Thailand was founded in 1984 under the National Museums Division of the Fine Arts Department in the Ministry of Education. We do not have a Ministry of Culture, so both Education and Culture are under the same Minister. In 1985 the National Film Archive was transferred to the National Archives Division, which is a member of ICA.

Harald Brandes:
I now present Penpan Jarernporn from the National Film Archive of Thailand, in Bangkok.

The Film Archive is in Bangkok, the capital of Thailand, which is not an ideal environment for film preservation because of the climate. The city is located at a latitude of 13° 44' N, a longitude of 100° 34' E and an elevation of two metres above sea level. The temperature reaches a maximum of 40°C in April and a minimum of 9.9°C in January. As you can see, there is a wide seasonal variation in temperature, and the temperature variation between day and night is about 15°C.

Bangkok is very hot and humid. The highest recorded rainfall was 248.6 mm per day in May, and the rainy season lasts from May to October. On rainy days, the relative humidity can reach 100% and, during the dry season in February and March, the relative humidity can drop as low as 17%.

The Film Archive is in an old mint building constructed about forty years ago. It is about two hundred metres away from the Chao Phraya River, and the old city moat passes the front of the archive. The underground water level depends very much upon the level of the water in the river and in the moat, and is usually not more than a few metres below the ground level. The water from underground is a big problem to old monuments and buildings, and the archive building faces the same problem: water penetrates the walls and greatly increases the humidity.

In such conditions, it is very difficult to control the environment to be suitable for films. Besides, the films were hardly in good care before the archive acquired them. Some were placed in storage; many were neglected in various parts of houses, warehouses and other places.

George Brock-Nannestad:
May I comment on what history may teach us? In the early days from 1905 to the 1930s, the Gramophone Company of India stored its original master copper negatives of records by sealing them in paraffin wax. When required, the wax was removed and the corrosion-free master used to produce records. This technique was demonstrated to them within the first month of production. Without this coating, the copper plates would be unusable after a few months. Eighty years later, these wax-covered metals still

And most of the films in the archive collection earlier than 1970 are the only copies we have. So they have to be preserved despite their very poor condition, and our technicians therefore face a lot of problems trying to preserve all these films.

Staff training is always the first priority of film archiving. This is because, with one trained film technician and a pair of simple film winders, films in the archive can be inspected, repaired and treated within a small budget. The archivists in the Thai Film Archive were trained by experts from well established archives such as the Swedish Film Institute, the Bundesarchiv in Germany and the British National Film Archive. These experts each spent 10 days or more working with the Thai archivists. After all the training, the

exist, and are still in perfect condition. They are the best preserved metals in the world. This demonstrates that items can survive adverse conditions provided that they are stored in the correct conditions and with correct treatment. The problem is that our present day media are not good enough.

Christopher Roads:
From what I understand, the Thai Archive may be in a fortunate position with regard to power supplies. My own experience is that it is rather difficult to get the constructors of archives to admit that the power supply is inadequate and unreliable, and to install back-up generators. It is loss of power that causes most problems. There have also been cases where security within the building has resulted in the close-down of power as well. Officials do not like to admit that the public supply is less than reliable. It is a problem in the UK and other developed countries as well as in developing countries. The installation of reserve power generators is essential in any audio-visual archive storage facility, and must be insisted upon. The optical disc media offer a storage system that is proof against a very wide range of temperatures and relative humidities. Until these new formats are cheap enough to be taken up by archives, we are going to be at the mercy of power supplies.

Thai archivists feel confident about working with their cultural heritage.

Not all the problems can be solved, however. The Thai Film Archive is a small institution with a very small budget. It is not of great interest to commercial laboratories and equipment suppliers. Such essential supplies as black-and-white raw stock and sprocketed tape are not available on the local market. It can take six months to receive orders placed abroad. When the archive sends its films to be printed or developed at the commercial laboratories, it takes more than a month for them to be returned. This the reason that the Archive decided to set up its own laboratory for printing black-and-white film. This processing requires great experience to achieve the quality standards required. This experience requires time to be built up. The Thai Archive has about 30,000 metres of nitrate film in its collection. Some has been copied to acetate stock, but we keep the original nitrates to permit re-copying in the future when better copies may be possible.

There are two film vaults at the archive. The first has a domestic air conditioner donated by a film director from his own house. When first installed, the temperature was set to 5°C. This, however, caused the humidity to rise to over 90%. The temperature was finally set to 17–20°C. With one small dehumidifier, the internal relative humidity is held at 10–15% below the normal relative humidity outside the vault.

The second vault was once the safe of the Royal Mint. The environmental control unit of this vault consists of one air conditioner with two compressors, and one dehumidifier. The temperature of this vault is set to 10–15°C and the humidity is 40–45%. It is difficult to maintain this range of temperature and humidity in this vault, partly because an emergency exit was installed, which breached the existing insulation.

Neither of these vaults is for nitrate storage. The Thai Film Archive is now planning to build a film preservation centre at a new site about thirty kilometres outside Bangkok. The centre will include film vaults for originals, masters and nitrates, preservation laboratories, and also a national training centre for film preservation. Construction will begin in 1991. By 1993 the National Film Archive hopes to be able to offer a film preservation service to other film collections in the region, as well as staff training. The archive does not expect to solve all the problems with its new centre but expects that, with all the facilities at the centre, film archivists from all over the country will meet and work together to solve the problems. With that, the film heritage of our country will be in good hands.

Are There Alternatives to the Traditional Air-Conditioned Film Stores?

Harald Brandes

This paper may cause some controversy. Even so, I am convinced that alternative possibilities for the storage of films should be discussed. I believe this is necessary because the permanent air-conditioning of repositories very often cannot be ensured.

First of all let us look at the traditional storage technology for film; it is probably more or less the same for other audio-visual materials.

Black-and-white film should be stored at a temperature between 10°C and 15°C or lower and a relative humidity around 45%, bearing in mind that there is a move towards reducing the humidity values. This move is one result of the research programme of the Manchester Polytechnic into the stability of triacetate film.

Colour films should be stored at a temperature below 0°C and a relative humidity of 25%.

The technical requirements of the repositories for black-and-white film are few, and an adequate climate can be established with relatively small compressors and vaporizers inside the storage rooms.

The investment is clearly greater for colour material: compressors for the compression of the coolant and a sophisticated evaporation technology are required to achieve very low relative humidity at low temperatures. The cost of equipment is very high, and this is matched by the high costs of energy to run the system.

The experience of the Bundesarchiv in Germany shows that between 10,000 and 20,0000 German marks per month are spent on the electricity needed to run the air conditioning in a storage room of 500 square metres. These costs depend on the extent of the film storage on the shelves.

Repositories for movie films, especially cold stores, have to be insulated very effectively. The insulated cell stands separated from the massive walls, the storage floor, and the ceiling. The temperature in the room between the cell and the wall must be controlled, and must never be below 0°C. It might even be necessary to heat the air of this confined room, otherwise the building could be damaged by sub-zero temperatures.

The technical installations for the black-and-white or colour storage rooms require a high standard of maintenance with repair facilities. If all the air-conditioning equipment, such as compressors and evaporators, could be duplicated, standstills of the air-conditioning systems could probably be greatly reduced, but I believe such double

systems are very rare – I don't know of such technology in a stationary air-conditioning unit.

In reality, air-conditioning systems frequently have to be repaired, and do not operate efficiently for long periods. This leads to the situation where repositories may not be air-conditioned for several days, weeks, even months at a time. According to our experience at the Bundesarchiv, radical and often repeated changes of climate are hazardous for the stability of triacetate layers, even for nitrate material. It is quite evident that the negative impact increases if the differences in temperature and humidity are large. Therefore the situation in tropical countries is much more critical than in countries with moderate climates.

Air-conditioned storage is the most expensive storage technique. To optimize the efficiency of the air-conditioned storage rooms, as much film as possible should be stored per square metre. Mobile shelving should be installed if possible, because this can increase the storage by 40–70%.

Of course such mobile shelving systems are very expensive, and would prove a special burden for archive administrations in tropical countries where budgets and technical facilities may be limited.

As far as running costs are concerned, there is a more economic method for air-conditioning: the FICA system in which the film is sealed at low humidity (about 25%) in an air-tight plastic bag. Before the bag is sealed, the air has to extracted from the bag. The film, packed into a foil bag, can be stored in a repository in which only the temperature is controlled, not the humidity. Using this method, the energy costs can be greatly reduced.

It is critical, and perhaps even dangerous, to store film material in a vacuum, for it is possible that this could accelerate deterioration processes such as the vinegar syndrome. If you decide in favour of FICA, where the film is packed in to such a bag, then you must inspect the material regularly – every twelve months. Also, the foil bags are expensive, and will have to be replaced after each inspection. The economics of the FICA system need to be properly checked, but the system may be a solution for some of the smaller collections.

Alternatives

Are there alternatives to the storage systems just mentioned? There may be!

It often happens that archives receive nitrate or triacetate films from private individuals. In my experience, these films are very often in good condition – perhaps somewhat dried up, but seldom badly deteriorated. If you ask about the storage conditions of those films, you often find that they have been stored in a desk or in a cupboard for several decades. And there are other examples of the storage of films under comparatively primitive conditions.

Some years ago, at the beginning of the 1980s, the Bundesarchiv took over a large collection of nitrate films. These films had been stored since about the end of World War II in an open barn, protected against the rain under a roof, but exposed to fresh air from all sides.

Remarkably, most of the films were in an excellent state. No film showed deterioration. The climate in this region varies greatly in the course of the year between temperatures of minus 10 to minus 15°C with low humidity in winter and temperatures of up to 20–30°C with relative humidities of up to 80%, or even 90%, in the summer.

Another observation: close to Koblenz there is a small laboratory; the storage rooms for the safety films are not air-conditioned, but a large amount of fresh air can pass through the open windows. About eight months ago I personally inspected several hundred films in this storage facility, and I could not find any deteriorating material, and no smell of vinegar syndrome.

And an additional example: two or three years ago, I spent several days with a colleague João Socrates de Oliviera in São Paulo, Brazil. I checked several hundred reels of film on a winder, and once more I couldn't find any deteriorating material.

The small storage buildings for nitrate material in São Paulo are constructed in a very simple way. In the lower parts of the surrounding brick walls, there are small holes to ensure plenty of ventilation. There are also openings in the building between the roof and the walls. This construction means that there is an ongoing natural exchange of air in these buildings. Protected against direct sun, the buildings are located under large leafy trees, permanently in shadow, and therefore comparatively cool.

One final remark: in the Bundesarchiv, we stored still negatives from World War II for about twenty-five years in a climate without air-conditioning. These stills are not on a tie reel, but are mounted in to a paper cone. All of these negatives are in a fairly good condition.

It is most remarkable that these results can be achieved by very simple technical means. Fresh air, in my opinion, has a very important impact on the stability of films. No deterioration vapours are in contact with films that are still in good condition.

Certainly storage buildings such as those I have just described cannot replace a storage facility with optimum air-conditioning. But they can be regarded as an alternative to a repository in which reliable air-conditioning cannot be ensured. They can also be regarded as an alternative to a repository where a technically sophisticated storage system cannot be installed because of budgetary considerations.

In general, it should always be technically possible to blow fresh air into a film repository. If the fresh air is polluted, the air should pass through filters, such as active carbon filters and dust filters. If these filters are not available, consideration should be given to building storage facilities in areas where the air is still clean and not polluted by traffic or industry. Under certain circumstances, in order to reduce the permanent energy costs, it might be justifiable to build film storage buildings where the climate is cool and dry, for example in mountain regions. Even in tropical countries, there are places that are better for the storage of films. If the entire archive cannot

be built in ideal surroundings, one should try to store at least the most valuable archive materials there.

And if it is not possible to build modern storage buildings, the traditional way of building houses might be of interest for the storage of film material. I believe that storage buildings like these are much better than concrete storage buildings with an air-conditioning system that is not working.

Another possibility for film storage is to use the air-conditioned containers used for the transportation of goods on ships or on trucks. The air-conditioning systems of these containers are very good and, in general, duplicated. Such systems can operate with electricity or diesel motors. They have to be slightly modified in order not only to cool but also to de-humidify. In extremely dry regions, the air in the container has to be humidified to prevent drying out. It is of course possible to install control units, such as fire alarms or burglar alarms, in these containers.

In the Bundesarchiv, such containers are used to store nitrate film. The entrance door has special plastic curtains to balance the climate. The entrance door also serves as a pressure valve, and the door opens automatically in case of fire. Under normal conditions the door is locked only by two permanent magnets. There is enough space in each container for 2500–3000 film cans.

There are two reasons for using containers. First: they can be bought comparatively cheaply second-hand, and the total cost for a container with special equipment for archival needs is about $30,000 US. Second, such containers have excellent insulation and, if the compressor stops working, the temperature and humidity changes very little in a twenty four hour period. The good insulation means that the consumption of energy is very limited. The containers can also be resold if they are no longer needed for archival purposes.

To briefly summarize: the best, but also the most expensive, solution for the storage of audio-visual materials is air-conditioning. But, if the air-conditioning of a massive storage building is not available or economically possible, other solutions using natural air-conditioning or the containers just mentioned should be considered.

This report is not based on exhaustive enquiry or sophisticated research, rather it reflects personal experience, and any feedback from colleagues with similar experiences would be valuable.

Session 2:
The Breakdown of the Components of Signal Carriers with Age

Chairman: Henning Schou

The first part of this session is an assessment of the stability of film material, and looks at the stability of the emulsion carrier, then at the stability of the image or information carriers. The rest of the session is about the life expectancy of new media for storage of audio-visual information, namely metal-particle tape and optical recordings including compact discs.

[The Organizing Committee regret that it has not proved possible to print the paper presented by Dr Klaus Hendriks in this volume. If circumstances change, it may be possible to publish Dr Hendriks's paper, entitled *The Stability and Preservation of Image Layers in Photographic Film*, as a supplement at a later date.]

The Deterioration of Polymers in Audio-Visual Materials

Michelle Edge

Introduction

In Manchester we are setting up a Centre that will provide a service to all archives and museums – dealing primarily with polymer stability. I will start by summarizing the problems that we have to date: we once believed that we could just acquire and save audio-visual collections and amass data; but, once acquired, the collections truly become a nuisance because they have, as a major constituent, polymers. Now all polymers are unstable with time and therefore have a limited life span. So any materials that contain a polymer system will be unstable and will deteriorate, and that includes all current information storage material.

Why do polymers break down?

Polymer degradation is a feature both of the intrinsic chemical structure of the material itself and of environmental parameters. For a given material, a number of external and environmental factors can influence the rate of degradation. These include:

- the effects of oxygen,
- the effects of moisture in the atmosphere, leading to hydrolytic breakdown,
- heat, leading to thermal degradation,
- mechanical stress, leading to loss in tensile properties, for example,
- the effects of light,
- radiative breakdown,
- chemical breakdown due to atmospheric pollutants,
- biological breakdown – the growth of fungi, mould etc on the surface of polymer materials,
- ultrasonic breakdown.

The action of all those factors upon a particular polymer results in a number of property changes that can be divided into two groups, physical and chemical changes. **Physical changes** include a decrease in molecular weight and hence loss in tensile strength for the polymer system, loss of gloss, elongation, distortion, etc. **Chemical changes** are those that result in discoloration of the system, production of new groups within the polymer system itself.

The same changes happen in motion picture film, which is essentially composed of a polymeric support. It does not matter whether it is cellulose nitrate, cellulose triacetate, or polyester, and the same is true for magnetic media, and for emulsion containing the silver image and gelatine or a urethane binder and magnetic oxide. In all cases, the binders are polymeric and the support materials are polymeric.

Henning Schou:
The next speaker is Michelle Edge, who obtained BSc and PhD degrees from Manchester Polytechnic and is currently a Lecturer in the Chemistry Department of the same institution. She has widespread experience in photographic image related materials, especially with regard to their deterioration and stabilization, with twenty research publications to her credit. Together with Professor Norman Allen and Dr Jewitt of the Polytechnic and Mr Velson Horie of the Manchester Museum, she has been primarily responsible for establishing the Centre for Archival Polymeric Materials, whose concern is to provide a consultative service to the archival and conservation worlds regarding polymeric materials.

I said earlier that the stability of a given polymer will be dependent upon both the innate structural features and external environmental parameters. The **structural features** of most polymers are:

- the main polymer unit itself, the form in which it's present, its physical form, whether it's present as a film, whether it's present in bulk, or whether it's present as a powder – all these influence stability;

- the presence of impurities within the system from manufacturing catalysts, for example metal trace ions that it has picked up from washing procedures;

- the presence of incorporated additives, such as plasticizers (which are generally added to polymers to render them flexible), pigments, antistatic agents and flame retardants.

What is a polymer?

A polymer is essentially made up from small organic molecules linked up into long chains. In some cases the structures are linear, others have pendant groups that project on either side of the main chain (the monomer unit).

If we look at the chemical structure of a typical motion picture film support such as cellulose nitrate and cellulose triacetate (included in Figure 1), we see that basically it's composed of a cellulose backbone made of small hydroglucose units linked together to form a long chain polymer; substituted in that main backbone are either nitrate groups (in the case of cellulose nitrate) or acetate groups (in the case of cellulose acetate and cellulose triacetate). So, our support material is a polymer which is a backbone with pendant groups.

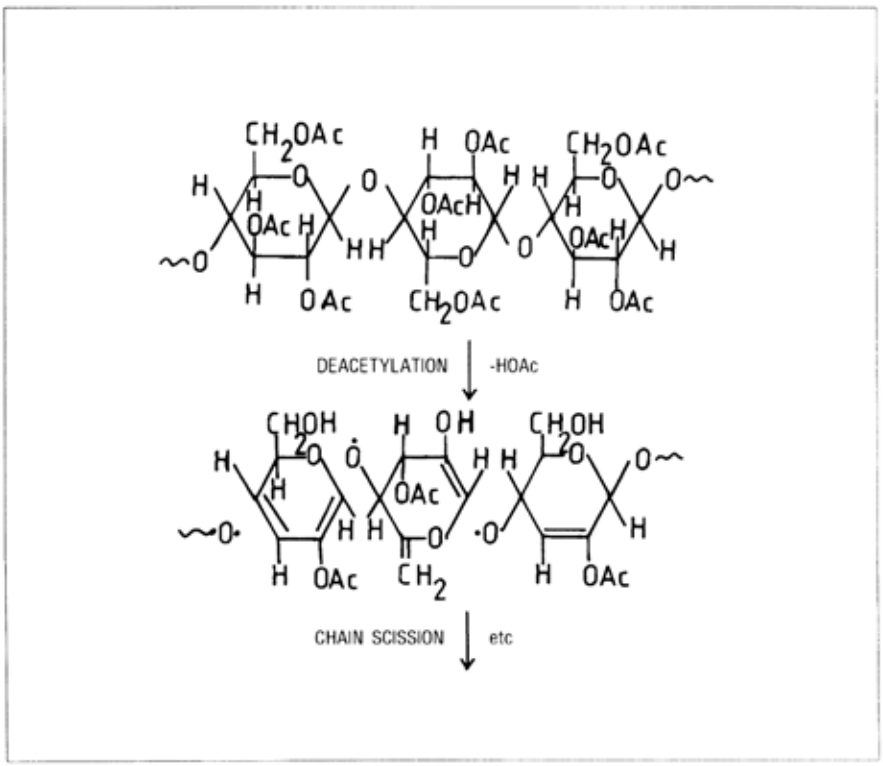


Figure 1

A number of energy considerations have to be taken into account when looking at the stability of a particular structure. The first is the **intramolecular forces** – the bonds between each atom within the molecule. Basically, the stronger the chemical bond, the more stable the polymer will be and the more energy it takes to break that bond. For example, 116kCal of energy per mole would be needed to break a carbon–fluorine bond; the carbon–hydrogen bond (present in cellulose acetate and cellulose nitrate) requires only 97kCal per mole; the carbon–carbon bond (also present in both support materials) requires only 83kCal per mole.

The stability of the polymer also depends on the type of carbon–hydrogen bond present. If the carbon's bonded to three hydrogen atoms, for example, it's more stable than if the carbon's doubly-bonded to another carbon: instead of just one bond, there are two.

If we look at **intermolecular forces**, we find that the many, many polymer chains within our plastic support will interact with each other and form weak links between the chains.

If you wrote a league table of bond strengths within polymer systems, then the bonds between the atoms that constitute the polymer chain take most energy to be broken, the intermolecular forces take a little less, and there's essentially a cohesive energy between the chains. The cohesive energy in a rubber system, an elastomer which you can stretch, is pretty low compared to, say, a nylon or cellulose fibre where the cohesive forces will be much stronger. The presence of polar groups and hydrogen bonding provides the possibility of relatively strong links between each particular chain. So when you examine a polymer structure, you have to take into account whether all those forces or bond linkages can actually occur.

What happens when support materials break down?

Using the particular examples of the support materials cellulose acetate and cellulose nitrate, how do we actually utilize information about the structure and structural stability to study what's occurring when those two support materials breakdown?

A particularly important feature of cellulose acetate and triacetate and, to a lesser degree, cellulose nitrate base is the extent to which the polymer can interact with the environment and take up moisture. Studies have shown that, as you increase the degree of substitution (as you go from monoacetate to diacetate to triacetate, see Figure 1), then you lower the moisture uptake of the polymer. The higher the degree of substitution, the less moisture it takes up. So conversely, if the polymer is degrading – giving off acetic acid, losing acetate groups, lowering the degree of substitution – it will start to take up more moisture (Figure 2).

Another feature is the polymer's solubility. The specific structural composition of the molecule will influence the way it interacts with solvents and hence will influence which solvent systems it can actually dissolve in. For example, at higher degrees of substitution, cellulose acetate is soluble in systems like methyline chloride and methanol which is actually used to cast film base and, as at lower

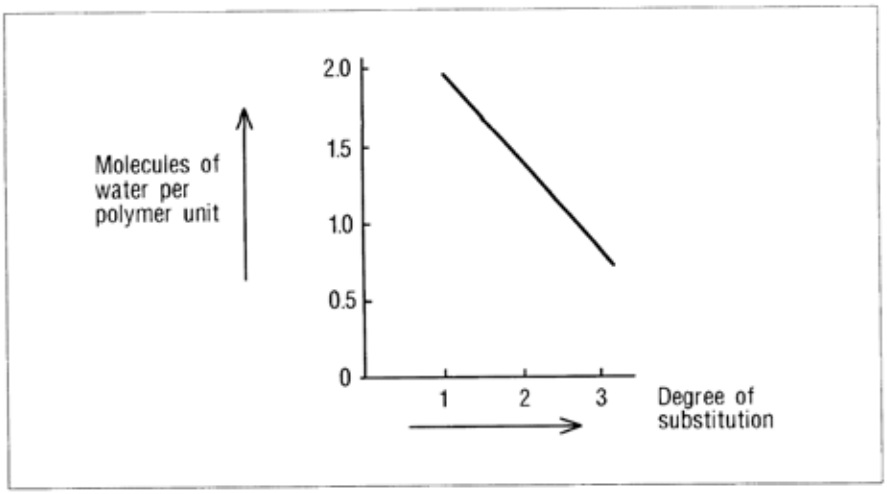


Figure 2
Moisture regain of cellulose acetates of varying degree of substitution

degrees of substitution, it becomes increasingly soluble in more polar solvents until, at degrees of substitution of only 0.6 acetate groups per anhydroglucose monomer unit, the system should be soluble in water. You can actually utilize that information to study what is happening in your film material.

At Manchester Polytechnic, we took a series of films – naturally aged cellulose acetate films of unknown history, and a number of negative and positive films that we knew the dates of – and looked at them in several ways. Our initial observations of what happens to triacetate film when it degrades suggest that, when we smell acetic acid, this has come from acetate groups – the pendant groups that are substituted on the main chain. If we're losing those groups, we're lowering the degree of substitution and, therefore, we should see an increase in the uptake of moisture. We should also see, as we form acetic acid, a lowering in what we call the pH of the system. [If something has a high pH, say 13 or 14, it's essentially alkaline/basic. If it has a very low pH, it's tending towards being acidic.]

We can also utilize the information on solubility in a given solvent by measuring what we call **percentage insoluble polymer**. If we're losing acetate groups (lowering the degree of substitution) then, if we could dissolve our original triacetate material in something like methyline chloride and methanol, it should become progressively insoluble in that particular solvent. So we can get a measure of percentage insoluble polymer.

We can also measure the **viscosity** of the system. We're losing the pendant groups from our long chain to form acetic acid and the fact that we see a loss in tensile strength when we project films (the film snaps in the projector), suggests that the polymer unit itself, the main backbone, is also breaking down to smaller fragments. For a long chain, you can imagine that all the chains are entangled and it's a relatively viscous solution. As the chain breaks into smaller fragments, it flows more freely. We should be able to follow that by measuring how viscous the solution is.

When we look through films taken from an archive, we find that some films have lost their image and also smell of acetic acid and that, the more degraded the film material, the higher percentage insoluble polymer it has, the lower its pH, the higher the moisture regain, and the lower the viscosity number. This seems consistent with the idea that the polymer is actually losing acetate groups to form acetic acid, and its main chain backbone is breaking down to smaller fragments.

The effect of age

It is difficult to find any age-related changes; some of the older films are in much better condition than some of the newer ones. In an archival situation, you do not know the previous history of the films that come into the archive. So we decided to take the same set of readings for films that had actually been produced on site at an archive and stored under archival conditions (45–50% RH and ambient temperatures). There we did see a trend: the older the material, the lower the viscosity, the higher the moisture regain, the lower the pH, and the higher the percentage insoluble polymer. So the environment does have an effect, and the age of the polymer is relevant. But, remember, archivists often don't know where films have come from; they could have been exposed to any environment, giving a whole range of deterioration characteristics.

After looking at a series of naturally aged film stocks, we used all the same testing procedures and simulated degradation to see if we could, perhaps, predict how long a film would last under a given set of conditions. We took the same parameters and looked at what happens to film in dry conditions, in conditions of 100% RH, and in conditions of one molar acetic acid, all at a series of three different temperatures. Taking moisture regain as an example: as the temperature is increased, the onset of moisture regain is more rapid. So, increasing the temperature speeds up the rate of degradation.

That's not new, but the effect of moisture in the environment is particularly significant, and is much more marked than the effect of temperature. At 90°C, in molar acetic acid conditions, the moisture regain – which corresponds with the loss of acetate groups and the formation of acetic acid – is almost catalytic. There's only a very, very small induction period before the acetate groups start to be lost.

What's happening to the polymer is a complex interplay between the acetylation and the breakdown of the main chain: chain degradation is occurring and also what we call hydrolytic de-esterification – in other words, the loss of acetate groups is enhanced by the presence of moisture.

The effect of plasticizers

But that's not the whole story. Photographic film base incorporates a plasticizer at around 15% by weight of the film base and that's, typically, a phthalate ester combination with triphenyl phosphate. In many severely degraded films, white crystalline deposits can be seen on the surface of the film material itself. We ran chemical tests and discovered that the crystalline deposit was plasticizer material. What influence might the plasticizer have? It must be playing some

part, whether it be active or merely facile, because it's changing – coming out of the support material itself.

Most phthalate testers (which include dimethyl, diethyl and dibutyl) have lots of CH_2 linkages that are particularly unstable and susceptible to breakdown by the presence of oxygen. In going from dimethyl to diethyl to dibutyl, the amount of oxygen taken up increases. We believe that, under the influence of oxygen, those systems then break down to produce what we call peroxides and acid. Triphenyl phosphate doesn't possess any of those units and so apparently doesn't absorb any oxygen and doesn't produce any acid or peroxide.

When polymers break down, when they interact with oxygen, they produce peroxides, which are notoriously unstable, and break down to form radicals. Now a chemical bond is composed of two electrons and is relatively stable, but when a chemical bond is broken to produce radicals, the radicals have only one electron – and electrons, like people, don't like being alone. They'd rather be paired up. So any radical on its own will seek another electron; if the electron is paired up in another bond, it will grab hold of it and break the bond. This will produce more radicals, and the whole thing takes off and produces more and more radicals. The result is more and more broken chemical bonds. The presence of peroxides in a polymer system is, therefore, particularly important.

We decided to artificially age polymer systems – movie film – with and without plasticizer material, and look at the viscosity retention as one parameter relating to that breakdown. In the presence of plasticizer, the film seemed be in much better condition and retained its viscosity to a much higher degree than when no plasticizer was present. We wondered if the plasticizers somehow contributed to the stability of the polymer itself. The plasticizer was obviously being lost from the polymer, so we looked at percentage plasticizer loss in a given time, at a given temperature, under conditions of high relative humidity and acetic acid conditions. In the presence of acetic acid, a far greater proportion of plasticizer was lost from the film.

The plasticizer is designed so that its chemical structure is specifically compatible with the original base material. We believe that, as the base material changes its chemical composition (loses acetate groups, the chain breaks down, etc), the plasticizer is no longer compatible with that system and is pushed to the surface, where it crystallizes out. So, plasticizers don't contribute to the instability of the material, rather they are lost because the material itself is breaking down.

The effect of the film can

But that's still not the whole story. The film is not just sitting on the shelf tightly wound into a reel, it's actually in a film can. Is the can itself contributing to the instability of the material?

Metal ions are notorious in the breakdown of polymers. The chemical literature tells us that metal ions contribute to the instability of almost every known polymer system: they act as catalysts for their breakdown. We looked at what happens to

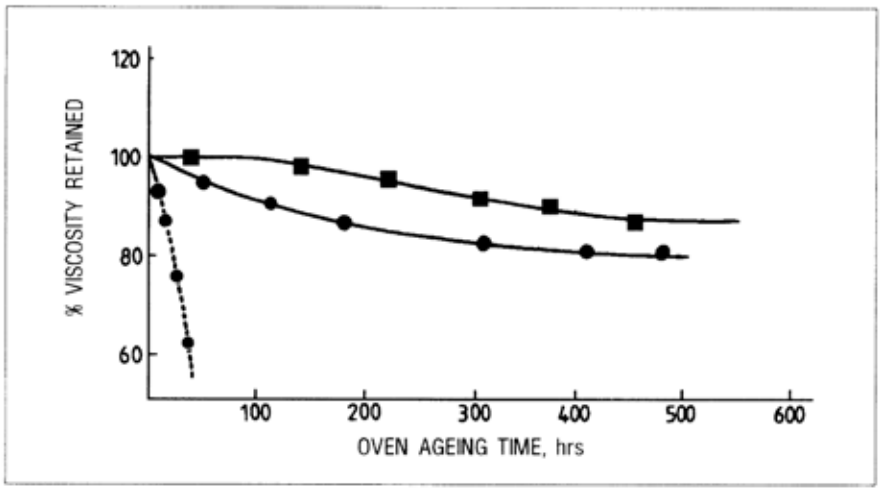


Figure 3
Percentage viscosity retention versus oven ageing time for cellulose triacetate base cinematographic film with (—) and without (- - -) emulsion layer in glass ■ and tin-plated iron ● container aged at 90°C and 100% RH.

photographic film, motion picture film and triacetate base in contact with a can. In one case, we removed the emulsion from the film, in another we left it on, and in a third case we left the emulsion on and aged the film in contact with glass rather than with a metal storage can (Figure 3). The support without emulsion tends to degrade first, the film with emulsion in contact with the can takes a little longer, but the film in a glass container is much more stable.

We also looked at a number of naturally aged film materials taken from film archives, at new materials, at film that was exhibiting acetic acid odour, at films that had plasticizer deposits, and at films that had lost the image altogether. The analysis was done by Kodak in England who found that, the more degraded the film was, the greater its iron content. In other words, the film material, as it degrades, seems to be taking up iron. Now it's difficult to tell from those two studies whether or not this is a facile feature of the degradation. It may be that, because the film takes up more moisture it also takes up more metal ions along with that; so the iron isn't actually contributing to the degradation, it's just being taken up as the film degrades.

To check that, we actively incorporated different concentrations of metal ions within a number of different films (Figure 4). When we put one part per million of ions into the material, there wasn't much change in the viscosity – the film wasn't degrading very much. But, as we increased the concentration to ten parts per million, there was significant loss of viscosity – significant degradation. In other words, iron contributes to the instability of the material. So it's likely that the film can is contributing to the instability of the material.

And with magnetic track media, because the magnetic track is an iron oxide or iron itself, then that must also be contributing to the instability. We took from the archives a cross section of materials that we knew were exhibiting degradation and we looked at the percentages of degraded film materials exhibiting acetic acid odour (or vinegar syndrome). We found that 78% of the degraded materials

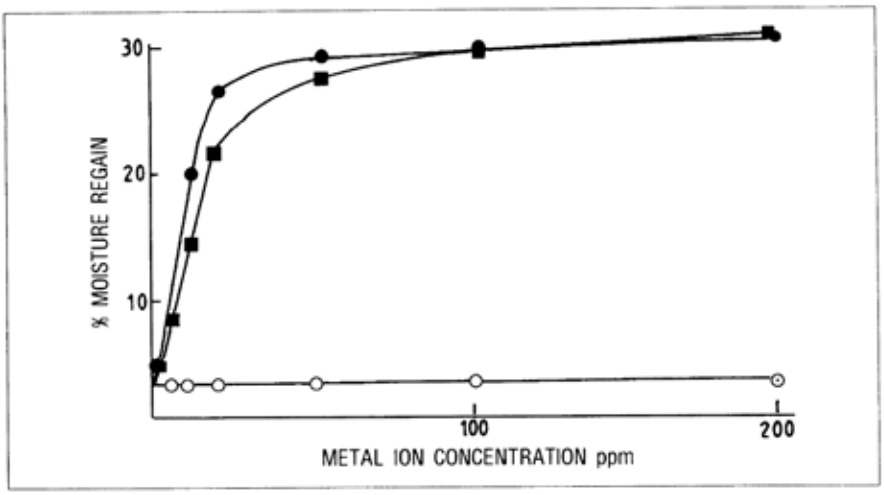


Figure 4
Percentage moisture regain versus metal ion concentration (ppm) for solvent cast cellulose triacetate films (150mm): iron ●, chromium ■, silver ○

(or vinegar syndrome). We found that 78% of the degraded materials were magnetic track materials, compared with only 22% that had no magnetic track and so had no iron present in the base material.

Because we realized that the effect of the film can was particularly important, we used Arrhenius testing methods to ascertain the time taken for a given loss in a physical property of the material. For example, we plotted the time taken for a 10% loss in viscosity against temperature in various storage media. At 50% relative humidity (the humidity level found in many archival storage facilities), we found that film was most stable in glass, then plastic, then aluminium, and least stable in contact with a tin-plated can. We predicted that the lifetime of the material in contact with a typical tin-plated can in an archive would be around 35 years (Figure 5). Allowing for experimental error and any error in our plotting (given that we're plotting against a log scale, our line could be out by ±10 years), this corresponds reasonably well with what we actually find because, if you recall, triacetate was introduced in the early fifties and we're seeing degradation now.

The effect of the emulsion

Because film without emulsion breaks down more rapidly, another question arises: what part is played by the emulsion itself – by the presence of gelatine? It seems that the gelatine is actually acting to stabilize the material, probably mainly because gelatine is itself a polymer system made up of amino acids and linked into long chains, into a protein-type material. When the degradation products (the acetic acid) from the base hit the emulsion, the emulsion serves as a mop for the acid. When it takes up the acid, the emulsion itself is broken up and is lost: you can then wipe off the silver image and the emulsion becomes sticky. Because film is wound tightly into a reel and is, therefore, a sandwich of support material and emulsion, we believe that the emulsion also somehow acts as a diffusion barrier to, perhaps, the ingress of oxygen.

Also, negative film has a thicker layer of emulsion than positive film, so we took a cross section of degraded stocks in an archive and

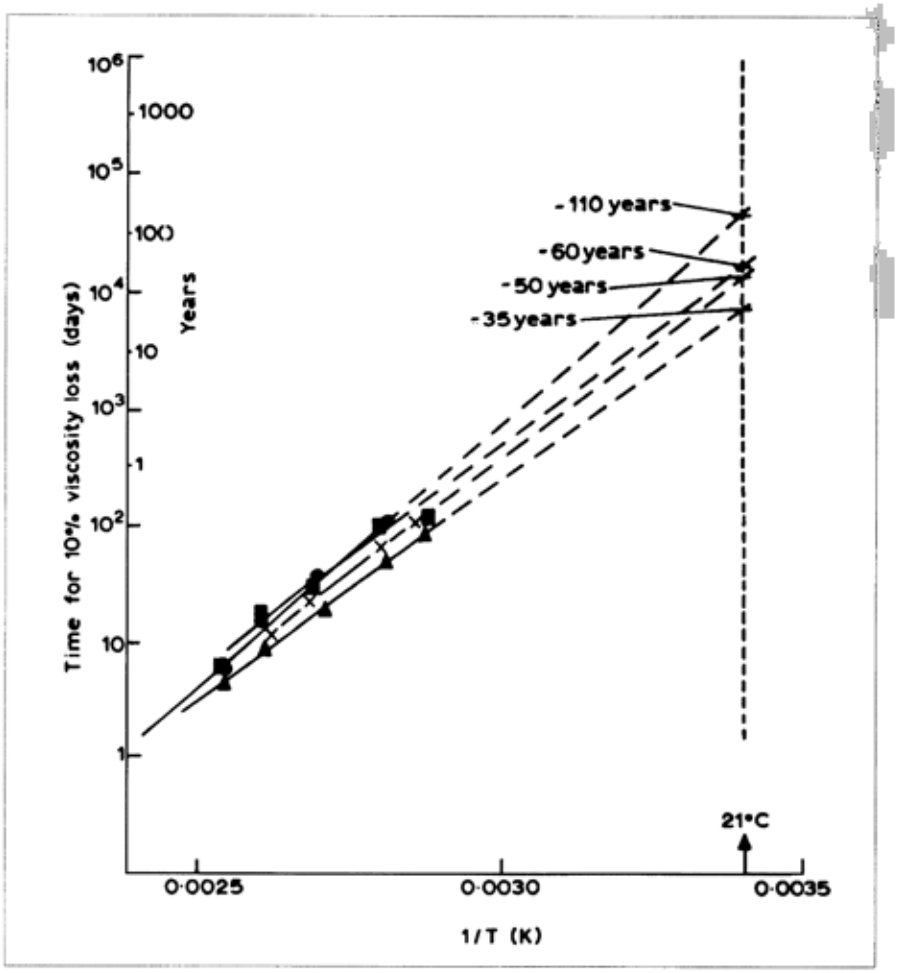


Figure 5
Time for a 10% loss in viscosity of the cellulose triacetate film (days and years) versus recciprocal temperature of degradation (K) in glass ■, polyethylene ●, tin-plated iron ▲, and aluminium × containers at 50% RH.

compared percentage incidences of positive and negative films exhibiting vinegar syndrome. We found that positive films formed around 59% of degraded material compared to negative films only 41%. The emulsion layer itself is beneficial.

The effect of an enclosed environment

So far we had looked at all the constituents and at the fact that the film is in a can; but what about the fact that, because the film is in a can, it is in a smaller environment than if it was just on a shelf? We ran infra-red spectra, which give a trace corresponding to particular groups in the molecule.

We looked at some cinematograph films, and the first thing we noticed was that the moisture content was changing significantly: it was taking up moisture. We already knew this, but the loss of acetate groups did not appear to be particularly great. Not many acetate groups are actually being lost in a film ageing from new to loss of image.

We were lucky enough to get hold of a triacetate sculpture that had stood in an open environment for 20 or 30 years. It was exhibiting

the formation of acetic acid – the vinegar syndrome – but, in this case, the degradation patterns were quite different. It didn't appear that the sculpture was taking up moisture but that, in the place of the acetate groups on the polymer backbone, we were actually substituting hydroxyl groups in some way, and there was a massive loss of acetic acid. So it seems that in an open environment we are promoting loss of acid, and in a closed environment we are setting up some kind of equilibrium that prevents further loss of acid.

We decided to check that by artificial ageing techniques and found that, in an open environment, the onset of moisture regain (which corresponds to loss of acetate groups) is much greater. The onset is much more rapid than in an enclosed environment, where the loss of acetate groups will be suppressed. Unfortunately, however, we seem to have this Catch 22 situation whereby, although we're subduing loss of acetate groups and de-esterification and forming less acetic acid than in an open environment, the polymer chain is breaking up instead. In an open environment we see very little decrease in viscosity or loss of tensile properties compared to an enclosed environment where it appears that, because we're actually containing the acid impurities within the film can, they can serve to break down the main polymer chain which loses its viscosity and will also lose its tensile properties.

Using the information

Now we know more or less what happens when storing film. Storing it in contact with iron isn't good; the emulsion is beneficial, but it will be lost as a consequence of base degradation, humidity is more important than temperature in controlling film stability. Having gained this information, what do we do about all these things? One option is to utilize this information to help decide when to copy the material that is degrading: we can use the chemical information about how degraded the film is to produce stability tests so that, at least, we can prioritize copying. Alternatively, we can stabilize the material itself, though to stabilize an individual polymer requires a recognition of the fact that it is contributing to its own instability.

Bearing in mind the major features that contribute to the instability of the film, if we are to stabilize the material, we must introduce something that can block the effects of all those particular factors: oxygen, the presence of any metal ions, the presence of elevated temperatures and moisture – all of which help to produce radicals or acetic acid that break the system down.

The particular combination that we have looked at is a tris-stabilizer, which is a combination of:

- a hindered piperidine **stabilizer**, Tinuvin 770, which acts as a mop for radicals and also, because it is basic, as a mop for any acid products,
- a **metal de-activator**, Irganox MD1024, which complexes the metal ions so that they cannot accelerate the break down of peroxides to radical species,
- an **anti-oxidant** to counteract the effects of any radicals or any oxygen.

Comparing the property retention, the viscosity retention, of a controlled material with no stabilizer and a material with this tris-stabilizer system, you can see that the retention of properties is much superior with the stabilizer present (Figure 6). Our Arrhenius testing predicted that in a metal can, stored at 50% RH, with no stabilizer the film would last 35 years. We believe that the stabilizer will give a six-fold increase in life to around 215 years (Figure 7).

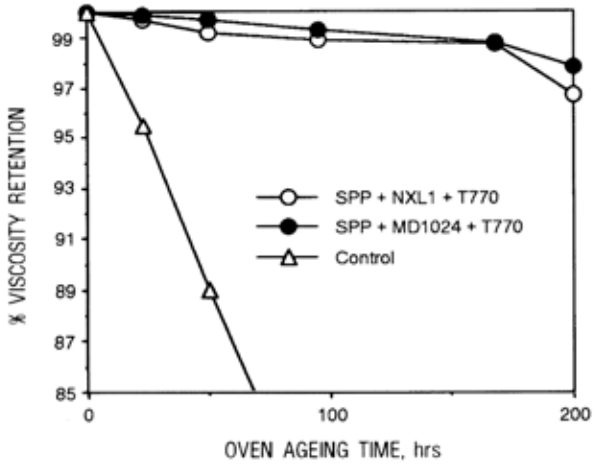


Figure 6
Percentage viscosity retention versus oven-ageing time (h) for cellulose acetate base cinematographic film containing tris combinations of stabilizers.

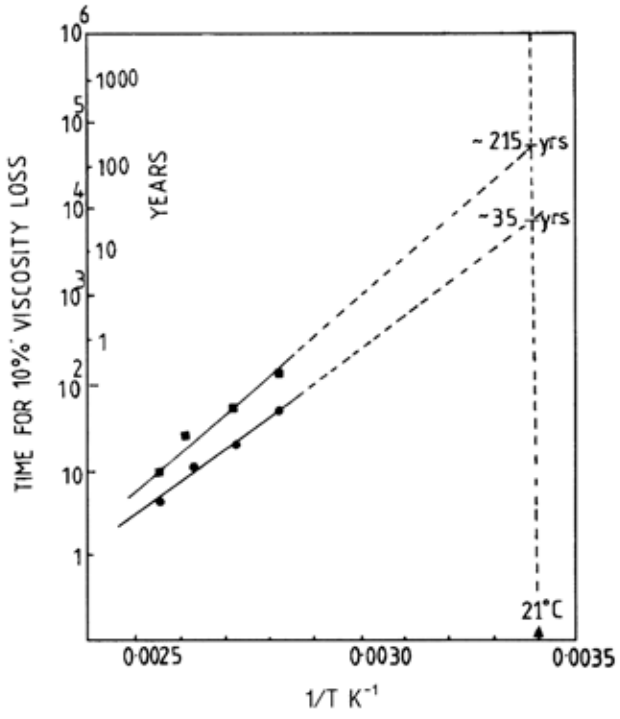


Figure 7
Time taken for 10% loss in the viscosity of cellulose triacetate base cinematograph film (years) versus reciprocal temperature of degradation (K) for films aged in contact with metal can at 50% RH containing no stabilizer ● and a tris stabilizer ■ combination of Irganox MD1024, Tinuvin 770 and sodium phenyl phosphinate.

Question:
Will having painted or enameled cans, instead of bare metal cans, retard the problems with iron?

Michelle Edge:
The problem is that, when you coat a metal can, you can't exclude trace metal ions from the surface, and as little as 10 parts per million actually promotes degradation. The other factor is that, if you coat a can, you're introducing another plastic material that can itself degrade: over the long term, we have problems. Think of library books with sticky-back plastic covers; if you leave them in the drawer for too long, you'll find that they stick together. That's basically because you get inter-migration of additives between the systems and, because the additives in one system aren't compatible with those in the other, breakdown is accelerated.

Factors Influencing the Degradation of Polyester-Based Cinematographic Film and Audio-Visual Tapes

Norman Allen, Martin Hayes, Michelle Edge, T S Jewitt and Karel Brems

Henning Schou: *I'll now call on Doctor Norman Allen to read his paper on 'Factors Influencing the Degradation of Polyester-Based Cinematographic Film and Audio-Visual Tapes,' co-authored with Martin Hayes, Michelle Edge and Dr T S Jewitt from Manchester Polytechnic, and Karel Brems from Agfa-Gevaert in Belgium. Dr Allen obtained his Bachelor of Science from the University of Wales, Cardiff and his Doctor of Philosophy and Doctor of Science degrees from the University of Salford. He's currently Professor of Chemistry at Manchester Polytechnic, where he actively supervises a large research school of twelve PhD students in areas associated with the degradation and stabilization of polymers, dyes and pigments, and various aspects of the photochemistry of polymers. He is an international authority in these fields, with over 250 research publications and reviews and 10 technical books to his credit.*

Introduction

Polyethyleneterephthalate (PET) is a thermoplastic material, commonly known as polyester, widely used in the form of fibres and films. The stability of film, sheet and moulded PET is of considerable interest with respect to environmental pollution. On the other hand, where PET is used as a support for photographic and magnetic media, longevity is of prime importance.

The degradation of PET has recently been reviewed by Zimmerman (1) and is shown to be characterized by its complexity. Although the thermal stability of this polymer is high, its sensitivity to impurities and the microenvironment places constraints on its longevity. Factors such as relative humidity and the presence of trace metal ions may play a significant role in the rate of degradation. The latter may be particularly important, since metal oxides are used as catalysts during the manufacture of PET. Furthermore, during the manufacture and processing of PET into film or moulded products, the polymer is subjected to temperatures in the range of 200–300°C which are sufficient to instigate thermal breakdown.

The initial stage of thermal degradation is a random scission of the in-chain ester linkage resulting in the formation of a vinyl ester end-group and a carboxyl end-group. Transesterification of the vinyl ester then occurs to give vinyl alcohol, which is transformed immediately into acetaldehyde. The polyester chain is thus regenerated, and an average degree of polymerization maintained. The net result of such reaction is the replacement of hydroxyl end-groups by carboxylic acid end-groups, producing in the process an equivalent amount of acetaldehyde (as shown in the reaction scheme, Figure 1). Hydrogen atom abstraction may also occur to some extent when impurities in the polymer generate macroradical sites. These will react with oxygen producing peroxy radicals and subsequently hydroperoxides which are themselves thermally and photochemically unstable, and will induce further breakdown of the polymer.

The presence of moisture and acid/alkaline impurities will effect hydrolysis. Hydrolysis of PET is a little-understood process; albeit an essentially hydrophobic polymer sensitive to moisture and hence overall hydrophilicity is thought to be determined by the nature of its chain ends. In this respect an increase in the carboxyl end-group concentration increases the rate of hydrolysis of the polymer.

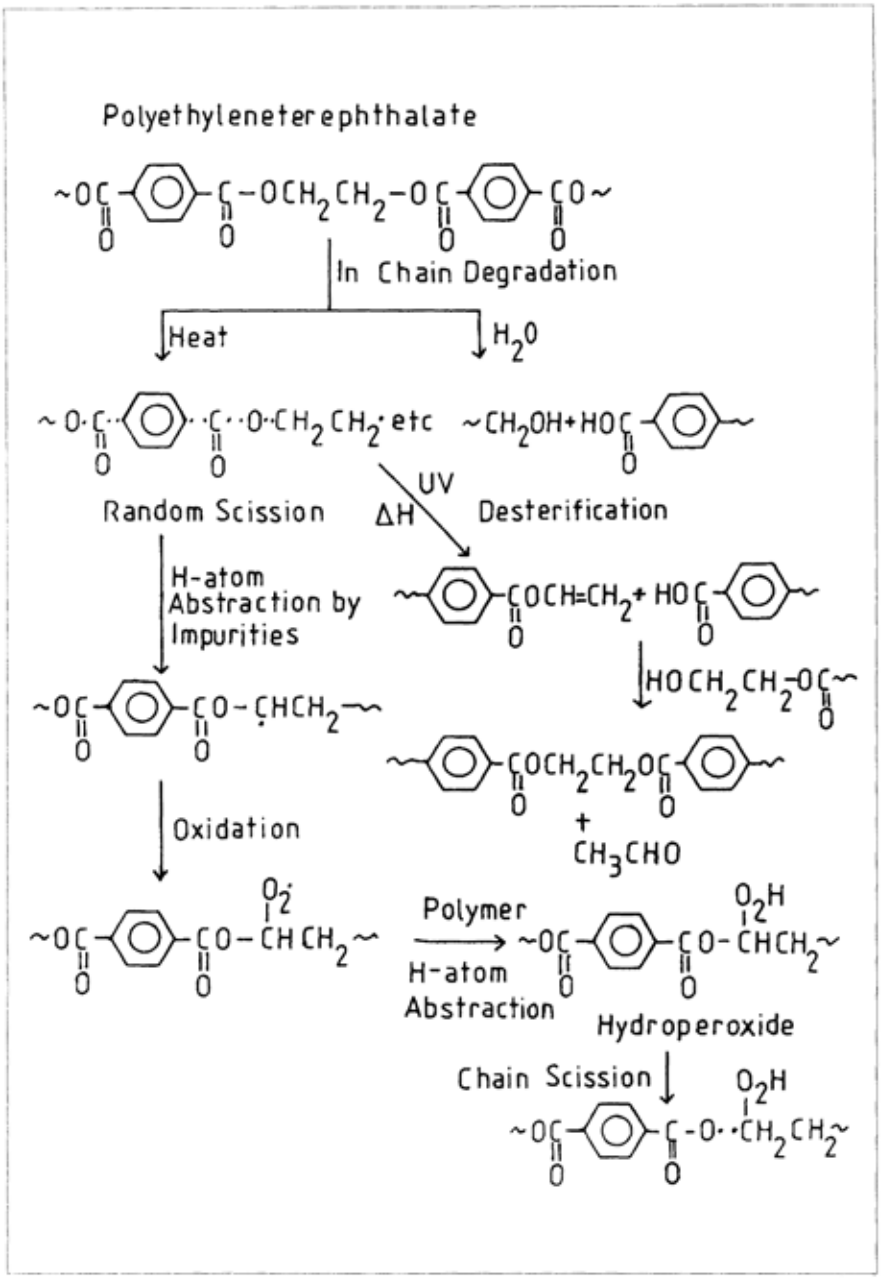


Figure 1
Degradation mechanisms of polyester

Photodegradation of PET occurs on exposure to near ultraviolet light resulting in both chain scission by analogues of Norrish type I and II processes shown in the reaction scheme or photo-Fries type reaction. Crosslinking also takes place, polymer films becoming brittle, discoloured and developing crazed surfaces. Infra-red and gas-chromatographic analysis studies have shown both hydroxy- and carboxylic end-groups along with carbon monoxide and carbon dioxide to be the main products of photodegradation. Attenuated total reflectance spectroscopy has indicated carboxyl end-group formation to be surface concentrated. Hydroxyl groups have also been found to arise as a consequence of substitution reactions in the aromatic ring, resulting in the formation of mono- and di-hydroxyterephthalate units. The latter have been identified by fluorescent spectroscopy.

Although some aspects of the stability of PET have already been considered in the literature, its end use will be the most significant feature with regard to subsequent longevity. Such considerations are necessary not only for a reliable assessment of the performance of this polymer, but for a realistic interpretation of the mechanistic processes involved.

Degradation pathways occurring by possibly different and complementary mechanisms may serve to exacerbate the underlying situation. This study therefore considers the inter-relationship between such interactive processes as relative humidity, pH, temperature, light and microenvironment.

Experimental

Materials and suppliers

Samples of PET film (200 microns thick) and bottles were supplied by ICI Chemicals and Polymers of Wilton. Samples of non-processed 35mm cinematograph film were provided by Agfa-Gevaert of Mortsel in Belgium. The cinematograph film is composed of a PET substrate, cross-linked polyurethane/epoxy acrylate adhesive layers, and a non-photographic-processed emulsion.

Accelerated ageing of PET film and bottles

Samples of polyester film and bottles were oven-aged in dry soil, wet soil, 45% and 100% relative humidity conditions at 60°C, 70°C, 80°C and 90°C. Samples of polymer were also irradiated in the absence and presence of soil in quartz tubes using a Microscal Light exposure unit (Microscal Ltd, London) utilizing a 500 watt high pressure mercury/tungsten fluorescent lamp (50°C and ambient humidity).

Accelerated ageing of PET substrate cinematograph film

Samples of non-processed cinematograph film were oven-aged in dry, 45% and 100% RH conditions at temperatures of 60°C, 70°C, 80°C and 90°C.

Viiscometry

In the case of PET sheet and bottles, 0.1g of polymer was dissolved in 10cc 60:40 w/v phenol/tetrachloroethane, and a flow time obtained using a U-tube viscometer at 25°C. For cinematograph film the emulsion was first removed by dipping in dilute sodium hypochlorite solution and washing thoroughly. Backing layers were then removed by placing the film in sodium carbonate solution (10g/litre). The PET substrate (0.1g) was then dissolved in 10cc o-chlorophenol and a flow time obtained using a U-tube viscometer at 25°C.

Values of intrinsic viscosity (IV) were obtained from standard calibration tables supplied by the Analytical Department of ICI C & P Group of Middlesborough using corrected relative viscosity values for each solvent system (flow rate of sample solution (t_s)/flow rate of solvent (t_o) x correction factor). The correction factors were determined by comparing the ratio of the measured IV values obtained for standard samples of polyester with those given in the

standard table. Number average molecular weight values were obtained from the following relationship:

$$IV = 1.7 \times 10^{-4} \times Mn^{0.83}$$

Chain scissions are then obtained by the standard relationship:

$$CS = \frac{Mn_0}{Mn_t} - 1$$

Microscopic examination

The surface analysis of video tapes was carried out using a Vanox-T high-resolution light microscope, Model AH-2, available from Olympus Ltd of London. Surface magnification was 300x, and photographs were obtained using a standard high speed Polaroid Camera.

Results and discussion

Polyester film

The polyester film studied in this programme had a thickness of 200 microns and a crystalline content of only 1% obtained using an appropriate density column. Samples were degraded under wet soil, dry soil, 100% and 45% RH conditions at 90°C and 80°C, whereas at 70°C dry soil conditions showed negligible degradation and is excluded and at 60°C degradation was evident only under wet and 100% RH conditions. Thus, in terms of the degradation mechanism of polyester breakdown, hydrolysis appears to be the dominant reaction.

Changes in intrinsic viscosity for polyester film at 90°C are shown in Figure 2 for all the conditions studied. From the plots obtained it is interesting to note that the most severe degradation condition is that under wet soil, followed by 100% RH, 45% RH and then dry soil. From the plots of percentage decrease in intrinsic viscosity, plots of chain scissions versus degradation time were obtained. These graphs for the conditions at 90°C, 80°C, 70°C and 60°C are shown in Figures 3 to 6 respectively, and give a more quantitative indication of the differences in rates of degradation under the various conditions. Apart from wet soil at 60°C, the plots of chain scissions versus ageing time are virtually linear.

From these results there are two interesting features to note. The first is the observation that at 80°C and 90°C degradation rates under the wet soil condition are greater than that at 100% RH, whereas at lower temperatures the effect is reversed. This may be associated with the fact that at temperatures above 80°C the glass transition temperature of the polymer is exceeded, and metal ions from the soil are able to migrate more readily into the polymer and accentuate the degradation rate. The second interesting feature is the observation that differences in the rate of degradation are less significant at 90°C than at 80°C between dry conditions and 45% RH. Thus, at higher temperatures the effect of thermal degradation appears to be more prominent, whereas at lower temperatures hydrolytic degradation dominates the rate.

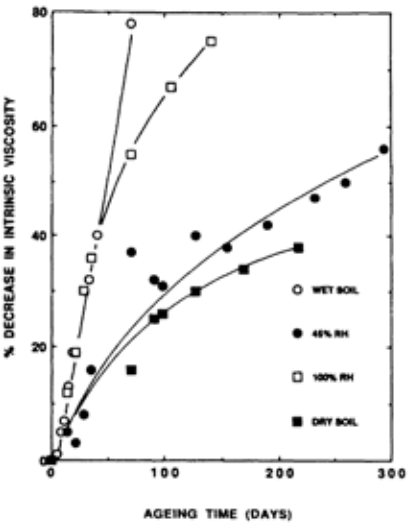


Figure 2
Percentage decrease in intrinsic viscosity versus ageing time for polyester film material (ICI) at 90°C.

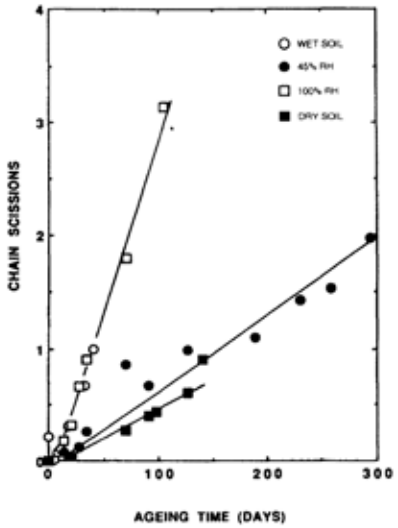


Figure 3
Increase in chain scissions versus ageing time in days for polyester film material (ICI) at 90°C.

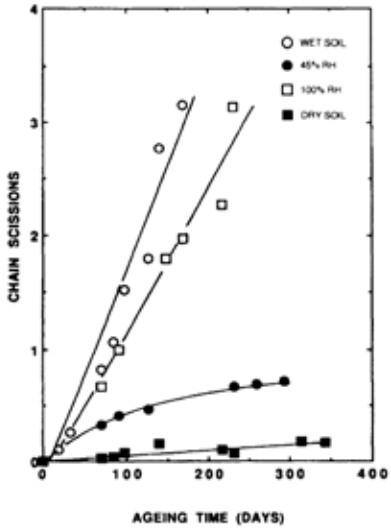


Figure 4
Increase in chain scissions versus ageing time in days for polyester film material (ICI) at 80°C.

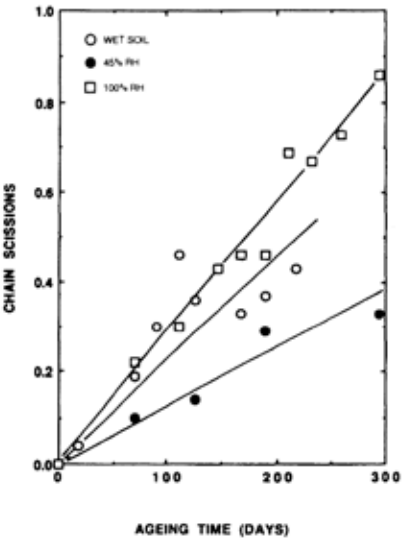


Figure 5
Increase in chain scissions versus ageing time in days for polyester film material (ICI) at 70°C.

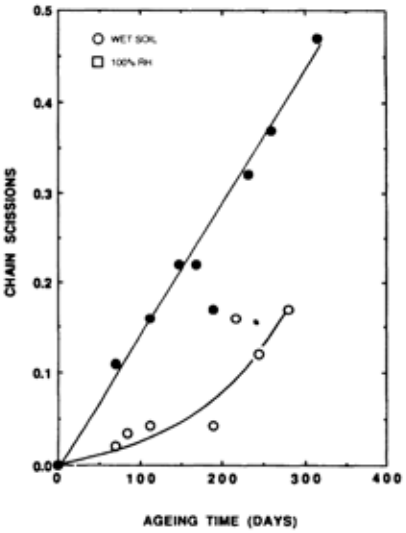


Figure 6
Increase in chain scissions versus ageing time in days for polyester film material (ICI) at 60°C.

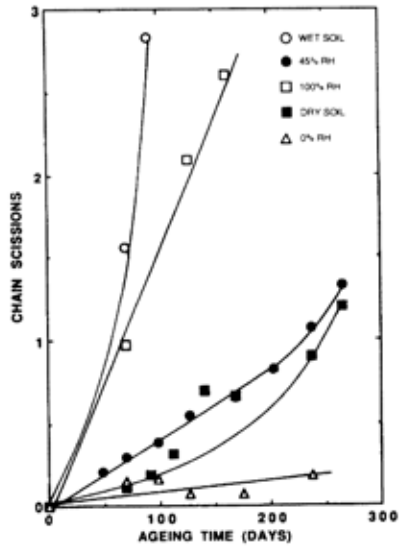


Figure 7
Increase in chain scissions versus ageing time in days for polyester bottle material (ICI) at 90°C.

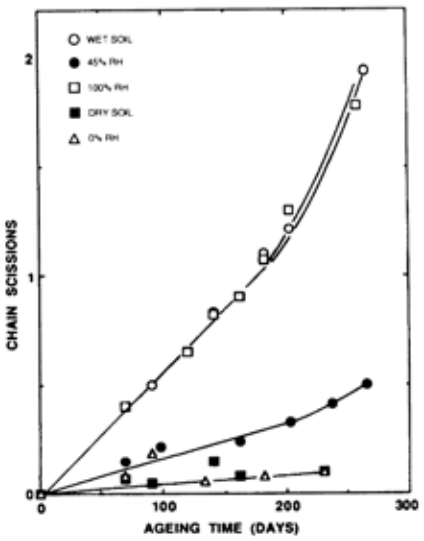


Figure 8
Increase in chain scissions versus ageing time in days for polyester bottle material (ICI) at 80°C.

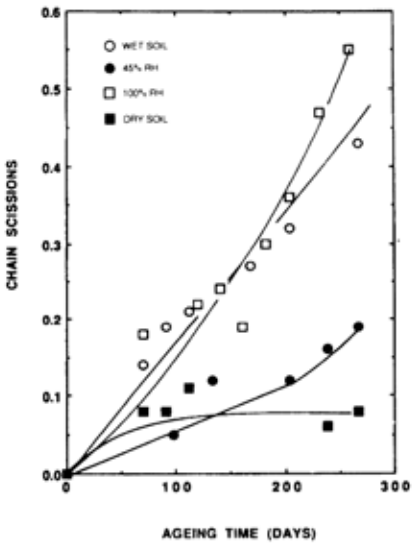


Figure 9
Increase in chain scissions versus ageing time in days for polyester bottle material (ICI) at 70°C.

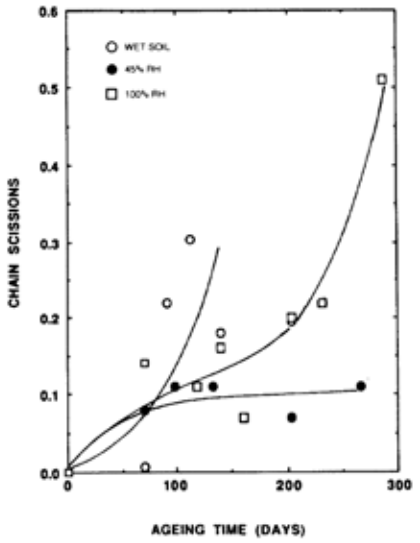


Figure 10
Increase in chain scissions versus ageing time in days for polyester bottle material (ICI) at 60°C.

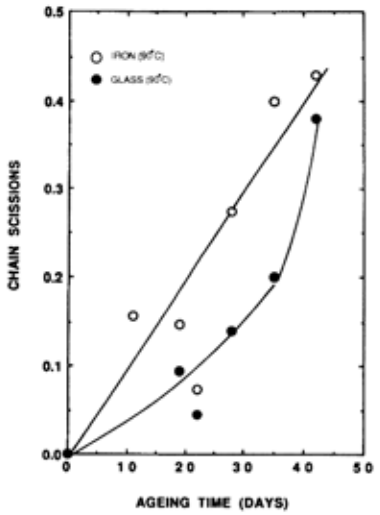


Figure 11
Increase in chain scissions versus ageing time in days for polyester motion picture film material (Agfa-Gevaert NV) at 90°C and 100% RH in the presence of glass and iron.

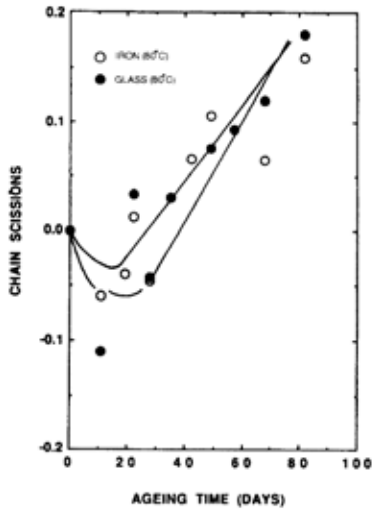


Figure 12
Increase in chain scissions versus ageing time in days for polyester motion picture film material (Agfa-Gevaert NV) at 80°C and 100% RH in the presence of glass and iron.

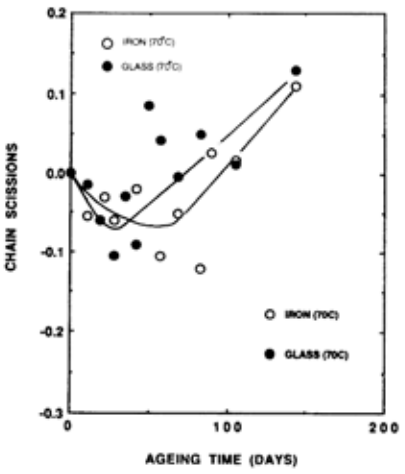


Figure 13
Increase in chain scissions versus ageing time in days for polyester motion picture film material (Agfa-Gevaert NV) at 70°C and 100% RH in the presence of glass and iron.

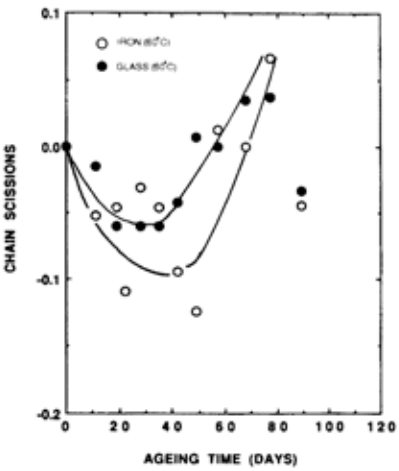


Figure 14
Increase in chain scissions versus ageing time in days for polyester motion picture film material (Agfa-Gevaert NV) at 60°C and 100% RH in the presence of glass and iron.

Polyester bottles

The rates of degradation of polyester bottles measured by chain scissions at 90°C, 80°C, 70°C and 60°C are shown in Figures 7 to 10 respectively. At 90°C the rate of degradation in wet soil is more significant than that at 100% RH, and at 80°C the differences are minor. At 70°C the rates are reversed, whereas at 60°C differences in degradation rates are difficult to predict owing to the low rates of degradation and scattering of points. However, the differences between rates of degradation under dry conditions and at 45% RH are similar to those observed for the polyester film material. Thus, at 90°C differences in the rates of degradation are minimal, whereas at 80°C and 70°C the differences become more marked. One interesting feature of the results for the bottles is the marked difference in the rate of degradation between 0% RH and dry soil at 90°C. At 80°C this difference is not evident and supports the hypothesis of metal ion migration into the polymer at higher temperatures.

Motion picture film (non-processed)

The degradation rate of non-processed polyester motion picture film material with emulsion layer at 90°C, 80°C, 70°C and 60°C at 100% RH are shown in Figures 11 to 14 respectively. These plots illustrate the changes in chain scission rates and show a number of interesting features. Intercomparative studies on other conditions are still ongoing and will be published later in a full article dealing specifically with aspects of motion picture film material.

In this study, films were aged as small reels in Pyrex dishes with and without an iron base cut out from the metal container used to store the film. At 90°C it is seen that the degradation rate of the polyester motion picture film is greater in the presence of the iron base, whereas at lower temperatures the effect is reversed but only to a minor extent. The one interesting feature of these results, however, is that at temperatures lower than 90°C there is an initial crosslinking of the polyester, the extent of which increases as the degradation temperature decreases. This effect would appear to be associated with the emulsion layer on the film which would impair the diffusion of oxygen into the polymer base at the temperatures below the glass transition temperature of the polymer. The lower the temperature, the greater the degree of crosslinking. The iron also appears to be catalysing the crosslinking to a minor extent.

Irradiation effects

The effect of irradiation of the polyester film and bottle materials as determined by the rate of change in chain scission is shown in Figure 15. Unlike thermal degradation, the rate is autocatalytic in both cases except for the bottle material which displays an initial induction period before the onset of severe chain scission. This induction period may be associated with the higher crystallinity of the bottle material compared with that of film. One interesting feature of these results is that in contact with soil the polyester degrades at a faster rate. Again, contact of the polyester with metal ions on the surface may be important.

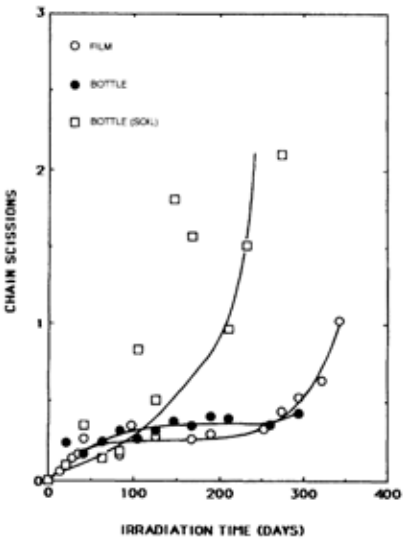


Figure 15
Increase in chain scissions versus irradiation time in days in a Microscal Unit for polyester film and bottle materials in the absence and presence of soil.

Henning Schou:
In your work on polyester, you plotted chain scissions against time. How is that measured?

Norman Allen:
Chain scission is a scientific method of actually measuring the rate of degradation of a polymer. Viscosity is not, on a scientific basis, a good representative method of measuring the rate of degradation – you must measure what is actually happening, and we measure it simply from viscosity measurements. But we use a scientific equation to interpret the change in viscosity into actual number of chain scissions, There's a special expression that polymer scientists world-wide use to actually do this.

Klaus Hendriks:
Experimentally, it's based on viscosity measurements?

Norman Allen:
Yes, it is based on viscosity measurements, but it's more correct when you talk about the degradation rate of a polymer to talk about chain scission. It's the only way you can talk about it in that sense because, at the end of the day, your main parameter that's changing is the backbone of the polymer. It's breaking down.

Klaus Hendriks:
What's the unit? You referred to 0.1, 0.2, etc.

Norman Allen:
Yes, 0.1 of a chain scission means 0.1 chain scissions per unit average chain – a piece of polymer could have thousands and thousands of chains.

Klaus Hendriks:
So you'd need 10 units to have 1 chain scission?

Intercomparison of data and Arrhenius predictions

Comparison of the above data shows a number of similar trends. However, it is noticeable that the motion picture film material degrades in a totally different manner owing to the emulsion layer. Furthermore, the motion picture film is significantly more stable than that of normal polyester film material, and this is confirmed by the results shown in Figure 16 for chain scission rates at 90°C. This is associated with the much higher crystallinity of the former polyester which was determined to be 55%. The normal Melinex polyester film has a crystallinity content of about 1%.

Predicting the stability of polymer materials at ambient temperatures is theoretically possible through modification of the Arrhenius expression assuming that the rates of degradation follow first-order kinetics (10,11). This is invariably not the same, and such predictions therefore serve only as an approximation. Our results here are no exception and, even with the aid of computer predictions and data extrapolation, are in error by +/- 10 years.

In this work the logarithm of the times for polyester film and bottle materials to achieve a 50% loss in intrinsic viscosity are plotted (Figures 17 and 18) against the reciprocal temperature (in K) and the data extrapolated to 20°C (293K) (11). For these materials, this is a suitable point in time when the polyester is assumed to be environmentally degradable, ie all physical characteristics are lost and the material crumbles to a powder. On the basis of these results therefore, polyester film has an average life expectancy at 45% RH, wet soil and 100% RH of 32, 30 and 25 years respectively (Figure 17). For polyester bottles on the other hand, the life expectancies are longer with predictions of 48, 35 and 27 years for the same conditions (Figure 18).

In the case of motion picture film material, degradability must be a minimum in order to preserve the photographic image for archival purposes, and a 20% loss in intrinsic or relative viscosity would result in an irrevocable loss in the physical characteristics of the film materials. Figure 19 shows such a plot of the logarithm of the time for the film to achieve a 20% loss in relative viscosity versus the reciprocal of the temperature. In this case it is determined that, at 100% RH, the polyester has an archival life of 91 and 87 years in glass and iron containers respectively. Predictions at relative humidities lower than 45% are expected to exceed 1000 years (10), and will be reported on later.

Microscopic examination of video tapes

Samples of 2-inch commercial video tapes of various archival histories were supplied by the National Film Archive (NFA) of Berkhamsted in the UK and examined under the high resolution light microscope at 300x magnification. Polaroid photographs were taken and compared with those taken for new 1-inch video tape as well as video tape that had been aged at 90°C for 63 days in contact with iron.

The surface of new 1-inch home Agfa-Gevaert video tape showed no evident signs of any deterioration or surface deposits, while Scotch 2-inch video tape manufactured in 1986 was beginning to show

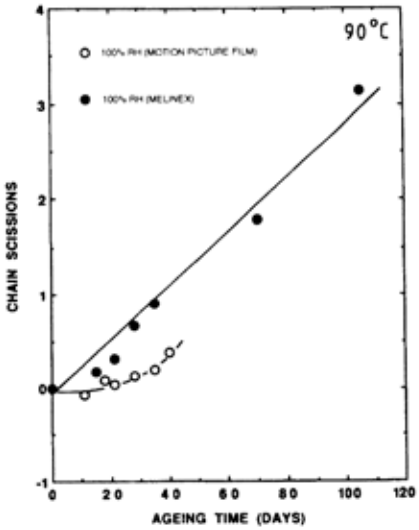


Figure 16
Increase in chain scissions versus ageing time in days at 90°C and 100% RH for normal polyester film (ICI) and polyester motion picture film.

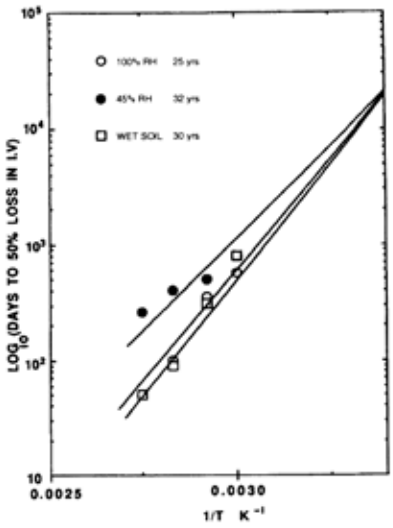


Figure 17
Arrhenius plot of logarithm of time to 50% loss in intrinsic viscosity (days) versus reciprocal temperature in K^{-1} for polyester film (ICI) material.

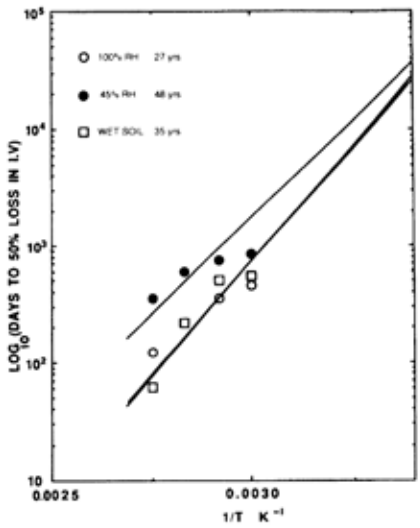


Figure 18
Arrhenius plot of the logarithm of time to 50% loss in intrinsic viscosity (days) versus the reciprocal temperature in K^{-1} for polyester bottle (ICI) material.

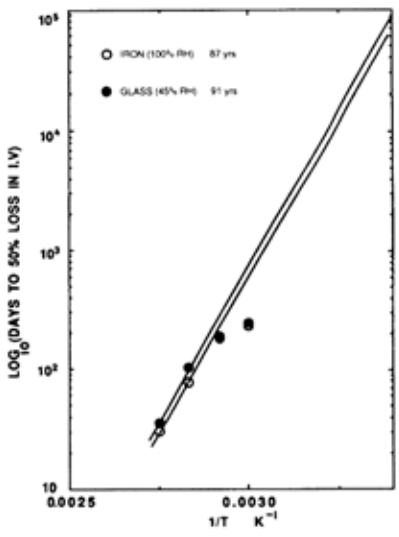


Figure 19
Arrhenius plot of logarithm of time to 20% loss in reciprocal temperature in K^{-1} for polyester (Agfa-Gevaert NV) film at 100% RH in glass containers and in the presence of iron.

Norman Allen:
Yes.

Dietrich Schüller:
I am a little bit relieved to hear that polyester seems to be quite stable. What worries me is your statement that video tape is not an archival carrier, and you predict a lifetime of 10 to 15 years. This is obviously totally against experience – shouldn't such a statement be based on a thorough investigation of the varying binder technology which seems to constitute a problem? I don't think that it is possible simply to compare a photomicrograph of a randomly chosen tape from 1986 with one of a randomly chosen tape from 1990 and draw any conclusions about their stability or non-stability. We have been finding that some very old tapes are very stable, yet some very young tapes have severe problems because of chemical interactions with other things. So I would like to point out that what you say is in a way against experience – fortunately.

Norman Allen:
Yes, you are right. There are many examples where video tapes are still usable after many many years. The life predictability depends on the usage of the tape material, and also on the chemical composition, which varies enormously from one manufacturer to another. Today it's becoming more and more standardized, but I believe the chemical composition may not becorrect.

Jim Wheeler:
For many years we've known high moisture to be a real problem of video tape. We recommended storing at very

low humidity conditions and you're talking to different people and saying 10 to 15 years – I'd like to know what kind of moisture conditions they are stored in.

Norman Allen:
They were actual films taken from archives, which vary enormously. I don't want to mention the archive names, but I guess an average RH would be around 45%.

Jim Wheeler:
But that's an absolutely critical factor; at 60%, you get fungus on tapes.

Norman Allen:
Yes, particularly for coatings.

Alan Lewis:
You mentioned that the crystalline deposits that you see on the surface of the tape may very well be the lubricants crystallizing out. Do we know anything about the quality of those crystals? We are concerned that older video formats are becoming increasingly difficult to maintain, to get spare parts for, heads re-built, and so on. Is it safe to assume that these crystals are in fact making the tapes more abrasive so that, as we continue to play them, we are in fact destroying our machines?

Norman Allen:
That may be possible. We did re-examine some of the older video tapes recently under the microscope and we did see lines on some of them, deep-cut into the surface, and Karel Brems from Agfa-Gevaert was actually there when we were looking at them under the microscope. He believed that maybe it was the deposits which are cutting into the surface. That's possible.

some signs of surface deterioration, and 2-inch video tape manufactured in 1976 clearly showed severe white deposits on the surface that may be due to the lubricant. Of particular interest however, is the Scotch 2-inch video tape manufactured in 1968 which showed very severe signs of degradation with globular conglomerates on the surface. Similar degradation was found on the surface of a 1-inch Agfa-Gevaert video tapethat had been aged under accelerated condition at 90°C for 63 days.

In terms of surface analysis of video tape coatings, natural and artificial ageing conditions undergo similar degradation reactions. The degradation phenomena observed in the case of the video tapes studied here were common to materials from all manufacturers.

Conclusion

From the results to date, we conclude that the degradation rate of polyethyleneterephthalate (PET) is dependent upon the nature of the material. Thus, motion picture film is more stable than bottles, which are themselves more stable than normal film. This effect is associated with differences in the crystallinity of the polymer. Degradation rates of polyester increase with increasing temperature, especially above the glass transition temperature.

The degradation rate increases significantly with increasing humidity owing to an increase in the rate of hydrolysis. At temperatures above 80°C, differences in the rates of degradation up to 45% RH are not significant. Thus, at lower temperatures hydrolysis is the dominant process. At temperatures below the glass transition, polyester motion picture film materials exhibit some initial crosslinking. Here the emulsion layer is inhibiting the diffusion of oxygen into the polymer. The presence of iron from the container has an accelerating effect on the rate of degradation of polyester motion picture film, but only at temperatures above the glass transition (80°C).

Acknowledgments

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George Brock-Nannestad:
Do white specks on the surface of the video tapes really mean a problem because there is a loss of oxide and therefore information, or is it just a phenomenon we can observe and eventually there will be a loss and a drop-out? In other words, what I'm looking for is quantitative data (how many specks per square centimetre, for instance) so that we can relate that to tape width, track width and length, and so on.

Norman Allen:
This is what we hope to do eventually. Our machine is coupled to a computer and a television camera that will actually give us the number of spots, or whatever medium it is, per unit area. We are starting to look more at the side that you're interested in at the end of the day, which is the image itself: the sound or the visual image and its quality. At the moment I am a degradation scientist, and concerned more with the degradation. I know very little about sound and vision.

Peter Adelstein:
Experience of polyester tape has also shown that dimer can migrate to the surface, and the white material you see could be that.

Norman Allen:
That is possible. I did publish a paper in the 1970s on dimer formation in polyesters. The problem is getting enough of the material to actually do an analysis on it.

Simulated Ageing of Processed Cellulose Triacetate Motion Picture Films

Tulsi Ram, S Masaryk-Morris, David Kopperl and Richard W Bauer

Henning Schou:
I would like to ask Dr Tulsi Ram of the Eastman Kodak Company in Rochester to come up and read his paper, co-written with Maseryk-Morris, David Kopperl and Richard Bauer, also of the Eastman Kodak Company.

Dr Ram is involved in research into material degradation and properties of photographic film. He's secretary of the ANSI (American National Standards Institute) IT9 committee on image permanence and physical properties, and he's chairman of the IT9-4 committee on stability of thermal processed silver films. Dr Ram is actively involved with archival film concerns and film preservation.

Introduction

This paper is a prelude to a more extensive study that's currently being undertaken at the Eastman Kodak research laboratory, primarily based on world-wide concern about the vinegar syndrome. We are concerned about the stability of the cellulose triacetate support material, and are anxious to identify the factors involved in open versus confined storage – this is the basic issue that we have undertaken to study.

As Michelle Edge and Norman Allen have also done, we have tried to simulate ageing at two or three different kinds of humidities to compare the response. Today I'm going to talk about:

- the definition of archival films
- previous and predicted estimates of longevity
- the performance of the cellulose triacetate support
- the vinegar syndrome: destructive and non-destructive techniques for detection in the early stages (I think that is of prime importance to archivists around the world, who need to know whether or not the film that they receive for storage has potentially degraded)
- the chemistry of hydrolytic degradation
- recommendations for proper storage
- conclusions.

Archival films

Archival films are basically storage copies, they are not used copies. If you use them and then try to store them, you do not know the history of the material. Archival film requires careful processing conditions. It must be made on stable support material, and it must also be properly stored and cared for. So archival assurance is a combined responsibility of the manufacturer, the processing laboratory and the consumer.

Estimating longevity

The estimates for the longevity of silver gelatine photographic films were carried out at Eastman Kodak laboratories by Peter Adelstein

and Jim McCrea on both polyester and cellulose triacetate materials. The estimates were based on confined storage: large amounts of film were kept in the closed environment of Pyrex glass tubes or Kodak tin cans, and then their physical properties were measured. We measured physical retention, intrinsic viscosity (which relates to the molecular weight of the material), tensile properties: loss in tensile strength, tensile elongation (which relates to the mechanical response of the polymer, because of course we need to know that the material will function in a projector or in a microfilm reader and so we looked at its end-use from the mechanical point of view). Chemically, we did not look at the degradation reactions except for the acetylation/de-acetylation reactions in the initial stages.

Our predictions are based on loss of intrinsic viscosity, loss of tensile strength, and tensile elongation for both triacetate and polyester-based materals. In all three factors, the polyester material was quite superior. We estimated the time needed for a 10% loss in property (which is not a failure criterion by any means, it's just a method of detection; the material can withstand a lot more without affecting its mechanical performance). For cellulose triacetate materials this time would be at least 300 years, and for polyester materials it would be about 2000 years, provided the materials are kept from the very beginning at a temperature not exceeding 21°C and at a relative humidity of 50% or less.

Cellulose triacetate degradation

We talked about hydrolytic degradation of cellulose triacetate films, and moisture is the number one factor. In this study the films were equilibrated at 50% RH, 30% RH and 15% RH, and stored in metal cans – 100-foot rolls were festooned or equilibrated for three days, kept in metal cans and heated. We studied the degradation reaction in terms of the loss in intrinsic viscosity and tensile strength. As we decrease the relative humidity, the useful life (the time to reach 10% loss at 21°C and 50% RH) becomes increasingly much longer.

Cellulose triacetate film degradation was first known in India as early as 1954. The incident became known to us at Kodak immediately after introducing cellulose triacetate. The high temperature/high humidity conditions had always been a source of major concern and, combined with the confined storage, the acid catalysis (which is autocatalytic) seemed to show degradation effects. This had been noticed by the National Film Archive in London (as has already been mentioned by Michelle Edge and Norman Allen), and Pollakowski in East Germany and Karel Brems in Belgium have questioned the archival nature of cellulose triacetate, while Horvath has done a survey on the US collections. The concern is the **vinegar syndrome**: the material looks as if it is going into powder, as if it's going to disintegrate. We wanted to find out if this is caused by confined storage or by keeping the material in open storage.

Detecting cellulose triacetate degradation

We have two different types of techniques for detecting cellulose acetate degradation: non-destructive methods and destructive methods. We took 5296 processed Eastman colour high-speed negative film and processed about 2000 feet, cut it in 100-foot

lengths and equilibrated at 60% RH and 40% RH in 100-foot roll cans. We then kept it in metal cans to see the effect of confined storage, and the implications for easier detection techniques.

Non-destructive techniques

There are basically three non-destructive techniques. We have not yet reached the point of being able to recommend which is good and which is not.

We use **Drager tubes** that we obtain from the National Mines Services Co, and which contain an acid-indicating material that changes from blue to yellow in the presence of acetic acid. In fact, your nose is the perfect detector, because your nose can detect as low as one part per million of acetic acid, whereas the detector we use can detect at a level of five parts per million – but it's a quantitative means of knowing how much acetic acid is there in the volatile form. We also have an infra-red technique and densitometry – I'll take these one at a time.

We looked at the effect of accelerated keeping at 60°C at 40°C and 60% RH, and also at 81°C at 40 and 60% RH. At the end of two weeks, one month and two months at 60°C, independent of the humidity, the amount of acetic acid generated was below the detection level. But at 81°C the amount of acetic acid was as high as greater than 80 parts per million. This is a very quick way of identifying and quantifying the level of acetic acid present, especially in a large can containing 2000 feet of roll film – it's a quick means of detecting that the film has ae potential degradation problem.

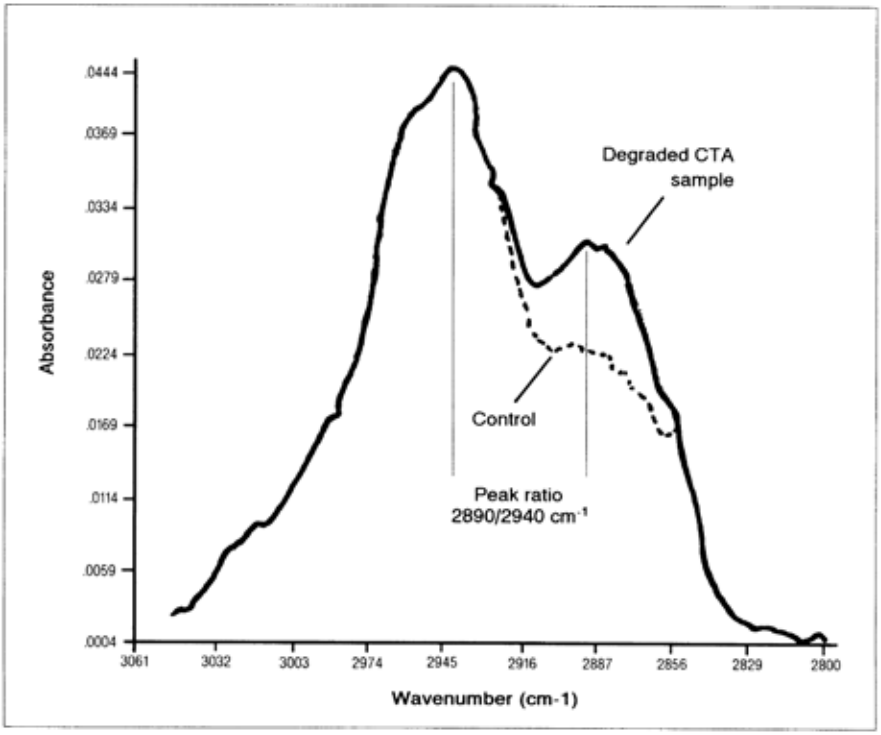


Figure 1
Attenuated total reflectance (ATR) spectra of control and degraded (2 months at 81°C and 60% RH) cellulose triactetate samples

Infra-red is another useful technique (Figure 1). The control film does not have a peak at 2890 and, as the film degrades, you see a change in the infra-red spectrum. What we are trying to do here is to get a ratio of the 2890 to 2940 peaks to see whether they simulate the level of degradation noticed at 81°C. In fact, as the material ages we do see a difference in the peak ratio, and we believe this may be one way of detecting the early stages of cellulose acetate degradation. This is a non-destructive technique, and we could just use the film and then do it. We also did the tests with and without the emulsion layer because generally in chemical detection the plasticizer (the emulsion layer) does interfere. But in this technique there doesn't seem to be any indication that the emulsion layer is involved.

The third non-destructive technique we are trying to evaluate is **densitometry.** If you know the original density and you follow that density as a function of time, this may be an indication of how much degradation will take place, and this is what we are trying to see.

If we compare a free-hung sample compared with a confined sample then, as Michelle Edge has pointed out, we find that in the free-hung sample the acids diffuse out. We wanted to compare the dye stability in the free-hung mode with that in the confined mode – where it could be affected either by the lack of oxygen or by the presence of acids (acids destabilize the dyes). We see that, at 81°C and at 40% – and even more at 60% RH – if you look at the green dye in the free-hung mode at the end of two months the density is about 0.13 and in the confined mode it is about -0.41. We are continuing our studies at lower temperatures. We are not sure whether or not densitometry is an appropriate technique for characterizing degradation, but we are interested to know whether we should evaluate the dye stability for these materials if the film is kept in confined storage.

Destructive techniques

Destructive test methods include pH, potentiometric titration, the glass transition temperature of the polymer, and the inherent viscosity that I mentioned earlier under tensile properties. Table 1 shows the Drager tube analysis and the pH and the potentiometric analysis. Potentiometric analysis gives you a quantitative estimation in milli-equivalents per gram of film. The pH was very sensitive and revealed a couple of very interesting points about early stages of detection. Firstly if, after immersing one gram of the film in distilled water for three hours, the pH has dropped to 5, we say that it's the onset of degradation and, if the pH has dropped to 3.3 or 3.65, the degradation has proceeded far enough to lead to delamination of the gelatine emulsion. The moment we put the sample in water, the emulsion and the support layer separate. This is also consistent with the amount of acids that's generated, as determined by a different technique – except that pH determination would require cutting one gram of sample material, soaking it in water and measuring it. It is thus a destructive technique, but yields very accurate information about how much degradation has taken place.

Inherent viscosity (IV), tensile properties and the Tg (glass transition temperature) were the other techniques we looked at. We feel that the chemical techniques, like detection of the volatile acetic acid for Drager tubes or pH measurement, are much much earlier

and more sensitive detection techniques than the physical ones. Physical techniques like inherent viscosity are testing the effects of the degradation which take much longer to detect, and we feel strongly that chemical means are required for detecting the early stages of degradation. The IV took much longer to be noticed because at 40% RH there was not that much change, and it was only at 60% RH that we were beginning to see it. At 60°C at both humidities there was very little change, and the tensile properties – the strength, elongation and modulus – showed up only after an extended period of incubation, not at the initial onset of degradation.

One property that I don't want to go into any detail about is that, as the cellulose triacetate degrades and becomes a diacetate material, it is replaced with hydroxyl groups. As the degree of substitution drops from three to two, the glass transition temperature of the material increases, and this shows that the acetic acid is removed and is replaced by smaller hydroxyl groups. This ties in with the glass transition temperature for cellulose acetate of about 190°C and that for acetyl proprianate of about 150°C, because proprianate is a bulkier molecule than the acetate. In the case of butyrate, where you have 4 carbon ions, as you increase the butyl content the Tg decreases. Basically what's happening is that, as the degradation proceeds, the material has a higher glass transition temperature.

Incubation condition	Incubation times	Drager tubes ppm	pH	Potentiometric analysis, meq/g acetic acid
21°C/60% RH	Control	bdl	6.64	0.010
60°C/40% RH	2-week	bdl	6.86	0.0057
	1-month	bdl	6.58	0.0059
	2-month	bdl	6.23	0.020
60°C/60% RH	2-week	bdl	6.83	0.0095
	1-month	bdl	6.13	0.0065
	2-month	bdl	6.16	0.022
81°C/40% RH	2-week	bdl	6.37	0.012
	1-month	6	5.37	0.027
	2-month	>80	3.65*	0.200
81°C/60% RH	2-week	-5	5.95	0.013
	1-month#	15	4.71	0.058
	2-month#	>>80	3.33*	0.0200

Table 1
Detection of cellulose triacetate degradation by chemical analysis (5296 films kept in tin cans): bdl= below detection limit (<5ppm acetic acid), * = delamination of emulsion from support, # = films blocked and the cans were reusted inside.

Chemistry of hydrolytic degradation

Let me just take a few moments to describe the hydrolytic degradation of cellulose triacetate material. Figure 2 shows the structure of cellulose; the C6 carbon atom is outside the ring, and C2 and C3 are the ones adjacent to the oxygen group.

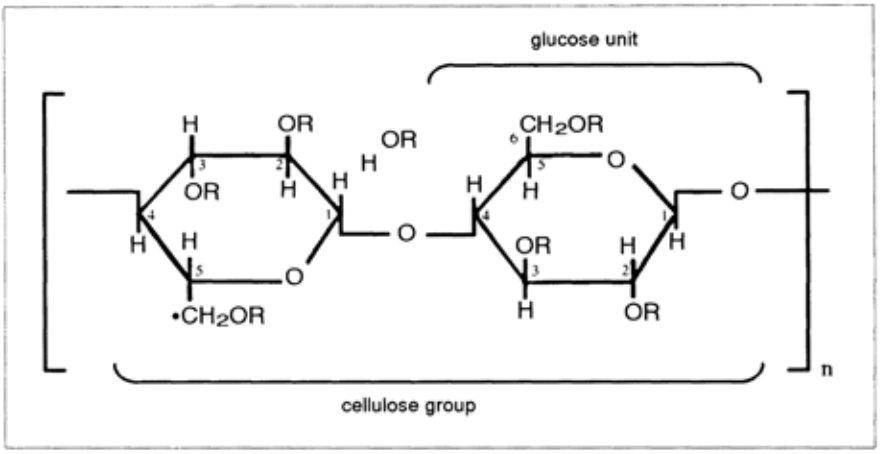


Figure 2
Cellulose (organic)esters:
R = CH_3CO (cellulose triacetate, CTA), or
C_2H_5CO (cellulose triproprionate, CTP) or
C_3H_7CO (cellulose tributyrate, CTB).
Mixed esters of cellulose are also possible:
R = H & CH_3CO (cellulose diacetate, CDA), or
CH_3CO and C_2H_5CO (cellulose acetate proprionate, CAP) or
CH_3CO & C_3H_7CO (cellulose acetate butyrate, CAB)

Basically the hydrolytic degradation goes through de-esterification of the primary hydroxyl group – that is, the water reacts with the acetic acid moiety (radical) on the sixth position and with the elimination it forms a hydroxyl group (Figure 3). The reaction rate for this (which was worked out in the early 1920s or 30s) is very low – only 14.3 kilocalories per mole. That is the easiest and the most labile system, which is easy to clean and undergoes instant hydrolysis.

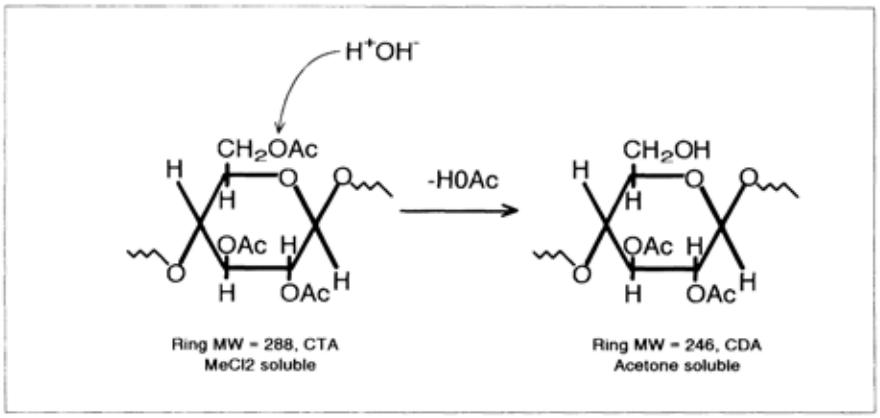


Figure 3
k_6 = 14.3 kcals/mole

The second thing to be substituted (Figure 4) is either C2 or C3, and the reaction rate for that is much higher – about 20.6 kilocalories per mole.

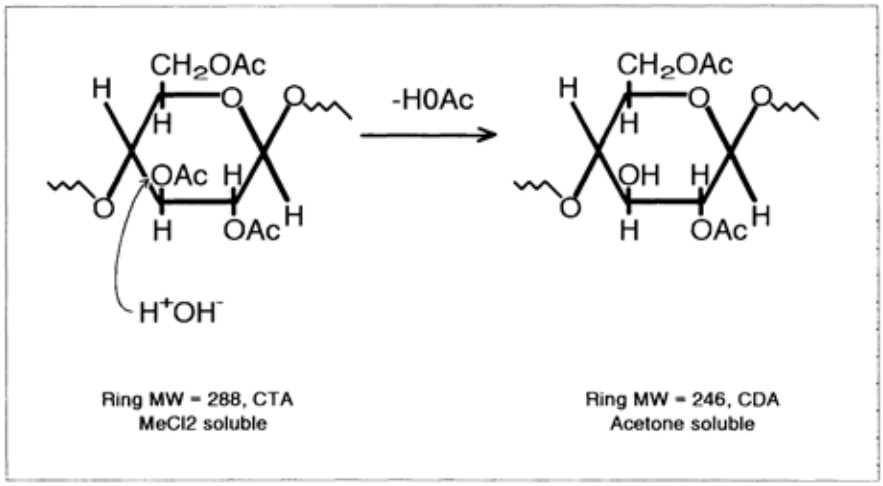


Figure 4
k_2 / k_3= 20.6 kcals/mole

The reaction rate for the chain scission (Figure 5), where the glycositic linkages break down, is about 29.6.

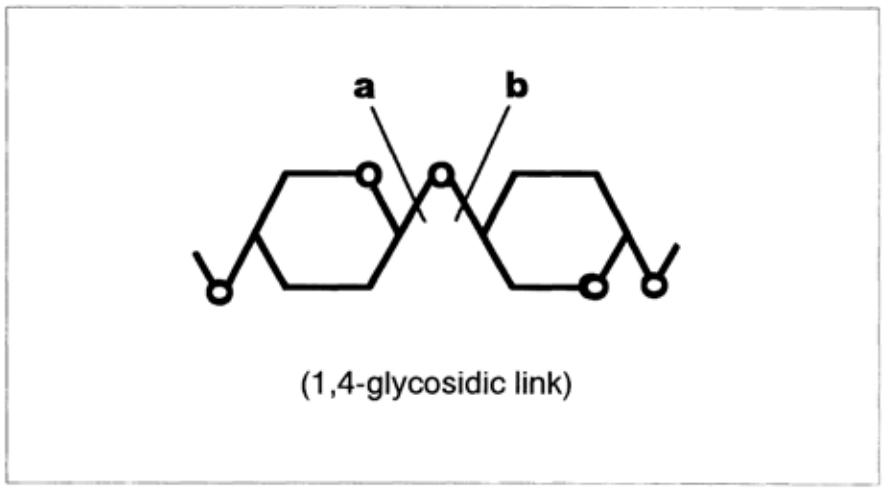


Figure 5
$k_{chain\text{-}scission}$ = 29.6 kcals/mole

So under ambient storage the most likely reaction to take place is the de-esterification of the carbon at the sixth position. That's why we get the smell of acetic acid more readily in the initial stages and only with further degradation do we see the evidence of break down in molecular weight. Of course the decrease in degree of substitution also lowers the molecular weight. When we say triacetate, it's not one single entity but a mixture of three acetyl groups, two acetyl groups or one acetyl group and hydroxyl groups, and the water can react in a variety of ways for initiation of the degradation. So the chemistry is very complex, and what we are saying is that we can detect it only by determining the amount of acetic acid.

Recommendations for storage

I may sound like a broken record here, but it's not the temperature that's critical for proper storage – it's the humidity. Table 2 summarizes the different storage recommendations for medium-term storage (10 years minimum) and for long-term or archival storage (100 years minimum). [The table shows the correct temperature and humidity for the storage of various types of materials as specified in ANSI IT9.11–1991, *Practice for Storage of Processed Safety Photographic Film*. This standard is now significantly revised from the earlier version ANSI PH1.45–1985 Storage Standard.]

Film type	Medium-term storage		Extended-term storage	
	Relative humidity range (%)	Maximum temperature	Relative humidity range (%)	Maximum temperature
Silver gelatin	20–50	25°C (77°F)	20–30	21°C (70°F)
Colour	20–30	10°C (50°F)	20–30	2°C (36°F)

Table 2
Recommended relative humidity and temperature conditions for storage

The most important point is that, for archival storage of black-and-white cellulose acetate materials, the humidity should be maintained at 15–40% RH at a temperature not exceeding 21°C. When it comes to colour materials, the humidity should be further reduced: 15–30% RH, and maximum temperature not above 2°C.

Films should never be stored above the temperature and humidity recommended for long-term storage: 21°C and 15–40% RH for black-and-white, and for colour we're talking about very low temperatures. I was very happy this morning to see the John F Kennedy Museum maintaining -18°C.

Films that have been stored under adverse storage conditions (this is what archivists are always concerned about – unknown storage history) should be inspected at least once every 2 years to see whether they show signs of degradation. We are fortunate that, in the case of acetate film, the vinegar syndrome is easy to detect: if it had been some other type of acid that cannot be smelled very readily, it would be very difficult to detect. Periodic inspection of the material being stored is a must, and films that have degraded should be segregated and duplicated on to new polyester-based support material films, because these are more durable and also more resistant to hydrolytic degradation.

Conclusions

- I have tried to discuss techniques for identifying the early stages of cellulose triacetate degradation.
- Hydrolytic degradation will proceed long before any changes to physical properties are noticeable.

- Strict adherence to archival storage is required: 21°C and 15–40% RH for black and white, and about 2°C and 15–30% RH for colour materials.
- Recorded information will be maintained, can be retrieved, or duplicated for its end use for many centuries.
- Chemical inertness of the support materials over the entire archival life span cannot be achieved, because the materials will change with time.

Archival Stability of Metal Video Tape as Used for Beta-CAM SP

Tokio Nakamura, A Hatai and K Okamoto

Introduction

In 1985, the first video tape coated with metal particles was launched on the domestic 8mm video market. Sony marketed Beta-CAM SP metal video tape in 1987 and D-2 metal video tape in 1988 for the broadcast and post-production fields.

However, some people who are responsible for tapes are seriously concerned about the archival stability of metal video tapes, because metal materials pose problems of chemical instability and corrosion. So this report looks at the change of magnetic properties, RF-out, video S/N and dropout of metal video tape stored under various environmental conditions.

The reason for choosing Beta-CAM SP metal tape is that Beta-CAM VCRs can use both metal and cobalt ferric oxide tapes, so we can conveniently compare the archival stability of both metal and Co-oxide (cobalt-doped gamma ferric oxide) tapes.

High density recording capability of metal video tapes

According to magnetic recording theory, magnetic tapes must have the following characteristics in order to achieve high density recording:

- higher coercivity (Hc) to decrease the demagnetizing field
- more remanence (Br) to increase the signal output of playback
- a smooth surface on the magnetic layer to reduce modulation noise.

Metal video tapes have all these characteristics, and permit high density recording of submicron wavelengths (less than 1.0μm) as seen in Figure 1 (overleaf).

Figure 1 illustrates how, in the history of video recording, improved recording capability has depended on the development of the magnetic materials coated on tape. It has progressed, for example, from a recording wavelength of 4.0μm using two-inch tape coated with gamma ferric oxide to a wavelength of 0.5μm using metal evaporated tape for the Hi-8 video recorder.

Figure 2 shows the B-H curves of Beta-CAM SP metal tape and Co-oxide tape. SP metal tape has a coercivity of 1500 oersted and remanence of 2300 gauss, while Co-oxide tape has 710 oersted and 1250 gauss respectively.

Henning Schou
I would like to welcome Tokio Nakamura, from Sony Magnetic Products in Japan. Mr Nakamura was born in Kyoto in Japan in 1943 and received his Bachelor of Science Degree in 1967 and his Master of Science Degree in 1968 from the Chemical Department of Kyoto University. He joined the Sony Corporation in Tokyo in 1969 and has been engaged in the development of magnetic particles and magnetic tapes. He is the General Manager of Professional Video Tape Division, Magnetic Products Group of the Sony Corporation, and is a member of the IEEE and the Magnetics Society of Japan.

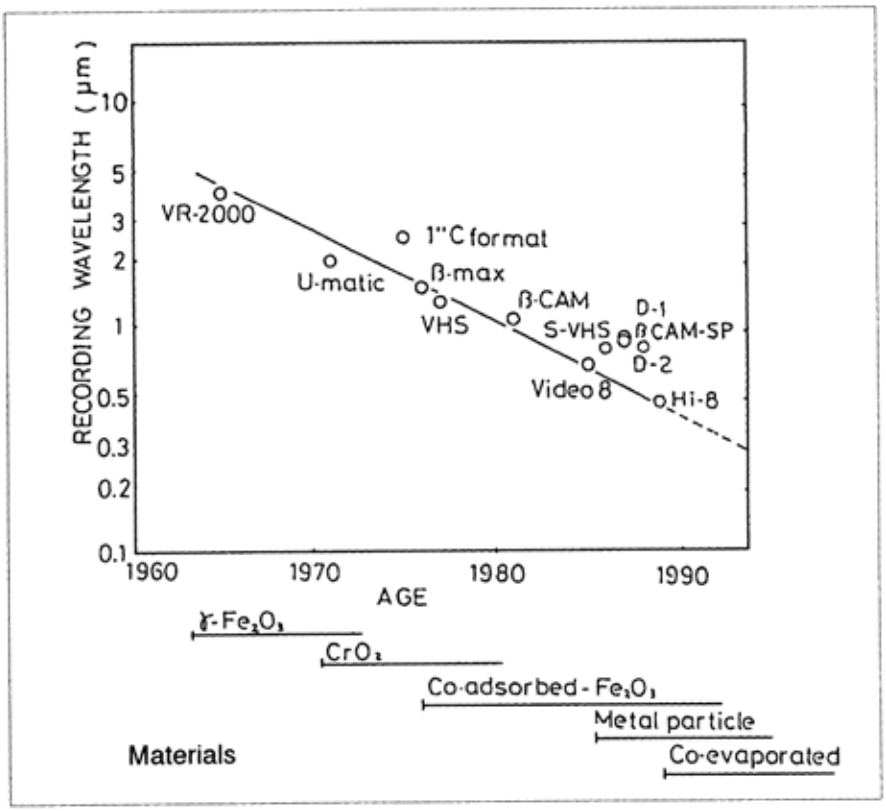


Figure 1
High density trend of video recording

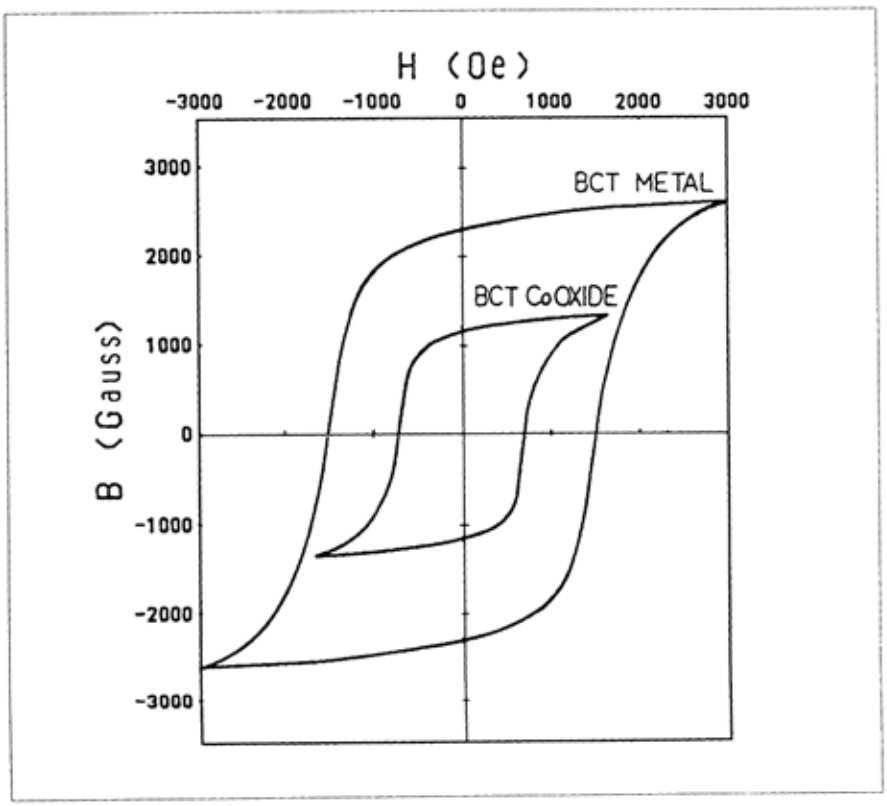


Figure 2
Hysteresis loop

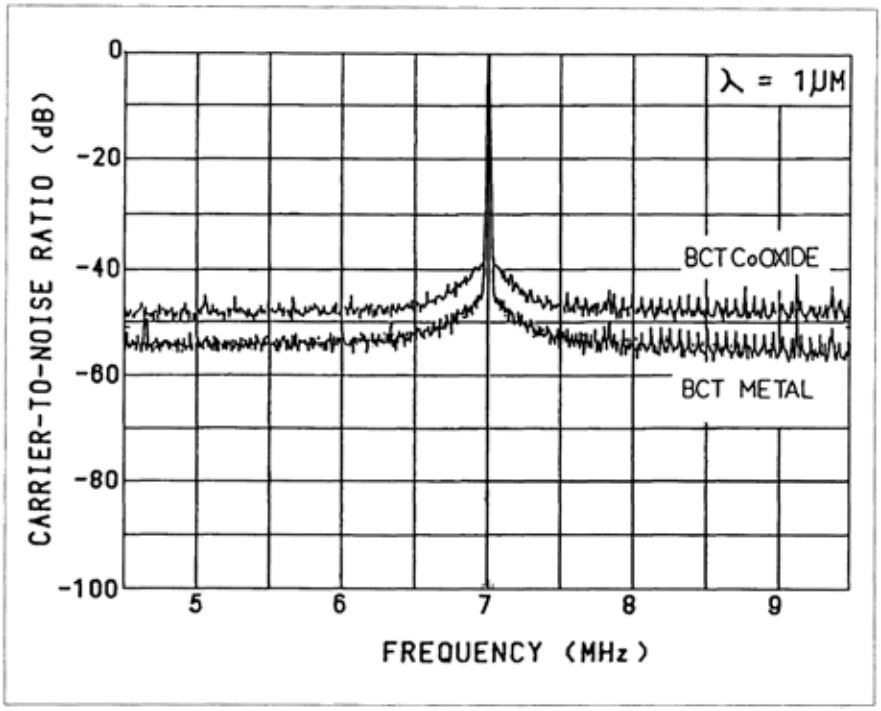


Figure 3
Modulation noise spectrum

The modulation noise spectra (carrier signal output versus noise) of both tapes are illustrated in Figure 3, which shows that Beta-CAM SP metal tape has an 8dB better video performance (C/N) than Co-oxide tape. In order to achieve 8dB, we must produce a very smooth magnetic layer surface (Figure 4), coat it with very fine metal particles (Figure 5), and have a binder system that can effectively disperse the agglomeration of metal particles.

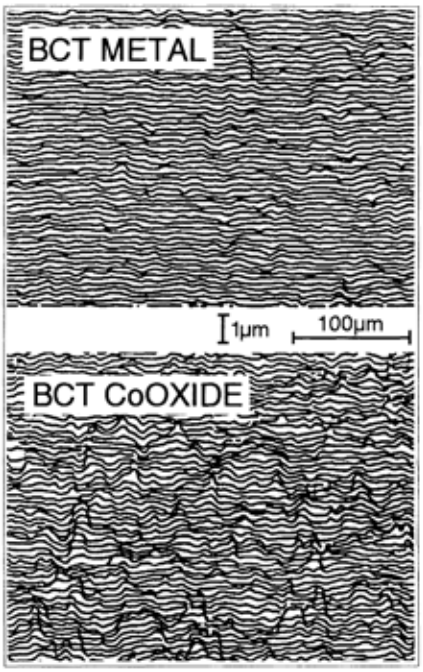


Figure 4
Roughness of tape surface



Figure 5
BCT metal particles

The protective layer of metal particles

We use very fine metal particles for video tapes. Figure 5 is an electron micrograph of metal particles that have an average length of 0.3–0.4μm and an aspect ratio of 10–15. The magnetization intensity (σs) of these metal particles is 125emu/gr, although the magnetization of iron metal bulk is 222emu/gr. The reason for the decreased magnetization of particles as compared with bulk metal is because of a protective layer, pre-treated with non-magnetic components (Al_2O_3-SiO_2) and iron oxide (Fe_3O_4), which covers the surface around the metal particles. When we examine a single metal particle at high magnification, we can clearly observe the protective oxide layer and the inner core of pure iron metal. The magnetization intensity of the metal particles is reduced to 125emu/gr, but it is still high compared with 75emu/gr for Co-oxide particles.

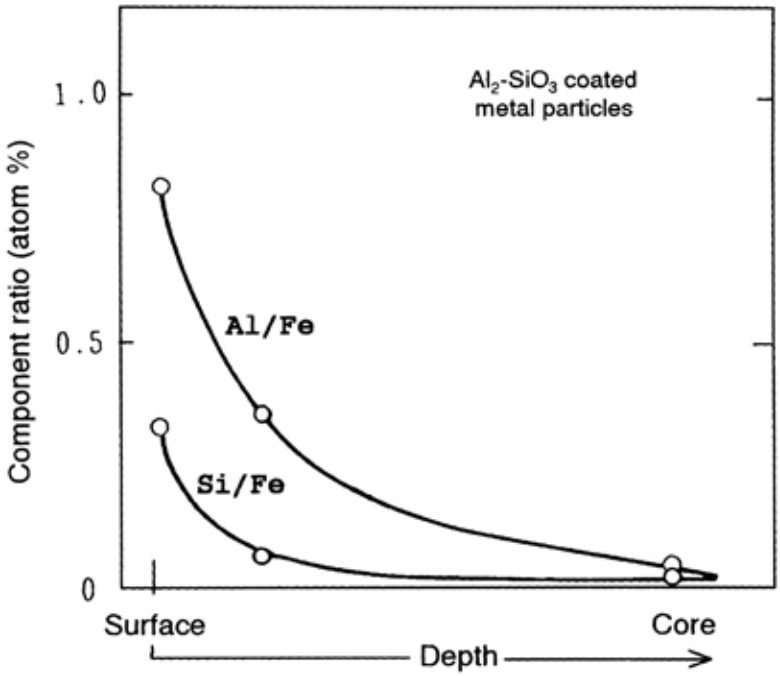


Figure 6
Surface chemical analysis of metal particles with ESCA

Figure 6 shows the results of chemical analysis near the surface of the metal particles using ESCA, and shows the composition change from the high ratio of Al_2O_3-SiO_2 near the surface towards the core of pure iron metal.

Figure 7 shows how the protective layer can maintain the magnetization of metal particles stored in an environment chamber at a temperature of 60°C (140°F) and humidity 90% RH. These pre-treated metal particles are mixed and dispersed with binder polymers, and coated on the base film. The binder that wraps around the metal particles also has the stabilizing effect of cutting off the oxygen and moisture in the air and protecting against excess oxidation.

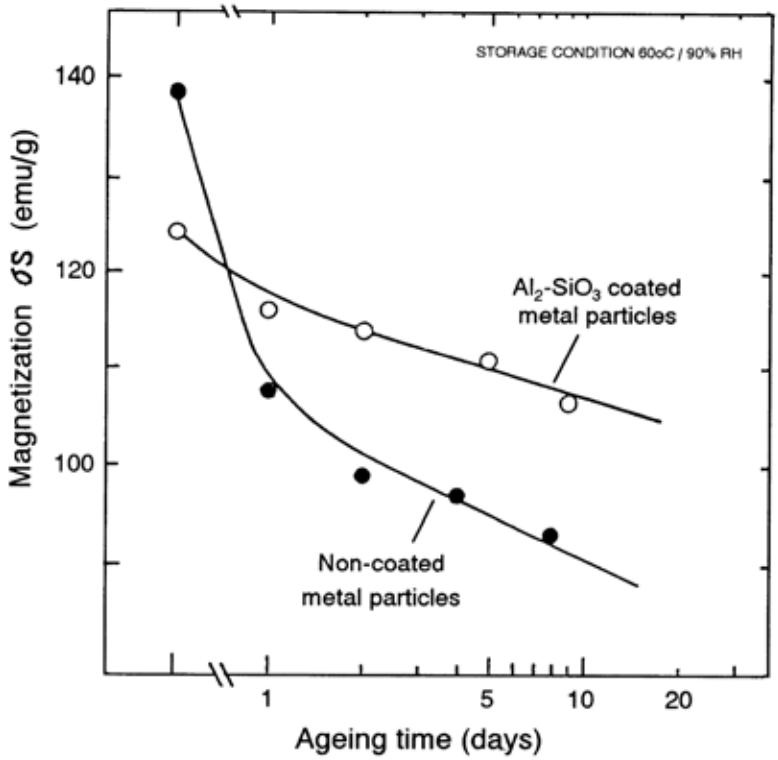


Figure 7
Magnetization change of metal particles

Finally, our metal video tape has a double protective layer. The first is a surface oxide layer of particles and the second is the binder polymer wrapped around the particles. Figure 8 shows the change of magnetic properties in Beta-CAM SP metal, stored under normal room conditions of 25°C (77°F) and 50% RH for three years. We did not find any change of the Hc and Br values over three years, except for measurement error.

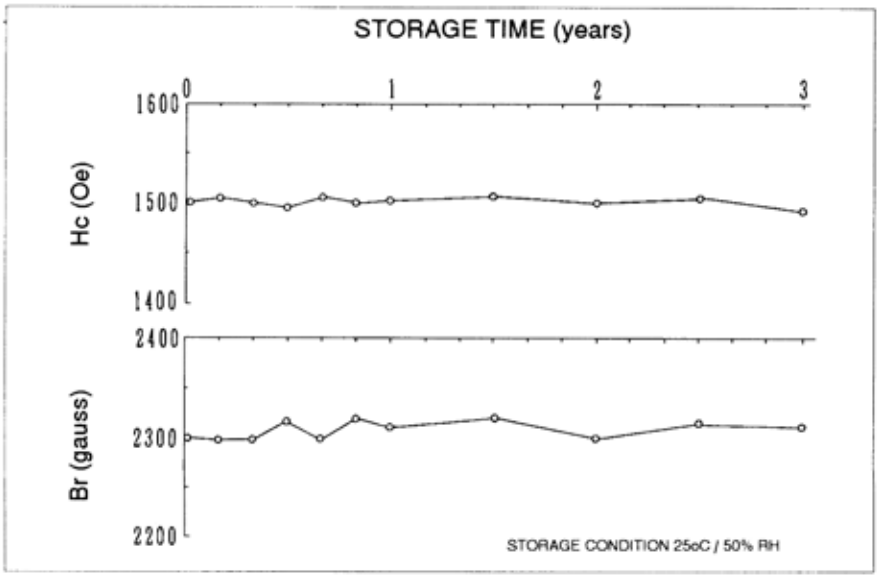


Figure 8
Change of magnetic properties with passage of time – Beta-CAM metal tape

Archival stability of video electrical characteristics

As previously described, Beta-CAM is the only format that uses both metal and Co-oxide tape. Co-oxide video tape has been very popular and has been adopted by various video formats and used without serious archival problems over the past 15 years. Therefore, if the stability test results of metal tape are equivalent to Co-oxide tape, more than 10 years of trouble-free storage and usage of metal video tape could be assured.

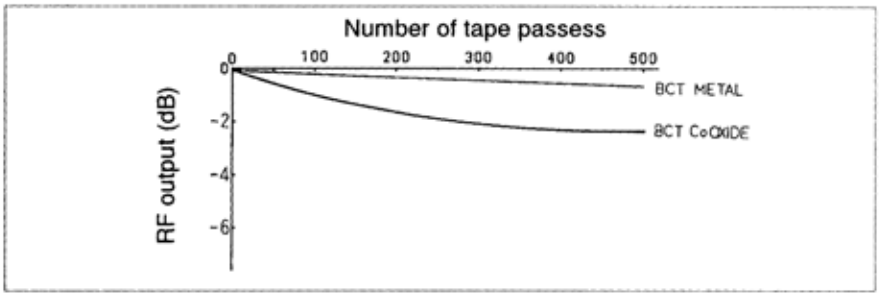


Figure 9
Runnability life – VTR: Sony BVW-75; test mode: 1/30 slow (fwd-rew)

Figure 9 shows the RF output degradation of metal and Co-oxide tape after 500 times playback and rewind with a search mode of 1/30 slow speed on a Sony BVW-75. The RF output degradation was 2.3dB for Co-oxide tape and 0.6dB for metal. It is not surprising that the degradation of the Co-oxide tape is greater than for metal tape, because the thermal loss and mechanical stress loss of Co-oxide materials are essentially poorer than those of metal, as magnetic physics text books teach us; the magnetization of iron metal is physically more stable than Co-oxide. Figure 10 shows that the temperature dependence of metal tape coercivity is smaller than that of Co-oxide tape.

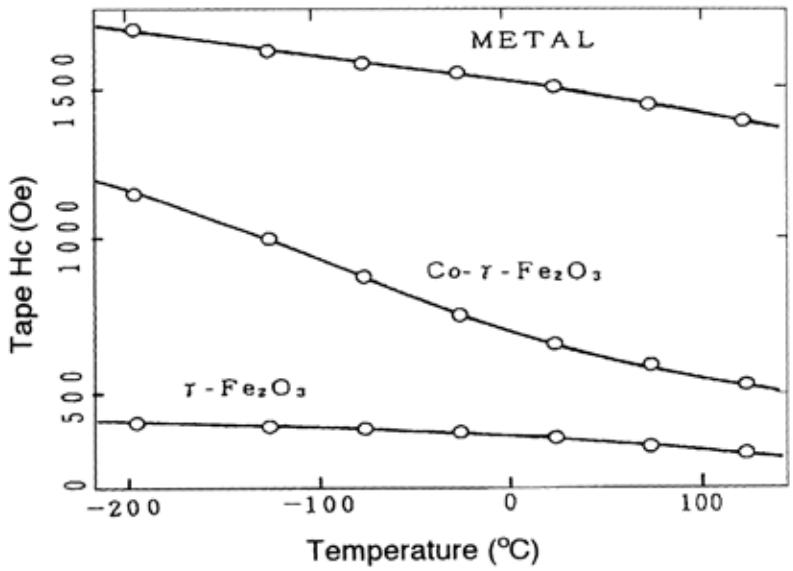


Figure 10
Temperature dependence of tape Hc

Next, we measured the RF output degradation when video cassettes were stored under normal room conditions of 25°C (77°F), 50% RH and under hotter and more humid conditions – 45°C (113°F), 80% RH. We can see in Figure 11 that the RF output degradation after 16 weeks is 0.3dB for metal tape and 0.1dB for Co-oxide tape stored at 45°C, 80% RH, but the RF output does not decrease and is still stable after 8 weeks. These values of RF output degradation for metal and Co-oxide tapes are negligible compared with the C/N of 55dB for metal and 47db for Co-oxide previously shown in Figure 3. The RF output degradation at 45°C, 80% RH was almost entirely caused by the decrease of tape remanence shown in Figure 12. The tape coercivity shown in Figure 13 did not change. We took the pictures of the RF output envelope on an oscilloscope screen stored under conditions of 45°C, 80% RH, but could find no change in the envelope form.

The change of video S/N ratio is shown in Figure 14. After 16 weeks, we found only 0.1dB of video S/N degradation for both metal and Co-oxide tape under normal room conditions, and 0.5dB for metal tape and 0.2dB for Co-oxide tape even under the high temperature and high humidity conditions of 45°C and 80% RH. These values of S/N change are very slight and do not affect the picture quality seen on a TV screen during playback. Figure 15 shows the results when we checked the increase in dropout level (-16dB, 10μsec) after storage. We observed almost no change in dropout levels for both metal and Co-oxide tape stored at 25°C, 50% RH; on the other hand at 45°C and 80% RH, the dropout level increased to about double that in the earlier time, but remained less than 10 counts/min.

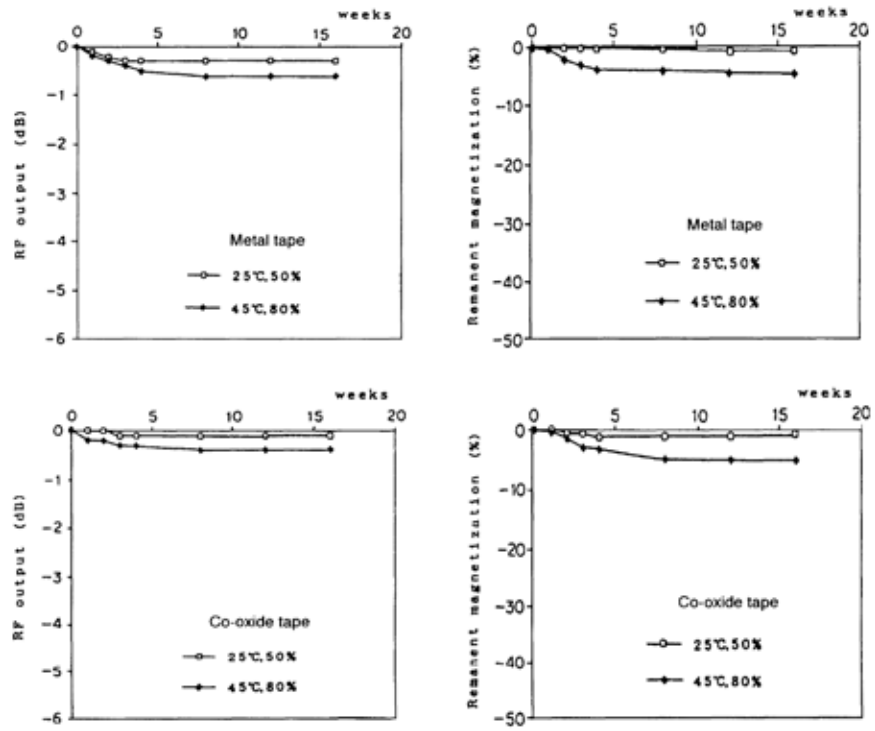


Figure 11
RF output stability of Beta-CAM metal and Co-oxide tape

Figure 12
Remanent magnetization stability of Beta-CAM metal and Co-oxide tapes

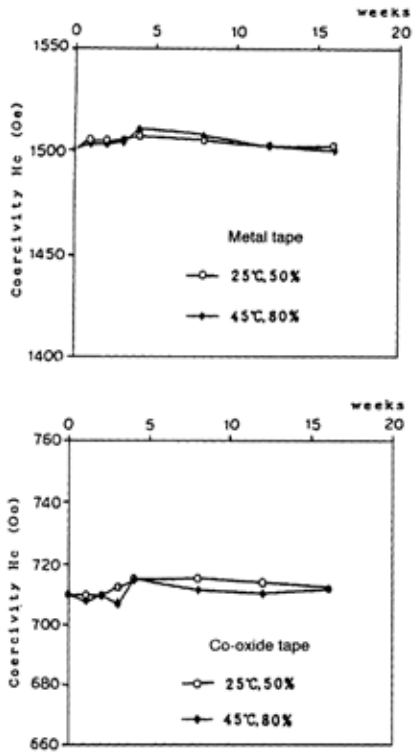


Figure 13
Coercivity stability of Beta-CAM metal and Co-oxide tapes

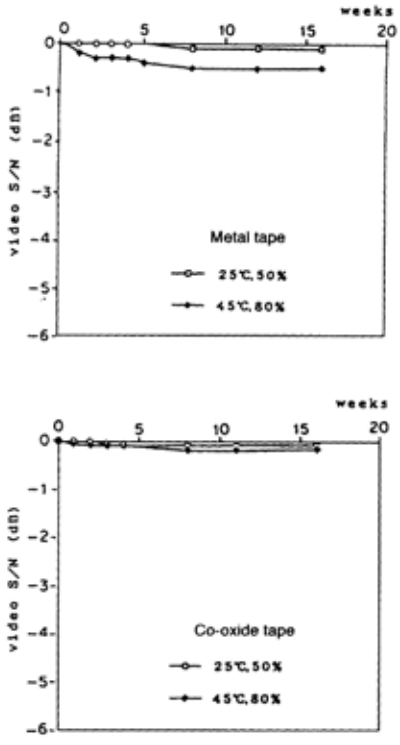


Figure 14
Video S/N stability of Beta-CAM metal and Co-oxide tapes

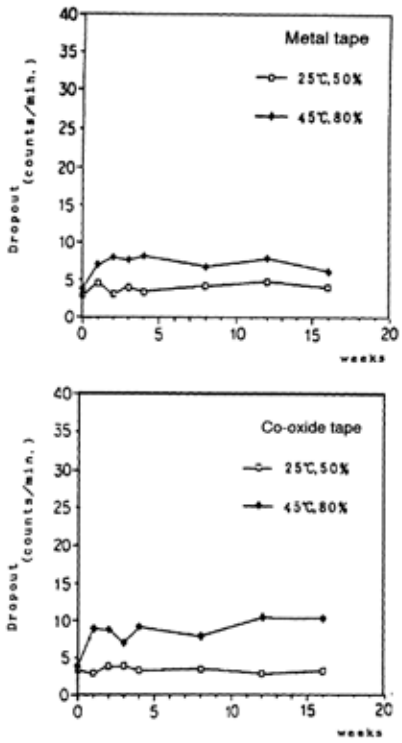


Figure 15
Dropout stability of Beta-CAM metal and Co-oxide tapes

Conclusion

We tested the archival stability of Beta-CAM SP metal and Co-oxide video tapes for their magnetic properties, RF output, video S/N and dropout level. As long as cassettes are stored under normal room environmental conditions of 25°C and 50% RH, our Beta-CAM SP metal tape (as well as our Co-oxide tape) is very stable and exhibits no change in video electrical performance. Even under conditions of high temperature and high humidity such as 45°C and 80% RH, the degradation of the video electrical performance was less then 0.6dB at worst. And this value would not affect the picture quality during playback.

As you know, the life of magnetic tapes basically depends on the decomposition of their chemical components, such as plastic-based film, binder polymers, back-coating materials, lubricants and dispersing agents. These chemical organic components are degraded very, very gradually and the degradation is accelerated with heat and moisture.

Therefore, tape manufacturers recommend users to store all magnetic tapes strictly in the temperature range 15–25°C (59–77°F) and humidity 40–60%. These conditions minimize the decomposition of organic materials. As long as metal video tape and current Co-oxide video tapes are stored in the recommended range, there should be no problems for at least ten years.

These metal tape technologies are applied to our other products, D-2, and 8mm video cassettes; so these also have an excellent archival stability performance.

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M P Sharrock, 'Particulate magnetic recording media: a review,' *IEEE Trans. Mag.*, vol 25, no. 6, Nov 1989, p 4374.

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Henning Schou:
Thank you very much Mr Nakamura for your interesting paper on a product about which I've heard one manufacturer complain that now we've finally learned to master the production of oxide tape, we have to start making metal particle tape. Have you looked into the possible oxidation of the tapes when they are stored, especially at elevated humidity?

Tokio Nakamura:
For example, 65°C affects the residual magnetization of the metal particles, but a temperature of 65°C affects not only the magnetization of the metal particle, but it also affects the base material. We cannot use magnetic video tape that has stretched after exposure to temperatures in excess of 65°C. For example, stretching affects the exact placing of the magnetic tracks that were laid down by the record head. Dimension changes may prevent the replay head from correctly tracking the original recorded tracks. So we must keep to the recommended temperature and humidity conditions for metal particle tapes.

Henning Schou:
I was also concerned that this huge amount of finely divided metal powder sitting on the surface, would be fairly susceptible to oxidation.

Tokio Nakamura:
That's the function of the oxide protection layer that covers the pure metal particle. Mr Allen talked earlier about iron being a catalyst of polymer degradation, therefore we must prevent direct contact between the iron particles and polymers. The protection layer is a very effective way of doing this.

The Life Expectancy of Optical Recordings

Michael Croll

Henning Schou:
Michael Croll is from the BBC Research Department Kingswood Warren in the UK. He graduated from the Imperial College of Science and Technology in London in 1966 with an honours degree in physics and then joined the BBC's research department. After completing initial training, Mr Croll became involved in digital audio projects, including the development of the BBC's digital sound distribution system. He then became involved with the field testing of the teletext system, and transferred to Storage and Recording. He led a team to develop a video animation system, and was associated with other video storage projects before being appointed Head of Storage and Recording in 1981. In this post he has directed a wide range of projects associated with digital video storage and recording and the processing of video signals as may be required in new broadcast systems where a number of standards may be used. Mr Croll is a member of the EBU Magnum Group.

Introduction

The use of optical recordings in broadcasting has so far been largely limited to playing compact discs. However, the advent of recordable and erasable optical disc technologies might change that given the development of suitable recording/replaying equipment.

Audio recording has for many years exploited the low cost, convenience and rapid edit capability of $^1/_4$" tape. This has enabled considerable efficiencies to be achieved both in the speed with which programmes can be recorded and edited for broadcasting, and in the economical use of the recording medium. These efficiencies arise because the same recording is frequently edited, broadcast and archived with no fundamental reason for the recording to be copied at any stage.

These advantages have prevented major exploitation of digital audio tape recording. Despite the improved potential quality, no digital recording system exists where the same master recording can be edited, broadcast and archived without the need to make copies.

However, there are now reasons for seeking an alternative. New developments in audio recordings include digital disc-based editing systems and the extremely portable DAT recording machines. Also the quality achieved with analogue recording and the large physical size of the reels are serious limitations in the continued dependence on $^1/_4$" tape, and the disc-based audio editing systems now need a removable medium to enable edit jobs to be loaded quickly.

For any alternative to $^1/_4$" tape to be attractive, however, there must be no reduction in operational flexibility or increase in cost, and some improved operational flexibility as well as improved technical quality would be expected. Digital Audio Optical Disc Recording Systems may eventually provide this universally applicable medium.

Disc-based removable recording media are well suited to audio recording, especially where the recordings might need minimal editing prior to their broadcasting. Optical technologies are well suited to archival applications since the recording is buried below the surface. In many other ways, the optical disc recording systems that are being developed for computer applications appear well suited to audio recording applications. It is not considered that the broadcaster's requirements are so much different from domestic or other industrial applications of the technology. Therefore, the potential of optical discs has been examined and some methods devised that might allow the broadcaster to capitalize on the development of this technology, which is at present targeted to domestic and computer industry applications.

At present it is most important that the prospective users of optical discs assess fully their potential and the likely life expectancy for both the formats and the media associated with an optical recorder. This paper addresses these issues at a time when there is considerable investigation in progress, and the rate of change of technology is still very vast. This paper, is therefore, unable to present any final conclusions or results that would enable judgements to be made about the suitability of applying optical recording in the broadcast environment. It is, however, able to discuss the requirements and describe investigations and tests currently in hand. It also opens the debate on how audio recording formats could be standardized.

Main user requirement

The main broadcaster's requirement is for economy and efficiency in the recording and editing of audio. This introduces a range of economic and marketing features that are outside the scope of this paper. However, it is important to recognize that the achievement of these goals depends to a large extent on whether broadcasting can use equipment and media that are made in large numbers primarily for much larger scale applications, such as the domestic or computer-based industries.

In seeking out new media for audio recording, the need for a medium that can be edited without the need to copy could be satisfied with a recording medium which provides a degree of random access controllable by data recorded on the medium. This would provide similar operational benefits to the present analogue tape based system, with the additional advantage that the original recording is neither handled nor cut up to remove segments. In this way, the same master recording could have different replay programme control sequences, enabling it to be replayed in different ways to satisfy different programme requirements.

In cases where copies need to be made or the digital audio data transferred between audio systems, it would be necessary for this to be done at a speed significantly faster than real-time. Thus, where it is seen necessary to make a recording of the edited programme once the edits have been made (maybe within a semiconductor/magnetic disc-based system), this can be completed with the minimum of delay.

The extent to which such a medium might become 'universal' would depend on how many of the different requirements for broadcasting could be satisfied with the one medium considering the cost/record duration and ability to record/reply multi-channel sound. It is, however, paramount that the random access capability of this new medium is fully exploited to satisfy the central need to find a replacement for analogue tape.

After some discussion within the BBC, it seems that the following basic specification would satisfy the central requirement for:

- **Record duration:** 35 minutes stereo is the minimum duration that would satisfy a wide range of applications. In some cases less than 20 minutes would be acceptable, but there are a significant number of instances where 90 minutes duration would be

required. If the medium allows the number of tracks and record duration to be interchanged, then multi-channel applications may be satisfied with such a medium. Multi-channel audio recording is not common in broadcasting at present because of economic constraints, but may become more widespread if multi-channel sound is broadcast with HDTV or as a new sound service.

- **Data resolution:** 20 bits per sample minimum; ideally the full AES/EBU interface datastream of 24 bits and control data would be recorded, with provisions for the recording of additional recorder and edit control data. This is essentially more than the broadcast resolution to accommodate excess peaks in sound level and allow several stages of level control and spectral adjustment without introducing audible noise (Manson 1985).

- **Sample rate:** 48 kHz, but a dual operation with a 44.1 kHz may also be desirable.

- **Data transfer speed:** Ideally better than 8 times stereo data rates, but lower rates may initially be acceptable. The replication of discs and the 'load' and 'save' times when backing sound edited at a workstation must be fast to achieve efficiencies equivalent to those achieved at present with tape. The higher the rate (up to about 16 times) the better, and the greater chance of satisfying multi-channel requirements.

- **Access time:** Better than 100 milliseconds. Poorer rates would severely limit operations where the sound is edited by replaying segments recorded in different places on the medium.

- **Physical size:** Ideally pocketable: $5^1/_4$" diameter median would be acceptable.

- **Media characteristics:** Magnetic tape is erasable. WORM (write once, read many) media would be acceptable if they led to economies or had better archival properties.

- **Media ruggedness:** It should not be handled directly and should be contained in a cassette. It should have a proven ruggedness.

Discs

The benefits of random access with discs or cylindrical forms of recording media are well known and understood. These represent fundamental potential improvements over tape in record/replay flexibility and would, in turn, provide the capability to satisfy many of the requirements above, whether the recording method is magnetic/optical or some other new method yet to be invented.

Computer disks versus optical discs

Of the various types of optical disc being proposed, the broadcaster's application has greatest commonality with the computer application field, where a replacement for the floppy disk is needed with greater capacity and ruggedness. However, the main computer application does not need the same high data capacity that we require, and it might be satisfied with a disk that would provide substantially less than the minimum half hour stereo we require.

A substantial benefit of using computer standard disks would be that unmodified drives could be used to replicate disks or convey their contents via standard data networks between broadcasting centres and other places around the world that are already equipped with the means for communicating data. This could be a vital feature in freeing the broadcaster from always being a special case.

There has been a proposal for a recordable compact disc format. This may not become a common item of domestic equipment, as magnetic tape could remain cheaper and more tolerant of the domestic environment for some time to come. Should the recordable CD become established, then its format will be optimized for domestic audio replay and will likely be based on maximizing the record duration, 44.1 kHz sampling frequency, 16 bits per sample, and no cassette so that it is interchangeable with CDs. One of the important differences between a compact disc format and our requirements is that a CD is recorded with a constant linear velocity (ie the disc goes slower when the outer tracks are being replayed). This is unlikely to be consistent with our requirement for fast random access, although good access has been achieved where different 'bands' (or groups of tracks) of a disc are recorded at different angular velocities.

Formats could be devised for audio recording on both CD and computer disks, particularly since the CD-ROM format allows free format data which could, for instance, be 48 kHz sampled 24 bit per sample stereo audio. However, formats that have been designed are less efficient in their use of the CD format for professional digital audio recording. This stems from the need to accommodate blocks of audio that are sensibly related to time-codes where there is a difference between the sample rate used and the 44.1 kHz sample rate around which the CD format is designed. Also, the provisions for ancillary data in that format are not well suited to conveying ancillary data carried with the digital audio via AES/EBU digital audio interfaces.

Loss of efficiency would reduce the record duration and slow the maximum sustainable audio transfer rate.

Present optical disc-based recording systems

We have seen magnetic recording constantly providing an improving recording density that still seems capable of further improvement as the media, magnetic guidance, and head tape technology improve. A continuing series of announcements indicates that the margin for improvement with the magnetic recording technology is large, and that substantial improvements in performance can be expected. However, magnetic recording relies on intimate contact between read/write heads and medium, and is therefore vulnerable to mechanical damage and problems caused by dirt and debris. With optical recording systems, the compact disc provides a very high level of performance that is only now being matched with systems able to write data as well as read it.

The limitations on packing density are set partly by the wavelength of the light used to read/write and partly by the ability to guide a laser around a track. In assessing whether the present level of achievement, in terms of data packing density, represents a plateau

George Brock-Nannestad: *The paper you have presented is something which should really be in our minds at all times – the basic fundamentals – instead of getting bogged down in small details. You mentioned the longevity of the magnetic tape, because of its universality and its simple use. Of course anybody will be able to build a magnetic replay machine from scratch in 50 years' time with only a minimum amount of technical or workshop assistance. It is feasible to get a signal out of a tape because it is not a coded medium.*

The only long-term hope for coded media is if there are decoders available in future to play them, otherwise there's nothing on them except perhaps some sort of shiny mirror which is beautiful, but not very useful. So I hope that we can persuade manufacturers to have a standardized machine that will last long enough. I'm quite certain our ears won't change so, if you say that 20 bits is enough for human ears and for production to accommodate peaks and that that gives a medium that is better than the distribution medium, then that won't change. It won't become 30 bit in future; 20 bit will probably be enough. So manufacturers should be able to make 20-bit equipment for quite some time to come – to make standardized plug-in modules. And that is what we must hope for, otherwise it is not an archival medium.

Michael Croll:
At the risk of damaging the good work I've done so far, let me just point to the standardization dilemma which says that, if you decide to make no further technical progress and stick with what you've got, you might still be in the situation where you are unable to maintain that medium because you lose the expertise to produce and develop the support for that medium. If you continue to develop the medium, you might still lose the means to be able to replay the earlier recordings and the earlier uses of similar media. That's our dilemma, isn't it?

Henning Schou:
This was a very challenging paper, because its opened some new horizons. I have two questions. First of all, do you

that will be held for some time, and therefore become secure in terms of a long lifetime of support, it is necessary to try and understand where any improvements might come and who might demand these improvements. Whilst a shorter wavelength of laser light might provide efficient reading of more closely packed data, it becomes difficult to deliver enough heat for heat-based writing systems. For this reason, significantly shorter wavelengths of light will probably not be used in WORM drives. Mechanical tracking is efficiently achieved with the present system, although some improvements in track-to-track spacing have been achieved with the latest series of drives. Formatting the data so that it is efficiently written as spots or holes has also produced some advantages, and it is not clear whether much improvement could still be achieved without sacrificing ruggedness and the ability to recover data in the presence of errors.

The present level of technology achieves about 20 minutes of stereo recording per side on a 5¼" disk, and could be used in a disk-based digital audio editing system to provide about half the number of edits per second of the presently used Winchester magnetic fixed disk drives. The new optical drives could sustain stereo data transfer, in the terms specified earlier, of just better than three times real-time, thus meeting many of the requirements listed above. It is possible that the record duration could be increased to the magical 35 minutes, but at present it may only be the broadcaster who is demanding this. If we are able to achieve our requirements in the next year or two, it is possible that the level of technology could remain for some time.

The existence of the CD format might help to secure optical-disc recording as a method, but it is unlikely that a format very close to that of the CD would be acceptable for computer applications that also need fast random access.

The BBC is involved in advising and assisting the British Library in accelerated life tests on a range of optical disc media. They are considering transferring the whole of the National Sound Archive recordings to optical discs, and need confirmation of a long predicted lifetime. It is expected that these tests will confirm that the present level of optical disc technology has already produced media suitable for archiving.

Establishing the life expectancy of the optical-disc recording media

The optical recording and replay process is so fundamentally different from established magnetic-tape based record/replay systems that we cannot directly apply knowledge and expertise with those media to give us a direct indication of any weak links that might limit the lifetime of optical discs.

We can study the detail of all the factors that we think might be significant and as a result limit the possibility of being let down by this new medium and existing media. Because the signal to be recorded will be digital, we can apply computer techniques to verify that any recording is a faithful replica of the original signal. The recording format will also include the ability to correct errors that have been introduced. However, that can only apply up to a limit beyond which the recording would have to be declared unusable or

at least incapable of being replayed to provide the same high quality signal that was originally recorded. The mechanisms by which errors are introduced into optical recording are associated with physical changes that might affect either the recorded signal or the base media which carries this signal and through which light is shone to read the recording. Any physical distortion of the disc that causes it to rotate unevenly might limit our ability to recover the signal. Tests are constantly conducted with base materials, and it is hoped that a number of laboratories are analysing the mechanical stability and any chemical deterioration process that might apply to the base material.

The transparency of the base material and the reflectivity of the recorded surface may also be measured directly, since they contribute to our ability to recover the recorded signal.

However, some mechanisms are more sophisticated and require a different approach. Any deterioration that causes holes recorded into the reflective layer to increase or reduce in size affects our ability to recover recorded data.

Whilst such changes, if they are small, might not change the recorded data, they will reduce the margin available for other variations in performance before errors start appearing. Such effects happen on a microscopic scale, but it is possible to analyse the recovered electronic signal to give some indication as to whether the replay margin is becoming eroded and to predict how quickly data might become irrecoverably distorted. One method of electronic analysis that has become widely established uses the statistics of the intervals between the transitions in the recovered electronic waveform. Any physical change in the disc causes the statistics of the recovered intervals between edges to become more widely distributed, indicating that the edges of holes are no longer where they are expected to be. In the electronic domain, it is normal to resolve edge position detail in nanoseconds, which may be the equivalent of less than 1% of the size of a hole. The only alternative method of achieving such resolution would require the use of an electron microscope, and may involve destroying the medium. These electronic methods will therefore become particularly important in monitoring recording quality in an archive.

The work conducted by the National Sound Archives, in which the BBC is collaborating, includes the analysis of a wide range of related factors that may eventually prove important in identifying any weak links in optical recording and in establishing the use of new measurement techniques. To date, there have been no negative results. After the first phase of tests it was clear that we needed to concentrate much more on achieving reliable and consistent measurements, since the variation of these seemed larger than any ageing trend of the media. Further tests are planned, and these will include analysis of a number of different media and formats.

Standardization procedures

The CD format is well established. It is worth noting that it is based on technology demonstrated in 1979 by Philips, and that the format emerged as an agreement between Philips and Sony in 1980 (Pohlmann 1989). When considering the widespread use of a new

really need 20 bit, especially for radio application? Second, is 5¼" another must? If you take an 8" disk, you get three times more space on to it, and solve some of your problems, especially if you want to squeeze 20-bit resolution on to your disk.

Michael Croll:
The 20-bit issue is a very big issue as far as the broadcaster is concerned. It is probably not realized how much work is done in maintaining very high standards and very high quality where you have the ability to do digital mastering. A great deal of work has been conducted both within the BBC and within other organizations, and has led to the important need for the broadcaster himself to be able to master and standardize on something more than 16 bits. It sounds very expensive to use additional bits like that, but the move from 16 to 20 is really not very expensive in terms of the use of the medium because of the tremendous increase in facility that it gives you.

As for 5¼" versus 8", I'd actually like 3½"! I think that 8" is too big, though.

Michael Biel:
The 5¼" size was mentioned as being an attribute that helped it from being damaged. But I don't feel that is really the case, because the discs get scratched in handling all the time in broadcast situations – they are just laid down and slid around, and so they do get damaged.

Michael Croll:
I'm sorry, but I think you missed the point. I was not talking about a compact disc there, I was talking about a recordable disc. Most of these

recordable discs are actually double-sided, and what I showed as the other side was an equally well recordable surface. I'm sorry for the misunderstanding. I should have highlighted the fact that for most of my presentation I was not talking about the CD, but the recordable disc.

Christopher Roads:
Mike Croll has had an interestingly challenging task in presenting to you work that we at the National Sound Archive have been doing in conjunction with the rest of the British Library, the National Preservation Office and the BBC. Within the parameters he established, I think he has put it over extremely clearly. But I'd like just to say that, even in the applications required in the National Sound Archive, it's not purely an audio application that is the end as far as we are concerned. If, in order to protect them, we are to take out of circulation the records that we possess at the moment in their sleeves, we need to be able to provide simultaneously the colour photograph interleaved with the sound – a colour photograph of the label, the colour photograph of the sleeve, and other documentation. So what we are looking at is a system – an optical disc – that will give us that versatility in terms of the original documentary source.

That has the advantage that what we need is what the rest of the British Library needs – what many other organizations require. Because we are not thinking purely in audio terms, but in that totality of documentary record. It means that our collective muscle is immense. If we can keep on track, we

medium in broadcasting, the prolonged supply and support for it and the equipment to record it is as important as its durability and long predicted lifetime. In the world of computer optical disks, there are at present more formats than manufacturers – and there are many manufacturers. Dominant factors in the latter market are seen as the main companies involved in computer PC and small computer industries. For instance, it is likely that the acceptance of a particular format for widespread use with, say, IBM PCs would establish it as a *de facto* format.

The one manufacturer who seems to have established a format for the recordable compact disc is Yamaha, who use Fuji media. Many CD masters now delivered for pressing are recorded in this way.

Several organizations, including the AES, now have working groups trying to identify where standards can be agreed for the exchange of audio data on optical discs. This is at the request of users and audio editing equipment manufacturers, who want to be able to use optical discs to convey audio between workstations.

Practical ways forward

Allowing for the time being a degree of uncertainty as to how different media and data recording equipment will develop, it is becoming important to establish standards for how a wide range of media could be used for recording digital audio. The computer industry has established a 'data-block' based format system that is applied universally to data input to or read from recording devices. These data-blocks are adapted within application-specific software and/or hardware, whether it is for wordprocessing or graphic design. In each of these specific fields, standards exist that allow data prepared using one system to be input and further edited using a system manufactured by a different company.

Using these analogies, it seems sensible to develop hardware/software systems that allow audio data to be reformatted into computer data-blocks and applied to recording devices using the computer industry interconnection standards. In this way, disc or tape formats become standardized in so far as any medium replayable on a particular drive can be used in an audio system for recording and replaying audio. The drive performance, in terms of speed/access time, determines the edit capability of the system with that particular drive.

Transcoders that convert between the digital audio signals and the standard interfaces of drives (SCSI, the Small Computer Standard Interface) could use the minimum of customized components and depend heavily on the computer industry. [It is worth noting that the current series of PCs have bus rates far in excess of that required for digital audio.]

As with many changes of technology, it seems now that the direct development from analogue tape recording to digital tape recording is unlikely to satisfy the core requirement for the broadcaster. The use of discs rather than tape might provide the ideal sideways change of technology that would enable the broadcasters' use of audio recording to develop. It is vital that the possibilities of new optical

media are widely debated so that a considered view is developed of how technology can be applied.

Conclusions

Where it is cost effective to do so, manufacturers may make specialized audio recording equipment for the broadcasting industry. However, it seems increasingly likely that the industry will have to depend heavily on other larger industries if it is to exploit the latest technologies. In some cases it will be able to take domestic equipment and apply it directly. In others it must seek to adapt commonly-available units for its purposes.

Initial tests with optical media show that they may well achieve the longevity claimed by their manufacturers. It is now most important that the users and the manufacturers develop and agree on test methods so that we can understand how best to keep optical disc media. It is also vital that the manufacturers assist the users to reduce the range of formats proposed at present.

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should be able to find the tens if not hundreds of millions of pounds that we require to apply the technology that we're developing. It equally means that we can't go on indefinitely, because there are windows that have to be recognized and utilized or we've lost out.

As far as damage is concerned, without revealing any of the secrets of our testing, I can say that the kind of tests that we include are very severe daily cycling such as from -20°C to +60°C. We are mimicking the severest rigours of tropical air travel for the discs. We are thinking in practical terms of the applicability of the medium universally throughout the Tropics. We are trying to do a job that is comprehensive, and not just purely directed towards audio ends.

The Preservation of Compact Discs – Principles of Analysis

Jean-Marc Fontaine

Henning Schou: *Our final speaker today is Jean-Marc Fontaine, an acoustic engineer who has specialized in research into architectural acoustics. He has been with the Ministry for Culture and Communication in Paris for ten years. There he has worked for the Sound and Audio-Visual department of the national library, the Bibliothèque Nationale. Jean-Marc Fontaine is charged with the responsibility of solving problems associated with the department's preservation and restoration of collections, problems connected with storage area conditions, dubbing equipment and detection of degradation of different media – especially magnetic tapes.*

Introduction

We clearly lack information about the long-term behaviour of CDs. Some constituents of the disc and elements of the moulding process (which determine the life expectancy) vary according to the way in which they are made, so we might well expect considerable differences among the types of product. The Sound and Audio-visual Department of the Bibliothèque Nationale is responsible for patents, and needs to address this problem.

This paper describes two types of study aimed at improving knowledge of how CDs will behave in the long-term:

- analysis of the signals recorded on the disc,
- analysis of chemical changes following controlled ageing trials.

An example of an indirect application – the study of identification markings of CDs irrespective of the base material – will illustrate the precautions that must be taken.

These studies were carried out under the auspices of the Convention created by the Bibliothèque Nationale (Marie-France Calas, Director of the Département de la Phonothèque et de l'Audiovisuel), the University of Paris-VI and the CNRS (Professor Jean Sapaly, Director of the Laboratoire d'Acoustique de Saint-Cyr l'Ecole).

Analysis of the parameters of a compact disc

Whatever its origin (optical, magnetic, on disc, or on tape), a **digital recording** enables one to supply the institutions – in addition to the audio information (the final objective!) – with extremely useful information enabling them to optimize the administration of stocks, to communicate advice to the user, and to efficiently monitor the state of the recordings at any time.

The specifications in the *Red Book* allow four types of information to be extracted from the recording:

- the audio signal of the final recording, which reflects all the different steps in the recording process (recording, post-production, mastering, pressing – the reproduction and listening system);
- the identification protocol that permanently links the disc with the information recorded on it;
- the state of the recording – the digital information carries all the data which, when processed, permit a diagnosis of the quality of

recording. The robustness of the recording can be appraised in relation to degradation of any kind;

- several physical aspects can be determined from the data supplied by the reproduction system, for example accuracy of tracking and degree of optical reflectivity.

The audio signal

The **analogue** sound derived from a digital recording does not satisfy all listeners, who exhibit varying degrees of dissatisfaction. Recent studies have cast light upon the deficiencies of some reproduction equipment, such as converters, and some manufacturers are trying to remedy this. When you are specifically interested in determining the faults of the disc itself, it is essential not to incorporate the shortcomings of the reproduction equipment into the investigations.

There are insufficient means of analysing audio recordings of **digital origin**; more knowledge is needed about the relationship between disc faults and the perceptible sound changes that they generate after the correction circuits. This will not be dealt with here.

The identification protocol

The table of contents (TOC) and the sub-code Q provide the following data:

- the number of the tracks with temporary check-points,
- the number of channels,
- whether or not pre-emphasis was used for the recording,
- whether or not digital copying is to be prevented.

The sub-code Q may contain the references of the recording, in the form of a UPC/EAN code repeated as a barcode on the casing and sometimes printed clearly in the centre of the disc. Products carrying this code seem to be extremely rare.

This information enables us to identify the production of the recording (country, year, copyright holder) in the form of the normalized code IRSC. But still, as far as we can tell, this code is never used.

It is interesting to note that, if we do not have a sophisticated code reproducer, it is possible to access this information with an appropriately-programmed CD-ROM player.

Audio-diagnostic parameters

The use of local correction codes – to compensate for errors before and after the demultiplexing of bits grouped together in blocks – very slightly increases the resistance of the recording to all types of defects and attacks. As each act of detection and correction of the circuits can be identified, it is easy to establish exactly what state the recording is in. If the quantified values of these parameters are

followed all along the replay chain, the quality of the digital information can be confidently determined. But remember this will also include errors originating in the processes of digitizing, mastering and pressing.

Diagnosis is even more precise if the signal (the eye) of the photoelectric cell (HF) is observed. This reveals the quality of the inscription of the data on the disc (pits). The reflectance characteristics of the laser beam on the metal layer can also be measured.

Studies linked to the long-term durability of recordings yield even more interesting information. The amount the laser beam is offset compared with an ideal track (radial noise) gives a general picture, but also reveals imperfections in the polycarbonate, surface deposits, etc.

Physical characteristics of the disc

Two essential physical properties of a CD can be determined using the laser beam as a measuring tool. These are the degree of trueness of tracking (warp, angular deviation) and optical reflectivity (the reflecting capability of the metal layer combined with the transparency of the polycarbonate).

Objectives followed in this study

Before we could begin, we had to be sure that our budget would allow us to carry out experimental research based on means of control that would provide useful parameters to characterize the quality of the disc. Of the different methods that could be used, we became interested in those that carry out quality controls during manufacture. After a very detailed study, we chose the system established by a Swedish Company, Audio Development, for its CD-CATS analyser (Philips/Studer player); this provides all the data that we have mentioned, including the identification protocol. This system permits:

- identification of the documentation, insofar as the information contained in the UPC/EAN and ISRC codes is recorded. It is, anyway, interesting to know whether these identification protocols are generally taken into account;

- a statistical control of the quality of CDs entering collections, given that listening on reproduction equipment does not provide sufficient data (basically whether reproduction is satisfactory or unsatisfactory). As far as we know, manufacturers carry out quality evaluation, but we are not aware that any comparative tests have ever been published;

- the extension of the experience already acquired to the new range of base materials known to be sensitive to ageing (but without tangible data). For example, discs that can be recorded only once, which are of great interest to the archive institutions: the WORM principle. Studies can already begin on compatible recordable discs, such as CD-A by SONY/THAT'S, GOTHAM, KENWOOD;

- the improvement of knowledge in the field of conservation of optical memories, for which published numerical statistics are rare. We can define the reliability of a CD only in relation to the original manufacturing data which, according to what we have observed so far on new discs, varies a great deal.

Of course these studies must be accompanied by work on the fundamental degradation process, which is why we are now concentrating on chemical properties.

Studies on the long-term chemical behaviour of CDs

The Centre National d'Evaluation de Photoprotection (CNEP), affiliated to the University Blaise-Pascal of Clermont-Ferrand (The Laboratoire de Photochimie Moléculaire et Macro-moléculaire, UA CNRS 433) specializes in the study of the ageing of polymers. The primary process of change of the materials is studied through exposure to light. Since 1973, an analytical investigation into the chemical reactions has replaced an empirical approach whereby the degree of degradation was noted without any complex reactions being interpreted.

This new approach is based on the identification of the mechanisms of chemical changes caused by photo-ageing, and on the recognition of the principal mechanisms in natural ageing conditions. The natural evolution can then be forecast, and we can forecast the development of photo-stabilization techniques using additives with known properties.

Jacques Lemaire, Director of CNEP, has carried out some research for the national Département de la Phonothèque, first on different sound and audio-visual materials and then on CDs; we can give the initial results of this study.

Long-term behaviour under the laser beam

To establish whether the polycarbonate (PC) could be degraded by intensive playing of CDs, either full length or only on sections in a loop, a laser beam of wavelength and power similar to that of a playing beam was applied to a zone of 0.04mm^2 for 1097 hours.

This zone was then sectioned by depth in order to perform analyses in the different layers.

Remember that the surface of the disc is exposed to a laser beam of about 1mm in diameter. Because of the refracting effects of PC, this diameter progressively shrinks within the disc and reduces to 1µm on the reflective metallic layer. The overlapping of the zones that are exposed during the playing of the tracks, the width of which is 1.6µm, must also be taken into account: it is thought that the beam leaves a surface zone when it has read 625 tracks.

The sweeping speed of the laser beam on the disc is 1.2 metres per second, and the surface is exposed for 0.83 milliseconds per revolution.

For a disc with a total length of an hour, each zone on the surface suffers an exposure of 0.52s. If we accept the hypothesis that the

energy received is proportional to the length of exposure (ignoring the restrictions due to the change from 'dead' state to 'live' state), then the ratio of exposed surfaces between the simulation beam and the playing beam is about 20 to 1. Under these conditions, the continued exposure duration of 1097 hours is the same as continuous playing (24 hours a day) for 380,000 hours (43 years).

Let us now consider the section that is listened to repeatedly. The most unfavourable conditions are represented by the exposure of a 'closed' track. On an average beam of, say, 4cm, it takes 0.2s to go round once (a distance of 0.25m covered at 1.2 metres per second). At 5 revolutions per second, the closed track is read 18,000 times per hour. This corresponds to an exposure time of about 15 seconds per hour for a zone of 1mm in diameter. The corresponding length of simulation is of 13,100 hours (1.5 years).

Analyses carried out on the infra-red microspectro-photometer with Fourier transformations have revealed no change to the PC. We therefore conclude that the action of the laser beam is unlikely to lead to significant degradation of the disc, even when playing is looped (as is the case when optical memories are used – with the CD-ROM, for example).

Long-term behaviour of CDs in shops

Analysis of thermal ageing of polycarbonate

In order to simulate the ageing of CDs in shops (in darkness), trials have been carried out whereby discs were submitted to different temperatures (60°C, 80°C, 100°C, 140°C) in a dry atmosphere. In the most severe conditions (140°C for 3.5 months) no change in the oxidation of the PC was observed (analysis by microspectro-photometry IR). In view of the laboratory studies into the influence of water on the photo-ageing of the PC, the joint influence of heat, oxygen and water will need to be considered only when the behaviour of each of the elements in the system is judged to be satisfactory.

Analysis of thermal ageing of the protective coat of varnish

A different technique must be used to analyse this very thin layer of varnish. The ratio of ATR (attenuated total reflection) to MIR (multiple internal reflection) allows very early detection of the evolution of the physical state of this coat. High-temperature trials (80–100°C, and 140°C) carried out for periods of 280 hours show that the varnish is subject to considerable change, making it impossible to register the IR spectrum on to ATR. At 100°C and 140°C, moreover, marked yellowing appears. It was not possible to register an IR spectrum on samples that had had 45 hours at 50°C and 25 hours at 60°C. This suggests that the behaviour at room temperature will be very poor indeed (despite an eventual strong energy activation of the thermo-ageing).

Analysis of natural ageing of records made in 1985

The polycarbonate has not changed at all (microspectro-photometry IR). However, the varnish no longer permits the

recording of the ATR spectrum. These observations confirm the foregoing analyses.

Analysis of the constituents

The following results were obtained from samples of polycarbonate and preparatory varnish, together with samples of these products after transformation (obtained from MPO-France, for whose assistance we are grateful).

Photo-ageing of polycarbon (film)

Using methods developed by the Laboratoire de Photochimie, trials of photo-ageing were carried out on a PC film, 30µ m thick, prepared in cold conditions. The analysis (spectrum IRTF and UV) and the identification of the resulting photoproducts of oxidation, reveal the behaviour of a non-stabilized polycarbonate. Chemical change can be shown when the PC is submitted to photo-oxidation. A yellowing effect has also been shown through similar studies of intense but fully controlled degradation; such studies contribute well to a deep understanding of the product.

Thermal ageing of the polycarbon (film)

A 25µ m thick film, prepared under the same conditions as above, was subjected to temperatures of 60°C, 80°C, 100°C and 140°C for periods from 100 hours to more than 1100 hours. No significant chemical change was noted, only some dehydration (from 60°C).

Thermal ageing of the varnish (film)

A 120µ m thick sample subjected to 140°C for 3 hours loses all its mechanical properties.

Measurement of the state of oxidation of a 50µ m thick film, submitted to temperatures of 50°C, 60°C, 80°C and 100°C for different lengths of time (up to 600 hours), enables one to determine the activation energy and to judge the behaviour of the product at normal room temperature. The variation in optical density is a consequence of extremely early degradation, which gives a marked change in the varnish within 2000 hours at 20°C. Measuring another parameter, the speed of yellowing of the varnish, the oxidative character of which has already been shown, leads to similar results, which confirm the extreme sensitivity of these types of cellulose varnishes to ageing.

Remarks:

- The behaviour of the varnish is greatly affected by the presence of the marking film.
- The specialists are not very optimistic about the metallic layer.
- MPO is in the process of carrying out some work with a view to developing different photo-reticular varnishes.
- Finally, Prof Jean Lemaire observes that, for products that include those nitro-cellulosic varnishes that have a fast degradation

Denis Oudard:
Why have you found it necessary to inscribe on the CD, rather than using the identification band?

Jean-Marc Fontaine:
The Phonotèque feels that it is necessary to identify the CD directly and if necessary to indicate its ownership. For instance, every document of the National Library is marked; and it's also for security purposes, to prevent copying or illegal sales. I think this technique is also used to identify the disc when separated from the box, for instance. We need a clear identification.

Paul Mawhinney:
How long a period of time is the life projected in the experiments that you've performed?

Jean-Marc Fontaine:
We stopped the experiment at the equivalent of 8000 years. It's not the major problem – we can now study another problem, the varnish.

Paul Mawhinney:
That's my next question: what about the varnish? Have they improved that? Is there a new material coming?

Jean-Marc Fontaine:
I believe this laboratory is working with the manufacturer to change the formulation, to use a reticulate polymer. They have certainly come up with a good product but another question is to make it in quantity. At the Phonothèque Nationale, we have 10,000 CDs. So we now have a problem for those CDs, but we hope to influence the new manufacturers.

Paul Mawhinney:
What about the discs that are already out there? Are they positively going to break down?

Jean-Marc Fontaine:
I can't really answer this question; it's a question for the chemist, because we hope that the varnish is physically not very badly degraded. These results are only a few weeks old, but we think that the varnish is mechanically not in a very bad state, just discoloured.

Paul Mawhinney:
One other thing I'd like to point out is that, on the numbering, not only have they painted or coated some of the sides so you can't read the

through oxidation, stabilization could be envisaged through impregnation or the addition of specific additives. For finished products, the possibility must be rather complex, but it is there.

Marking of compact discs

All items entering the collection of the Bibliothèque Nationale have to have markings of ownership and identification applied to them. It is not usually difficult to find a zone suitable for marking (be it marking stamps, self-adhesive labels of a topographic type, or barcodes), for example, on the central part of a black record, on cassette boxes, or on the container of a magnetic tape. However, such methods cannot be used on CDs such as the CD-V of 20cm and 30cm, which do not have a central part suitable for fixing labels.

A mistake: the self-adhesive label

It would be tempting to use the back of the disc to fix labels or self-adhesive films. But that would be a double error:

For chemical reasons: The study described earlier shows the degradation of the very thin varnished layer caused by the action of the glue, against which there is no known safeguard in the formulation. This is similar to the use of inks without sufficient safeguard at the beginning of the manufacture of CDs.

These fears are confirmed by various studies: a reputable industrial label manufacturer requested an equally reputable CD manufacturer to analyse the reaction of his products. The results were extremely unfavourable: the glue badly destroys the varnish layer.

For mechanical reasons: The label itself, or the de-centering of the films that cover the surface of the disc, creates a counter-weight that can generate vibration that is bad both for reproduction and for the reproduction equipment.

Sometimes one has to choose between two evils. The problems vary with the institutions; some will give preference to communication, others to conservation. For certain establishments where theft (an instantaneous form of destruction!) is a major risk, the introduction of a discernible device under a film remains preferable. The demands of different institutions must be respected. For the Phonothèque Nationale, which does not lend and for whom long-term durability is a priority, the use of such labels or self-adhesive films must be rejected at all costs.

Only one suitable place

Which zone of the disc accepts a marking that can be visible to the naked eye? Observation of the disc and of the specifications in the *Red Book* leads us rapidly to consider the central zone of the disc, which is not a recording area. But maximum safeguards must be used to protect the part that fixes to the player, because of the high demands of trueness and of surface quality.

What sort of markings?

The following methods were investigated:

- a circular **label** in the prescribed zone: chemical risk, and intolerable depth;
- **hand writing** in the prescribed zone: not very practical, and with a risk of chemical contamination;
- **heat marking**: an interesting solution, but not a satisfactory proposition at present;
- a **photo-sensitive** process: same comment as above;
- **ink jet**: the trials that have been carried out were inconclusive;
- engraving, or better still, **scratching**.

Scratching

We tried engraving with a turning tool (with eventual wax overlay to improve the legibility of the inscriptions), but we turned to a scratching technique, which uses a non-turning diamond point, fixed on an X–Y table, controlled by a microcomputer. The text is shown on the monitor before being printed on the disc, and this permits alterations.

A diamond point, moving under controlled pressure, superficially scratches the protecting layer of the disc. The material is pushed back under the pressure of the diamond point. The depth of this pushed-back material has been measured at different pressures to see if this change in the smoothness of the surface remains compatible with the demands of the specifications in an area reserved for the fixing of the disc. The results were positive. Among the main advantages of this method, it must be noted that it does not cause the formation of splinters or of dust, to which digital recordings are so sensitive.

numbers, but the numbers are backwards, so they have to be read with a mirror if you're cataloguing them.

Jean-Marc Fontaine:
Yes. We can just read it on the side. We have just one inscription.

Henning Schou:
You were mentioning the production-process generated numbers that are difficult to read. The numbers in the presentation are not difficult to read, because they are written from the same side that you would read the other information. They are engraved and filled with wax crayon, or something like that.

Steve Smolian:
On the question of the varnish, do you have any idea from your projections what will be the minimum and maximum number of years of survival of those discs you've tested?

Jean-Marc Fontaine:
Not at all. We need to know more about the processes of degradation, but this work is only just beginning, and the projections are not reliable.

Session 3:
New Carriers

Chairman: Frederick Granger

I have the honour this morning of representing four people who are dealing with this technology problem. I've met Jim Wheeler many times at different technology sessions related to standards; Denis Oudard is representing Digipress, a firm that has progressed very very well in developing the long-term carrier; William Nugent is from the Library of Congress; and, finally, I'm sure many of you know Dietrich Schüller very well.

Issues in Optical Disc Longevity

From Trithemius to Arrhenius Testing

William R Nugent

Introduction

My topic today is issues in optical disc longevity from Trithemius to Arrhenius Testing. Basically, I want to concentrate on Arrhenius Testing. Dr Edge has told us that the Arrhenius model was, on the whole, suspect. So I want to concentrate on testing methodologies that tend to make it less suspect.

Now it is both traditional and prudent to be suspicious of the longevity of new carriers. Dr Edge gave us, in effect, a new version of the classic Aristotelian syllogism: all polymers are unstable and mortal, almost all contemporary information carriers contain polymers, therefore almost all contemporary information carriers are unstable and mortal. I certainly agree with this, and this has been a concern for at least five hundred years.

But let's start with Trithemius, Abbot of Sponheim, who lived about five hundred years ago and said:

> 'If writing is inscribed on parchment it will last for a thousand years. But if on paper, how long will it last? Two hundred years would be a lot.'

And that's when they made good paper with long cotton fibres, not the stuff we see today! So he had a legitimate concern and he, of course, was a Benedictine monk who was valiantly trying to save the scribal culture at a time when Gutenberg's engines were already pumping out books in high volume. But I think even today we have cause to be worried about new carriers, especially if they haven't been tested.

So, how long **should** records last? The following are just rules of thumb:

- office records – 3 years
- correspondence (one technology generation, ie when you either have to migrate your data to a new hard disk or ignore it) – 5 years
- financial records – 7 years
- medical records – 20 years
- weapons documentation – 40 years
- real estate, insurance – 100 years
- archives – forever.

Frederick Granger:
William Nugent is Director of Technology at the Center for Innovative Managment and Technology at the Library of Congress.

How long do other media last? Perhaps we can see where optical discs fit in. According to our National Bureau of Standards (now NIST):

- magnetic tape – 20 years (and usually it's the binder that goes first)
- ordinary paper, books – 75 years
- acid-free paper – 500 years
- parchment – 1000 years
- silver halide film (kept under carefully controlled conditions and with carefully controlled processing) – 2000 years
- baked incised clay (the old Sumerian clay tablets with cuneiform inscriptions) – 3000 years
- chiseled stone – 3000 years (provided you don't leave it out for acid rain to destroy!)

At the Library of Congress we have many concerns with preservation and we're very proud of our diethyl zinc (DEZ) process for vapour phase mass deacidification of books. If done properly, this can give books an extra four to six hundred years of life, provided they are already in good condition. We're building a new book preservation facility for DEZ processing.

How long do optical discs last? Well, nobody had any information at all about the early optical discs, so when one vendor said 10 years, everybody else copied. There was absolutely no basis for claiming even a 10-year life, and now we have some current claims for about 100. So libraries and other institutions are presently recording information of long-term importance on what is still basically a short-term medium that is rarely certified for more than 10 years.

So what are the approaches to achieving a longer lifetime?

- **more durable substrates** –glass is more durable than polycarbonate, which is better than polymethylmethacrylate (PMMA);
- **more stable recording layers** – gold platinum alloys are a lot better than tellurium, which was the early material;
- **irreversible recording systems** – by this I mean once you make a mark it will not become unmarked, although other marks may or may not form depending on what happens to the material. Sony, for instance, is creating a bi-metal alloy. Plasmon of the UK has a nice system: they're melting a patterned non-reflective surface, a so-called moth-eye surface. Once it's melted, you will no longer be able to restore that moth-eye surface – so it's a one-way process. And Digipress of France etches a tempered glass substrate. Now glass has some unique properties: it's not a polymer, it's basically a supercooled liquid. So we have some high hopes for glass.

So some of the 100-year candidates (and I say candidates only, because the testing is not conclusive yet) are Sony, Plasmon and Digipress.

One frequent criticism we get is: 'So what if some discs last a hundred years? There won't be any machines around to play them on.' There are a couple of counter arguments to that.

First, any technology can recreate the mechanisms of a prior technology if the specifications have been preserved. So again the key is the information, the specifications, not the preservation of the artefact machine itself.

Second, if you want a new stereopticon, a new zoetrope, a new playback system for Edison wax cylinder recordings or old piano rolls, or old 78 rpm records, these can be produced. But you make them with newer parts. You wouldn't use mechanical feelers to play a piano roll, you'd obviously use photo electronics. But this approach would rarely be necessary, and now I'll discuss why that is.

Standards should be important, but they're not important right now for longevity. This is not a parameter for standardization, it's considered to be a competitive quality factor. But, if it is a competitive quality factor, then it should make different claims. So we should at least standardize the methodologies for validating claims of longevity, and this is being developed in an ANSI (American National Standards Institute) X3B11 subcommittee.

Arrhenius testing

So how do we validate? Well, we don't have too many options, as there aren't many methods for longevity claims validation. We have Arrhenius extrapolation based on accelerated ageing. This is over a hundred years old. [Svante Arrhenius first published in 1889; he was a Swedish electrochemist Nobel prize winner.] At the Library of Congress, we're trying to preserve all our collections, including those recorded on optical storage. So our immediate operational objectives are:

- to determine the longevity of our optical discs
- to determine degradation rates and physical/chemical causes
- to establish principles of archive management – once we've put these things away, how do we care for them? Such principles include inspection procedures and schedules, and criteria for rewriting ageing media.

Principles of preservation say that digitally encoded information, if it is protected by an effective error detection and correction (EDAC) system, can signal its own increasing degradation of the recording medium (soft errors) and permit error-free copies to be made before the occurrence of uncorrectable (hard errors). Now the price of this, of course, is periodic testing, and it's all based on the Arrhenius relation, about which many things have been written.

The Arrhenius relation expresses a general condition of the kinetics of molecular collision:

$$k = A\, e^{-E/RT}$$

A is a constant, E is the key factor (the thing we are looking for) which is the activation energy, R is the universal gas constant, and T is the absolute temperature in degrees Kelvin. (I will describe the testing itself later.) In its pure form, this formula is pretty basic and solid, but it gets more difficult when you start introducing other factors such as humidity.

Now the basis of the Arrhenius method is:

- degradation with age is assumed to be a chemical reaction
- most chemical reactions are accelerated with heating
- the object is to age the material gracefully and not to cause catastrophic injury.

To summarize the methodology:

- Select a measurable key parameter, measure its initial value and establish an end-of-life or half-life value. The parameter should be key to the usage of the media, and we have chosen bit error rate, which is a nice measurable quantity. The important thing about choosing bit error rate is that we know the capability of the EDAC system. We know what it can do and so we know the end of life: the end of life is defined at that point when the EDAC system can no longer correct it. We have start-of-life error rate around 10^{-5} or better, and we have end-of-life error rate as defined by the typical EDAC as being, say, 10^{-4} or worse.
- Establish a test plan and select: 3–5 temperatures, the relative humidity (that's a difficult factor), the duration of each bake and the minimum number of bakes. We like to bake for 500 hours, which is almost precisely three weeks, which makes it easy. And the minimum number of bakes? We do five, because you need about five points on a curve if you want to plot a straight line.
- Measure and plot the log parameter versus time after each bake.
- At the end of testing, fit the best rate line and extract log slope.
- Plot log slope versus 1000/K.
- Extrapolate to normal ambient temperature.

There are some important considerations in testing:

- It should be graceful ageing, not destructive testing. We have occasionally done inadvertent destructive testing when we thought we were doing graceful ageing, and so we have to lower the temperature.
- When does destruction begin? That's a good question; you have to define destruction. For instance, delamination does occur, and

when we bake optical discs at high temperatures we have arbitrarily said that local small blistering is normal ageing, but blistering over a larger area is destructive. So, again, it's a matter of judgement.

- Avoid thermal shock during ramp-up and ramp-down of the temperatures Most specifications for optical discs say that your temperature gradient should not exceed 10°C, or 15°C or 20°C per hour, so we try to honour that spec when we're testing a disc. That sometimes means using a second oven to bring the disc out of the normal oven and ramp it down to ensure that you're not exceeding those limits.

- What is the effect of humidity? There is an important paper (about the only one I know of) by Milch and Tasaico (1980) that shows a U-shaped curve. Now a U-shaped curve is almost improper in Arrhenius Testing, and this I think is an area for further study – how do we usefully introduce the aspect of humidity into Arrhenius Testing? I would emphasize that Arrhenius Testing is not an exercise in empirical equations; you should be able to find a credible molecular basis for the reactions that are occurring, and not just arbitrarily plot curves and extrapolate curved areas.

- Be suspicious of excessive non-linearity in plots. That's again basic Arrhenius: anything that's unusually curved is probably not susceptible to Arrhenius Testing. In other words, you're getting not just a primary reaction, but secondary reactions or things that cannot be properly extrapolated.

- Recall that this is based in molecular kinetics.

- Is the sample size adequate? What range of error will you accept in estimating the key parameter of the population? Now this has been one of the failures of some testing, too. Basically, we want to use normal statistical procedures; we are trying to sample a population of a disc, and a disc has many many bits on it. So, if we're looking at bit error rates, this can become very large. Now we've been testing the 12-inch ATG write-once discs and, because we wanted to combine testing and archive management, we've said that we want to have at the start of life 2.5×10^{-6}. We want this measurement to be within that accuracy with a 95% degree of confidence. And, most importantly, at the end of life we want to make absolutely sure when we measure 9×10^{-5} that we're less than or equal to 1×10^{-4}, which is the cut-off point. If you work out these numbers, the minimum sample turns out to be about 300 tracks on a 12-inch disc, so that's not too bad at all. It also turns out with that number that you have one chance in a million that the population error will ever be greater than 6×10^{-6} of the sample error.

So those are the things to consider, and that's why you should distinguish between longevity testing and archive management. Archive management is a process whereby you're testing to determine when you must re-write because your error rate is creeping up, and you're running out of power with the EDAC system. We depend upon EDAC, and a great moment for EDAC was with Voyager, where a little 25 Watt radio transmitter about as big as a

campus radio station sent back perfect images to Earth two billion miles away.

But you have to worry about the Catch 22s: physical deformation is the worst one because of the 'potato chip' effect, which is to say you're getting multiple degrees of curvature in the disc. That's particularly true of PMMA, slightly less true of polycarbonate, and fortunately significantly less true of glass. You can also get axial run-out and radial run-out. So you must know the manufacturer's limits of the tracking servo and the focus servo, because your error rate can be very fine and in good shape and well within the limits of the EDAC. But, it's no good if you can't track it. So physical deformation is one of the worst things that can happen.

I have described the Arrhenius methodology in a paper to the testing methods group of ANSI's Optical Discs Standards Committee (Nugent, 1989) and I would be interested in any critiques on the paper.

Optical bench testing

A metallurgical optical microscope allows us to see artefacts. One of the things we are trying to do is see if there are visual artefacts that correlate with high increases in error rates, and we are looking for things like edge sloppiness. An optical microscope is almost good enough, but a scanning electron microscope is much better – though you have to put the sample in a vacuum chamber that will only accept 4-inch x 4-inch samples, so this is definitely destructive testing. It's good for post mortems, but not very good for non-destructive testing – though it does give you beautiful pictures!

When we put a PMMA disc in the same oven with the glass disc, we didn't need a microscope to see the rivulets of moisture. The minute any moisture hits it, the whole disc becomes totally unreadable and you get little rivulets of moisture. But that's an unfair test for the PMMA, because it is destructive. In fact one of the vendors told us not to heat PMMA over 50°C and yet we were heating the discs up to 80°C, so that's an unfair test for PMMA.

Transmigration of information

A common computer room practice is the transmigration of information (as one of my colleagues calls it): new generation mass storage equipment routinely replaces older devices every 4–5 years, and old data that is still required is migrated to the new system. In other words, as the new technology becomes more cost effective and the old equipment gets too expensive to maintain, you migrate old material. The cost of migration is most often offset by increased cost effectiveness of the new system. So we won't need to become a museum and keep these old machines, because normally we will upgrade. In fact one of the things our standards group is working on is the second generation 12-inch disc, so maybe in a couple of years we'll have that, then we'll migrate all of the data that we've recorded on the old 12-inch discs.

Summary

- Materials research is increasing the life expectancy of optical discs.

- Thanks to error detection and correction (EDAC) systems, perfect new originals of ageing digital discs can be made.

- Archives and libraries are not museums; like other modern organizations, they regularly upgrade their information systems, so do not like to keep old equipment hanging around.

- Standard testing methods for validating vendors' longevity claims are still important.

Finally, to get back to Trithemius – he would have been a good proposal writer, because he gave you the awful consequences of things that would happen if you didn't preserve scribal culture. In *De laude scriptarium* he wrote:

> 'Scribes, therefore, give strength to words, remembrance to deeds, significance to events. If you deprive the Church of them, faith wavers, charity cools, hope fails, righteousness perishes, the law is overthrown, and the Gospel passes in to oblivion.'

I think we could make a modern translation of the horrors of losing information today.

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Long-Term Archiving on Optical Disc – A Market Response Approach

Denis Oudard

Summary

The Century Disc™ is a compact disc made of tempered glass, a reflector of gold and labeled with a coating of chromium oxide. Early tests results show it to have a life expectancy of well over 100 years.

The Century Glass Master™ (*Mère Gravée* in French) is a new intermediate product in the mastering of CDs. In this new process, the traditional master and the father and the mother are all replaced by the Century Glass Master.

The Century Disc, announced in January 1989, is being investigated by some of the leading National Libraries in the world. We are pleased by the level of interest shown by these institutions. However, the long testing period that the disc is submitted to before being included in a long-term archival programme has kept the sales volumes low.

Introduced only in February 1990, the Century Glass Master, a passive archive, already has some major manufacturers of compact discs showing a deep interest in the technology. We believe that a key to this early sign of success is the 'by-product' nature of the technology. Indeed, manufacturers of compact discs that will use the Century Glass Master technology will enjoy faster turn-around, cost reduction, and at the end of the process will have an archivable piece that does not require any special conditions.

Introduction

First I want to very briefly present Digipress, which is a French firm based in the pastures of Normandy that was founded by Jean Ledieu in late 1985 and has a fully owned subsidiary in the United States. From the outset, the company has had two main drives. The first is to manufacture masters for CD plants across Europe. We have been doing that quite successfully, and are now the leading manufacturers of masters in Europe with about 13% of the market. Second, there has been a strong drive to research and development of the Century technology, and Digipress now owns patents on several crucial steps in the manufacturing of Century products.

The Century Disc

Century research set out to meet the challenges offered by the weaknesses of the polycarbonate compact disc. These weaknesses were identified as:

- **mechanical deformation** caused by
  - fast temperature gradient
  - G force (if you wanted to put a CD on a drive and read it while the Shuttle takes off, for example)
- **scratches** (the effect of scratches is not so obvious on audio, but is certainly a problem on CD-ROM; I have personal experience of using CD-ROMs that were probably about a month old and wouldn't read because there was a scratch on an index)
- **delamination and oxidation** caused by
  - absorption of humidity
  - porosity of some of the materials

From there, Digipress's research team, headed by Jean Ledieu himself, established guidelines to develop a technology that would overcome these problems. These guidelines were to:

- **substitute minerals for the less stable materials**
  - hardened glass for plastic [substrate]
  - gold for chromium [reflector]
  - chromium for resin [protective layer]
  - chromium dioxide for ink [labeling]
- **stick to CD standards** to ensure
  - compatibility (it would be quite useless to create a whole new media that we couldn't use on the available machines)
  - longevity

With these guidelines in mind, Digipress set out what these combined materials could be expected to achieve. These were the primary specifications:

- **temperature:**
  - permanent (-60°F, +260°F)
  - intermittent (+300°F)
  - 10 minutes (+500°F)
  - shock (-60°F, +300°F)
- **pressure:**
  - no affect
- **humidity:**
  - 0 to 100% without condensation

- **rotation:**
  - 57,000 rpm
- **shocks:**
  - 350,000 drops from 4 feet high
- **hardness:**
  - 600 kg/mm^2 (vickers)
- **military standard:**
  - norm MIL-E-5400 T
- **life expectancy:**
  - more than 100 years in an office environment
- **expected cost:**
  - master set up: $2000
  - copy : $300

Now these were primary specifications, and we are happy to report that according to our tests we have met or exceeded all these values. One of our customers has even submitted a Century Disc to 2 hours at 600°F. We have seen the disc, but have not yet had the opportunity to test it ourselves.

After two years of development we have achieved the following:

- **mechanical and chemical stability**
  - high resistance to high and low temperatures
  - resistance to humidity
  - resistance to corrosive gases and saline atmosphere
  - resistance to etching
  - resistance to mechanical vibrations (this is also important in other areas; if you have read reviews such as the *Audiophile*, you will know that some people are worried about what they call 'CD jitter', and vibration is also important in systems that are on board vehicles such as boats or planes,
  - resistance to mechanical deformation
  - resistance to scratches and to aggression of external surface (this is important if you want to continue using a CD-ROM in a normal office environment)
- **complete insensitivity to electromagnetic interference** (perhaps less important now that the risk of a nuclear war seems to be receding)

Comparing the polycarbonate disc with the glass-etched disc, this is what we find:

Substrate	**Polycarbonate**	**Glass**
Process	Injection moulding	Etching
1. Optical		
transmission:	90%	>95%
refractive index:	1.58	1.50
birefringence:	30nm	<1nm
2. Mechanical		
surface hardness:	+	++++
Young's modulus:	1	3000
breaking modulus:	1	>40
3. Temperature		
maximum:	250°F	600°F
expansion coeff.:	7	1
4. Chemical		
humidity absorption:	25%	<.1%
typical lifetime (in years):	10	>100

The Century Disc was the first product that resulted from our research programme. We have identified several markets for its use:

- **very long term archiving**
  - cultural patrimony
  - archiving satellite images
  - scientific patrimony
  - legal archiving
  - strategic or high security data
- **severe environment applications**
  - on boats
  - in space
  - militarized systems (up to class 4)
- **luxury editions**
  - audiophile editions
  - 'gold discs' and awards
  - numbered series
  - prestige advertising

- **small numbered professional editions.**

Today, because of cuts in military spending, the most promising markets are archiving and luxury editions. In the archiving market, we have provided the Grande Bibliothèque and the British Library with samples for tests. The Library of Congress and Digipress are conducting a joint research programme to further evaluate Century technology for the long-term archival market. A large private collection of sound documents has just begun to put its most important holdings on Century Disc. These quality projects, combined with projections of lowered costs of production, give us good reasons to be optimistic about the future of the Century Disc in the long-term archival market.

A final note on the 'active' archive provided by the Century Disc is that its manufacturing process is applicable to all types of formats: we have Century CD-ROM, Century Audio and Century CD-Video and we are starting to experiment with large formats such as the Laser Disc.

The Century Glass Master

In 1989 Digipress thought of a new use for Century technology, and the Century Glass Master was born, at least in the mind of Digipress researchers. In January 1990, Digipress was ready to announce and exhibit it.

The Century Glass Master is a new intermediate product for producing the stampers used in the injection moulding of compact discs. The manufacture of a polycarbonate disc involves the creation of a master, which traditionally is roughly a sandwich of resin in between a glass substrate and a silver coating. Through electrolysis, nickel is deposited on this master and is then separated away from it, creating a nickel piece known as a 'father'. This is a process that takes about ninety minutes and destroys the master. From the father, we go back to electrolysis and obtain another nickel piece, the 'mother' from which, again through electrolysis (and it's a ninety minutes process every time) we can obtain stampers that are cut and placed in the bottom of the moulding machine.

In the new process, the traditional master and the nickel mother and father are all replaced by the Century Glass Master. This is an 8" diameter, thin, tempered glass disc into which the information is etched through Reactive Ion Etching (RIE). The new technology has three major advantages: the product is ideal for both short- and long-term archiving, processing time is reduced, and a master is created that can be used several times.

Archiving

In the conventional process, because the master is destroyed, it is the nickel mother that is archived. Nickel is not very stable, and generally pits quite quickly. In the new process, it is the master that is archived. Moreover, the Century Glass Master has inherited the 100 year life expectancy of its cousins, the Century Master and the Century Disc. Since the data, represented by the pits of the compact disc format, is actually etched in the tempered glass, it becomes one of the longest lasting archiving pieces known to man. No humidity,

oxidation, radiation or any other alteration common in a normal environment can damage the Century Glass Master – not even 10 minutes at 350°C (600°F).

Processing time

Multiple stampers can be produced directly from the Century Glass Master, thereby cutting out two stages in electroplating. When multiple stampers are needed, no special cleaning or re-coating is necessary and using the Century Glass Master will enable manufacturers to cut their processing time by as much as 40%, increase their capacity, and improve productivity.

Multiple use

The Century Glass Master is coated with chromium and chromium oxide. The characteristics of this structure allow for the production of multiple stampers that keep the same quality, time after time. In case this metallic coating were damaged because of an error of manipulation, Digipress has developed a simple process to restore its original quality.

Potential users of the technology are quite enthusiastic about this new technology. In the normal running of their plant, it will save them time and money. The impact of the archival quality of the Century Glass Master and the opportunities it offers are not yet fully measured.

For sound tracks, the Century Glass Master could replace the more conventional choice of 'Master' such as the U-matic or other magnetic media. In the same way, eventually, the Century Glass Master, in its laser disc or CD format could replace the less stable film masters.

A year ago we made a video to present the Century technology. The plant that mastered the video kept a nickel mother in its archives. This year, we needed more discs for promotion, so we called for a re-run. They made this re-run from the nickel mother. Well, the quality of the picture has gone down tremendously: there seems to be a veil all through the screen. We had proved our point that manufacturers need a more stable passive archive than that provided by nickel pieces. With the added advantage of lower costs, we are very happy with the interest shown by the manufacturers of compact discs.

Another aspect of archiving on optical media that has become evident is that not all material is well suited for archiving in this way, at least not yet. The most suitable are music and moving pictures. The reason is simply because, once finished, the recording or music or a movie does not change, or should we say 'should not change'. Indeed, unless they paste colour on this eternal classic as well, *Casablanca* will always be *Casablanca*..

One would expect it to be the same for some written documents, or for pictures. The main reason why these are not ready to be archival media yet is the lack of standards. And we do not expect any standard to come up and change the state of things. The *de facto* standard in the written word remains books, and the *de facto* standard for

pictures ranges from framed artwork to books. In the same way that the paperless office predicted in the late 1970s never happened, we do not see the CD-ROM replacing books, nor do we see high-definition video terminals replacing museums, artwork, photography and statues. At best, CD-ROM and books will be used for different types of work. Research might be done on CD-ROM to facilitate the search, but reading will continue to be done on books.

Another reason that text archiving on CD will only be a niche market is the constantly changing world of software that is made to access the written word, the changing nature of the indexing and flagging methodologies. As you probably know, the various flags and indexes are stored along with the test on the CD-ROM.

From these observations one can extrapolate that optic media will be used as a semi-active archival tool; call it semi-passive if you will. Its *raison d'être* will be as an insurance against total destruction of the books whose content it shares. The archive could have just straight text, or just scanned images of the book pages, or a combination of both. This archive could be either a Century Disc or a Century Glass Master. Indeed, as of today, there doesn't seem to be any rationale supporting the long-term archival of software and indexes that will soon be obsolete for a host of reasons, including the lack of machines to run them on.

The last argument, or course, brings with full force the problem of longevity. How long will we have machines that can read what is considered today to be at the very forefront of the high-tech world? Isn't it true that the tapes from the Gemini mission are unreadable, not because the tapes decayed but because there are no readers for this type of tape any more? The strength of the world-wide imposed and accepted standard for optical media – *Red and Yellow Book* – is encouraging; the number of CD-ROM drives will reach a million at the end of 1990. There is strength in numbers. On the other hand, the relatively short life (60 years) of the LP is most discouraging: this is against the favourable odds given by the large installed base of pick-ups. Will the compact disc have more luck, or will it soon be replaced by a *better* mouse trap?

An Overview of the D1 and D2 Digital Video Tape Format

Or D1, D2, Which One for You?

James Wheeler

Frederick Granger:
Our next speaker is Jim Wheeler, who has been involved for some time in the archival community of both the United States and Canada. I'm very pleased that he's here to present his information.

Introduction

After many years of anticipation, a digital video tape recorder is now a reality. We now have a video medium that can be easily duplicated, and the copies are clones of the originals. At the moment, this pertains only to professional video tape recorders because there are no consumer digital video tape recorders in existence yet.

At present there are two professional digital video tape formats available, the D1 and the D2. You are already familiar with the analogue professional video format, the C. Now you will learn about the D format.

D1 and D2 were introduced in 1987 and 88 respectively. D2 records the video in its composite form, which is the normal single cable form familiar in the NTSC, PAL and SEC systems. The D1 requires multiple video cables since it records the video in its separate components: colour, black and white and the synchronization signals. A digital component recorder is meant to be used in an all-digital studio, but can be adapted to any present day video facility.

What most people are familiar with are the composite analogue recorders: the professionals (the Quad, the B and the C), the consumers (Beta, ED Beta, VHS and SVHS); and also the U-matic and the 8mm. Then there are the component analogue machines, the M2 and the BetaCAM SP recorders, which are primarily for electronic news gathering, but are used in other areas too. Most people seem to be happy with the analogue video recording system which was developed by Ampex in 1956, so why do we need digital?

Copy quality

A major problem with analogue video tapes is the copy quality: the copies are always inferior to the original. But with digital, the copy quality is fantastic. Only the most critical eye can distinguish a twentieth-generation copy from the original. To my eye, fortieth and fiftieth generation copies look as good as the originals.

Error correction

The second benefit of digital video tape recording requires a brief explanation. The recorder has a built-in ability for checking the quality of the recording without disturbing the recording. This cannot be done with an analogue recording – you have to re-record on the tape to find out what shape the tape is in, and that's not a good idea. But the information on the digital tape is recorded as

digital data and can be easily checked to determine if the recorded data has errors or not. The number of errors can be noted every year, or whenever you want to check them, and if there is an increase you can turn on the error-correction circuits and produce an error-free picture.

Picture quality

A third advantage with digital video tape recording is that it eliminates the familiar unwanted analogue artifacts, such as drop-out and banding. The digital produces a remarkably clear picture. In fact seeing the playback video of a digital video recorder is quite an experience – you'll ask yourself, is it live or is it digital?

D1 and D2 compared

Broadly speaking, D1 is intended for an all-digital facility, and D2 is intended to upgrade an existing facility.

The D1 is a **component recorder** designed for an all-digital facility. If you're planning to change your facility to be totally digital, then D1 is for you. D1 is also the best recorder for blue screen matting and for multiple graphic image work. D1 is also the best for standards conversion, because the digitized video signals are multiples of both 525 NTSC and 625 PAL and SECAM.

By comparison, the D2 is a **composite video recorder** that is compatible with existing television equipment. The D2 is much cheaper than the D1 recorders. The Ampex D2 recorders sell for $65k–90k, which is comparable to a C-format recorder with a timebase corrector. You don't need a timebase corrector with a digital machine – it's built in, in effect. The D1 recorders sell for $120k–150k, a much higher price tag. Third, the D2 tapes take less storage space than other professional tape formats; D2 tapes require about one-third the shelf volume of D1 tapes and about half that of B or C tapes. Fourth, the D2 does not require large-size cassettes for most applications; it requires them only for programmes of 2 and 3 hours, whereas the D1 requires a large-size cassette to record anything longer than a half an hour.

Tape lengths

There are three sizes of cassette available in D1 and D2. Most of the machines in the D1 and D2 are designed to take all three cassette sizes, though some cheaper models can take only the small or the medium size. The small cassette records up to 11 minutes on the D1 and up to 32 minutes on the D2. The medium cassette records up to 34 minutes on the D1 and up to 90 minutes on the D2; the large cassette records up to 76 minutes on the D1 and up to 200 minutes on the D2. I might add that a single D2 32-minute cassette stores about 300 gigabits of information – an incredible amount of data.

Archival use

The next logical question is whether or not D2 has any major disadvantage for archival use. You might argue that a price tag of $65,000 is a major disadvantage, but that's not my department. My

first concern is that the large-size cassette, which has a large diameter pack over a smaller-sized hub, may become distorted with time. To prevent this from happening requires a rewinding every couple of years or so. Fortunately the large cassette is seldom used in the D2 formats. The second consideration is the thin tape. I can report that I have been testing thin tapes on Ampex D2 recorders for about five years and I have had no problems with the thin tape; problems such as print-through don't exist because we're working on very short wavelengths. The thin tape handling problem is solved by using air-lubricated tape guides to reduce the friction; as a result the tape tension is kept low, and the tape can be handled very gently.

There has also been some concern expressed about metal particle tape. This was also a concern of mine ten years ago before metal particle manufacturers developed methods of coating the iron particles to protect them from oxidizing. Ampex chemists and engineers have performed extensive tests over several years and are completely convinced that the special coating process creates a stable metal particle tape. As with other tape types, metal particle tape must be stored in a cool, dry environment – definitely below 30°C and 60% relative humidity, and preferably below 20°C and 30% relative humidity.

Summary

From the archival point of view, the best characteristics of the digital video tape formats are that they allow near-perfect copies, and provide both high quality video and audio. On top of that, the D2 format has a smaller storage volume than the other professional formats. You should now understand why I'm an advocate of digital video tape recording in general, and of D2 in particular.

Towards the Automated 'Eternal' Sound Archive

Dietrich Schüller

Frederick Granger:
We're going to conclude with Dietrich Schüller, who is on so many standards committees that I'm very proud and honoured to have him with us today.

A lot of what I intended to present has been said already, so this communication can be brief. The title of this paper is 'Towards the Automated Eternal Sound Archive' but, after Jim Wheeler's talk, I think it could also be called, 'Towards the Automated Eternal Sound and Video Archive.' Previously in this conference we have heard a lot about WORM optical discs ('Write Once Read Many' drives) from Michael Croll, and also Bill Nugent has been talking most interestingly about the lifetime of optical discs. This paper, however, is one step beyond what we have heard so far.

No carrier is permanent and never will be – except perhaps for nickel masters or glass plates. Even relatively permanent carriers run into the problem of the obsolescence of sophisticated hardware once the commercial lifetime of a format is expired. It is very questionable whether it would be feasible to rebuild, for example, a CD player once mass production has ceased and the last spare part has been sold. Furthermore, formats existing for a comparatively long time tend to preserve technical development in the state it was at the time of their introduction, thus hindering the use of modern developments. Therefore it seems necessary to establish a new preservation policy. Archives should not necessarily go for the long-term preservation of carriers, formats and their equipment, but for the preservation of the **contents** of our documents.

Such a policy implies, speaking in terms of centuries of course, subsequent copying on from one carrier to the next. It is well known that analogue copying degrades the signal only slightly from copy to copy. But it does degrade it nonetheless and, after some hundred years and after some generations, there will be substantial distortion of the original signal. So copying must be done digitally. As has already been explained in other papers in this symposium, digital copying enables us to clone information – to make copies that are identical to the original.

On the other hand, the amount of material stored world-wide and considered to be worth keeping for eternity is gigantic. [IASA is currently undertaking a worldwide investigation to explore how many hours of stored audio materials are considered to be of exceptional value and, consequently, should be stored for posterity. As a first result, American colleagues have worked out that the amount of audio data currently stored in US archives exceeds – speaking in digital terms – 5000 terabytes (5 million gigabytes). This amount will be multiplied explosively if we consider video material as well.] Even if copying were carried out in the digital domain, it would still involve too much manpower to be done manually in the future. This manual operation could be afforded only once, for transferring the existing analogue carriers into the digital domain. Thereafter, it would have to be done automatically.

Let us imagine a vault with storage racks that are accessible fully automatically, where either the carrier can be picked up and transported to one or several copying machines, or machines can be transported to the carriers. These carriers could perhaps be WORM optical discs, optimized for data security rather than for data density. [Contrary to popular belief, storage costs are almost negligible compared to the overall costs of sound archives (1).] Such a system should be flexible to accommodate various bit rates and various sampling frequencies. Normally 16 bits, 48 or 44.1kHz is considered sufficient for modern stereo recording. But it should also allow recordings of 20 bits, as demanded by Michael Croll. For historical recordings 12 or 14 bits may be enough at a sampling rate of 32kHz; mono, where applicable, doubles the capacity of such a carrier.

Let us also imagine that, when the system is idle, these carriers are automatically checked for their error rate according to age and to the number of replays. Whenever it is detected that the error rate exceeds a defined threshold – which has to be low enough for full error correction and thereby complete recovery of the original signal – a new copy is made fully automatically and put in the place of the old one.

Beside its capacity for self regeneration, such a fully automated system would be most attractive for radio broadcast archives as well as for big national sound archives, record libraries, etc. Radio programming from the journalists' desks will be possible, as well as self service by users of sound archives without the need for being serviced manually. Even remote access via a telephone from home is not Utopian.

Most importantly, such a system would also enable future automatic trans-formatting. So if after, say, twenty or thirty years the chosen storage format should become obsolete and be replaced by another format in whatever form (cassette, vertically magnetized disks, etc) then new racks designed to accommodate this new physical format must be installed. Then would begin an automated transfer of the old format on to the new one, and the two systems would exist side by side until this transfer was complete.

This is no dream. All these components exist: the carriers, the drives, the robot systems. There is also, in the analogue domain, a fully automated sound archive in existence at the Süddeutscher Rundfunk in Stuttgart. [This Sekamos system was designed in the 1970s for fully automated radio transmissions of programmes. It uses the Unisette, a studio cassette system designed by BASF. (2,3).]

If there everything is available, the question is: 'What is missing?' Agreement is missing. We simply have to agree that we want to have such a system, and we can have it tomorrow. Such an agreement quite naturally would have to be made by the great national radio stations within the EBU (European Broadcasting Union) in cooperation with the great national sound archives. Such a decision, however it might look technically, would have a standardizing character, and the chosen system would then become financially affordable. Its worldwide adaptation would also prevent the too-frequent change of formats that we see today in the video field. There is good reason to hope that such a decision will be made as the great European national radio stations are beginning to

understand that their archives are their most important weapon against the commercial stations that are now very rapidly springing up all over Europe. After the investment of the first transfer of their holdings into such an eternal archive system, the treasures of their holdings will be available in a very attractive, inspiring and – most importantly – cheap way.

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Christopher Roads:
What Dietrich Schüller has just described is what we've being trying to set up over the last two or three years in London, and I agree entirely with what he said. But we believe that it's important from the very beginning to incorporate the colour photograph of the documentation – the sleeve or the label. It's equally important that we do not forget that video is alongside us, so it's essential that technologically we embrace the digital video domain and, in due course, high-definition television as well. We have begun to work with the world leaders in video compression, so that the whole thing can genuinely operate in a remote sense, and we can use telephone cable links. We're informed that we will be able to use those for all types of material we send down them.

But we cannot achieve this goal solely with the assent and agreement of the National Sound Archives and the EBU. It's quite clear from my negotiations in the United Kingdom that we also need to carry with us the British phonographic industry and the rights societies. I'm pleased that in Britain the Mechanical Copyright Protection Society is as interested in this realizable vision of the future as we are. So in order to implement this, we need to get in all parties – the rights, the industry, as well as the broadcasting side. I'm sure that our experience will be equally valid elsewhere in Europe.

Paul Mawhinney:
I'd like to add one step further to that: I think we now have a wonderful opportunity to include on all carriers – not just audio and video – cataloguing information that would be machine-readable and that would be of real benefit to all historians and archivists.

Henning Scho:
Concerning the estimation of longevity of the optical disc... I was very pleased that Mr Nugent mentioned the limitations of the Arrhenius Test, because we shouldn't forget that what Arrhenius did was to use a simple first-order reaction. Unless one can prove that it actually is that, it's very difficult if not impossible to use that equation. And I would assess that it would be very difficult to extrapolate any information when you have such a complex system as a disc. Could I just ask Mr Nugent, can you tell us a bit about the phenomenon you call laser rot?

William Nugent:
That appears to have been a copywriters' term for the oxidation of an aluminium reflective layer, which was observed on some early versions of the analogue video disc. It has not been observed lately, and I suspect that it was due to the poor sealing or porosity of the PMMA in a hostile airborne environment. Obviously oxidation is inimical to the reflective layer if that layer is aluminium.

One nice thing about the Arrhenius method is that it is

self-correcting. If your log plots are non-linear, you know the Arrhenius method will probably not work because there may be second-order or third-order reactions taking place which the method does not take into account. But if you get nice straight lines, then that is some assurance that you are probably dealing with a first-order reaction and hence the Arrhenius method does apply. It has been used in the past with complex material such as photographic film, colour-printing paper and textiles, and so I think we have some confidence that it's a reasonably good method if its principles are observed. And the other fact is, we don't have too many other methodologies for extrapolating.

Question:
Did you get straight lines?

William Nugent:
Yes, we got some straight lines for the ATG discs.

George Brock-Nannestad:
My comment is on Dr Schüller's very important and general philosophical paper. It might surprise people that early recordings require so few bits and such a narrow band width, but in fact that is compatible with their content. So, provided we can replay the original material in such a way that we don't create artefacts, we don't need any more and a system would then have to be compatible as Dietrich has suggested. On the other hand, what happens in practice is that you let the original material deteriorate to such a degree that you then save what is remaining of the content digitally, and you are happy because look at what a lot you've been able to save! The future, which will work well with digitally generated material and will be self perpetuating that way, will not save the past as it stands today and as the past will be in about ten years. We will still have to put a lot of effort into replaying the original; otherwise we'll need the full band width in order to take care of what is then the sum of content and deterioration.

I also have one specific question about the glass base. For centuries glass has been known to be sensitive to high humidity, and I noticed that the 100-year expectancy was in 'office conditions'. Now the nicely controlled office conditions in our climate are not the same as in an office in Thailand, for instance, or the Philippines, and I wonder how the glass fares under condensation of moisture?

Denis Oudard:
I'm sorry. I am honestly at a loss as to how to answer this question, but I'd be happy to investigate it and get back to you.

Bill Storm:
Regarding the glass format at Digipress… are there any plans to put that in to a mode where an archive can actually do its own recording on to it as opposed to sending it to a facility to have the work done?

Denis Oudard:
We have a deposit of patents to have a WORM disc that would be recorded by the individual user. The WORM disc would then be sent to a facility for the more complex technical steps such as etching and coating, and returned as a Century disc. So "C'est dans le carton" , as we say in French. It's in our plans.

Lionel Ditz:
Mr Nugent, you ended off your speech by saying that archives and libraries are not museums, and yet at the beginning of your speech you said archives should be kept forever. Could you please elaborate on that statement?

William Nugent:
Yes, the Archivist of the United States at one point made a statement that archival means for ever. This was in rebuke of the many vendors of media who were saying theirs is archival media, meaning, 'This is something you can store and put away some place.'

What I meant in the later statement was that archives and museums have contemporary data processing centres, they don't keep their old equipment around. On our highly advanced disc systems at the Library of Congress, we probably have some old material that might have been around on 23/14 discs. But we certainly have not preserved any of the 23/14 disc players. Again this is what we're calling the transmigration of information: we're preserving information, not the artefact. So as new generations of disc files come out, it is a routine practice in the computer field just to migrate the data to a new medium. In fact I sometimes shock some of our people at the library when I told them how just a few years ago we decided we needed the faster transfer rates of the cartridge discs, so we routinely took all of our reel-to-reel tapes, and transferred them to cartridges. We didn't tell anybody about it; if we had, there'd have been seventeen committees formed that said, 'My goodness, is this something you should really

do?' But this is what is done in the computer field routinely.

Lloyd Stickells:
I think Mr Nugent got his era of software out by a degree of magnitude, because in the audio field I would have thought most systems have lasted 40–50 years. Now that is an awful lot of data to just transfer to a new medium. Whilst I'd agree it would be possible for a few computer tapes, if you'd had fifty years of computer tapes that would be a very major undertaking.

William Nugent:
That's certainly true. The migration is only possible with digital media. It is not possible without degradation in audio, where you lose a minimum of 3dB per generation. And if you're talking about video, you lose a lot more than that since you're getting phase shifts and all kinds of ugly things happening. In fact a while ago just to prove the point to management, we had a demonstration that we called 'A hundred generations of Mr Jefferson.' We took a video image of the Houdon bust of Jefferson and made twelve successive analogue video tape images. He looked horrible by generation six, and he looked like Dorian Gray by twelve. We then did a hundred successive images in digital video, and it was impeccably perfect – you couldn't tell the difference. Obviously this transmigration business can only be done in the digital domain; it's the only domain in which you do not have accumulative error and in which you do have the power of the Error Detection and Correction systems.

Lloyd Stickells:
Yes. It's just that the audio archivist is faced with a backlog of analogue material, and to copy five million LPs that may be around is going to take at least five million man hours to do – not to mention the cost of the material on which it's got to be done. On another point, perhaps manufacturers of subsequent systems might look in to the fact that data transfer at far higher than real time would be a great advantage.

Dietrich Schüller:
Of course Lloyd is right, and my guess is that we have hundreds of millions of hours in the analogue domain. But the alternative is to lose them by not doing anything and wait until they break down. Of course it would be nonsense to transfer them all into the digital domain; but from country to country one would have to decide what is really the essence of our national heritage, historical heritage, cultural heritage, and so on. This then would go in to the vault and would be perpetuated through this self-copying process. The alternative is, if nothing happens, it rots anyway.

Session 4:
Do we have Format Standards Suitable for the Long-Term Storage of Audio-Visual and Film Materials?

An update on the work of the standards organizations

Chairman: William Storm

This particular session was put on the agenda as a debate. The implication seems to be that discussion of standards with audio and visual is debatable. I can't imagine that, but the idea is to encourage dialogue after the speakers have given their presentations.

For me, one of the most memorable parts of our last symposium in Berlin was what followed the meeting, when we had a consultation with manufacturers. What we quickly found out is that individual archivists were saying, 'Gee, I need a new reel for my machine,' or 'I need a new plug to make things work properly,' and so on. This was very difficult for the manufacturing community to relate to, because this was not what they really needed. What they needed was for us to express our needs as a profession, and that is something we hadn't done – at least not from a technical perspective. We were all so caught up with our individual problems that we'd really never sat down together to work out our common goals: Where are we headed? What do we need to accomplish in the field?

That really provided the catalyst for the standards activities that have taken place since that time, and today we're very fortunate to have two people who'll give you some idea of what we're starting to do in terms of creating a way of communicating our needs in the field through the activities of standardization.

Status of Permanence Standards of Imaging Materials

Peter Z Adelstein

Introduction

The preservation of our history, technology and cultural heritage requires not only the preservation of published text, but also of images. As society is becoming more aware of the importance of the past, image preservation is becoming of increasing importance, particularly since image deterioration is being observed at greater frequencies. This has been found with both photographic images and magnetic signals. To date optical discs have not been used for long-term storage, and there is limited experience with their ultimate life.

To obtain the maximum life of images requires the use of recommended materials that are stored under satisfactory conditions. The establishment of both materials and storage parameters can best be accomplished through the recommendations of published standards. The recognized standards body in the United States is the American National Standards Institute (ANSI). It is the purpose of this paper to give an overview of the committee structure of ANSI which prepares image permanence standards, the types of documents that are now published, changes that have been made in these documents in recent years, and current work.

Organization

Image permanence standards fall under the jurisdiction of accredited Committee IT9, for which the secretariat is the National Association of Photographic Manufacturers. The scope of this committee is preparation of standards on the 'physical properties and permanence of imaging materials'. This scope was expanded several years ago from photographic imaging to include electronic imaging, and the numerical designation was therefore changed from a photographic (PH) to an imaging technology (IT) committee. Membership of IT9 is open to all organizations or individuals who have an interest and can make a contribution to the field. It is extremely important that membership is balanced between manufacturers, government agencies and consumers or general interest. At the present time there is an excellent balance, with representation from seven manufacturers, seven government agencies and nine general interest or consumer organizations.

The variety of topics and materials that fall under the jurisdiction of committee IT9 requires the establishment of five subcommittees, and these in turn can be divided into task groups. A description of this organizational structure is given in Table 1, and the exact responsibility of each group will be more evident when the individual documents are described. These subcommittees and task groups have a more limited scope, usually dealing with a single area

William Storm
Our first speaker is Dr Peter Adelstein, who was born here in this country and received his bachelor of chemical engineering in 1946 at McGill University. In 1949 he received his PhD in physical chemistry from the same university. He subsequently joined the Eastman Kodak company in the manufacturing experiments division at Kodak Park. In 1958 Dr Adelstein was appointed supervisor of the physical property section; he retired in 1986 as unit director of the physical performance section, and since then has been a consultant to the Image Permanence Institute at Rochester Institute of Technology. His areas of work include the physical properties of plastics, gelatine, photographic film and magnetic tape. He has published papers on brittleness, dimensional stability, film base, chemical stability, storage behaviour and stability standards of these materials. He has also participated in national and international symposia on these topics – he's an extremely well qualified man.

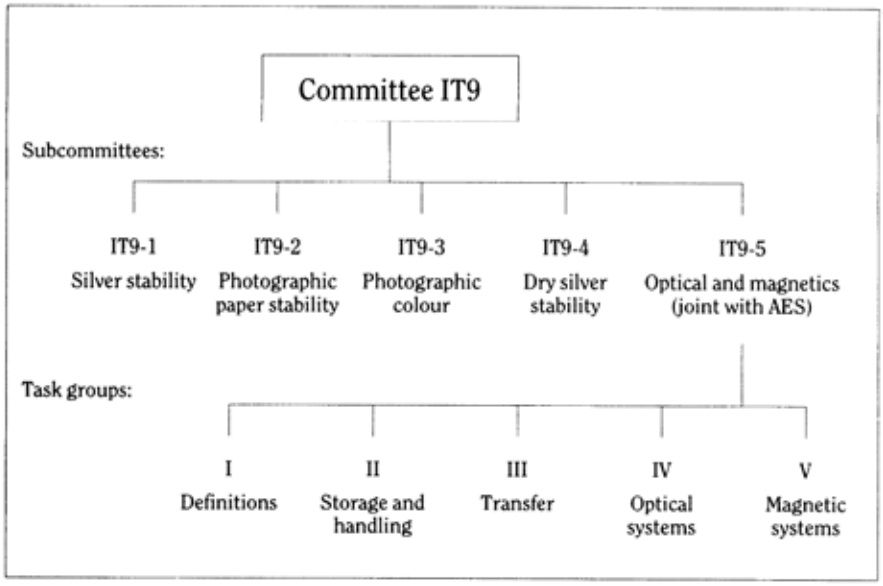


Table 1
Accredited Committee on Physical Properties and Permanence of Imaging

of concern that cannot be effectively handled by the committee. Membership consists of experts in a particular field, and these may not necessarily be members of the parent IT9 committee. Several of the subcommittees include experts from outside the United States. This adds greatly to the technical strength of the body, and facilitates subsequent standardization at an international level. It is the responsibility of these subgroups to assemble all the background information, to plan additional laboratory experiments and eventually to write a document that can be forwarded to committee IT9 and then to ANSI for ballot. The subcommittees and task groups are not standing committees, and may be dissolved when their assignments are completed.

All specifications prepared by committee IT9 contain the IT letters. However, it is important to differentiate between a document and a subcommittee. Subcommittees include a hyphen in their designation, while documents contain a period [full stop]. For example, IT9-1 is a subcommittee, IT9.1 is a document. Documents prepared prior to the reorganization of IT9 contain the letters PH, but these will be changed when the specifications are revised.

Three types of documents are issued by committee IT9:

- **Specifications** are minimum property values, along with appropriate test methods for materials to meet a specific classification. Examples are the specifications for the life expectancy of photographic films.

- **Standard practices** are recommended operating procedures. Within IT9, these have concerned conditions for storage for optimum preservation.

- **Test methods** are issued as separate documents when they are too complex to be included in a material specification, or they have wider application than for a single specification.

ANSI documents on permanence

To date, IT9 has prepared documents only on photographic materials. Although work has started on electronic imaging, this activity is much too recent to result in publications. The preservation of photographic materials is quite complex since it is dependent upon three factors, each of which is the responsibility of a different organization:

- the photographic material itself, which is the responsibility of the manufacturer;
- the photographic processing, which is controlled by the processing laboratory, and
- the storage conditions, which are determined by the consumer.

An arbitrary division has been made in which the requirements of the photographic material and its processing are combined into one specification, and the storage conditions are put into a separate document. The ANSI permanence standards that have been published to date are listed in Table 2.

Product	Material & Processing		Storage	
	Designation	Group Responsible	Designation	Group Responsible
B & W silver (wet) film	IT9.1	IT9-1	IT9.11, IT9.2	IT9
Diazo film	PH1.60	IT9	IT9.11, IT9.2	IT9
Vesicular film	PH1.67	IT9	IT9.11, IT9.2	IT9
Colour film	IT9.9	IT9-3	IT9.11, IT9.2	IT9
B & W silver (dry) film	under study	IT9-4	IT9.11, IT9.2	IT9
B & W paper	under study	IT9-2	PH1.48, IT9.2	IT9
Plates	—	—	PH1.45, IT9.2	IT9

Table 2
ANSI permanence standards

Eight documents on photographic film, paper, and plates are in print, and work is under way on several additional documents. These specifications and standards are continually being revised and updated as new information is obtained. Since 1988, three of these documents have been revised, and one is a new specification.

Each of the published standards, as well as the documents currently being worked on, will be briefly reviewed. The material specifications are discussed first.

Material specifications

All the ANSI documents on permanence of photographic materials refer to 'storage' media or 'work' copies. The distinction between these two should be clearly recognized. If photographic materials

are to be kept for extended periods, they should be viewed or printed only infrequently. Because of the use and abuse given to 'work' copies, predictions cannot be made of their life.

Black-and-white silver (wet) images

IT9.1 is the specification for conventionally (wet) processed black-and-white silver gelatinee emulsions. It is an expansion of the first ANSI specification in this field, published in 1945. Originally it only featured residual hypo limits and a stability test for the cellulose ester support. Tests have subsequently been added for residual silver halide limits, image stability, stability of the gelatinee emulsion, and adhesion of the emulsion to the base.

A major modification was made in 1988 when IT9.1 was rewritten to include films on both cellulose ester and polyester supports, and tensile measurements were used as a measure of the base stability for both supports. Based on research by the Eastman Kodak Company, a quantitative test was established for the image stability of radiographic films, and microfilms (1,2). Of greater importance to the microfilm industry was the increase in the upper limits of residual hypo. This was also based on the above-referenced Kodak papers, and was the result of work done under the auspices of subcommittee IT9-1.

Revisions to IT9.1 are not complete. Changes have been proposed to modify the residual hypo limits for aerial film, and laboratory work is in progress to obtain recommended hypo limits for motion picture, professional, mapping and roll films.

Film classification

Another aspect of IT9.1 that is under active discussion is the film classification system. There are currently three film classifications within this specification:

- medium-term film with a life expectancy of at least 10 years,
- long-term film with a life expectancy of at least 100 years, and
- archival film, which is film having permanent value.

A useful life in years has never been specified for 'archival film', but it was the intent that this term be reserved for photographic films having the maximum stability possible. The decision was made in 1976 that archival film should have a life expectancy at least equal to black-and-white emulsions that have been optimally processed (3). This has not been a satisfactory situation. The term 'archival' has been frequently used as a promotional adjective without any regard to the ANSI standard. It has also been used by different industries to mean different life spans. The magnetics industry has used archival to mean 50 years, and the optical disc industry has applied it to a life of only two years. This has led to dismay and confusion in the imaging field.

To address this problem, an ad hoc group (Task Group 1) was formed between IT9 and IT9-5, with representatives from the photographic, magnetic and optical disc industries. Agreement was reached to

eliminate the term 'archival', and to use a 'life expectancy' or 'LE' rating which indicates the expected life span in years when stored under specified conditions. In other words, medium-term film would be designated LE-10 and long-term film LE-100. Decisions have yet to be made about the LE rating to be assigned to 'archival' film. While progress is definitely being made with respect to the concept, considerable work is required to assign an appropriate LE number. After this is done, it must be approved by a ballot of committee IT9.

Diazo film

PH1.60 is the ANSI specification for diazo film of primary interest to the microfilm industry. It was prepared as a result of a sustained and cooperative effort of an ad hoc task group during the 1970s. This document took over 10 years to prepare because the necessary database was not available. There was sufficient background on the stability of the support (4,5), but extremely little quantitative information on the permanence of the diazo image.

Representatives of the various manufacturers exchanged samples, agreed on test parameters, and jointly planned stability tests that were carried out in their respective laboratories. This resulted in the necessary information to standardize on dark keeping image stability (6), light fading and physical tests.

Since diazo images are dye images, they are not considered suitable as 'archival' media, but specification limits are given in PH1.60 for both long-term and medium-term film.

Vesicular film

Another photographic product of importance primarily to the microfilm users is vesicular film. Vesicular images are composed of tiny bubbles in a polymer matrix, and are capable of high resolution. The diazo ad hoc task group also wrote a permanence specification for vesicular film. Although there was more published information on this product type (8,9) compared to diazo film, there was still insufficient data or experience to prepare a specification. Similar cooperative efforts among many laboratories resulted in appropriate tests and limits.

Establishing the image stability tests proved to be more difficult with vesicular than with diazo film. At high temperatures, the polymer binder of vesicular film softens and collapses the image. Since this behaviour does not occur at normal storage temperatures, extrapolation of high temperature behaviour to more moderate temperatures cannot be made.

This specification was published in 1985. As with diazo products, it specifies tests for long-term and for medium-term films. Archival films are not specified, because it is not possible to predict image stability greater than 100 years on the basis of laboratory tests for this product.

Colour film

There has never been an ANSI specification on the stability of colour photographic materials, although there was an obsolete test method to compare the colour stability. In 1978, subcommittee IT9-3 was organized to update this older procedure. This subcommittee not only included representatives from manufacturers, government and consumer interests, but also included the very active participation of organizations from Canada, Germany, Switzerland, Japan and the United Kingdom. The goals of this subcommittee were formidable. There was a need to standardize a test method to determine the stability of colour images under dark storage conditions and a variety of light exposure conditions, and to establish the criteria for the colour changes that are important. This test method (IT9.9) was finally approved by ANSI in 1990.

The determination of the degree of colour change that renders the image unsatisfactory is very complex, and there are many criteria that must be considered:

- % dye loss of colour patch
- % dye loss of neutral-density patch
- hue shift (difference in fade between dyes)
- stain growth in D_{min}
- colour of stain in D_{min}.

Measurement of the percent dye loss is obviously important, and this can differ depending upon whether a single dye patch or a neutral density patch is studied. In the latter case, the dye stability of one layer may be affected by the presence of dye in adjacent emulsion layers. Of equal importance to the fading of an individual dye is the relative change between dyes, since this causes a hue shift that can be very objectionable. Stain growth of the D_{min} area and the colour of any stain are also very critical considerations for consumer acceptance. Since there are three dyes involved in a colour image, the acceptability of a colour image is dependent upon many parameters.

There are also a large number of variables involved in standardizing a test method for the dark keeping of colour images. It is desirable to use a short time, accelerated condition to predict long-term behaviour. Previous work on image stability has used high temperature studies, and the results have been extrapolated to room temperature using the mathematical approach established by Arrhenius for classical chemical kinetics (6,10). However, the temperature dependence of colour change is quite dependent upon the dye involved. Consequently, the relative stability of different dyes at room temperature will differ from their relative stability under accelerated test conditions. Therefore a single accelerated test condition could not be used, and IT9.9 specifies incubation tests at a minimum of four temperatures. Arrhenius treatment of the data can then produce a predicted life at the recommended storage temperature. Unfortunately this requires extensive laboratory work and analysis.

The problems associated with standardizing a light-fading test are also very complex (11). Colour images may be subjected to a wide range of light exposure conditions, and the relative stability of different dyes is very dependent upon the spectral distribution of the light, the light intensity and the relative humidity. For this reason, five standardized light exposures have been specified in IT9.9. These simulate indirect daylight, fluorescent, tungsten, sunlight and slide projection illumination. Unlike the dark-stability tests, the light-exposure tests are not predictive, but are comparative only.

Additional work is planned in subcommittee IT9-3 to improve document IT9.9 so that it applies to colour negatives. Consideration will also be given to hard colour copy systems and the possibility of using colorimetry rather than densitometry.

Black-and-white silver (dry) images

Silver images developed by heat are an important product for microfilm users. Several papers (12,13) have been written about their stability, and predictions have been made for a relatively long life. In 1988 subcommittee IT9-4 was established with the purpose of preparing a specification for dry silver film. Several meetings have been held, and work is now in progress to establish predictive life expectancy ratings using the approach in the publications.

Silver images on paper

Although there is an ANSI specification for the processing of photographic paper prints, this document is not current. Moreover there are no test methods for the physical characteristics of the photographic paper. Accordingly subcommittee IT9-2 was organized in 1982. The goal was to prepare a specification for the permanence of photographic paper and to establish tests and test limits for the physical characteristics, the image requirements, and the photographic processing. Separate specifications are planned for fibre and for RC (resin-coated) photographic paper. As with some of the other subcommittees, membership of IT9-2 represents manufacturers, government and consumer interests. Again to broaden the technical base, representatives from overseas manufacturers are also participating.

One of the difficulties in preparing a specification for photographic paper is the determination of residual hypo. Problems exist in determining the hypo that has been absorbed by the paper base itself. Moreover, work performed in subcommittee IT9-2 indicated that the methylene blue test procedure is not satisfactory for photographic papers with incorporated developers, and this has led to the publication of an alternative test procedure (14). Work is currently under way in subcommittee IT9-1 to establish the residual hypo levels for photographic papers.

Activities in subcommittee IT9-2 are now concentrated on the physical tests. Procedures and limits for the brittleness, tensile properties and yellowness after artificial ageing have been tentatively established. Experimental studies are now being conducted to evaluate any cracking tendencies of the resin layer in RC paper and the resistance of the photographic emulsion to

oxidative attack. There is also work directed towards the development of a practical picture frame test.

Storage standards

It has been pointed out earlier in this paper that the permanence of photographic materials is heavily influenced by the storage conditions, as well as by the stability characteristics of the media itself. In addition to the material specifications already discussed, there are four published documents dealing with storage conditions and enclosures.

Film storage

IT9.11 describes the conditions for film storage, covering topics of relative humidity, temperature and air purity. Additional topics include recommended storage housings, storage rooms, and considerations for fire protection. This standard practice specifies two types of storage conditions: those for a 10 year life and those for 100 years or longer. Currently IT9.11 is undergoing a revision in which it is proposed to lower the recommended relative humidity for extended storage to 20–30%. This would reflect recent experimental studies which indicate a very marked improvement in life expectancy when the humidity is reduced from the current 50% RH recommendation.

Filing enclosures

A separate publication IT9.2 describes the recommended materials to be used for filing enclosures. These include enclosures in direct contact with the photographic image such as folder, sleeves, jackets and envelopes, as well as those enclosures not in direct contact such as cans, boxes and cartons. The materials covered are paper, plastics, inks and adhesives. Test methods and requirements for acceptable paper are specified.

Enclosure materials must also meet a photographic activity test that measures any susceptibility of an enclosure to chemically interact with and adversely affect the photographic silver image. In 1988, IT9.2 was modified by increasing the sensitivity of the photographic test. It now involves incubation of the enclosure material in contact with two sensitive detectors: one that reflects any effect on silver, and another that shows any staining of gelatine (15). Further work on test improvements is planned so that the procedure is more suitable for plastics and for non-contacting surfaces such as containers or boxes.

Paper storage

The companion document for paper storage is PH1.48. It is similar to IT9.11, but covers only subjects of importance to paper prints.

Plate storage

Plate storage is discussed in PH1.45. Of particular interest to this product is the type of storage container and housing for relatively brittle and heavy materials. These vary with the size and resolution of the plates. Recommendations are made about storing plates flat

or on edge, and about fire protection, water protection and air conditioning requirements.

International standardization

The standards activities discussed have all involved work within the American National Standards Institute (ANSI). However, there is also standardization on the international level through the International Standards Organization (ISO). Work on the preservation of photographic images falls under the jurisdiction of working group 5 of committee TC-42. Ten countries are represented in this working group. Progress on standardization is slower in ISO than in the United States, as ISO meetings are held only every three years. This contrasts with semi-annual and annual meetings for the ANSI groups. Approval of standards has been greatly facilitated because of the involvement of international experts in the ANSI subcommittees.

Table 3 illustrates the organization of the ISO permanence documents and the similarity to the ANSI organization (*see* Table 2) is quite evident. Eight documents have been published, or are in the advanced stage of balloting.

Product	Material & Processing	Storage
B & W Silver (wet) film	10602	5466, 10214
Diazo film	8225	5466, 10214
Vesicular film	9718	5466, 10214
Colour film	10069	5466, 10214
B & W Silver (dry) film	no activity	5466, 10214
B & W paper	no activity	6051, 10214
Plates	no activity	3897, 10214

Table 3
ISO permanence standards

Electronic imaging

At the present time there are no specifications or standard practices on the permanence of images on magnetic media or optical discs. This has been of serious concern to those involved in the preservation of electronic images (16). As mentioned earlier, the scope of the ANSI accredited committee IT9 was expanded to address this need. At the same time, there were efforts to prepare permanence standards in the Audio Engineering Society. These two groups have joined forces to create ANSI subcommittee IT9-5 (also known as the Joint Technical Commission). This subcommittee was formed in 1989, but it will be a long time before any documents are approved. However, some progress can be reported.

Subcommittee IT9-5 divided into five task groups as shown in Table 1. As already discussed, task group I on definitions has approved in principle the use of the LE designation and the elimination of the word 'archival' in ANSI standards. This change is being balloted in several of the photographic standards.

A major difference between photographic and electronic images is that the latter are only machine readable, whereas photographic information can be retrieved without equipment or with only a simple magnifying glass. Consequently photographic specifications are concerned only with the permanence of the media, whereas electronic images require the availability and functioning of the appropriate hardware and software. The rapid technological advances in electronic imaging and consequent obsolescence of hardware has aggravated the problem of retrievability (17). Recognizing this situation, task groups IV and V on specifications have included in their scope the permanence of the complete system.

Conclusion

A great deal of progress has been made in the standardization of the permanence of photographic materials. However, there are still many areas that need to be covered or improved. Consequently there is considerable activity in standards bodies within both ANSI and ISO. Much-needed work is just beginning on the permanence of electronic images.

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The Work of the Audio Engineering Society Subcommittee for Audio Preservation and Restoration

Delos Eilers

William Storm:
Our next speaker is Delos Eilers, who's the senior technical service specialist with the Professional Audio/Video Speciality Products Division of the 3M Company in Minnesota, Iowa. He has worked with 3M with audio magnetic tape since 1963 after graduating from Iowa State University with a BSc in electrical engineering. He is the author of several Audio Engineering Society (AES) papers and other technical articles on the performance and applications of magnetic tape. He has served on standards committees of the NAB, EIA, IEC, AES and ITA as they generated audio magnetic tape system performance standards. He is a member of the transmission and signal processing technical advisory committees of the AES, as well as the SE60A technical advisory group of the EIA and AN for ANSI. His current responsibilities at 3M include the technical customer service support of 3M's professional audio magnetic tape products. Del will update you on the activities AES's standards subcommittee for audio preservation and restoration.

Introduction

The AES standards subcommittee met for the first time about two and a half years ago, just prior to the AES convention in New York City, and we've been meeting annually ever since – so we've had three meetings so far. The idea for the meetings, which came out of the Berlin conference about three years ago, was to form an organization to be pro-active in the area of standards. Sometimes when you get involved in standards, you get into the situation of, 'We can't standardize on it unless it exists.' That means that the marketplace has to decide what standard before you can write a standard about it. That's not necessarily the best way to do things, but the other way is to dictate what you will get by writing a standard beforehand. That isn't right either; it has to be a little bit of both.

I will now give an overview of what happened in those first three meetings, so that you can see what progress we have made.

The first meeting

The first meeting was very productive, because we decided what to call ourselves, and what our functions and goals were going to be. We ended up being called the AES Standards Subcommittee for Audio Preservation and Restoration and our agreed functions were:

- to write proposed recommended practices for audio preservation and restoration,
- to write proposals for measurement techniques to be used in audio preservation and restoration,
- to put together proposals for equipment and media specifications for these ends,
- to define terms that are relative to audio preservation and restoration.

A lot of work there! But what's the goal? Our goal is to spawn a cooperative effort between manufacturers (such as the one I work for) and archivists aimed at understanding each others' needs and responding to those needs in the mutual interests of both parties – specifically in the field of audio preservation and restoration.

Who made up the committee? There were archivists from the United States, from Canada and from Europe, plus a fairly good cross-

section of hardware manufacturers, magnetic tape manufacturers, some recording industry representatives, and of course a few interested individuals.

The first thing we did, besides putting together all these grand and glorious statements of functions and goals, was to decide whether the AES is a proper form for the committee to exist in. That was pretty well determined, and the AES basic standards committee that we report to agreed that it was a good form, and so we kept meeting.

The archivists put together a list of basic system and media needs so that manufacturers like myself could have a better idea of what they were looking for. A basic system should:

- be self-documenting,
- be capable of having some sort of a diagnostic system or signal on it so that you can determine whether you've lost any signal, whether aging is occurring and is damaging your information material,
- have an automatic calibration for record and play so that you're sure that it's set up correctly,
- have a sound carrier that doesn't deteriorate with wear and use,
- be clonable, so that you can make an exact copy,
- have a shelf life that is predictable both in the package that you have the information on and in the signal itself,
- have a function for automatic, unattended copying capable of high speeds,
- have a built-in and irreversible system to prevent re-recording
- be keyable to be able to restrict record playback process,
- be storable in the same environment as your normal use and living conditions – the Kennedy library storing photographic film at 0°C is a nice idea, but it obviously had some complications, and you wouldn't do it if you didn't have to,
- be space-conservative without sound compression; in other words, you don't want to compress an hour's worth of recording on to ten minutes' worth of tape unless you can to it without degrading the sound and affecting the original,
- be fire-resistant,
- be non-toxic,
- be halogen-resistant,
- be a standard interface or have a standard interface for networking in exchange of information,
- have random access,

William Storm:
I'd like you to bear in mind that, when Del mentioned analogue versus digital, under no circumstances is the AES group saying that one is superior to the other. This was a management decision: it's a case of when do you make a change to something and how do you do it in a logical manner that allows you to say, 'I may get an opportunity once in my lifetime to make the transfer. So when I'm ready to leap, I want to leap with the consensus of a group who's really sat down and thought about this.' So please do not take it as an anti-digital stance. If anything, I suspect that this audience will stress the technology to a greater degree than anyone else, because of our goals of permanence. Now I'd like to open up the floor to questions.

George Brock-Nannestad:
I'm in a way being the devil's advocate, but I want to know to what degree I am the devil's advocate. I'm the advocate of the small archive, the very poorly funded archive. I would like to know why the compact cassette analogue recording slow-speed plastic is not an archival medium or a back-up medium. We hear all the time that it should not be, but the arguments have not been convincing and I wonder if we'll ever find a complete report saying why it cannot be used or, if it can be used, under what circumstances? Because there is a lot of it out there, and by now it has age to speak for it.

Del Eilers:
That's a good question. I don't think there's an archive that doesn't use compact cassettes in some form or other. The basic reason comes down to

- be a universal medium that can be used for audio, video or data,
- not have a laminated carrier – thus avoiding the 'potato chip' effect already mentioned,
- be able to be copied forwards or backwards – an interesting idea, and again it saves on time,
- have a minimum life expectancy of 50 years.

If you look at this list, you have to acknowledge that no current archival medium for sound fits all those needs. So after we had listed them all and said, 'This is crazy!' we went back to the basics and agreed on some basic criteria for medium, format, and equipment to be used.

Firstly, for archival storage of sound, you should use equipment that meets professional audio needs: a professional medium, and professional recording equipment. You should be using something that is standardized by a national standards organization; a non-standard system might not be reproducible, because it isn't documented any more. Recording reproduction of the system in the medium should be possible in an archival setting. Lastly, you should be using a system or medium that has proved to be reliable – one of the reasons that more progress has been made on standards for photographic film is that it has been around much longer than magnetic recording has. The committee agreed to review this list, and any archival system that a manufacturer might want to propose, and agreed that that could be one of our additional functions.

There was a great deal of discussion, but the basic upshot of the whole first committee was to say that recommended practice for you today is to use a professional analogue reel-to-reel magnetic tape recorder – that's the closest to meeting your needs. The problem with most of the digital systems is proven reliability; could you rebuild the boxes in later years?

That's quite a bit to accomplish in one meeting, and was a good start.

The second meeting

Now when you get in to standards committee work, one of the things you find out is that the same people don't show up for each meeting, and sometimes you have to re-plough old ground. So when we had the second AES committee meeting the following year, we re-hashed some of these issues, but the key result was to get some working groups established. The list of working groups is much the same as in the ANSI committee mentioned by Peter Adelstein. We have a working group on each of the following:

- definitions,
- tape storage and handling,
- acoustic environment and monitoring,

- tape documentation – maybe giving some suggestion on recommended practices on how you keep track of what's on there, what you put on the box,
- compact disc testing,
- playback systems,
- digital formats for archival consideration.

Once we'd agreed to those splits and breakdowns, we went home to start building some basic documents – something on paper that we could start working with.

The third meeting

The third meeting took place last autumn, and the first thing we decided was not to change our stand on digital versus analogue. If you really have to find out where tracks are, you can move heads up and down, you can do all sorts of things. You can pretty well get the same information off an analogue recording, that you can off a digital. We spent a lot of time going through the preliminary documents that had been started: documents on minimum recording standards, on tape recording and handling recommendations, and so on. We also had a tutorial on the acoustic environments and monitoring and how you measure those. Basically the net result was to say, 'This is a good start, keep writing!'

The last thing that we did at that meeting was to make everybody aware of what other groups and organizations are trying to do in the field of preservation and restoration.

Conclusion

In many respects we're just getting started. We're nowhere near where we'd like to be; we're not able to say, 'Here's AES standard 6.3,' or whatever. Meeting only once a year, it will take a number of years to get there. But the key benefit of these meetings is that we do have some manufacturers talking to users talking to archivists – and hopefully listening to each other and finding out that, while archivists want to have permanent magnetic recordings, magnetic tape manufacturers are thinking that's not possible. Hopefully we can find a practical answer in the middle somewhere.

copyability, and so on. You're starting off with such a poor signal-to-noise ratio, such poor limitations on things like modulation noise, that before you go down many generations, you may have a signal that is not very good. It's an excellent medium for collection of material, because there are so many devices available at a reasonable cost. It's an excellent medium for giving to people to make exchanges or to study with so that they don't have to get their hands on the original archive material. But it uses very thin tape; most of the tape is tensilized base tape which is more heat sensitive than the kinds that are used on reel-to-reel professional tapes. And you're starting with a much poorer signal-to-noise ratio, much more flutter, much more modulation noise. So if you really wanted to do it, you ought to start with a better system so that when you lose something you're less likely to risk as much. When you make a copy of a copy, you add the noise of the original to the copy. The same applies to flutter.

Michael Biel:
I want to back up what Bill said about digital. At the first of the AES meetings, I stressed my feeling that we need to have digital machines that don't crash the entire recording just because there's one tiny problem. Somebody mentioned earlier this morning about not being able to read an entire disc because something was wrong with the index of the head. We need to have machines that can bypass such problems and, if there is a scratch in the audio portion, don't mute the signal but give us what is there so we can retrieve it, just as we can retrieve it – not perfectly –

when we have a damaged analogue signal. With digital, the machines that are being made now are all or nothing, and that's one of the things that the manufacturers will have to overcome.

I also have a question. At that first meeting we were trying to identify things that the archival community could suggest in the way of an actual product requirement of the manufacturers. I think our archives need analogue tape recorders with absolutely no stationary guides whatsoever; the only stationary thing that the tape passes over is the playback head that you are playing the tape back on. Has there been any work by the manufacturers to design machines like that?

Del Eilers:
Not that I'm aware of, but I'm not a recorder manufacturer. It's hard to say how much enquiry the recorder manufacturers get for machines that are specifically tuned to the archivists' needs. I think a couple of them did hear some interesting things at those AES meetings, but I don't know if they're acting on them.

The digital recording systems all use a significant amount of error correction, whether it be audio or video; they reconstruct data where individual blocks are obviously bad, based on correction systems that they use. But they all have their Achilles heel. I recall seeing a demonstration of a professional one-inch 32-channel digital recorder in which someone took a paper punch and punched three quarter-inch holes diagonally across the one-inch width, played it back, and it sounded great. On that particular format, if the three holes had been laid out in a different way, they would mute it, because of the way the data format is laid out and the blocks are reconstructed. So it all gets pretty complicated.

Kurt Degeller:
I would like to know if this subcommittee couldn't meet once at the European AES meetings, not only because of our travelling budgets, but also because there is a real problem of communication. I knew at the Montreal AES meeting that Nagra Kudelski in Switzerland is developing a long-term storage medium for sound and images, and Kudelski doesn't know anything about this subcommittee. I think it's a pity that we can't resolve this little communication problem through the AES channel as well.

Del Eilers:
That's a good criticism. The AES should be publishing their minutes; I'm not sure whether they are or not.

William Storm:
At the last meeting the AES had in New York, it was brought to their attention that, if any society is really serious about trying to establish standards, then it should help sponsor those activities. Not everybody involved in standards activities has the budget to keep up the communication and, as Peter Adelstein pointed out at our ANSI meeting, the only effective way of establishing standards is face to face. It's not something you achieve through correspondence. So in front of the AES right now there is a proposal to seek some funding so that these activities can occur on a global basis. It's supposed to be a global Society, so we're going to put it to the test.

Del Eilers:
Returning to Dr Kudelski – he has apparently been working with the standards committee of the EBU, which was trying to put together what should be the digital audio format for the European broadcasters. He's been trying to slow them down so that they don't standardize on R-DAT and might look at his format. I don't know how successful he's been.

William Storm:
Any other questions? Peter, perhaps you could extend an invitation for participants, thinking of some of the needs we have at ANSI?

Peter Adelstein:
I assume you're referring to the work on the magnetics and optical disc. We need more representatives, particularly hardware manufacturers. If you noticed, in the set up of the five task groups in magnetics and optical disc, we talked about systems, not about media. So we need to have representation from people who are involved in systems as well. Many manufacturers have not responded to our invitation to join us. They have done this at their own risk, because documents are going to be written, and we will lose because they won't have the benefit of manufacturers' input, and they will lose because they won't have any input themselves to what has been printed. So if you have any interest at all, please let me or Bill Storm know.

Session 5:
The Practice of Signal Carrier Restoration

Chairman: Dietrich Schüller

The Uses and Dangers of Solvents in Film Archives

Harald Brandes

Dietrich Schüller:
Our first speaker is Harald Brandes, who comes from the German Bundesarchiv in Koblenz, where he is responsible for all technical matters in the archive. Harald gives an overview of the uses and dangers of solvents in film archives.

Different solvents have to be used in the treatment of films, but solvents and their vapours are detrimental to health to varying extents. Unfortunately handling of these solvents does not always take account of the inherent danger, and they are often used without necessary care, especially where solvents are used to clean film manually. This problem will now be discussed briefly, and a report and explanation will be given on the procedures used to measure and survey the concentration of vapour in the air.

A certain concentration of these vapours of solvents is legally permissible, and the permitted legal concentrations differ in different national regulations. This paper concentrates on the regulations in force in the Federal Republic of Germany.

The level of solvent in the air of a laboratory or other working area is indicated in ml/m^3. For individual chemicals there are detailed regulations for the use and handling of solvents.

Freon TR-E is used for cleaning film either manually or by machine. Concentrations up to 10,000 ml/m^3 are permissible. But Freon leads to the destruction of the ozone layer. The vapours of Freon in contact with an open flame might change in character and become highly dangerous decomposition products such as chlorine, fluorine and phosgene.

Acetone is an essential element in film cements and is also used for film polishing in larger quantities. Concentrations of 1000 ml/m^3 are permissible. If acetone is not handled with care and gets into the eyes, severe damage to the cornea may result. Acetone and vapours of acetone, which are heavier than air, are extremely inflammable. If the concentration exceeds 2.5–13 volume percent, then these vapours might explode. And of course most of these chemicals should not be touched unless special gloves are worn.

1.1.1.Trichloroethane (CH_3-CCl_3) is used for film cleaning but also is an admixture for wet print purposes. The permissible quantity of this chemical in the inhaled air is 200 ml/m^3. The storage of foods in rooms in which Trichlor is used should be forbidden. In the event of fire, only trained and qualified specialists from the fire brigade should operate in areas in which this chemical is stored.

Tetrachloroethene ($ClC_2C=CC_{12}$) is used for wet printing, either as a pure chemical or as an admixture. It is very hazardous to health, and only 50 ml/m^3 in the air is permissible. Pregnant women should never be in contact with this chemical, because a negative influence on the unborn child cannot be excluded. Tetrachloroethene might also have a negative impact on the central nervous system, the liver and the kidneys. The danger of cancer cannot be excluded. If a

laboratory is obliged to use this chemical, the permissible level must be kept as low as possible.

Trichloroethene ($CHCl{=}CCl_2$) (Trichlorethen), is used for the floating test to identify safety and nitrate film and for this 50 ml/m³ is permissible. Pregnant women should never be in contact with this chemical, because of the negative influence on the unborn child. Trichloroethene is extremely dangerous in water, and must never be allowed to get into the ground water. In the event of fire, only trained and qualified specialists from the fire brigade should be allowed to operate in areas in which this chemical is used or stored.

Methanol (Spiritus) is used for manual film cleaning. It is comparatively safe: the only problem is that it can easily catch fire.

The air in working areas can be controlled with special test control units, which include test tubes for the various chemicals, which change colour according to the amount of that particular chemical in the air. There is a difference between test control units for short-term tests and those for long-term tests, which last several hours. To avoid health problems for people working in film archives, such test units should be used. If staff members are exposed to high concentrations of solvents in the inhaled air, severe health problems, including cancer, are possible.

People should be exposed to only very low levels of these chemicals. The legally permissible concentrations should never be exceeded, but as far as possible concentrations should be kept to a minimum. This can be controlled by an exchange of air in the working areas and by the installation of separate suction plants at single working stations. Machines in which solvents are used have to be equipped with effective suction plants.

Klaus Hendriks:
Those people who are not from Canada may be interested to know that the Canadian Federal government has provided legislation that requires manufacturers of chemicals to provide that same information, and it is known as Material Safety Data Sheets (MSTS). So any time you buy a chemical, the manufacturer is obliged to give you along with the product these data sheets that inform you about the various potential dangers.

Harald Brandes:
Yes, there is the same regulation in Germany, but very often you have to ask for these papers from the producer or from the company.

The chemicals mentioned might also pollute the environment. The vapours of solvents in the outgoing air should always be cleaned and extracted. The simplest way to achieve this goal is to use activated carbon filters, which have to be recharged from time to time. The legal regulations for the cleaning of the outgoing air will become stricter in the future.

If chemicals are accidently spilled, they should be absorbed with special binders to prevent unnecessary percolation or evaporation.

In addition, one has to be careful when handling safety film that shows signs of deterioration. The evaporating acetic acid is hazardous to health even in small quantities, and only 50 ml/m³ permissible. The same applies to the deterioration products of nitrate film, which have to be controlled because the chemicals involved are also health hazards. Two different vapours from decomposition products can be controlled: nitric acid vapour, where 10 ml/m³ is permissible, and nitrogen dioxide, where 5 ml/m³ is permissible.

A final word: whenever there is a need to use a new chemical for film handling or other uses in your archive, check very carefully whether or not the product is harmful – dangerous for people or, of course, for your collection.

The Effects of Temperature and Humidity on Motion Picture Film

Henning Schou and Mark Nizett

Introduction

This is a preliminary report on a research project that we are currently undertaking at the National Film and Sound Archive in Canberra. Unfortunately, many of the results and conclusions are still to come.

All modern photographic materials, including cinematographic film, carry the image in an emulsion layer composed primarily of gelatine. This protein reacts quickly with water to cause gross swelling, and may eventually totally dissolve.

The problems

The major problems associated with movie film being exposed to excessive amounts of moisture for long periods of time include mould growth, ferrotyping, adhesion, emulsion lift and vinegar syndrome.

Vinegar syndrome

Besides the strong smell of acetic acid, the vinegar syndrome is characterized by a limpness of the base, a grey crystalline deposit of plasticizer on the surface, also some fading of the image and in some cases a complete softening of the photographic emulsion to a degree that results in the layers sticking together.

Mould

Gelatine is an ideal food for microorganisms. If the relative humidity of the film storage environment is allowed to rise above 60% even for short periods of time one may expect mould growth to occur. It is impossible to exclude or eliminate the tens of millions of mould spores found in our environment, and the only safe way of preventing their growth is to ensure that they have insufficient moisture to germinate. The growth of mould has a number of detrimental effects on the emulsion of archival film. The organism itself marks the emulsion, making the viewing or copying of the film inferior. In addition the mould actually consumes the gelatine in the emulsion, thus destroying the image. Waste products of the mould's metabolic processes cause staining and further damage to the film. Finally, the mould has the effect of increasing the solubility of the gelatine, making normal water-based treatments for the cleaning of films dangerous and often impossible.

Ferrotyping

Another type of blemish is called ferrotyping. On a microscopic scale, the normal emulsion surfaces of a film is relatively rough,

Dietrich Schüller:
Our next speaker is Henning Schou who, together with co-author Mark Nizett, will present a paper on the effects of temperature and humidity on motion picture films. Henning Schou is head of film video and sound preservation and technical service at the National Film and Sound Archive in Canberra, Australia. He's president of the Preservation Commission of FIAF, which carries out research and publishes guidelines and recommendations on all aspects of motion picture preservation. Dr Schou has undertaken research on deterioration of colour dyes and film stocks and on the decomposition of cellulose nitrate film – two of the major problems facing film archives world-wide. He's edited and written numerous patents, technical texts, papers, etc, and has published in journals such as the Journal of the Motion Picture Society. Dr Schou is also a film buff and an expert in film animation.

being composed of a number of hills and valleys. This gives the emulsion a matte appearance. Ferrotyping is the name given to the process of leveling this micro-relief to form a flat shiny plateau. It corresponds a bit to the way you make a glossy photograph: after you've processed the paper photograph, you turn it emulsion-down on to a highly polished stainless steel plate which is heated, and this gives the gelatine layer a glossy surface. With movie film, ferrotyping occurs when tightly wound reels become wet or very humid, which causes the emulsion to swell. This is then compressed against the neighbouring layer of the film base and becomes very smooth. If allowed to remain for too long, this process may prove irreversible.

Adhesion

This is an even more serious problem because, when the gelatine is moist, it is capable of becoming a very efficient adhesive. Animal skin glues, used for many centuries, are an impure form of gelatine adhesive. With moist film there's always a risk that the emulsion will stick to whatever it is in contact with. So, in the case of tightly wound reels of film, the emulsion will often adhere to the layer of film base it is wound against. If allowed to set, the separation and unrolling of the reel will prove extremely difficult and may eventually become impossible. The action of trying to force apart the adhesive emulsion layer and the overlaying film base may tear or destroy the emulsion.

The destruction of the emulsion layer may take a number of forms depending upon the tenacity of the adhesion. In its mildest form, only the upper surface of the emulsion is ribbed and roughened. To the naked eye, it appears as a white powdery coating on the film's surface. The resulting increase in surface area makes the film susceptible to many other forces of deterioration such as mould growth, and the image is susceptible to oxidation. In addition this roughening has the effect of absorbing the light, making the viewing or copying of the film unsatisfactory, as dark patches will be seen where this deterioration occurs.

The most serious adhesion problem is when the bond between emulsion and base is so strong that any attempt to separate the two results in the tearing and removal of the dye layers from the film.

Of course, once we've lifted the dye layer from the film, this is totally irreversible, and results in the complete destruction of that part of the film.

If this kind of emulsion lift is extensive throughout the reel, the entire footage on the reel will be lost. Gelatine emulsions sometimes appear to have memory, and often try to regain the form they were given during manufacture. If moist emulsions are attended to soon enough, it may be possible to reverse most of the deterioration. The situation becomes increasingly dangerous the longer the deformed emulsions are allowed to retain or to remain unattended. After a while in their swollen or adhesive state, they might lose their original memories and remember only their new-found state. As this occurs, the deformation and deterioration of the emulsion becomes increasingly irreversible.

Let's now look at some of the treatments that we tried. We carried out a series of tests to determine the extent of the damage to the

film stock, and possible treatments to reverse these problems. As previously mentioned, the deterioration may be broken into two types: mould growth and problems associated with the swelling of the gelatine emulsion.

Treatment of swelling and adhesion problems

As many films are routinely cleaned in a solution of 1,1,1-trichloroethane in an ultrasonic bath, we assessed the use of this solvent in the removal of those problems caused by adhesion. Other organic solvents such as ethanol and methanol were also used. As anticipated, this had no effect in the reduction of these defects. Because the problem originated from excessive moisture and the consequent swelling of the gelatine emulsion, the use of non-aqueous solution was not expected to be effective anyway.

Water was applied with a cotton swab to areas of ferrotyping to try to swell the emulsion and counteract the deterioration effect. After the emulsion had dried, these areas appeared to have been successfully treated.

Further tests conducted with a solution of water and a wetting agent (we used Kodak Photoflow) proved equally promising. I should perhaps add that the additional wetting agent ensures even drying of the film; that was the only reason for adding the surfactant.

One of our concerns with the removal of these defects is whether they may also be effectively removed after the film has dried completely. Do we need to act while it's still moist? It has been observed with still negatives and with photographic prints that, once certain forms of deterioration are allowed to dry in the emulsion and set, they become increasingly difficult to remove. So samples of film exhibiting ferrotyping were air-dried at room temperature, air-dried at elevated temperatures (40°C) and also dried in a solvent (1,1,1-trichloroethane). The aqueous treatment described above was successful in removing the ferrotyping from all the samples. So the drying had not caused any irreversible effect – we could still remove the ferrotyping and the emulsion lift.

In anticipation of the necessity to automate the cleaning and conservation process, possibly through a converted film processor, we established the minimum immersion time for effective treatment: two to three seconds at room temperature. Similar tests were carried out on the other emulsion defects of frilling and lifting. (Frilling is where the adhesion is such that the surface of the gelatine is just roughened.) These also appeared to be reversible in water and wetting agent solution in a spot test situation.

Having established that ordinary solutions of water and wetting agent were capable of reversing these forms of deterioration in a laboratory test situation, our concerns shifted to the effect such treatment would have on the long-term stability of the film base and the dye stuffs – whether it would introduce any vinegar syndrome or fading of the colour dyes. We anticipated that a converted film processor would be employed to clean and conserve the affected films and, as a consequence, the film would be subjected to aqueous solutions for at least ten to fifteen minutes.

Tulsi Ram:
Have you tried ethylene oxide treatment for moving the spores instead of gamma radiation?

Henning Schou:
We would have liked to do that, but the only chamber available in Canberra is the Australian War Memorial Archive, and after two years they still haven't managed to make it work. But that is one thing that we are going to try.

Tulsi Ram:
It's a very innocuous media, and they say it's pretty good for stabilizing and removing spores. It will still leave tracks in the gelatine emulsion.

Also, when you use washing treatment to eliminate ferrotyping swelling by adding borax and sodium sulphite and all that, you may be also removing some of the vinegar syndrome in the acetate support and your developing agent. It may be that it could be useful to incorporate a mild alkaline material in your washing procedure.

Henning Schou:
Thank you very much for that suggestion. That thought has occurred to me but, of course, if the vinegar syndrome has started the decomposition, then you would have the acetic acid not only on the surface of the film but also internally, where the water can't reach. So I wouldn't imagine it would stop the decomposition. We would certainly also remove any residual chemicals in the emulsion by re-washing.

Tulsi Ram:
It's better to check a small piece of sample before you wet it because, if degradation has progressed far enough to

This raised the concern that such long wet times might cause the gelatine to soften excessively, and that the stability of the dyes might be compromised. In addition it was possible that badly damaged portions of the emulsion might dissolve or be lost in the processor. The last thing you want it to get a clear piece of film out from your processor, and it gives you a very cold feeling down your spine when you see your precious film emulsion floating around in the processor. Although new emulsions are designed to be processed for long periods of time, sometimes even at elevated temperatures, when gelatine begins to age it becomes less tolerant and more susceptible to water damage.

We explored the use of a cross-linking agent (actually an emulsion hardening agent, like formaldehyde) to determine whether this would decrease the likelihood of damage in the processor and whether it would assist in increasing the stability of damaged film. We also conducted a test to determine whether the use of formaldehyde would adversely affect the stability of the dyes. Samples from four different types of film stock were each washed in one of three different washing solutions. Transmission densities were recorded for areas of maximum and minimum densities, and readings for red, green and blue were taken from the maximum density areas. These readings were taken before and after washing, and at regular intervals after accelerated aging – and here we settled for an environment of 75°C and 60% relative humidity. The result showed no obvious effect from the presence of formaldehyde.

From the above tests, we established that moist rolls of movie film exhibiting emulsion, swelling and adhesion problems could be dried either by manual winding, or by drying through a processor's drying cabinet, or by cleaning and drying through mixtures of organic solvents though with a danger of causing these problems with gelatine to become irreversible. However, under different or natural long-term drying, these problems may become more difficult to reverse. In addition, we decided that the use of formaldehyde would be permitted if we believed that the emulsion was sufficiently unstable to warrant it.

Following the laboratory spot tests a film processor was modified so that a whole roll of affected film could be cleaned, and the effectiveness of this mass treatment assessed. After passing through an initial bath, followed by immersion in water and a spray rinse, the film was wet for a total of 14 minutes before entering the drying chamber. Four different initial baths were used to determine whether one had an advantage over the other; the aim was that these baths would give a different degree of swelling of the gelatine.

The two first baths we used were water at room temperature (20°C) and pH 7, and water at 28°C and pH 7 but with 5ml formaldehyde. The other three solutions were virtually the same temperature, but we increased the alkalinity and in the fourth test we increased the temperature to 30°C. All that was to try to make the gelatine swell even more. That's exactly what Dr Hendricks' 'swellometer' would be able to do, to determine the swelling of the gelatine. As we make the emulsion more alkaline, the swelling is increased. You might then ask me, why increase the swelling? Well the test showed that all of the solutions were equally successful in removing emulsion defects in both positive and negative stock. But the blemishes on

hardened colour-reversed intermediate stock (what we call CRI) were not so easily removed. That's a kind of reversal negative film stock that has been processed at a higher temperature, and for that reason needs a pre-hardening bath before it can go through the other bath in the processor. So you end up with a fairly hardened emulsion, and we had trouble removing any blemishes from it.

As I mentioned, the fourth solution was the same as the third, except that the temperature has been raised in an attempt to assist in the removal of the ferrotyping, of hardened emulsion, and that's also the reason we increased the alkalinity. Although many of the defects were reduced to some extent on hardened stock, the ferrotyping has so far been impossible to remove completely.

Treatment of mould

A few words about mould: in addition to the above problems associated with motion picture films stored in high humidities, the problem of excessive and uncontrolled mould growth must be addressed.

As previously mentioned, mould has the capacity to destroy film stock in a number of ways, including digestion of the emulsion and staining of the gelatine and dye layers. Given the right environmental conditions, mould may rapidly multiply, posing a danger to adjacent films and to workers handling the material. In a situation where film has been flooded and where storage humidities are extremely high, there there's every likelihood that a great deal of film has been contaminated, and all of it needs immediate action.

We decided to investigate the use of gamma radiation as a means of effectively killing mould spores found in these situations to protect the health of the workers and to provide more time to clean the infected film. You really have a dilemma if you have a significant amount of film: if you leave it moist, then you know the mould will grow like anything; if you start drying it out, you run the risk that the convolutions will adhere and you will never be able to separate the film again to unwind it. With the use of large commercial food irradiation chambers, many millions of feet can be sterilized in a short time. We irradiated samples of cellulose triacetate film with actually 1.2 million rads, and also at 0.6, 0.3 and 0.15 million rads. This is much more than you need to actually kill off bacteria and fungus on the surface, but we wanted to know whether subjecting the film to that amount of energy would initiate breakdown of the film base and also fade the colours. Changes in the dye density and the pH of the base will be recorded after periods of accelerated aging at 90°C and 100% relative humidity, and we hope to have these results soon.

Other research is being carried out to explain an interesting observation we've made: spores of penicillium and aspergillus taken from various cans of contaminated film were cultured for positive identification and we observed that, of the estimated one hundred million spores sampled, only two were alive. Such an extremely small number of live spores is so far unexplained, and we're researching to find out what might have caused this odd phenomenon. The acetic acid and other deterioration products that *initiate delamination, then it may not be worthwhile proceeding. But you should be able to arrest the initial stages of degradation.*

Henning Schou:
Yes, we do a lot of spot tests before we send the whole reel through the processor.

George Brock-Nannestad:
I'm not from the film field... I can understand ferrotyping being a problem as long as you have the layers still together, because of the high compression and possible delamination and so on. But what if you unwind it? As far as I could see ferrotyping is a sort of polishing of the emulsion surface. Is it impractical to have it like that if you have separated the surfaces? Is the phenomenon itself bad? Do you always want to have a matte surface on the emulsion side?

Henning Schou:
If the ferrotyping is so extensive that you have ferrotyped the entire surface of the film, then there shouldn't be a problem. But it's the fact that you go from a matte to a glossy surface that causes problems in printing. But let me add that ferrotyping is not really a problem; it's not a deterioration, it's what I would call a blemish because you can still make beautiful copies from ferrotype film by using the wet gate technique.

Bill O'Farrell:
My senior conservator Dennis Waugh wants me to say that, since 1978, at the National Archives of Canada we've been using a re-wash treatment very similar to what you're describing. We used it to retrieve and stabilize the Dawson collection that some

of you may have heard of. Most of those films are still quite stable today; most of the reels that were re-washed have not deteriorated, and these were found underground and were subject to cyclical freezing and thawing for many years up in Dawson.

Because the treatment was so successful back in 1978, we now use it as a regular conservation treatment when the situation calls for it. It tends to be a treatment of last resort, though, when you've got a film resembling a hockey puck, for example. We found that it does eliminate the ferrotyping and the mould growth. In fact we've started to stock up vinegar-syndrome material and plan to re-wash it to try and stabilize it. Also we did a video last year for the FATOX conference describing the process, and if anyone would like to see that video they should talk either to me or to Dennis Waugh.

Henning Schou:
They were all black-and-white films, weren't they?

Bill O'Farrell:
Yes, black-and-white.

Henning Schou:
It wasn't colour. For black-and-white there's a very good formula in the Kodak Book of Film Care, where you have a very high concentration of salt in the first bath to prevent any swelling, and there's also a certain amount of formaldehyde in the solution. But it takes a while for the formaldehyde to act. So to avoid running the risk of losing your emulsion, you have very high ion strength in the first bath to prevent pre-swelling.

may be found within the can could possibly be responsible – so perhaps the vinegar syndrome has one good effect!

One of the deteriorating effects of mould can be found when the growth is removed. You might think it's just a matter of doing a bit of cosmetic treatment on the film and then removing the mould. But, once the mould has gone, you will see that it has left a nice footprint on your film. An interesting fern-like structure may be seen where the mould has digested the gelatine protein and left a series of tracks radiating out from the centre of the contamination.

These footprints interfere with the transmission density of the film, and are difficult to remove by washing. It's possible to use water to swill the emulsion of normal positive and negative film stocks to reduce the effect of this fern-like growth. However, this treatment has little effect on some of the hardened gelatine emulsions that we found in the CRI stock.

I'd just like to say a few things about the research we intend to within the next six weeks or so. The investigations are continuing to determine the minimum dose of radiation required to kill the two commonly occurring species, penicillium and aspergillus, and whether the radiation has any adverse effect on the film base and the dye layers of the film. We're also determining the bacteriocidal effect of the cleaning agent and acetic acid against the two types of bacteria. We're investigating and researching other ways of removing the footprints of bacteria and mould. These results and the results of further dye-stability tests conducted after the re-washing of film should be available in a few weeks' time.

Finally, I'd just like to roll the credits and thank my co-author Mark Nizette. Later on with the research into the killing of the bacteria, we had the assistance of microbiologist Dr Arnold Mulbacha from the Australian National University, and I'd also like to mention that the vinegar syndrome slides were courtesy of Tony Cook from the National Film Archive in London.

Fungal and Bacterial Attack on Motion Picture Film

Vladimir Opela

Introduction

Three years ago in Berlin I made a reference to the fact that we have been researching and monitoring the occurrence of micro-organisms in archive depositories for several years. The research programme, which took place between 1984 and 1988, was completed in 1989, and this paper will introduce some of the conclusions. The research was carried out by Dr Fassatiová, Dr Svobodová and Dr Konopásek of the Charles University in Prague. The research concentrated on several fundamental questions:

- quantitative occurrence of microorganisms in storage depot air,
- the extent of surface contamination of film-reel cans, floor, walls,
- seasonal fluctuations in microorganism levels,
- qualitative analysis of the microorganisms collected from both depositories.

Characteristics of the depositories

Hradištko is the depository for safety film stock material. The building is without air-conditioning and it is possible to regulate the relative humidity of the air. During the course of the year the temperature ranges gradually from 0°C to 18°C, and the relative humidity fluctuates between 50% and 75%. Structurally, the depository is in a good state and is divided into five sections of the following dimensions:

length	width	height	volume
14.7m	12m	5.0m	882m^3
14.7m	12m	5.0m	882m^3
19.8m	12m	5.0m	1188m^3
19.8m	12m	5.0m	1188m^3
24.0m	12m	4.5m	1296m^3

The base of the first floor is made from metal grating, which joins this storey with the ground floor. The depository has a capacity for 200,000 film-reel cases holding 600 metres of film, and 85% of this space is filled. In-going and out-going film material totals about 3000 cans a week.

Trebsín is the depository for highly inflammable film material. During the initial stages of the research in 1984, the depository was in an entirely unsuitable state: in five sectors more than 150 tonnes of film material was being stored – 15 to 40 tonnes in each sector –

and some of the material was being stored on the first floor. In the continually damp storage rooms, there was a build up of micromycetes, especially in the cellar areas. During 1984 and 1985, the reconstruction of the depository was carried out by the Film Archive itself: 14 cells with dimensions of 3.95m (length) x 1.35m (width) x 2.6m height = volume 13.9m^3, plus 8 cells with dimension of 4.25 (length) x 1.7 (width) x 2.6m (height) = volume 18.8m^3.

Other pipes for air conditioning were installed. The capacity of the depository is now 16,000 cans holding 300 metres of film, and 7000 cans holding 600 metres of film. The depository is overcrowded. In-going and out-going film material is about 100 cans a week. The temperature during the year ranges from 0–18°C, the relative humidity after reconstruction is maintained at 50–70%. The installation of the air-conditioning is now being completed.

In order to collect microorganism samples, standard microbiological techniques were used: petri-dish collection, filtration of the air, and replica plating. Czapek-Dox agar with saccharides was used as the optimum growth medium. In Hradištko the collections were taken regularly in 9 places over a period of 5 years; in Trebsín they were taken in 3 places. The moulds were isolated and systematically classified.

In all, 2000 petri-dish collections were carried out in Hradištko and 500 at Trebsín. The contamination of the surfaces of film cans, floors and walls was monitored by the replica plating method on 140 samples. In order to compare the spectrum of moulds found in the depositories with the micromycetes found in the vicinity of the archive buildings, 120 tests were carried out: 90 around Hradištko and 30 around Trebsín.

	Hradištko depository		**Trebsín depository**	
	mildew (fungi)	bacteria	mildew (fungi)	bacteria
1984	47	112	443	302
1985	64	36	749	31
1986	48	31	249	70
1987	53	23	196	7
1988	65	16	107	18

Table 1
Microbial contamination of the air at the Film Archives of Hradištko and Trebsín. Development of the situation after 5 years study. Values are taken as an average number occurring in 1 cubic metre of air space.

The results of the five-year study of air-contamination show that the incidence of micromycetes and bacteria in the well-maintained Hradištko depository was stable during the whole study period. The reconstruction of the Trebsín depot, from its original desolate state to a normal level, resulted in a fourfold drop in microbial contamination. In 1984 the number of micromycetes at Trebsín was 10 times greater than at Hradištko; in 1988 only 1.7 times higher.

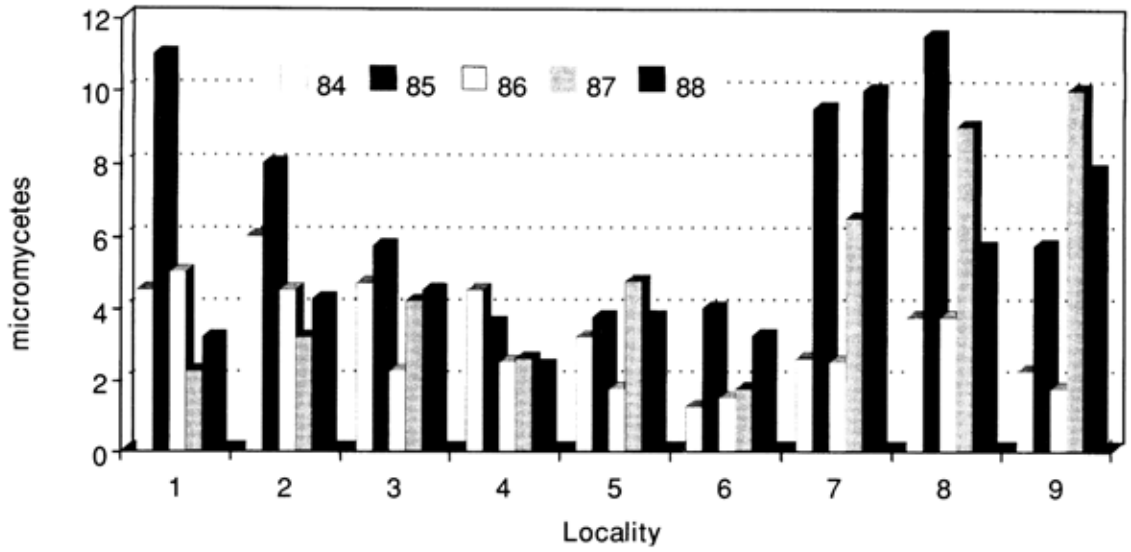


Figure 1
Hradištko depository: number of micromycetes spores in one location in one collection after one year.

Figure 1 shows the contamination of individual locations at the Hradištko depository. In 1985 the first two localities near to the entrance of the depository were contaminated from the outside. In 1987 it was established that there was a higher occurrence of micromycetes after the roof had been damaged in a storm.

Figure 2 shows the increase in microbial contamination during the reconstruction of the deposit in 1984 and 1985, and the substantial drop in the number of airborne microorganisms as a result of the improvements to the depository.

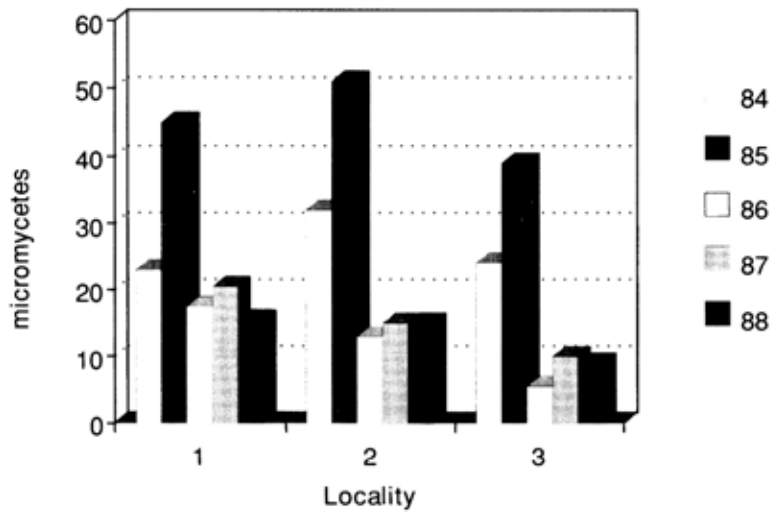


Figure 2
Trebsín depository: number of micromycetes spores in one location in one collection after one year.

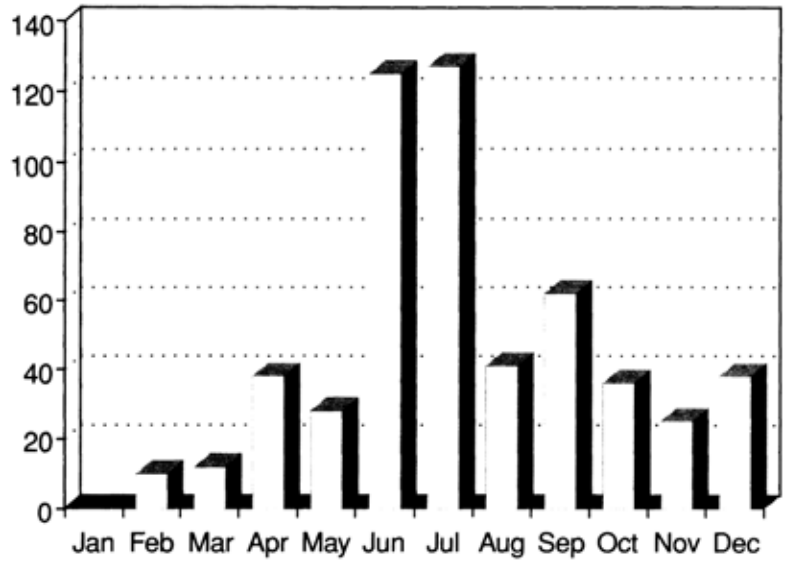


Figure 3
Hradištko depository: number of spores occurring in one collection after one month

Figure 3 shows that, at Hradištko, during the autumn, winter and spring seasons no substantial fluctuation of internal contamination is evident. Each summer, however, saw an extremely large fluctuation of micromycetes – a reflection of the situation outside the archives.

In the Trebsín depository (figure 4) during 1984 and 1985 the summer increase in the number of micromycetes was not so significant. A likely reason for this was the high level of internal contamination in the depository. The improved isolation of the depository from the external environment began to take effect, during 1986 and 1988.

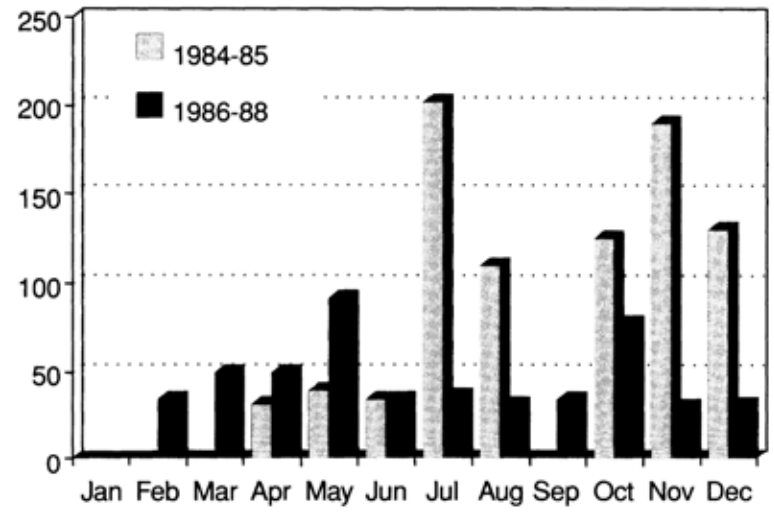


Figure 4
Trebsín depository: average number of spores occurring in one collection after one month

Mildew (fungi)		
Trebsín depository air	**Hradištko depository air**	**On the film**
Aspergillus versicolor (50%)	Aspergillus versicolor	x
Cladosporium cladosporioides (20%)	Cladosporium cladosporioides	x
Penicillium frequentens (10%)	Penicillium frequentens	x
Penicillium lanosocoeruleum (10%)	Penicillium lanosocoeruleum	
Penicillium citrinum	Penicillium citrinum	
Aspergillus repens	Aspergillus repens	
Botrytis cinerea	Botrytis cinerea	
Trichoderma viridiae	Trichoderma viridiae	x
Mucor spp	Mucor spp	x
Rhizopus spp	Rhizopus spp	
Epicoccum purpurascens	Epicoccum purpurascens	
Alternaria	Alternaria	
	Penicillium roquefortii	
	Penicillium lanosum	x

Table 2

Table 2 shows the types of moulds found in the Trebsín and Hradištko depositories and on our film materials. Most of the micromycetes contamination in the Trebsín depository was caused by the first four moulds (90%); this means that they have originated within the depository. The main sources of micromycetes in the Hradištko depository are those moulds carried in from the external environment as a result of unsuitable ventilation or on cans of film material.

The predominant occurrence in the depositories of the Penicillium and Aspergillus genuses corresponds to their ability to multiply in a poorly illuminated and draught-free environment and in drier conditions than exist outside the building. This can result in substantial damage of the film material. The species *Aspergillus versicolor* is known to be an opportunist pathogen that can lead to infection of open wounds.

Conclusion

The air at the depositories contains both fungal and bacterial spores that come to rest on the surfaces. Dust particles present in the air increase the danger of fungal attacks since they adsorb the fungal spores on to their surfaces, encouraging condensation and thus introducing material conducive to fungal growth.

The results of the study show that the number of microorganisms in the depository fluctuate between tens and hundreds per cubic metre and depend on:

- what state the depository is in,
- the flow of air within the depository,
- the flow of air into the depository from outside,
- personnel movement within the depository, and consequent air disturbances.

The incidence of microorganisms on the film cans is 1000 times higher than the airborne levels. The number of microorganisms on the floor is practically identical to that on the cans. A large dispersion was ascertained during collection from wall surfaces (2–500 colonies on one dish). The reason is patently the variety of dampness of the walls.

The regularly observed increase in the incidence of micromycetes in the depositories during the summer is a reflection of the situation outside the archive building.

A qualitative analysis revealed 15 genuses, the most prevalent being Aspergillus, Penicillium, Mucor, Rhizopus, Epicoccum, Alternaria; however numerous other types were found in insignificant quantities.

To minimize the danger of microbial attack on film materials stored in the depository, the following must be considered:

- Constant maintenance of low relative humidity of the air in the depository (below 65%) and low temperature (below 12°C), thus reducing the possibility of spore germination and growth.
- Eliminating the spores from the surface of film-reel cans, walls and floor at the depositories is impractical in view of the circulation of films and their constant state of contamination outside the archives. It is, however, possible to shut off the air current and prevent the influx of spores from outside and to limit the movement of personnel within the depository to a minimum, thus reducing the dispersal of spores.
- Maintenance of building with regular cleaning using various anti-fungal agents/chloramines, lactic acid, cresol, etc.
- The omnipresence of the spores, their ability to grow very rapidly during only a short spell of raised humidity even in air-conditioned depositories is a constant source of danger for film materials. Periodical examinations of these materials and regular scanning of the depositories (wall and floor surfaces) will ensure timely recognition of emerging danger, and thus prevent the destruction of film materials through microbial corrosion.

A Newly Constructed Cylinder Replay Machine for 2-inch Diameter Cylinders

Franz Lechleitner

Introduction

There are three different ways of playing back and re-recording the information on phonograph cylinders: the acoustical, the optical, and the electrical methods.

Acoustical

The acoustical method of playing the phonograph cylinders makes use of the equipment for which they were produced, or with which they were recorded. The sound is radiated by the replay horn and picked up by microphone. The microphone is placed either in the horn or at some distance from the replay machine in a suitable acoustically adjusted recording room. Re-recordings made by this method represent the aural impression of the contemporary listener. There are several shortcomings related to this type of re-recording. Nowadays it is not easy to find a suitable replay machine in good working condition. Replicas are extremely expensive, or simply impossible to produce. Moreover the uneven frequency response of the recording unit cannot be compensated for by the replay process. Generally, the non-linearities of the frequency response in the recording and replay chain are added to each other.

Optical

Several attempts have been made to replay cylinders by optical methods. In principle, they work like this: a laser beam focused on and reflected by the modulated groove delivers optical information that is subsequently transformed into the acoustical signal. The method is very complex, especially with regard to the control of the tracking mechanism. Such systems are still under development, and have not yet passed the experimental stage. The enormous advantage of such a system is the non-invasive, contactless pick-up of the signal. But digital processing of optically-retrieved signals is inevitable, because of the inherently low signal-to-noise ratio; this is much lower than with a mechanical or electrical playback method.

Electrical

The electrical method of playing cylinders is the most widely used. The groove information is picked up by a standard stereo pick-up cartridge, suitable pre-amplified, and recorded on a modern sound carrier. There are various possibilities for electrical re-recording, although there are only two basic methods: to adapt an original replay machine by replacing the replay sound box by a magnetic pick-up (a method widely used amongst amateurs), or to construct a new machine.

Dietrich Schüller:
We are moving now from film to sound, and I would like to call Franz Lechleitner. He graduated from technical university in Vienna and is chief technical engineer of Phonogrammarchiv where, besides his service and maintenance work, he has always been actively engaged in the preservation, the re-recording, of the holdings of the archive. Franz Lechleitner is a member of the Austrian branch of the Audio Engineering Society and of the IASA technical committee, and he also an active record collector.

Despite certain advantages, the first method has decisive shortcomings. Old cylinders are brittle, and often crack when placed too firmly under the mandrel that holds the cylinder, while they may come loose if they are mounted too delicately. Also, cylinders often exhibit vertical eccentricities due to poor manufacture or improper storage over long periods. Such cylinders are extremely difficult to replay with mandrel mounting. The needle position vis-à-vis the groove is random, normally pressing the stylus strongly to one groove wall or the other. Other disadvantages are mechanical vibration caused by the pick-up drive and, in the case of spring motor-driven machines, variable speeds.

Constructing a new machine

Several professional archivists have therefore made attempts at constructing new cylinder playback machines. A newly constructed machine should fulfil the following requirements:

- it should have a tolerant mounting mechanism for the cylinders,
- it should be free of mechanical interference,
- speed should be adjustable over a wide range,
- it should be capable of playing several groove pitches.

Based on the experiences of its first cylinder player, the Phonogrammarchiv of the Austrian Academy of Sciences has recently developed a second one.

The tone arm

This the most important part, but also the most difficult. A Rabco ST 7 carriage with a homemade short arm was used by their first cylinder player. The arm assembly was very expensive, and the

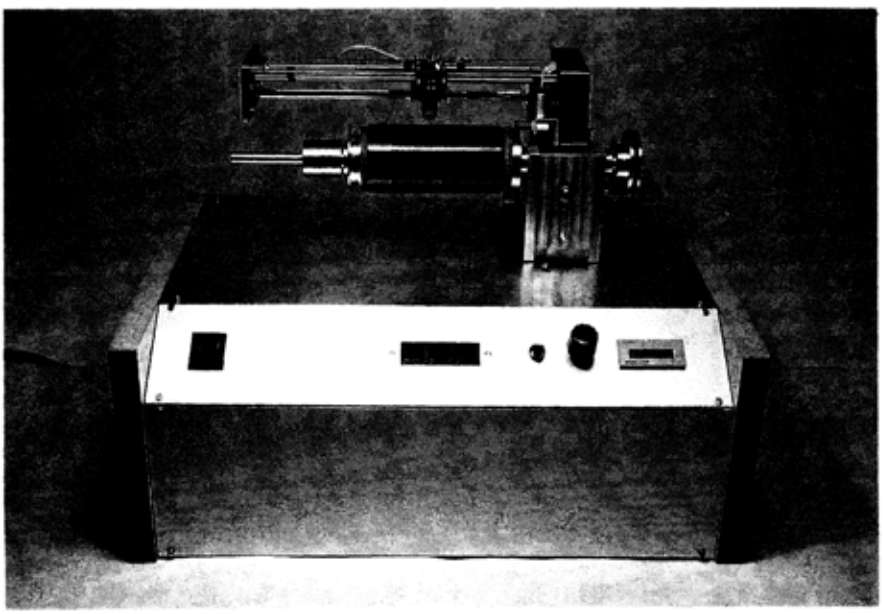


Figure 1
Cylinder replay machine

carriage is no longer available. Hearing favourable reports on the performance of the Revox Linatrack tangential tone arm, we decided to use that. The original tracking length, just enough to play two-inch standard cylinders, was lengthened by more than two and a half inches to cover the groove length of all common cylinder sizes. The solution to this problem was very simple: the original tracking rods were removed and replaced by longer ones.

The whole arm assembly can rotate through 90° in either direction, a useful feature enabling cylinders to be moved on and off without any risk of damage to the stylus. The arm is very short: it consists of the headshell only, causing no inertia problems. The arm electronics feature fast forward and backward, as well as up-and-down movement, simply by pushing three buttons.

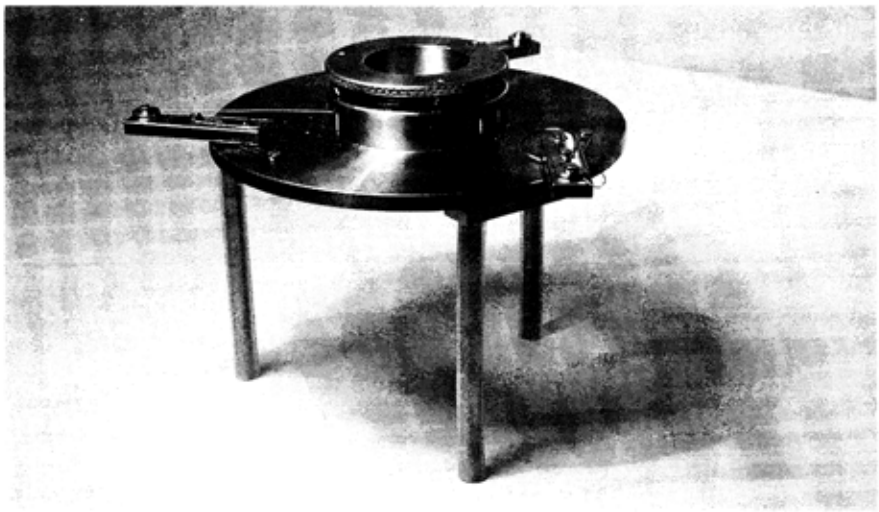


Figure 2a
Centring device

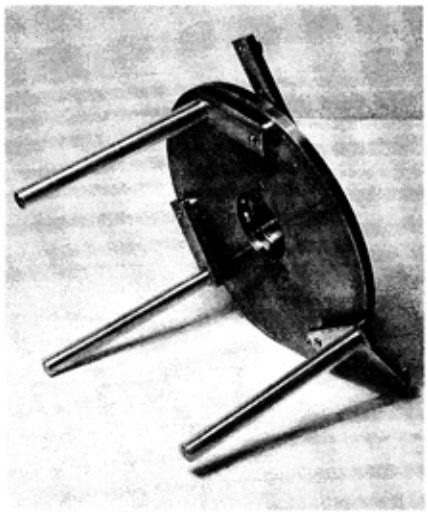


Figure 2b
Centring device, different view

The drive motor

The player is driven by a Studer A 80 capstan motor that features high-speed accuracy, freedom from mechanical noises, and the advantage of speed variation within a wide range. The control electronics allow easy adjustment of the speed over a range of more than one octave. A further advantage is that a connection between two points on the electronic circuit halves the motor speed. This latter feature is important where eccentricity of a cylinder causes serious tracking problems when played at the original speed. To avoid mechanical resonances, the drive unit was attached to the base plate by means of silent blocks.

The drive shaft and support bracket

The third important unit consists of the driving shaft and the supporting bracket, which also serves as a stand for the movable platform for the arm assembly. The shaft is belt-driven and runs in sliding bearings. We use push-in PTFE bearings because they are almost noiseless and need no maintenance. The speed is adjustable between 45 rpm and well over 220 rpm, and is controlled optically at the shaft itself by means of a high resolution index plate.

George Brock-Nannestad:
The real problem in cylinder replay now is that the linear velocity on the surface was constant at recording and, when you have a warped cylinder, you will have eccentricity – which means that you have a greater radius and hence a greater velocity

on replay and a reduced velocity at 90° to that. Since you can afford to experiment with these things, I would suggest that perhaps a small optical encoding wheel could track very close to the stylus, and this could generate a sort of time code. This would make your equipment different from the player that the BBC built, because you have made exactly the same solution that the BBC built for themselves by means of Studer and prolonged rods, except that your speed control is different.

Franz Lechleitner:
And the mounting of the cylinder is also different, because they use a mandrel. I think theirs is suitable only for one cylinder format: they can play back six-inch long cylinders, but not cylinders of a greater diameter.

It's impossible to control the speed; you cannot correct the distortion caused by the eccentricity. This distortion is like a vibrator. And you can correct the pitch, but not the interference caused by the surface and the movement of the stylus. The stylus actually changes the point at which it works, and this cannot be corrected.

Steven Smolian:
I'd like to know whether plans are available for this machine, and also some idea of the cost of building one.

Franz Lechleitner:
I can give you the cost of that model: the hardware was in the range of $2000 and the labour was in the same range. But if you want to produce it by means of a plant, you'd probably have to invest two or three times that amount for the manpower, and I think it would be about $6000.

Cylinder mounting

For the reasons already mentioned, the cylinder mounting does not use a mandrel. Cylinders are squeezed between rubber-coated discs, whereby any vertical eccentricities can be minimized with the help of a special centring device (Figure 2) similar to a three-yaw system.

Pick-up

Selected AKG P15 pick-ups are used, together with a range of styli.

Pre-amplifier

The pre-amplifier is adjusted to flat equalization, implying constant velocity. A simple linear sum-difference matrixing circuit is employed to obtain monaural reproduction of the vertical groove information from the two stereo channels of the pick-up. As many cylinders recorded by amateurs suffer from non-vertical pick-up tracking angles, it has proved advantageous to have variable matrixing coefficients by means of a potentiometer that allows for the electrical adjustment of the vertical pick-up vector angle, so that it will be matched with the original cutting angle.

At first we intended to construct a new machine for two-inch diameter standard cylinders only. It appears that the Revox Linatrack arm assembly could, however, to be modified to enable all two-inch diameter cylinders to be replayed. For cylinders of a different size, the rubber-coated discs have to be changed.

I'm especially grateful to AKG in Vienna, to Studer-Revox in Vienna, to Löffingen in the German Federal Republic and, last but not least, Lloyd Stickells of the British National Sound Archive in London for valuable cooperation and fruitful discussions.

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A Knowledge of the Content of Material as a Pre-Condition for Restoration

George Brock-Nannestad

Introduction

The approach to restoration is closely connected with respect for the recorded event, with **ethics**, as discussed in some detail during the first Joint Technical Symposium. Let me state that restoration may have two purposes: to get as close as possible to the signal present at the 'microphone' in the recording studio or as close as possible to the sound present during a replay situation in a particular, well-defined and possibly historical setting. Putting it another way: we may ask, 'Restoration to what?', and the answer may be either of the following: 'Recording as was,' or 'Sound as was.' Any other restoration will be incongruent and out of context. We must, however, recognize that partial restoration may be performed under certain circumstances.

Present status in the market

Publicly available restored material falls into two categories: commercial endeavours and archival endeavours. Among the first we must count RCA-Soundstream, BBC-Parker, and Philips No-Noise. Among the second are Phonogrammarchiv (Vienna) and Phonothéque Nationale.

Now, to a certain extent these all suffer from lack of knowledge of the material. But only Phonogrammarchiv has provided us with restored material accompanied by the **warning** that this is not the final word. We may briefly characterize the general shortcomings of the commercial publications. I must state that the interpretation of their respective results is mine, it is subjective, but based on some quite simple tests and to some extent on measurement.

RCA-Soundstream

This was developed for Caruso's voice (acoustically recorded), using the voice of Jussi Björling (electrically recorded) as a template. Result: the voice character of Björling with the style of Caruso. If the treble is lifted on replay of these RCA recordings, a striking resemblance to Björling's voice is obtained. The result was at least conceptually more correct in the case of the complete recordings of John McCormack, where the electrical recordings were used as a template for the correction of the acoustic recordings.

BBC-Parker

This refers to the BBC publications, *Classics in Digital Stereo*, which are provided by the Australian sound engineer Robert Parker. The basic test for any re-issue is to boost the treble, since this will

Dietrich Schüller:
George Brock-Nannestad graduated in 1971 from the Technical University of Copenhagen and specializes in signal processing. He is a patent attorney in a large Danish corporation. From 1981 to 1986 he received a grant from the Danish Research Council for the Humanities for a project entitled, 'Establishment of objective criteria for correct replay of historical sound recordings.' He has done various consultancies in this field, produced numerous publications, and is also a contributor to the Triple A project 'Audio Preservation'. In 1987 and 1988 he organized an exhibition in Denmark entitled 'Tracking the Sound.' He is a member of IASA technical committee, of ARSC, of AFAS and of the Danish Musicological Society.

Editor's note:
During the presentation of this paper, a number of sound examples were played in order to demonstrate the importance of correctly counteracting the linear distortion created in the acoustic recording process.

enhance any distortions generated in the process while possibly re-balancing the spectrum – the traditional logarithmic centre frequency of 800Hz adhered to. [Based on observation of sound quality it was recognized in the 1950s that the 'centre of gravity' of any well-balanced music or speech sound was at 800Hz, and that any reduction of upper limit had to be matched by a corresponding reduction of lower limit, so that the distance from the limits to the centre had to be the same on a logarithmic axis. Another model was that the product of lower cut-off and upper cut-off values had to be 400,000 (1)]

The sound of these publications is reminiscent of continuous 'end-of-side' distortion known from the days of spherical and perhaps worn styli or needles. This would indicate that distortion is introduced at replay of the originals, and heavy filtering is used to reduce hiss and some distortion components, thereby effectively increasing the high frequency content. Ambience is added by means of a stereo processor/expander. The 'Digital' refers to the type of master tape.

Philips No-Noise

This is fairly innocuous in its action; the limited edition sampler CD shows 'before' and 'after', and only a very slight addition of hiss on transients is notable. However, the knowledge of material in this commercial endeavour is totally absent.

Archival re-issues

The archival re-issues demonstrate a more 'honest' approach to restoration:

Phonogrammarchiv der Oesterreichischen Akademie der Wissenschaften takes the approach, supported by in-house measurement, that no worthwhile signal is present above 5 kHz, and consequently performs a low-pass filtering. In the early issues, this was the only signal processing performed (though not adhering to the '800 Hz rule'). Later issues have openly experimented with noise reduction performed by Kommision für Schallforschung der Oesterreichischen Akademie der Wissenschaften (2).

Phonothéque Nationale does not perform restoration as such, but rather attempts to present a re-recording that is not band limited. However, one issue of popular film music consistently shows an enhancement of the 2–3 kHz range. The re-recordings are well annotated. However, a recent review (3) of the major re-issue of the recordings of the 'Congrès de Caire 1932' points out that there is a lack of technical information, and that the calibration tones present in the original recordings have been deleted in the re-issue. This is to be deplored.

Principles and categories of signal

If the recording method is well documented as well as the equipment for replay, and if the sound carrier is in good condition, there is very little need for concern with the content: simply adjust the equipment, and the output will be a faithful reproduction of **whatever** has been recorded. The problems occur, and to varying

degrees, when one or more of the elements of the chain are unknown. The simple way to approach unknown factors is to apply the standards of present-day taste to the end result. However, this would be conceptually wrong. Rather, this is the time for searching for clues in the signals present on a recording.

The following can be identified:

- the intended signal,
- characteristics of the recording process that have transformed the intended signal,
- extraneous noises that accompany the intended signal,
- noise of the carrier. The contribution of the replay apparatus cannot be ignored, but it may be influenced by the restorer.

The intended signal may contain clues as to the speed of the sound carrier and of the spectral characteristics of the recording method. Both may be corrected during replay.

Extraneous noises are typically hum and (on mechanical recordings) whistles (the chatter of the cutter at a carrier speed that is too low for a smooth cut), rumble (gear noises) and wax noise (wax is not entirely without grain). Hum may be used for correcting the speed at replay, but should naturally be suppressed during restoration. Gear noises may be used for identifying the recording machine and so place the recording in its proper historical context, allowing the experience of other recordings to aid in correcting the signal during restoration. In acoustic recordings, the wax noise is transformed by the recording system while being recorded as a spectrally filtered noise (Figure 1).

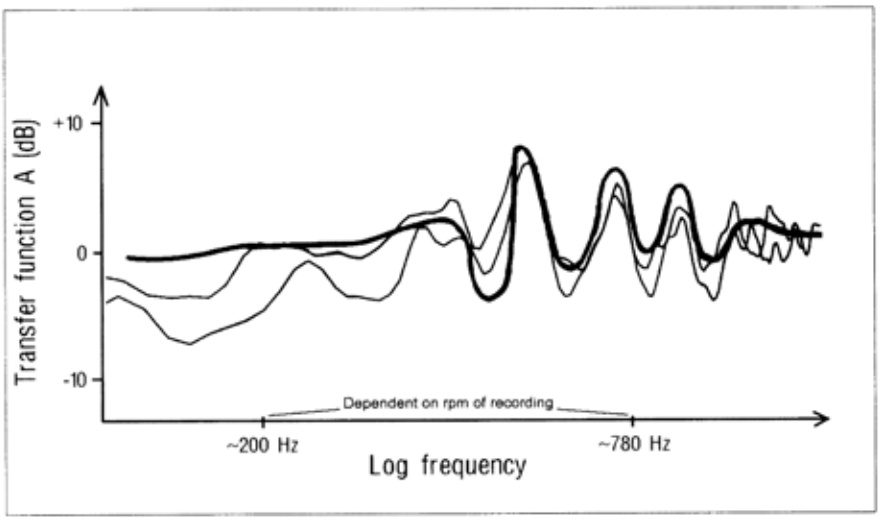


Figure 1
The juxtaposition of a number of integrated spectral distributions of wax noise from the run-in grooves of recordings by Adelina Patti in 1905/6. The general shape of the distributions is the same for all recordings, and their relative displacements using a logarithmic frequency axis demonstratethe relative differences in (rather ratios of) recording speeds of the turntable.

This will identify the recording system and has tentatively been used as an indicator of the spectral characteristics of the recording method, which may then be counteracted during replay (4).

The noise of the carrier carries very little information, but it will act as a noise input to the replay system and so give a spectrally filtered noise as the output (Figures 2 and 3).

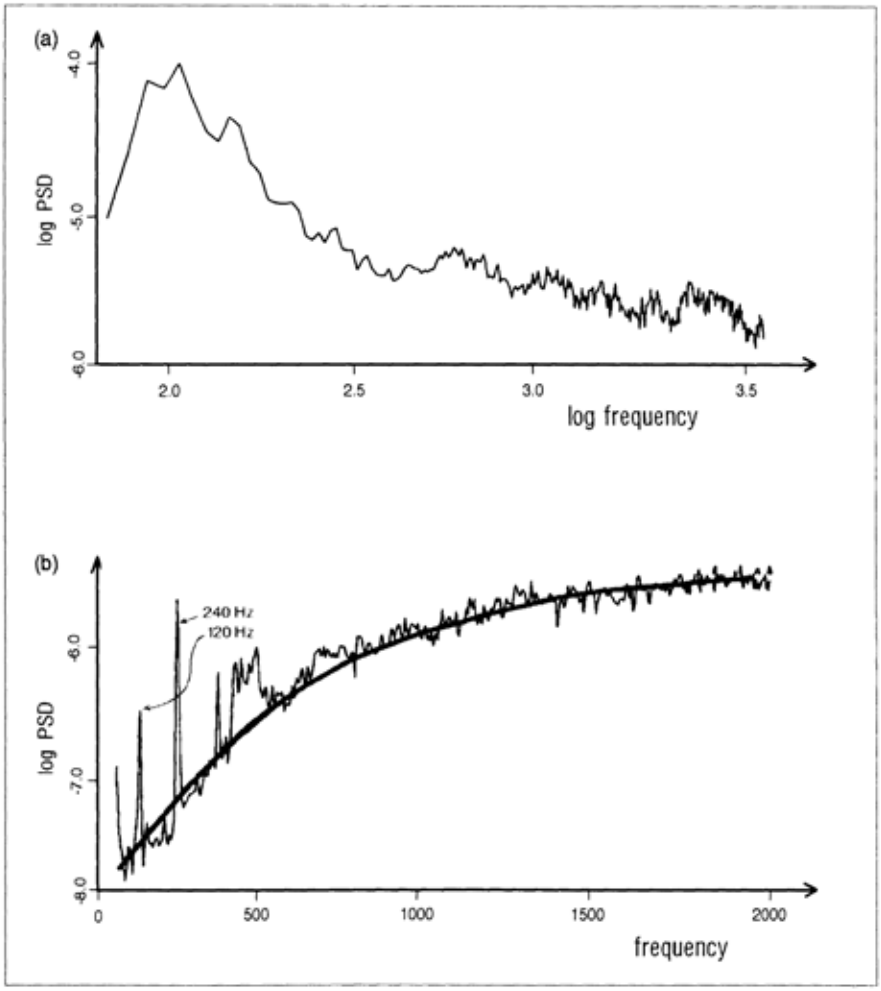
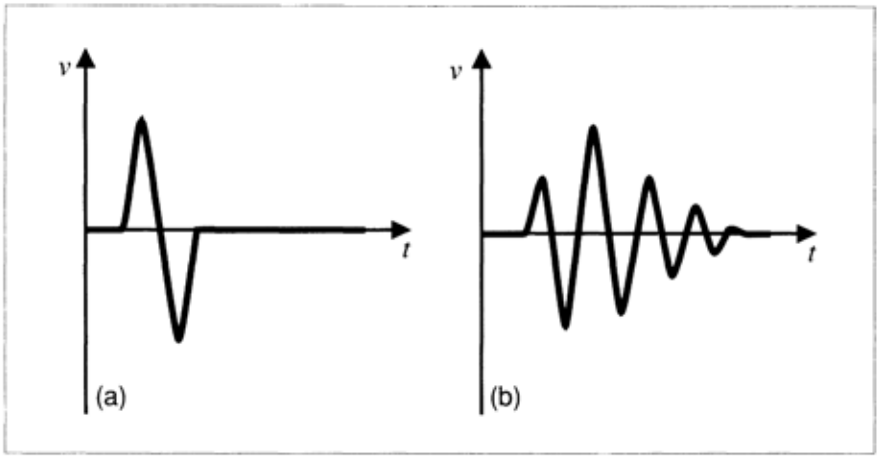


Figure 2
Integrated spectral distribution of carrier noise from a shellac record without modulation: (a) bass emphasis of pre-amplifier, (b) bass de-emphasis of pre-amplifier, plus a hum line spectrum.

For this reason certain adjustments of replay equipment may make the noise of the carrier very noticeable, particularly by contrast with modern recordings. So it is of extreme importance to remove the carrier noise before attempting equalization of, for example, recording system resonances of acoustic recordings. Otherwise it is quite possible that the narrow-band enhanced carrier noise will interact in a masking way with the intended signal in its equalized form. One of the declared goals of modern restoration is to get rid of carrier noise.



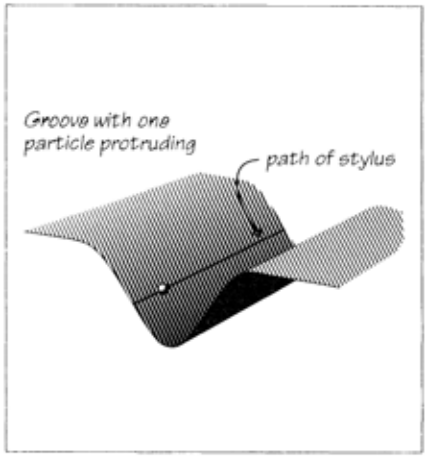


Figure 3
A comparison between: (a) the ideal time response of a velocity pick-up encountering a single impulsive noise from a particle in a groove wall, and (b) the time response available to Deutsch and Noll (2) for further processing. Resonances in their replay chain generate a replay artefact.

Noise reduction methods

The following is a brief overview of noise reduction methods for mechanical recordings and their basis in 'knowledge of content of material'.

H H Scott introduced the concept of dynamic noise filtering by constructing a filter with a bandwidth dependent on the level of signal in one or more bands (US Patent 2,606,969 and others issued in 1952; the invention was published at the National Electronics Conference in 1946 and in various papers in *Electronics* 1947–49). This type of construction has also been used in recent equipment, such as one section of the Packburn Audio Noise Suppressor. This type of equipment relies rather on the characteristics of the ear than on the content of material.

The Packburn Audio Noise Suppressor (in particular Model 323) consists of sections which may be used in series, and a good impression of the functioning may be had from US Patents 4,151,471, 4,155,041, 4,259,742, and 4,322,641. The fundamental difference between this equipment and any other equipment is that one section is based on the realization that in a mono recording the signals in the two groove walls are basically the same, whereas a noise pulse stemming from an unevenness of groove walls generally occurs in one wall only at any one instant. A stereo pick-up will generate individual signals for each groove wall. Hence it is advantageous to switch to the unperturbed groove wall when a noise pulse occurs. The result is somewhat dependent on the pick-up and its alignment.

The 'speech enhancement' methods (5) rely on a model of speech signal, ie the statistics of speech signals versus the statistics of the noise and form the theoretical basis for the method proposed by Deutsch and Noll (2) and of CEDAR (GB Patent Applications 2 217 902 and 2 218 307).

Bill Storm:
What would be the feasibility of documenting the characteristics of the recording prior to making a transfer copy for archival purposes on the same medium that you're transferring to, so you would have some kind of audit trial?

George Brock-Nannestad:
It would be an extremely sensible thing to do, and I'd like to see it included amongst good working suggestions for archives. In particular, if you're going to store noise-removed things, you should keep the Rosetta stone. The concept of a Rosetta tone was introduced by Richard Hissa back in 1974, I think. He didn't realize this; he talked

about 'one clap handing' and claimed that he had been able to restore some of the acoustics of early sound film from the clapper board sound, because you know what the clapper board sounds like. Of course there are clapper boards and clapper boards, but nonetheless a clapper board has a distinctive impulsive character that tells a lot about the recording chain all through replay.

Michael Biel:
Talking about the clapping – when I play the Benny Goodman Carnegie Hall concert recording that Columbia's put out once again, I do my equalization of it from listening to the audience in between. It turns out that the music sounds a lot better once I equalize the audience applause in between the selections!

George Brock-Nannestad:
I would like to briefly mention that during the early 30s, Siemens made recordings of choruses of men talking – lots of men saying lots of nonsense syllables – to generate background noises to use for equalization. So clapping is just as good, I would say.

Jean-Marc Fontaine:
[Précised from some comments in French, translated by George Brock-Nannestad and Dietrich Schüller.] The Phonothèque National is actively engaged in making more material available in increasing degrees of restoration that are more intelligible to the listener, while keeping a copy with the signal as it is. I endorse George's quest for an objective approach to these things and for documentation of the actual original sound recording.

From about 1981 onwards Bogatyrev and Birenberg took out a number of Soviet Union Inventor's Certificates on various analogue methods for signal processing relating to mechanical and film recordings. I do not know if any results of processing according to these methods are publicly available. [The numbers are given here for reference: 1171833, 1156127, 1107157, 1040518, 1014013, 987672, 1001165, 980136, 980134.]

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The Use of Digital Processing Techniques for the Restoration and Preservation of Sound Recordings

Frank Dufour and Gilbert Taieb

Dietrich Schüller:
I'm now calling upon Frank Dufour and Gilbert Taieb from INA, the Institut National de l'Audiovisuel in Paris, who will be talking about the use of digital processing techniques for the restoration and preservation of sound recordings. They didn't leave me biographical notes, so I'll just say that they are young members of Philippe Poncin's staff – Philippe is known to most of you.

Editor's note:
During this talk, a number of sound examples were played in order to demonstrate the work being described.

First we will introduce the Institut National de l'Audiovisuel (INA), which is a public establishment with an industrial and commercial brief. It comes from the Office de Radiodiffusion Télévision Française which was officially broken up in December 1974. INA has inherited the role of:

- preservation, restoration, archiving and valorization of the production of the French national broadcasting societies,
- professional audio-visual training,
- research, notably in electro-acoustic music and synthesized images,
- audio-visual production.

The sound library of INA is located in the premises of Radio France in Paris, and is part of the audio-visual archives department. The director of this department is Philippe Poncin, and Frank Dufour and I are responsible for all the technical devices and procedures required for consulting the archives, for restoration and for commercial issues.

The INA sound library keeps only the programmes broadcast by the French national radio: Radio PTT, then Radio National during the War, then RDF in the 1940s, RTF in the 50s, then ORTF, and now France Culture, France Musique and France Inter. They deposit almost 50,000 hours of material each year, so we store only the direct recording carriers used by the radio stations. First, the acetate direct-cut discs used since 1930, magnetic $^1/_4$ inch tapes since 1950, then the various digital recording carriers since just before 1980. These are the PCM systems F1, 701, 1610 and 1630 recorded on video tape (Betamax, VHS, U-matic) and also R-DAT and DASH formats.

The oldest and the most delicate carriers, those on which we focus our efforts, are the direct-cut discs. The collection constituted by those 255,000 discs is well known and catalogued. Recently we made a physical inventory of those carriers allowing us today to convert that collection to a database called Mistral. We also own half a million $^1/_4$ inch analogue tapes. Except for the oldest of these, we have no major problems with this carrier. The collection of discs is quite homogeneous from the technical point of view. They are all acetate on metallic discs of aluminium, zinc or steel. They have a

diameter of 24, 30 or 40 cm; the groove is almost 150 µm wide, and is laterally cut at a constant pitch; the speed is 78 rpm.

The ageing of those carriers causes many problems, such as cracks and de-lamination of the coating from the metal blank. The main purpose of the sound library is to transfer as many as possible of those discs to a new carrier and thus to make them accessible to the broadcaster. The steps of that transfer were clearly defined by Dietrich Schüller in Montreux, but I will summarize them in relation to our own recordings:

- The identification and evaluation of the document. Is this an original or a copy? Of what generation? What was the recording date, of course, and does the physical state allow further treatment?

- The cleaning and preparation of the disc. We now use an ultrasonic cleaner that gives very good results.

Dietrich Schüller:
Thank you very much for this most interesting and fascinating demonstration. May I ask you how long it takes you to remove all these crackles from a disc for one minute signal?

- The choice of pick-up: the size and the shape of the stylus, the weight of the cartridge, and the rotation speed.

- Equalization – we are lucky to have test records on which ranges of frequencies are recorded, and we also have material recorded both on disc and on magnetic tapes that allow us to be objective about the criteria of equalization.

- The carrier we use today for preservation is 1/4 inch analogue magnetic tape.

Frank Dufour:
About eight minutes.

- Editing – this operation is essential for damaged discs to restore the continuity of the message, and possibly to suppress impulse noises.

George Brock-Nannestad:
In the recording from the wartime with messages to the underground movement, why did you call it a caricature? Was it because the noise transmitter had been cut entirely out?

- Re-interpretation – for listening comfort, it's often desirable, in the case of commercial re-release, to re-equalize. The kind of re-interpretation and the criteria are not only technical criteria but aesthetic and historical. Filtering based only on listening comfort can lead to nonsense. Noise is sometimes as significant as signal.

Gilbert Taieb:
Yes, but it was not a true example; it was only a fake.

Of course errors can occur if the work is based on criteria of sound quality alone. For example, in one live recording of the work of the composer Janis Kanorkis, there is a temptation to cut off the nervous cough at the end of the recording. But a careful reading of the score indicates that this noise was intended by the composer!

George Brock-Nannestad:
So by removing the noise transmitter you discovered that it was a fake. But the messages were in principle that kind of message.

The defects of and damage to old records are well known today, but the product: (quality of treatment) by (time of treatment) reaches its limits, and we have to build new tools using the latest digital sound technology.

Michel Bourbener:
I've noticed that some of the discs that you're playing back have suffered catastrophic failure of the coding. Have you found a system to make these track easily, or are you

Several machines built around the hard disk and microcomputer have appeared on the market. They allow virtual editing, digital filtering, visual control, and adjustments of level. This is undeniable progress, because we can provide different kinds of facilities on the same equipment:

- After a direct transfer from the original, editing is directly possible on the same system. The image of the signal on the screen and the ability to repeat different editing processes at will gives accuracy and rapidity which you can't afford with analogue or digital tape recorders.

- We may insert in the system a library of filters for different equalizations as well as for every performance and optimized corrections.

- During each process, the system gives a visual control of the treatment either on the waveform or on an FFT representation.

- At the end of the work, back up is available on any digital or analogue recording system using magnetic or optical carriers.

Another advance linked to this kind of equipment means that we can produce algorithmic treatments for automatic correction or noise suppression. This allows us to define for ourselves the algorithms to correct the defects and troubles we recognize in our collections.

Our experience in the preservation and use of sound archives led us to build a research programme for the development of this equipment, addressing three aspects essential to good playback of original recordings:

- optimization of the 78 rpm readout with either mechanical or optical solutions,

- development of software for reducing transient noise or tape hiss,

- experimentation and development of the 'Melody system'.

We lead this programme together with the manufacturer Fujerol Incorporated and a research department of a French university in Le Mans. For us it is obvious that the parallel development of the best playback and of digital signal processing will be the only way to restore documents such as Mussorgsky's *Boris Gudenov* in the original version recorded by Ingel Brecht and the French National Orchestra in Marseilles in 1942. But the great demand for the re-issue of all recordings on CD may also cause some laboratories to limit their work to fully automatic processes only. In the meantime, they could fail to solve difficult but typical defects of all recordings such as a stretched tape.

slowing down the discs? Have you developed a way to track these discs? We found that discs that have suffered this type of catastrophic failure, where the grooves don't line up any more, tend to become completely out of context – it jumps from one groove to the next, and so on. Have you a special process to achieve this?

Gilbert Taieb:
It's only skill and experience. We have no particular process to read them, but we are hoping to develop one.

Michel Bourbener:
You mentioned that you were cleaning your discs ultrasonically. What kind of chemical are you using?

Frank Dufour:
It's only water with a little bit of solvent.

Dietrich Schüller:
Palmolive!

Steven Smolian:
I'm confused about this ultrasonic using water for cleaning records, especially acetates. In my experience, because of the capillary action it boils and melts. That's the reason the people that I know who have been using ultrasonic cleaners use Freon. Have you not had problems with the lacquer peeling off the disc using water in an ultrasonic bath?

Gilbert Taieb:
Using water? No, we just read the disc and then make sure that the water doesn't stay on the record. No problem.

Exploiting the Vinegar Syndrome

Steven Smolian

Dietrich Schüller
Our next speaker is Steven Smolian, who operates Smolian Sound Restoration Studios. He's presently working on two projects for the Smithsonian Institution Press, and he is sound archivist for the Chicago Symphony Orchestra. His paper, 'The Deterioration, Restoration and Preservation of Recording Tape,' appeared in a recent issue of the Journal of the Association for Recorded Sound Collections.

Our concern with the vinegar syndrome, a smell indicating decomposition in acetate-based sound and picture carriers through the conversion to or evaporation of acetic acid, has been instrumental in bringing us to this conference, which focuses upon physical changes in archival materials and what those changes imply.

Over the years I have accumulated papers, sometimes only scraps, relating to the replaying of acetate-based sound recordings. My purpose is to find out how the old-timers dealt with the problems these discs present – particularly crackly surfaces caused by exposure to water, ageing and poor storage conditions.

In one of these papers, unsigned, I found reference to treating the disc with a vinegar solution and playing it wet. It made sense; if that is what smelled coming out of materials of similar chemical composition, re-introducing it might have a positive effect. I tried this on an instantaneous record with poor results. The water in the vinegar solution evaporated, and though there was a minor reduction of impulse noise at the beginning, the effects were limited. I then intensified the process by applying the liquid (half clear 5% vinegar, and half distilled water with a touch of Photoflow 22) with a natural bristle paint brush while the record was playing, resulting in great reduction of background noise. (A significant amount of noise was once more apparent 12 hours after the vinegar treatment.)

When the application is effective, there is no apparent loss of high frequencies, certainly not within the range of AM broadcasts nor of what is saved on these discs I tested – which derive from 1950 FM broadcasts. On other discs of the same manufacturing vintage, the process is a complete flop.

This empirical procedure was also prompted by the haze I have noticed on the surface of a few older commercial 78s in excellent condition. Years ago it occurred to me that this may be material that has leached out of the record, either in its natural state or in combination with the oxygen it found when it got to the surface. I have isolated a few such items in my own collection and hope one day to determine if this substance can provide clues to physically restoring older commercial discs.

Ideally, one would take a record by a specific manufacturer, known to have been made at a particular time and hermetically sealed on that day, and perform a chemical analysis. Then one would do the same analysis on other discs made at the same time but subjected to various torture tests – air, wear and other aspects of record life which cause physical changes, each applied in a measured way. By comparing the make-up of each used disc against that of a sealed one, it may be possible to determine where they now differ, discover how to re-introduce into the worn discs the missing material, and

thus restore the object nearer to its original chemical composition before copying it.

Although this is not a practical process in the abstract (unless one goes about digging up cornerstones of old record factories), there are still enough excellent copies around from all eras to make a meaningful start, and there is certainly no shortage of worn discs to use for comparison.

I envisage a spectroscope-like machine into which one can place a small sliver from a given disc. An analysis would be performed by the machine. The number '42' would appear on a read-out screen. The technician would look in his manual under '42' and find that he was to paint the disc with the product in jar '17' and run it on a centrifuge (a turntable going at 500 rpm), take a pizza pan cover with a thermostatically controlled heating element in the top and a gasket around the rim, set it on 98.6°F, and place it over the turntable for 15 minutes, treating the other side the same way – a 'recordcipe' book.

Given the clear success of vinegar resuscitation with some acetate discs, there is every reason to assume that carrying this line of reasoning towards an investigation of other recorded products could be significantly productive. The restoration sequence should focus on devising a solution within the branch of science from which the problem stems. Chemistry should be employed to solve those with chemical sources and physics to solve the physical ones. Only when these have reached their productive limits should electronics be introduced.

Access to the technical files of a few record companies may help identify some basic record formulations.

I do not yet know whether I have stumbled on to a one-time-only quick fix that works on only some acetate discs manufactured during particular years, or a clue to the map for a whole new continent of audio restoration.

This should not be a super-expensive research project to carry out systematically, but it is certainly beyond the means of most individuals. Have the film people anything to contribute from their experience? This seems a natural project for a grant, but who will oversee it? Who will design the project? Such problems I place before this Symposium.

Lloyd Stickells:
On some acetates, you can get exactly the same effect using just water.

Steve Smolian:
On this particular disc, I haye tried a sequence of the things that I knew worked on some occasions: water, mineral oil, castor oil, and so forth, and soaked using mild library liquid and playing the records wet. In this case, this was the only thing that worked. So I think that there is a distinct difference between discs made even in the same years by different manufacturers. Some things work and some don't, and that's why I really think there has to be some way of identifying and correlating the chemical make-up of the disc with the appropriate treatment.

Lloyd Stickells:
I had noticed that with the so-called acetate discs sometimes if you put water on them they turn from 78s to LPs, and at other times it makes no difference whatever.

David Hall:
I'm going to go back to my days at Mercury records in 1950–51 when I was working with Bob Fine. In those days we had to go back to $33^{1}{}_{3}$ acetate originals and get them on to tape for LP. I'll simply say, for everybody's information, that we used mineral oil. Of course the acetates were dried out and had that characteristic 'wow-wow-wow'. It helped.

Michael Biel:
About twenty years ago there was a man in the Chicago area, John Steiner, who by profession was a chemist and by avocation a very noted jazz record collector. He mentioned to me that over the years he'd put together a set of formulas based on the chemistry of the individual records by different companies – we're talking about lacquer masters for Presto, for Audio Fidelity, for Audio Discs, Reeves and other manufacturers. These, however, were apparently proprietal secrets that he did not want to divulge, and I've not had contact with John for well over a dozen years. But this might be somewhere to start since I know that he is still around. Because the important thing is that first, before we think of a general fix on lacquered discs, we need to work on trying to identify which are the particular manufacturers of particular discs and go over their formulas as they have changed over time.

George Brock-Nannestad:
My question is concerning styluses; it would be interesting to know what sort of stylus you use, whether it's a spherical or a line-contact type. The reason I'm asking is that I've noticed that vinyl pressings of shellac records actually suffer from replay, because the material is so much softer than the original material. My reasonably good pick-up has worn my copy of one Adelina Patti record, the one with the heaviest modulation which is a shellac pressing. And when you do this I suppose you are getting in to a state that is softer than vinyl.

Steve Smolian:
First of all, it was a 2.75mm truncated spherical stylus. However, the question of playing weight as part of the equation of the playback brings us to a whole technical jungle. One issue it raises is that, with the laser turntable, there is no pressure as part of the playing. How does this affect what we're hearing from this $32,000 delightful little toy? At any rate it's a consideration and was part of the original playback equation, and I think we have to consider it now.

Dietrich Schüller:
I think it would be appropriate if one of the scientists in this round would answer the empiricalists.

Question:
Perhaps if I could just speak as a chemist: from a chemist's point of view, it's simple to understand. I think the effects you're seeing are very much dependent on the mechanism through which the esters have degraded, their history (certainly their manufacturing history), the effect of the acetic acid which is almost certainly a plasticizing effect. I think you might find varying effects or more effective ways by perhaps even varying the concentration of acid: maybe increasing or decreasing the acetic acid, perhaps even trying other less-corrosive acids. Butyric acid, propionic acid, all these are worth trying; they are probably the best solvents. Cellulose esters originate from acids, so some of the best plasticizers, which would not do any severe harm, would in fact be acids.

Electronic Correction of Archive Film

Don Kershaw

Introduction

This paper describes how television techniques can be used to handle faded colour negative film in order to correct colour balance and reduce physical blemishes.

At the 1987 Joint Technical Symposium in Berlin, Hans-Eckart Kärnstadt described an optical method used to print three colour layer films from the early 1940s, and his paper appears on page 131 of the report of that Symposium.

Method

The film used for this demonstration was roll 4 of a production titled *Immensee*, a cut negative consisting mainly of Agfacolour B nitrate stock, but also including some dye-masked interneg probably inserted from a previous salvage operation. The film was curled, shrunk, full of grading clips, but generally in good physical condition. The separate soundtrack was not supplied.

Most Telecine machines can produce a positive television image from negative film. The machine used for this demonstration was a Rank Cintel Mk III digiscan machine working on the 625 PAL television standard running the film at 25 fps. The machine was not equipped with a wet gate.

On first viewing the film, severe colour changes were observed between shots, there were blemishes due to dirt, occasional blank frames (probably inserted to maintain sound synch after the removal of damaged frames), chemically produced fades to black that did not quite make it, and some colour fluctuations (probably due to manufacturing or processing limitations of the aged stock or maybe just due to the passage of time!).

A programmable colour grading system, developed by the BBC, was employed to correct the colour of each shot. The system examines the picture content and automatically notes the frame number when an abrupt change occurs. This 'shot change detector' is the electronic equivalent of the grading clip. The operator then adjusts the colour balance and the parameters so determined are stored and applied to the whole shot on subsequent runs of the film.

The correction system can select various masking coefficients. It can adjust the contrast, brightness and gamma of each of the primary colours, and the overall colour saturation. The operator can also store additional correction points to make the colour changes dissolve from one shot to another. This dynamic control was used to improve the fade to black. It can also control the frame store in

Dietrich Schüller:
Don Kershaw joined the BBC in 1955 as an engineer after training in British Telecom and the Armed Forces Signal Regiment. After three years in Telecine, he joined the newly formed video tape section and became shift supervisor. In 1968 he became responsible for technical developments, and in 1982 he was appointed Head of Recording Engineering responsible for all operational engineering activities concerned with film and tape recording, post-production and transmission. He has just been appointed Head of Post-Production development to co-ordinate development and re-location of the BBC's new post-production facility at Television Centre in West London.

the telecine in order to repeat frames and make unwanted blank frames less visible.

The operator uses two joysticks to control the main grading adjustments, and the system allows the stored corrections to be trimmed and restored on subsequent runs of the film.

The BBC has also designed a digital processor which detects dirt and conceals the resulting blemish by replacing it with small portions of picture interpolated from adjacent frames. The signal from the Telecine was processed by this device with noticeable improvement.

The time taken to programme the computer to perform acceptable colour correction on this 10 minute roll was approximately 75 minutes and the result was stored on 1" C-format videotape, it being the current recording standard in the BBC. (High-quality digital recording is proposed for the future.)

Application

The use of television techniques to perform post-production operations on film material is not unusual. Computer generated graphics are often handled in this way and many American soaps such as *Dallas* are edited along with electronic 'opticals' to reduce the costs of traditional film post-production methods.

The end product is a video tape that can be transmitted to television viewers without further processing. The disadvantage is that the tape is only valid for the television line and frame standard used for the telecine transfer. Conversion to other standards usually degrades the signal, particularly if the frame standard is different.

If the final product is wanted on film stock, then a film recording has to be made of the television image, often using a laser beam recorder.

In the case of this test sample, a standards conversion was made from the 625 line/25 fps PAL one-inch tape to 525 line/30 fps NTSC half-inch VHS in order that it could be shown on the television projector used in Ottawa at the Symposium.

The quality of the picture shown is marred by the limited horizontal resolution of the VHS machine, the limited vertical resolution scanning system, the limited contrast range of the projection display, but most of all by the frame rate conversion where 30 frames have to be made from the original 25.

However, the display shows the effectiveness of the colour correction techniques employed, and the benefits of the electronic dirt removal system.

Finally the emergence of High Definition Television origination and broadcast systems will eventually allow the processes I have described to take place without any significant loss of quality.

Michael Biel:
One of the things that bothers me about European television, with all of the care that is taken in the picture and all the snide remarks that all my European friends talk about NTSC, and with all of the interest in film preservation and archival restoration of films, why was the film projected at 25 frames per second instead of at 24 frames per second as it was shot, when on the Rank Cintel telecine you have the provision for variable speed?

Don Kershaw:
If we play the film at 25 a second, that matches a television standard and we're not having to make additional frames which have to be done by interpolation and that again is a distortion of the original. What we're doing is replaying the film frame for frame on the television system. If I had bothered to make a film copy of this, this would also have been done at 25 frames per second and then we could have shown it here today at 24 frames a second, and you would have been quite happy.

Michael Biel:
You see that's something which people here in North America don't realize as TV shows, both film and video, are transferred back and forth. For the most part the motion picture cameras that are used for making the materials for a television programme are set to run at 25 frames so, if they send the film over to North America not knowing of that activity, we will be running that film at 24 frames per second – 4% slow. Until the last few years, European and British shows had a lot of film and video mixed: all the outdoor scenes were on film and all the indoor scenes were on video. So, if they sent over the raw parts, the video tape and the film, so that the conversion could be done here in the United States, the speed would change because the Americans didn't know that the film was to be played at 25 frames, not 24. So these are problems that the archivists have to be aware of and there are very few here in North America that are aware of that frame disparity.

Don Kershaw:
What you're really putting up with in America is a tremendous amount of distortion on the television image by having to invent these extra 5 or 6 frames per second. So it's a question of which do you want, do you want the good pictures, or do you want the right pitch of sound and the right pitched action? If it's important that we have the right action and the right pitch of sound, it can be put right. There's absolutely no reasons these days why we can't transfer the whole lot on to video tape, and run it at what ever speed you like – and a lot of people do that.

George Brock-Nannestad:
You mentioned a lot of problems that are well known in the transfer from one standard to the other, and what we have seen on the screen and with background lighting, and so on. Now you have seen the various stages, and you have seen what you have back at home in England and what you have got on the screen here. So perhaps you could tell me – there was a slight flicker in the density of some of the colours in large patches. Is that the result of your restoration process, reducing large changes to these small flickers? Or is it an artefact of the transfer to the US/Canadian system?

Don Kershaw:
No, I think that was a processing blemish on the original negative. It was nothing to do with the line standards transfer nor with the grading system. We obviously can't chase all the minor fluctuations throughout a shot. There was a number of fluctuations all the way through, but we're talking about stock that was very early in days of colour film. So it may have been processing problems – who knows, it may have been processed upstairs in the bathroom! Or it may be that these fluctuations were introduced as it aged. I don't know.

Developing Software for the CEDAR Restoration Project

Simon Godshill

Dietrich Schüller:
I would like now to call upon Simon Godshill. He studied electrical sciences at Cambridge University and, during the final year of his honours degree, he became involved with research in to sound restoration with Dr Peter Reiner, Reader in Information Sciences at the university. Through this research work he came into an on-going connection with the British Library National Sound Archives and CEDAR Audio Ltd. Simon became team leader in the development of the software for the CEDAR restoration systems.

Introduction

Probably most of you will have been at the Berlin 1987 Technical Symposium and seen the CEDAR system's first attempts at sound restoration. Well, development has gone on continuously since then, and we now have technology capable of an almost complete restoration of a huge range of damaged sound sources.

CEDAR evolved through a unique collaboration between the British Library National Sound Archive and Cambridge University. The expertise of the sound archive in the field of recordings, combined with the Cambridge University's expertise in algorithmic development and all the technical advances in digital signal processing, have together enabled us to produce the CEDAR system.

The CEDAR process is currently used very widely in the record industry, both in the United States and in Europe and in the Far East. It's also used in film material, broadcast material, and in archival work.

The CEDAR process itself is split into several stages of processing. The important point is that, once you have transferred your original recording to the system, you can use the three major CEDAR processes in any order you choose, so you have complete control over exactly what is done to your recording.

Thump removal

The first stage in processing is what we call thump removal. A thump might be caused, for example, by a break in the record that has been glued back together. Such scratching, thumping noises are not formed as a discrete click on the signal wave form, they're formed with a click followed by a low-frequency trail off. CEDAR tackles this by mapping out the complete recording, analyzing each occurrence of the thump and building up a picture of it. Using this as a template, CEDAR is able to remove the thump completely.

All those low-frequency tail off effects can be completely eliminated without actually touching the base sound at all.

Click and scratch removal

The second process is the removal of clicks and scratches. Some old recordings have a great many clicks, as many as 2500 clicks per second – sometimes more. These clicks produce little spikes along the wave form.

CEDAR is able to go through looking for and identifying the occurrence of these clicks and scratches by modelling the signal

only. That's the advanced bit, because it means that CEDAR is capable of detecting the tiniest of clicks hidden right in the middle of the signal that even the eye has difficulty detecting. Having found the position of these clicks, the system is able to re-build the signal where the clicks were. It looks at a good signal on either side of the scratch, and makes a best guess at what the signal should have been if the click not been there. Hence we hear a completely seamless result.

Hiss reduction

The final process is hiss reduction: eliminating broad-band noise. This is a problem common to 78s, tapes, any recording in fact. This broad-band noise appears as a 'hairiness' on the wave form, and CEDAR deals with this by a process analogous to the thump elimination process described earlier. It builds up its own finger print of what the hiss looks like, and is able to use that as the core of its hiss reduction system.

That gives you quite a good idea of the principles behind CEDAR.

The current system

Now I'll talk a little bit about the full production system that we actually have up and running. Many of the features that the system offers are in addition to the basic noise reduction processes described above, but they are all essential to the manipulation of signals and to produce precisely the restoration sound required by the user.

The hardware for the system is PC-based, with special CEDAR accelerator hardware – in fact some of the most powerful DSP hardware in the world. This has enabled us to produce a real-time hiss reduction system: you play in from an input DAT (digital audio tape) recorder and pass it straight through the computer out to a second DAT machine where you can listen to the results. Not only that, you can adjust them as the piece is playing, so within seconds you can fine-tune in on precisely the sound you require on that recording. You then go back and record the whole track on that setting.

The scratch removal process has speeded up dramatically since the Berlin 1987 symposium, probably by a factor of several hundred. It now runs from between 0.7 real time (that's faster than the hiss process) up to maximum of around 3 times real time. The reason it's variable, of course, is that some recordings have more scratches on them than others, and it takes the computer more time to fill in the gaps where the scratches were.

What of the future of CEDAR? Well, it has been developing continually for the last three or four years and it will continue to develop.

Question:
Could you talk to us about the costs of the process, and the service?

Simon Godshill:
The price for the full system with the full CEDAR modules comes to £60,000, but various options are available. We operate a bureau service in Cambridge where people can send their material to us in whatever form they choose; we process it and send it back to them. At the moment we charge a flat rate: a complete restoration of the equivalent of one CD's worth of material costs £1500.

Steven Smolian:
When you receive a tape, do you want it in the R-DAT format?

Simon Godshill:
We usually use R-DAT at the bureau, but we can have material transcribed from other formats if necessary.

Steven Smolian:
How would you want a 78 presented?

Simon Godshill:
The general philosophy behind it is to say as flat as possible, with as little done as possible. It's then up to the customer to produce the best possible result as far as transcription is concerned, so absolutely no Packburn, and as little EQ [equalization] or any other processing before it's sent to us.

Steven Smolian:
When you say EQ, do you mean EQ past the original EQ for which the record was designed, or do you want it absolutely flat?

Simon Godshill:
Either. If the customer wishes to allow for the EQ as the record was intended, he can do that and it will process perfectly well. However, if he wants to send us the EQ curve that's required, we'll put that in in our processing. CEDAR EQ operates noiselessly. It operates in conjunction with our hiss reduction process in a noiseless domain. So, if you put heavy boosts on, you don't get noise boosts along with it – just the signal boost.

George Brock-Nannestad:
Your presentation was extremely clear as to the principles of your work, and I wonder if the chairman might ask if someone from the French team from INA whom we heard yesterday would comment on differences or similarities in basic approach.

Philippe Poncin:
I think there was some misunderstanding yesterday during my colleagues' presentation, because the first samples you heard had been restored solely by manual facilities – mainly by editing. And the second part of the paper explained the work we are doing now with computer equipment. So comparison with CEDAR is quite easy in some areas, such as hiss reduction. The main difference I think concerns the editing facilities, which we need really when we have a very badly damaged disc.

Simon Godshill:
I would say that there will be a full editing module within the CEDAR system available soon.

Henning Schou:
Just a brief final word in the name of ethics. I must admit that in our archive, if we have a soundtrack that is very noisy because the laboratory happened to have a very dirty laboratory and copied the dust in, then even though it was mono, we have used a stereo recorder and split it into two tracks and sent it through the Packburn to eliminate the noise. I have no problems with that because it was not intentional: the director never intended it to be like that. But when I sit and listen to people wanting to clean up 'Mary had a little lamb', I think it certainly goes too far because there one wants to demonstrate what was technologically achievable at that time. So we also have to think about whether what we are doing is ethical. We keep both the record of sound as it sounded at the time the film was run, for instance, and then we do some filtering – but that's a separate track. Do I make my point clear?

Dietrich Schüller:
Thank you for your comment. I think that, however marvellous a restoration may sound, it is preliminary, because next year you are able to do it better. All of us working in sound restoration are experiencing that. So we never should abandon the original, however bad it was, unless it hopelessly disintegrates.

Michel Bourboner:
What are the limits of CEDAR in terms of re-building missing portions of sound, whether it's a click or an edit – in milliseconds, if you could?

Simon Godshill:
It's depends entirely on the type of material. In run-of-the-mill processing work on one of the tracks that you've heard, a typical maximum is around a hundredth of a second. But in special cases, we've got up to as much as a twentieth of a second.

Michel Bourboner:
Are you aware that some manufacturers are competing for a formulation they're claiming as much as 93 milliseconds?

Simon Godshill:
That would be an extremely long example, but it's quite conceivable.

Session 6:

Is a Multi-Media Format or System for Audio-Visual Material a Practical Proposition?

Chairman: Brian Jenkinson

The title of this final session is a question posed by Bill Storm in Vienna at a meeting of archivists and manufacturers.

A Work Station for the Modern Media Laboratory

David Wickstrom

Brian Jenkinson: *Our first speaker is David Wickstrom from the Belfer Audio Laboratory and Archive at Syracuse University, where he is Senior Audio Engineer. Before joining the Belfer Lab, he spent eight years as a supervising engineer at the Library of Natural Sounds at Cornell University.*

This paper comes as a result of my observing a number of archives; they may be is a select group, but they appear to have more copying work than they can cope with. I have wondered if there is a way to improve the productivity in the transfer part of archive activity and, over a couple of years, started to sketch out some ideas. I think at this point a system can be built. I hope it's a first-generation system. I think it will change the way we go about making a transfer, and it will teach us enough about the process to give us a very clear idea of what an ideal system would be. I can't identify that yet, but I think I can get a lot closer.

The major difficulty facing the archives that I'm familiar with is that there is an awful lot of work to do and the process of making a good transfer is very, very expensive. Typically, I have not in my own case been able to get the money needed to pay for the quality of staff that I felt was really needed to do the job of transferring. The person that makes the transfer is the only person that really comes into contact with it. There is very little checking of work done in archives and, in fact, there are many cases where people don't even know if they've successfully made a copy. They've taken a tape; they've taken a disc; they've made a copy; they make out the data card for the work; they put that copy on the shelf. The recorder's red light was on, therefore it has been copied. The copies are seldom checked.

If a trained audio technician is employed, another difficulty arises. The highly creative audio technician gets bored after about the first two hours, and proceeds to try to find new and ingenious ways to make the recordings sound different, or starts reading *Studio Sound* with the machines grinding away in the background. In one particular case, an entire collection had to be re-recorded because the technician was more attentive to other things. The requirements for music recording and archival recording are very different. A music recording engineer works for the duration of the recording session and participates in the creative process of making a modern recording; the archival recording technician keeps a pretty regular schedule, and copies as many recordings as possible during the day. The goal, I would hope, would be an absolutely accurate copy, with as little loss of information as possible. These are two very, very different tasks and I think it requires two different people. In my experience at Cornell, the best choice for archive technicians were people who were hired from a laboratory technical background. They had experience in following a specific set of procedures, following them very carefully and checking themselves. When taught the particular mechanics of making a sound recording copy, they did very, very good and consistent work. They could do very little, however, if anything went out of bounds. This required additional management time to resolve.

Another problem is that the archive, especially the sound archive, is generally using equipment designed for doing something else. The equipment is adapted from either a radio heritage or a sound recording heritage. I think we need to create a system that specifically addresses the needs of the archive and I'm going to talk about the idea of using a single computer to control the machinery of a transfer station within an audio archive. This doesn't have to be in any way limited to an audio archive, but that is where the Belfer Lab's need is and so this is where the majority of my thinking has been taking place.

This system, the control and transfer station computer, should be tied directly to the archive's main database computer so that, for the first time, we have an integration of the data record-keeping and the transfer work. They are actually aware of one another's activities. The textual records can be viewed and corrected during the transfer. At the same time as the copy is being made, the transfer control computer will write technical data back to the main database so that, for the first time, we've built what I like to call an audio trail of the transfer. This will mean that when the data on a particular track or cut that's in the archive is viewed, you also know every step of the path of that transfer. A researcher may not agree with the path used, or the path may later be proven to have some particular distortions that can be removed. If we don't know the path that the signal took during copying, we're going to have to guess, as we often have to do today, what may have happened.

Steven Smolian:
You talk about putting some kind of identification of the content on to the tape itself. What would be the means of doing that?

All the hardware required to make such a system is manufactured today. This isn't something that has yet to be built. The part that remains to be tackled is the writing of the software to control the various pieces of machinery, to configure and install the system. By using the machinery itself, by using standard buses (MIDI, RS232, RS422), all the equipment that is required (equalizers, tape recorders) and many of the control functions (signal routing or switching, gain control) can be controlled by a relatively small computer. Measurement of the signal, which can be incorporated into this system, can also be controlled by the computer.

David Wickstrom:
We had initially hoped to do it with a standard computer modem, for several reasons: firstly, it was a standard interface to the computer and secondly, you could buy it anywhere. We've run some experiments and that does not appear to be plausible mainly because the modem doesn't want to talk about anything unless it knows there's another modem out there listening. We contacted a couple of manufacturers [about the problem]. They said that it was an interesting question and asked us to tell them if we found an answer!

We think it [the restriction] is in the microcode [of the modem, and not something we can easily change]. We are now looking at a very simple method of writing the data using the same coding as a

The copy process itself has as it's central object a computer with a high-resolution display. The keyboard is augmented with an analogue level control and that would be the centre piece in the studio along with the monitor loudspeakers. The design goal for the system is not to make it machine specific because, if we've learned anything, we've learned that the computer is going to change and there may be better machines available within the development time of this project, by the time the software is written. The other thing that is developing now is a generation of computers that have on-board digital signal processing (DSP chips) and, in one case, the machine includes software for a spectrum analyser and a digital oscilloscope. It may be attractive to start with such a machine rather than buying the auxiliary equipment that would, in fact, cost more than the computer itself.

Let me take you through a typical copy procedure as I envisage it with this system. The material to be copied is a tape. It has been input to the collection and has been assigned a catalogue number, and a bar code label has been affixed to the box and the reel. A key piece of this is the elimination of duplicate data entry. This is one of

the things I've observed time and time again. The same, fundamental information gets keyed-in at several different locations. The other concern I've had is that all tapes look pretty much alike out of the box without a label. There are a couple of steps in this process that address the problem of, 'This is a tape; does anybody have any idea of what it might be?' This may have never happened in any other archive but, in case it has, or in case it might, the technician logs on to the work station; the computer recognizes the user and configures its graphic display in the style preferred by the technician – since it is software driven, the display doesn't have to be set to one layout only. I want the work environment as comfortable as possible because it's a pretty long day if you copy tapes for 7 or 8 hours a day.

Each technician has a specific level of authorization for making adjustments to the system that affects programme material. If the technician attempts adjustments that he is not authorized to make, the system will not enter record. If it is time for the system to have its calibration checked, the technician will be prompted to load the proper test tape. The computer controlling the audio analysis equipment tests it, and the recorders measure the performance of their system. The results are recorded in the technical data base and, if there is a measurement that is out of tolerance, the system will not record. If a measurement is approaching a maximum tolerance, a message is passed to the maintenance staff. The possibility of writing a trend-line of various performance parameters is, to me, a very exciting feature because it allows us to forecast a difficulty with the machine and programme maintained to occur before a breakdown while the studios are not in use. I think we'll learn a lot about exactly what machinery holds together and what doesn't.

After this system has been checked and calibrated, a copy can be made. The tape to be copied is removed from the pending work area, and the bar code is scanned. The work station queries the database computer and the data on the item is displayed, together with screens for data entry. At this point we get to the copy. The first step in making the copy will be a confirmation of the track layout on the original tape. We recently went through a collection of fifty tapes, all of which, we were told, were a certain track configuration. Forty five of them were; the others were something else. This was with good documentation from the donor.

The next thing that will occur will be a high-speed scan of the tape to locate the maximum levels. It is anticipated that five locations will be enough. As the tape is scanned, the addresses of the five highest levels on the tape will be displayed. The machine would proceed to each of them in turn and play the tape. It would then ask the operator if it is a valid high level, ie it is not a microphone being dropped, or a bad splice, or a number of other things. This is the reason for more than one loud point on the tape being checked; the loudest point on the tape may not be a piece of the actual programme. The computer will then display the correct level loss for the original tape and the level required for the target medium. When this information is acknowledged and accepted by the operator, the computer will automatically set that level offset into the console.

The operator will be prompted to load a blank carrier (tape, optical disc or whatever) on the record machine. The machine will then

standard computer modem. Essentially it is the same as a standard modem with the carrier detect disabled.

It is our intention to put the design in the public domain. It works with any computer serial port. The low data rate restricts how much data you can write but, again, we're looking for a system that will play in the worst case.

Steven Smolian:
So basically you'd be putting on tones in a particular sequence that would be translated by the computer into the identification code?

David Wickstrom:
Exactly, yes.

Steven Smolian:
You also talked about bar codes. Thinking back to some early history, there are a number of horror stories about this: how good is the adhesive on the bar code stickers?

David Wickstrom:
It depends on whether you ask the manufacturer or the user. The manufacturers say it's great; the users say it falls off. I feel that this is a problem that's within our degree of control. I may be over-confident, but I think we'll find a way, especially on the tape reel.

George Brock-Nannestad:
If you want to put information about the equipment that has been used on to your tape as part of the leader in a coded format, surely your equipment must be calibrated to certain standards that this information refers back to? In effect you need to work, particularly in archival copying, with well-calibrated equipment at all times. If you

don't, the information is worthless because it just says that back in 1992, or whenever, their equipment required settings equal to dial settings of that sort. The possibility of having standardized equipment is being discussed by the IASA Technical Committee. Would there be room within the first metre or so of recording tape to put signals on that represent certain test tones produced in a standardized fashion so that afterwards it would be possible to analyse the actual settings employed? This is really performing a measurement, rather than relying on a dial setting in the transfer situation.

David Wickstrom:
I think your first point is exactly correct. The recording settings themselves are next to worthless. This system will, of course, record (not on the tape) what it told the various items of equipment to do. I think that to presume that the equipment actually did precisely what it was instructed to do would be very dangerous. I have considered using some form of signal injected at the source, at the beginning of each transfer, but I think that's dangerous because of contamination [of the copy with the calibration signal, such as print-through with analog tape copies]. What I envisage is a self-calibration of the entire copy chain before each copying session. This is the transfer function and its technical description is written to the database along with, of course, what equipment was used, and this information forms part of the master database. At present, for every project, we always record what equipment was used: the brand, the model

enter play and look for a header recorded on the carrier medium. If it doesn't find one, it will assume that the tape is blank, and prompt the operator to set the automatic recording of a new header. This header should contain a number of pieces of information. One item would be some catalogue data – at least a common field number. This will help in locating lost tapes; in fact it should end that problem if the header is not, in some way, obliterated. It should also include an address specific in global record inhibit scheme and, also included in the header, should be a series of reference test signals for time and speed and to calibrate for later play-back. It can also check for signal degradation.

This is an area where the standards committees are operating. What exactly should be in that header? We need to agree on that and, the sooner we agree, the sooner a number of things could be happening. For one thing, we could interchange recordings a little more easily. Another thing that I would like to see in the header is something about the source and ownership of the recording. We face this when we hear our material coming from other places. I'm sure this header could be defeated, but it is worth a try.

Once the data header has been recorded, the system is ready to make a copy. The copy is made automatically and the appropriate index and technical information is automatically entered in the master database. This continues until the reel is almost full – the last two minutes of the tape will be used as a blank tape buffer and a short tail of data will be written to allow automatic determination of the recorded tape if it is loaded backwards. The machine will rewind to the header, update the data, and set the record inhibit for the recorded parts of the tape. If the tape is full, the record inhibit will be set for the entire tape, and the tape will only be played on a work station from then on.

The process of copying a disc will not differ a great deal from the method used to copy a tape. One difference will be that the operator will be prompted to manually sample the five loudest sections. The level scanner will continue to operate while copying is in progress for all types of transfer so that, if a wrong choice of level is made, there will be updated level data available. The worst case for this system would be one repeat of a wrong appraisal of the high level. Most of the technical data will be automatically entered in the central database. Copy processes that require some manual input of additional data, such as stylus selection, will not complete until the data is input or there is a management override. This ensures the generation of the audio trail that I spoke of earlier. The archiving of an item will include the audio trail, and this will be kept with the traditional catalogue information.

That pretty well completes the process of making a copy using this system. I personally feel somewhat inhibited about transferring audio using a computer keyboard instead of more familiar controls. Realizing that we are heading into the age of computers, keyboards and graphic screens, and maybe there are some advantages to those things, I have forced myself to work with audio using a keyboard. It took a couple of months to feel comfortable, but I have found that I can. I find in many ways I now prefer to use keyboard control and keyboard operations working with audio. If this is something that begins to occur in your work, do give it a chance. I had many years

of familiarity with analogue-type controls and I was certain that the interface through the keyboard would simply be inferior. It has not turned out to be the case for me.

Summary

What do I foresee as the benefits of this work station that I've described?

- All the functions within the archive are integrated – the documentation of the path materials take through the archive; the manipulation, what was done with them, is recorded.
- The elimination of duplication of data entry.
- The inclusion of catalogue information on the carrier itself.
- The inclusion of a record-inhibit capability.
- A restricted access to signal manipulation features so that only those that who have the talent and the ability to manipulate the spectrum are permitted to do so (this is a rare case for a preservation copy but in some cases it must be done).
- The automatic documentation of what exact steps were taken.
- The possibility of being able to make an absolutely unequalized, untreated preservation or archival copy and then use a menu of play-back options, of play-back equalizations, to select the sound that you would like for the use or access copy.
- The work station graphic and keyboard interface can be personalized for specific operators.
- The automatic calling of directory and catalogue information (if it is on a screen when the copy is being made, the operator may notice that the turntable is turning at 33 rpm and the catalogue data says it should be 78 rpm).
- The automatic generation of a safety copy is possible within this system.
- The system also permits a fairly easy move to a digital target medium and the automatic inclusion of a standard test-tone series to automatically monitor deterioration of the copies.
- A number-of-plays counter for the use of tapes.
- Automatic level scanning.
- Confidence replay systems for analogue recordings so that you can be certain that you're making a recording.
- Automatic intake testing of media to focus or to detect a bad batch.
- The automatic indication of external equipment having been put in in the copying chain. It can't say what item has been inserted *and the serial number. Then the technicians manually enter the settings. We also measure the operation of the equipment in the lab and archive that information as well; so we know that, if you set one particular equalizer to 200Hz, it is actually operating at 125Hz and that, if the slope was advertised as 24dB per octave, it was actually about 16.5dB per octave. That's very cumbersome, so this system will measure the actual transfer function.*

David Hall:
I have a question about headers, specifically as they relate to cataloguing input in terms of eventual public access to the material. How are you going to deal with this? It seems to me that you have got a bottle-neck here. We always had the problem at the Rodgers and Hammerstein Archive when I was there. You have a tape box or you have a disc – you have the raw data there which you may or may not slate on to the tape or whatever transfer medium you're using – but eventually, after you have your box numbered and put on the shelf, this data has to be translated into something that the public can read on a computer screen and be able to locate the recording. How do you bridge this gap? There must be a lag time between the header that you put in there for inventory purposes and what, eventually, has to be a public access point.

David Wickstrom:
I imagine that will be a formatting issue when the access copy is made. All the data is in the data base keyed to that actual recording and it might be nice to write all the data to the copy tape, but I don't think there's enough

room; it's a very inefficient way of storing this type of information. I would just indicate the information we want to append to the access copy, and it would be done at the time of making the copy; it would be done by the computer.

David Hall:
This lag time has always been a very, very serious thing. At Rodgers and Hammerstein we had a tremendous input of records and, for the LPs, we were reduced to just putting the material on the shelves and having our users go to a commercial catalogue. This was the only way we could cope with the problem, because we were literally years behind. Is there any way that your work station concept could deal with this lag time between getting your raw material on the shelf and providing an access point for the lay user?

David Wickstrom:
I'm not sure that it will, because the only thing that this system can do is show that data is missing and prompt people to enter it. I have some ideas about ways that you might be able to automatically scan documents to help enter data, but that's not part of this presentation. I can tell you one thing we did in our data-entry system. We provided look-up tables for each field so that, when somebody made a decision, it basically completed entries for you and gave an error indication if you were entering data that was outside the design and database parameters.

David Price:
One of our major problems at the BBC in London is the throughput of our record

into its patch point; only that the signal path response deviated somewhere.

- The automatic measurement of monitoring.
- The monitoring of system and component technical performance

The essence of this system is to define, organize and document the task of archiving. It uses a computer to assist and enhance the capability of the operator and acts as a watch-dog for out-of-parameter operations. It can be upgraded to an all-digital operation with the inclusion of appropriate hardware and, as I said before, this system can be built right now. All the hardware exists; the computers certainly exist and the Belfer Audio Lab is in the process of seeking funding to convert one of our studios to this system. I believe that it will not only improve our work, but that the productivity will be increased. I project that it will improve enough to pay back the cost of the system by savings in labour costs.

library. We have about 25 staff lending 1000 records every day of the year, which is a fairly major undertaking. Those records include about a dozen 78s every day. We don't lend out 78s any more, we dub them. Similarly, we don't lend out the last copy of our 45 rpm or our LP records, we dub them to tape. We have the same problem that you identified. We've reduced our costs so much that we don't have the technical expertise to do the dubbing, so the dubbing is done by trainee operators. Would you envisage that this technology could give us the ability to have untrained staff making good copies of 78s – analysing EQ problems, stylus sizes, and so on?

David Wickstrom:
I think it can help a lot. The way we envisage it helping most of all is by working up an artificial intelligence, if I may use the term, a database of waveforms based on the sampling. In other words, the machine is going to be sampling the waveform through the whole copy. It will eventually build up a database that says, 'Every time you've told me that you're using a 78 rpm record of this brand before, the waveform has always met this set of parameters. Now it's different. Why? Do you want to make an adjustment? Do you want to call for help?'

That's a first look at what can be done to help even a skilled operator to track problems. I also foresee integration with better analysis systems, and I was interested to hear CEDAR mention removal of distortion because I can think of some ways that that can be done, and that also says there are ways to detect that specific distortion.

David Price:
That's very exciting. We have experimentally used CEDAR. It's a very good product. Indeed, it was mentioned earlier that Christopher Roads was upset when few people brought in 78s to be restored. We have about 390,000 78s, and most of them are in very good condition. They don't wear out like our vinyl stock. I asked the CEDAR team what could they do about our one million vinyl records and I think they have modified the algorithms considerably over the last year to considerable effect. It is an irony that often we could have got round the problem by spending more time, more effort, on the original dub. And I would imagine that there are quite a number of public bodies like the BBC who simply are not resourced to take that level of care any more. CEDAR, I suppose, could offer an alternative, but at quite a cost.

David Wickstrom:
Well I wasn't necessarily suggesting using that exact system, although I know there are those who would favour it. I think you have to practice some kind of archival triage, and I think this system can help you. There is a probably a percentage of your recordings that can be copied fairly easily – there isn't too much wrong with them, and a relatively simple protocol will allow them to be transferred. Then there's a percentage that will require a little more effort. Finally, there are a few that will require what I would refer to as heroic measures to save them – they are so valuable. One of the things I've pleaded for is good indexing: why go to heroic measures to save a recording when there is a good copy in another collection? Of course, where there is only one copy, you have to do what you can to recover it. I think we must start to group and assign parameters to these various recordings, and then authorize people to copy recordings to a particular level of difficulty. If they are given a recording to copy that is above their level of competence, they stop. I don't, at present, envisage a system that can handle every difficulty, but I do envisage a system that can increase throughput of copying. My main concern is that it takes us three to four times real time to make a good copy and that is prohibitively expensive, especially as many of the recordings were in pretty good condition to begin with. We needed to find the highest level, know the EQ curve, and make a copy.

Christopher Roads:
I'd just like say to David Prices's point that the need for this development has been apparent for certainly a few months with current growth of CEDAR. We have actually got a research programme under way in this particular application. We haven't talked about it today because, until this moment, it hadn't really come to the fore. But certainly we have been discussing the ways in which it can be done in a module extension of CEDAR. I'm told by our scientists that they can solve it and we will very shortly be attempting to prove to you that we have solved it.

The Archivist's Requirement of a Format

William Storm

Brian Jenkinson:
Our next speaker is Bill Storm, Director of the Belfer Audio Laboratory and Archive at Syracuse University. I think it would be invidious to try and introduce him formally to you. What I would like to say is that, when he first asked that question in Vienna at the meeting of archivists and manufacturers, the rest of us wanted to talk about it. Bill said, 'Let's not talk about it, let's do it.' Bill, would you come and talk about it now?

This is one person's reflections upon the potential for a multi-media format or system for audio-visual archives. One of the things I was very fortunate to experience was the 1987 Joint Technical Symposium in Berlin. At that conference, a lot of what was discussed was: 'Here's what we're doing right now, here are all of the problems that we have, and this is the traditional way we've approached the solving of these problems.'

If any of you were fortunate enough to be at that conference as well, you will detect that there has been a shift in focus. Maybe it's subtle, maybe I'm prejudiced, but a lot of what I've been hearing in the last three days is, 'Where can we go?' as opposed to, 'Boy, we've got lots of problems.' There were some expressions of 'Where can we go?' in 1987 but, during the last three days, what we've heard is, 'We would like to propose that you use this media,' or 'We would like to propose that you use this system.'

This particular audience is now being challenged, is being given opportunities to find out where we are going to go in the archival field. This has been revealed in papers about signal processing equipment and about media, and in the reports from the groups that are now trying to formulate standards working in co-operation with the different manufacturers. So I think this conference has a very different kind of feel from the one in 1987. What I would like to say, what I would dream about is, in 1993 at the next JTS, a real, solid answer to the question that I've raised.

If we consider what we've heard in the last few days, one thing that we have to take into account is the source that we're trying to save. I mean that in the sense of: is it audio data? is it visual data? or is it textual data? One thing I would also like to propose is, instead of saying, 'Is it this? or Is it that? or Is it the other?,' we should now start to consider the word 'and' in between there instead of 'or'. Can we store audio and visuals and textual data on the same storage system? That's quite a challenge.

The next part of our chain is that we have to playback these individual types of source. The next logical thing that we envisage, as Dave Wickstrom said in the previous paper, is a transfer station. Wouldn't it be nice to get the accumulated knowledge of experts in the field and put some of that knowledge into a databank that could assist in the transfer of the source material into a target storage medium? Again I'm talking about audio and visual and text. So the transfer station concept plays a very important role in making sure we have good data integrity, that the source is played back properly via the computer-assisted transfer station and goes into the storage media. Now I'm not going to define the storage medium yet; let me first complete the chain.

The next thing we have to concern ourselves with (this is something that David Hall was referring to in the debate following David Wickstrom's paper) is access. We need to provide good retrieval systems as well and, if we do have a good retrieval system, the next thing we want to do is to disseminate that information. I want to get it into as many places as possible because some of us have the naive attitude that archives are actually set up to collect and disseminate information, not places set up to collect and warehouse information and keep it as our own private collection. That certainly is the purpose of my institution and, I suspect, it is the purpose of most of yours. We're not private collectors. I'm not trying to pick on private collectors, because they've been some of the most forward-thinking people I've run in to. They sometimes provide much better access than the institutions do, because of the quantities involved.

So these are some of the fundamental parts of the chain as I would lay them out. What I haven't mentioned, and it is distinct from any of these, is the signal processing that might be employed. It is possible to envisage signal processing at this stage. This has great appeal from an archivist's point of view because, if you could get the transfer station to log details of potential signal processing and not apply it to the transfer copy but call up the details on playback, then you'd really have the best of both worlds. That would mean that you could make a very linear, unprocessed transfer and then upon playback call up data and apply predetermined processing to a very straight transfer.

To implement that in terms of the question, 'Is a format or system a practical proposition?' my opinion is that we'd have to go into the digital domain. In the digital domain, we can do a lot of these things right now. It doesn't necessarily have to be a 100% digital. It could include an analogue/digital interface; using the best of both worlds until we have a situation where we can go in one direction.

Now, is this really practical? We've heard a few different storage systems mentioned, and some of the possibilities that we've heard mentioned are optical discs. I want to use this term in a very broad sense to cover glass discs, WORMs and all the other types. We've also heard about digital tape, and Jim Wheeler earlier mentioned systems such as D1, D2 and D3 and, of course, we also have the great 'miscellaneous'.

I'd like to talk about the WORM (Write Once, Read Many) optical disc systems and see how they fit into: 'Is this a practical application?' What I'm saying is, let's consider WORM as the storage medium. Firstly, does WORM have the capabilities that we desire? Can it store visuals? Can it store audio? Can it store text? The answer to these questions is definitely, yes. The problems, however, are many in the sense of time – how much data can it hold? For textual information, WORM certainly seems a very good idea; for audio information, it still looks promising; but for visual information things get a little scary because of the amount of data needed to capture an image with high fidelity.

So there are some limitations. But is the multi-media capability there? Yes. So, is this something that we should consider? In my opinion, absolutely.

Paul Mawhinney:
On the WORM disc, you can have messages in the subcode to detect what kind of drive mechanism you're using, so I don't think you have to be concerned about that. Also, in answer to David Hall's question: there are three different ways to eliminate the bottle-neck. One way is to print a catalogue (if you have a database you can do that easily); another way is to give the customer direct access to the database (by artist, by title, etc); the third way is to have a machine-readable code on the CD, album, whatever that you can read with a laser reader. These three different ways give instant access; as soon as the item is catalogued, as soon as the information had been put in, it's already on line and accessible.

Bill Storm:
One of the things I meant to mention in that regard is that, if we can go in the multi-media format, we fully expect to be able to provide access via the network not only at a local level but literally at a global level. So if we can get the components of a transfer station linked to a multi-media format, the capacity to send data over networks and over satellite becomes a reality. The lag time that David mentioned would then be minimized, because we'd be getting documentation as the process is occurring rather than having to wait for somebody to document what we've done. This is a very important part of the scheme as we envisage it in Belfer. Have you any comment on that, David?

David Wickstrom:
There's another element of this that is essentially an input function: at the time

Now consider this as a storage system – and when I say system, I refer to the medium plus the hardware and the software involved. We have the medium itself, the WORM disc, and we also have as a part of this system, the drive – the piece of hardware that's trying to collect the data from the medium. What are our concerns? The first one is the WORM disc itself. If we can believe some of the claims that are being made, we have a pretty good product. We're starting to hear terms like Century Media, Century Disc. Our concerns in this area are about life expectancy. If we can reduce that concern to a point where we, as archivists, feel comfortable with the life expectancy of WORMs, then we start saying, 'That's pretty good; the multi-media capability seems to exist.'

How do we reduce these concerns? With all due respect, I don't think we're going to reduce them with graphs from vending companies. I think an important part of what we need,is objective studies by user groups that can perform certain kinds of evaluations. Equally important, we need the cooperation of the vendors in these tests. We must all recognize that we're all trying to get to the same place, and it is to our mutual benefit to do so together. We have heard Christopher Roads on numerous occasions mention the research that the British National Sound Archive is involved with, and Michael Croll mentioned the optical disc research, so we do have an institutional body doing some research. In the United States – this is not meant as a plug – a number of institutions are seriously considering WORMs. I will read the precis from a grant application for funding to look at this particular medium:

> Optical discs of the WORM (Write Once, Read Many) – type are being considered by many archives as a medium for preservation transfer of recorded sound and video. The urgency of this arises from the unstable nature of magnetic tape and other sound recording media. Long life is claimed for some WORM disc media, but this must be objectively evaluated in light of the needs of archives. Moreover, standards must be created for longevity test methods, signal fidelity criteria, and data interchange ability. The transition to optical disc is also complicated by rapid obsolescence of formats and hardware. While this evolution will always occur, it is best managed by the preservation of a thoughtful, unified position which the archival community as a whole can endorse.
>
> This project seeks to address these technical and administrative issues in a systematic way by forming a cooperative for research in information sharing among three institutions – The Belfer Audio Laboratory of Syracuse University, The Image Permanence Institute and The Library of Congress. Working together, the cooperative can assemble the necessary resources to evaluate up to three WORM disc media, recommend systems and formats and forge a consensus position on the archival applications of this technology to be presented in ANSI, ISO and JIS standards committees and to the preservation community at large. Activities which are included in this proposed three year project are:
>
> - To establish the cooperative through a series of working sessions in Syracuse, Washington and Rochester and, as a footnote to that, this is by no means meant as an exclusive arrangement. All of these institutions are interested in as much international and national cooperation as we can get.

- To investigate existing media and prepare a bibliography of source materials relevant to the permanence of optical discs.
- Select up to three different WORM disc media, together with associated hardware for inclusion in actual performance tests.
- Develop a consensus among participants concerning test procedures for these media.
- Prepare a file of test data consisting of sound, images and textual matter for a test programme.
- Carry out a programme of permanence tests on the three disc media.
- Evaluate the effects of environmental tests on the fidelity of the sound, image and text reproduction and develop life-span predictions where possible.
- Prepare a report and recommendations to the ANSI/AES subcommittees and for publication to the preservation community.

What this proposal, and some of the other propositions you've heard, is saying is that we're serious; we think this is a viable alternative. We're not going to sit around and wait for what happens. We don't want to be victims of a system; we want to be the beneficiaries of one. The only way to be beneficiaries is to be a part of the evolutionary process, and I think that's what we're doing.

Let us be optimistic and say this is looking pretty good and, if it stays pretty good, what are our other liabilities from an archival stand-point? Our other liabilities are, of course, the computing system itself. One of the things that has come out of discussions is that this is not a liability at all. One of the things we all hope is that we'll get faster access, better computing power etc. We're not worried about the computers. That may seem silly but, in our opinion, it's not the problem.

The problem is communications. The problem is understanding the protocol of the computer so that it can talk to this factor, the drive. If we know the protocol, then it doesn't matter what happens with the computer. As long as we understand that language and the computer can be made to understand how to talk to a particular drive, then access to this media – and again I'm using this as an isolated example, I could just as easily have chosen digital tape as an example – is not a major concern. If we're now starting to test media and trying to find a comfort level with media, our primary concerns boil down to two particular factors: one is protocols and the other is the drive that accesses the medium.

In my opinion, when you talk about long life expectancy, it's silly to just talk about the medium. If you can't get access to the signal, you don't have long life expectancy. If we can convince the manufacturing community to really put some effort into the drive, all of a sudden the number of variables that we have to deal with are minimal. The protocol is critical. When people say it's impossible for us to have access to digital data in an optical format for a very long period of time, I disagree. If we can solve these two problems, can we get a manufacturer to back us up, knowing that there's a market place for this particular kind of a system? Build us a drive

something is acquired, the minute it enters the process, as much data as possible is keyed in and at that point it should be accessible. In the case of the national sound collection, it was. It might only read, 'We have it, this is when it was recorded, and this is what they called it at the time; but it has yet to be transferred and is not yet part of the accessible collection.' And that of course led to special pleadings for access to an uncatalogued or an untransferred tape. So these systems should dramatically improve access, at least letting you know that an item exists.

Christopher Roads:
Firstly, recognizing that we're talking about a fairly massive undertaking, it's quite clear that we can't proceed without very considerable investment. What has been described as the American intention is virtually identical to what we have been doing in London for the last year and a half. To ally the commercial interests, we've been looking at where they currently lie. When we look at the area that is moving masses of visual data around the world at high speed, the patent area is an obvious target: for example, there are 60 million computer tapes in London that are drawn upon regularly, and there is a massive communication of visual information between Tokyo, Washington, London and The Hague. So this is quite clearly an area that could carry a good deal of development, but the problem is that the manner in which it may be done may not be coincident with our interests. We are in deep discussion with the group for fax people who believe that that is the way that one should go. So my first point is that it is

complicated trying to ride on the back of those interests that could be allied with us.

Looking at the actual disc itself, we shouldn't ignore the fact that these optical discs have interested other parties. The difficulty is getting at the information. We know that the Ministry of Defence has been heavily testing the use of optical discs in military situations and, if we could get access to this work, we could save ourselves a great deal of effort as they are clearly just as concerned as we are with longevity, durability, etc.

Finally, the drive is obviously important; last year we met with Plasmon in England and discussed aspects of preventing the obsolescence of the drive. Of course Plasmon had recognized that the drive is critical and had already demonstrated that it was possible by deposition of specification to ensure that drives could continue to be manufactured indefinitely. As a company they were also concerned to give guarantees of supply on the discs for sixty years, and so on.

So we certainly concur about the components that you've identified, but I believe that the real way forward lies in finding natural unions with other interests, such as the patent offices, so that what we're talking about becomes a reality.

Bill Storm:
The American initiative does differ significantly in the sense that the first part of the project is to establish an agreed method of testing. We've found that different people are testing life expectancy and doing Arrhenius plotting in their that has a long life expectancy, that is documented very well, that we can continue to get support for and let us know the protocols. Then, if the computing changes, we're not going to worry a great deal about it.

So the answer to the question that I raised earlier is, I do think we have a viable way of putting audio and visual materials on a common medium? I would also add that there's an aesthetic that can never be forgotten. I would never for one minute, certainly at this stage in electronic development, try to apply this system to film. There is a wholly different aesthetic to it. On the other hand, is it a way to, maybe, help put in data that can be used to correct the film down the line? That's another issue. Perhaps, as the electronics get better, this system might even become a viable alternative for film. I certainly think that the practicality of this system is close at hand for video, for still images and for audio, and I'd like to believe that in 1993 we'll have a few different systems that demonstrate the realization of this.

own way, and at this point there is no standardization of testing. So we want to look at all the different ways the testing has been done and, based on the combined efforts of a number of institutions, to find out what we all agree on. Then, when we start to derive longevity predictions they will be based on a standardized series of tests rather than on specialist tests or a particular vendor's version of a test, otherwise I think that some of the predictions are meaningless. Some of the tests that we've seen here in the last three days have been carried out differently, and what we need is to get some common testing practices.

In terms of working with the allied interests, I would agree with you 100 percent and that is why that particular proposal is being done in concert with the ANSI group and with the AES group that includes the manufacturing community, people like NASA, and a lot of the computing people. That may end up being part of our salvation because, when we start talking multi-media and the concerns that we have for audio and visuals, we get so much support because computer data has the same needs. The computer market out there is infinitely bigger and stronger than we are, and it's ironic that we're actually the leaders in the area. So the areas of interest are very similar, but we need to work more cooperatively so that we can have conclusions.

Dietrich Schüller:
In my fifteen years' relationship with Bill Storm, I want for the first time to disagree. First of all, I question the feasibility of the means we have at hand to store moving images, television signals, in digital form on optical discs in a feasible length. We have an enormous lot of data to store, and we have learned from Jim Wheeler's lecture that we need 10s and 100s of giga bites to store a television programme. The second question is, how long do you want to test to arrive at a certain product that then is feasible? In five years' time you might perhaps conclude that product X, Y or Z lasts for 30, 40 or 50 years. But, coming back to the paper I read yesterday, there are products on the market that are guaranteed for 20 years and for the audio domain this is definitely enough. We could start our system tomorrow, we have everything we need. I think we have to give up the idea of the very long-lasting carrier and the very long-lasting drive, which in your terms is probably 50 years and longer – 20 years is enough! I've just been given a very valuable piece of paper by Gerald Gibson saying that in the US audio collections he has spotted two and half million hours of recorded programme that need preservation, for eternity presumably. So don't even start the testing, start and make a decision now.

Bill Storm:
First of all, as far as the moving image and video is concerned, I thought I had said that at present the WORM disc can't handle this. But there are some 12-inch discs that may offer more potential, and there are also some new discs coming out that show potential. On your other point, in terms of the need to get on with things now, I'm in total agreement you. That is one of the reasons that, from a management point of view, the audio engineering group said, 'Look we have to do something now, and let's at least make some kind of a statement as to how to do it for audio.' We do have an agreed upon standard for audio in that group; it may be controversial globally, but there is an agreed standard. So we're not stopping at all. And I'm very glad you brought up Gerry Gibson's scenario of two million recordings; that's all the more reason you have to test a material and test a system, because you can never afford to re-record them a second time. So, if you're going to go to a new medium, then it makes a great deal more sense to do some testing before you move from an agreed standard to something else.

Dietrich Schüller:
I'm sorry, I disagree. We can only afford it if we are prepared to re-record and re-record and re-record – automatically, without touching the material any more, and then we have to bring all our materials into the digital domain, and then this system that I described yesterday would care for itself from the moment that we put our material into it.

Bill Storm:
I think we're talking about two different issues. You're talking about the capacity of self re-recording and automation. That's not what I was addressing. If you want to integrate that into a system like this as well, I think it's very possible, and we should talk about it.

Appendix

The Session Chairmen and The Technical Coordinating Committee

George Boston

George Boston is the Manager, Audio and Cameras, at the BBC Open University Production Centre at Milton Keynes. He joined BBC Radio in London in 1962 and in 1967 transferred to Manchester, where he was introduced to Television. George was the Assistant Audio Manager in Manchester from 1975 until moving to Milton Keynes in 1982. He is a member of the IASA Technical Committee, of the Royal Television Society and of the Audio Engineering Society. He is the current Chairman of the Technical Coordinating Committee.

Harald Brandes

Harald Brandes is the Senior Technician of the Filmarchiv of the Bundesarchiv in Germany. He has been a member of the FIAF Preservation Committee for several years, and is a member of the ICA Audiovisual Committee. He was a founder member of the Technical Coordinating Committee, and has presented papers to the Joint Technical Symposia held in 1987 in Berlin and in 1990 in Ottawa. He regularly advises film archives in developing countries.

Frederick Granger

Fred Granger has been engaged in communications and museum collections management projects for over thirty years. During this time he has provided technical advice and support in areas such as the design and development of television studios, acoustical laboratories, interactive multimedia learning stations and optical or videodisc production.

His background is a composite of military telecommunications system development, film and television production, computer assisted learning and international archival and collections management standards. He is currently the Chair of the Standards Committee of the International Council of Multimedia Users (ICMU).

Fred has published material on image-text interactive systems for use in museums, and is actively involved in conference workshops and in training sessions for development and education of collections management staff.

Shortly after the Symposium he left the Museum and is currently working for the Canadian Heritage Information Network.

Brian Jenkinson

Until recently, Brian Jenkinson was the Manager, Engineering Systems and Investigations, Television Recording at BBC Television in London. He started to work with video tape in 1959 using the BBC experimental machines, which recorded on half-inch tape running at 200 ips, as well as the early Ampex quadruplex machines. He was

promoted to Head of VT Maintenance and then to Head of Recording Investigations. During this time, he was part of the team that was responsible for many innovations in video tape, and built up a strong reputation as an authority on both hardware and the medium.

Brian left the BBC in 1989 and now works as a consultant for, amongst others, the National Film Archive in England.

Eva Orbanz

Eva Orbanz worked at the German Film and Television School in Berlin from 1967 to 1972. She was a guest student at the Cinéathèque Royale de Belgique, Brussels and the British Film Institute in London and joined the Stiftung Deutsche Kinemathek in Berlin in 1973 as a coordinator. In 1985 she was appointed Head of the Film Department. She organized the Joint Technical Symposium and the Film Retrospective held in Berlin in May 1987.

Among the books that Eva has written are *Wolfgang Staudte* and *Journey to a Legend and Back: The British Realistic Film*. She has also edited and written numerous patents, technical texts and papers such as, 'An Experimental Quality Control Programme for Printing Archival films,' published in the *Journal of the Society of Motion Picture and Television Engineers*. She is the current Secretary-General of FIAF and the Rapporteur of the Technical Coordinating Committee.

Henning Schou

Henning Schou is the Head of Film, Sound and Television Preservation and Technical Services at the National Film and Sound Archive in Canberra, Australia. He is President of the FIAF Preservation Commission which carries out research and publishes guidelines and recommendfations on all aspects of motion picture preservation. He has undertaken research work on deterioration of colour dyes in film stocks and on the decomposition of nitrate film – two of the major problems facing film archives worldwide. He is a member of the FIAF Executive Committee and represents FIAF on the Technical Coordinating Committee.

Dietrich Schüller

Dietrich Schüller began his studies at the Technical University in Vienna with physics, but changed to ethnomusicology and cultural anthropology. He graduated in 1970. In 1961 he joined the Vienna Phonogrammarchiv as a student assistant and became its Director in 1972. He is actively involved in the technical and methodological aspects of sound recording for research purposes, especially field recordings, and the problems of sound preservation and re-recording. He is Lecturer on audiovisual carriers at Vienna University.

Dietrich has worked as a Consultant to a number of audiovisual archives in Africa, Arabia and the Caribbean. He was a member of the Executive Board of IASA from 1975 to 1987, and is Chairman of the IASA Technical Committee. He represents IASA on the Technical Coordinating Committee. He is a member of the Audio Engineering

Society and a member of the Austrian National Commission for Unesco.

Lloyd Stickells

Lloyd Stickells has worked on the restoration and re-recording of sounds for many years. He was trained in recording on disc and tape at the BBC and worked in their London studios until leaving to work for Radio Zambia. On returning to London, he was employed at the Imperial War Museum from 1975 and at the National Sound Archive from 1980. He is currently working as a Consultant to the National Film Archive. He is a member of the Audio Engineering Society Subcommittee on Preservation and of the IASA Technical Committee.

William Storm

William Storm is the Director of the Belfer Audio Laboratory and Archive at Syracuse University in the USA. He is also an alumnus of the University, with a Masters Degree in Television, Radio and Film. He is a member of the Technical Committee of IASA and represents IASA on the Technical Coordinating Committee. He He is the Chairman of several committees including the Technical Committee of the Association of Recorded Sound Collections, the Audio Engineering Society's Standards Conmmittee Subcommittee on Preservation of Audio, and Co-Chairman of the Joint Technical Commission of the American National Standards Institute and the AES, devising standards for optical and magnetic recording materials.

The Technical Coordinating Committee

The Technical Coordinating Committee (TCC) was formed after the 1987 Joint Technical Symposium in Berlin at the suggestion of the industrial representatives attending the 'Consultation of Users and Manufacturers of A-V Archive Equipment' organized by Unesco. The Committee is composed of two members of the technical commission of each participating non-governmental organization (NGO), plus a Chairman and Rapporteur appointed from outside the ranks of the committee. Its activities include the dissemination of information, both of problems and of solutions, the production of teaching materials, and suggesting and supporting research projects into topics of concern to audio-visual archivists. The Committee works closely with Unesco and the NGOs to achieve its goals.

The TCC organized the JTS on behalf of the International Round Table on Audio-Visual Records. This is a grouping of NGOs recognized by Unesco that work in different areas of sound and image archiving, but who try to coordinate their activities and cooperate on projects to promote their work. The TCC is a subcommittee of the Round Table. The organizations forming the Round Table are:

- The Fédération Internationale des Archives du Film (FIAF)
- The Fédération Internationale des Archives de Télévision (FIAT)

- The International Association of Sound Archives (IASA)
- The International Council of Archives (ICA)
- The International Federation of Library Associations (IFLA).

The last two organizations deal mainly with paper records, but both have a committee dealing with audio-visual materials.

Fédération Internationale des Archives du Film

FIAF was founded in 1938 to bring together the institutions of all countries that are dedicated to the collection and preservation of films, both as elements of the cultural heritage of the country and as historical documents. The term 'film' is used in a general sense. Article 1 of the FIAF Statutes states, 'By film is meant a recording of moving images, with or without accompanying sounds, registered on motion picture film, video tape, video disc or any other medium now known or to be invented.'

Today FIAF comprises 78 institutions in 56 countries. Of these, 53 are Full Members and 25 have Observer status. FIAF is administered by an Executive Council of thirteen members who are elected to serve for two years. The Council is supported by three specialist commissions: Cataloguing, Documentation and Preservation. It is the latter Commission that is represented on the Technical Coordinating Committee.

The **Preservation Commission** was set up in 1960 to assemble, study and publish the most reliable scientific information relating to the storage, preservation and restoration of film and associated sound recordings. The Commission's publications include a Technical Manual, which, to make the necessary continuous updating easier, is in loose-leaf form. It is published in three languages. Topics covered include basic film handling, the design and layout of film storage facilities, the handling, storage and preservation of nitrate films, the stability of colour films, the prevention and treatment of bacterial and fungal attacks, and the preservation and storage of magnetic materials.

Fédération Internationale des Archives de Télévision

FIAT was founded in 1977 and currently has some 60 member institutions. The majority of these are associated with television broadcasters, and provide a specialist film and video archive service for their parent organization. Most of them rely on their companies' technical facilities and staff to provide the necessary copying and preservation services.

The TV archive permanent staff deal mainly with the storage, cataloguing and stock control of the material. A number of the larger archives are investing in automatic shelving and retrieval systems, and are increasingly involved with the restoration and transfer of video and film recordings to modern formats.

International Association of Sound Archives

IASA was founded in 1969 to provide a channel for international cooperation between archives and collectors working with sound documents of all types. The Association is actively involved with the preservation, organization and use of sound recordings; the techniques of recording and reproducing sounds in all fields that use the medium of sound, the exchange of recordings and of related literature and information between archives, and all subjects relating to the professional work of archives and archivists such as acquisition, documentation, storage, copyright, access, distribution, preservation, recording, copying and play-back.

The Association has more than 400 members, both individual and institutional, in some 40 countries. The Executive Board is elected for a three-year term of office, and is supported by a number of committees with specialist subject interests.

The **Technical Committee**, which is represented on the Technical Coordinating Committee, provides an important forum for the technical staff of archives. It works to promote international links and to disseminate information about technical matters. The Committee takes a major role in communicating technical information to non-technical members of the Association. To further this educational function, the Committee has published technical articles in the *Phonographic Bulletin*, the Journal of the Association, and has organized tutorials at the Annual Conference. In addition to its own specialist work, it acts as an interactive teaching resource for the membership.

The International Council of Archives

The ICA was founded in 1948 to provide a forum for archives handling records of all types, including print and manuscripts as well as the modern audio-visual media. The member archives are at all levels of development from all regions of the world. The Council currently has over 700 members grouped into four categories:

- Category A: National and Federal Archives
- Category B: Associations of Archivists
- Category C: Regional and Local Archives
- Category D: Individual Archivists

Some 120 countries or territories are represented in the General Assembly, which meets every four years at the Annual Congress.

The right to vote is given to Category A and B members only. Between Congresses, the Council is administered by an Executive Committee of 30 members – nine of whom represent the nine Regional Branches (four African, two Asian, one Central and South American, one Caribbean and one Pacific). Among the various specialist commissions and committees is the Audio-Visual Committee, which is represented on the Technical Coordinating Committee. The Audio-Visual Committee represents the interests of those archives and archivists dealing with recorded images and

sound. These may be a section of a larger print archive, or a specialist audio-visual archive.

The International Federation of Library Associations

IFLA is an independent, international non-governmental association whose purpose is to promote international understanding, cooperation, discussion, research and development in all fields of library and information activity, and to provide a body through which librarianship can be represented in matters of international interest.

There are over 1200 members/affiliates/bodies within IFLA. More than 900 of these are institutional members, ranging from National Libraries to small independent information units. The work of IFLA is undertaken by 44 Sections and Round Tables, each specializing in a different aspect of library and information provision. There are also 6 Core Programmes relating to major areas of activity, eg UAP (Universal Availability of Publications), PAC (Preservation and Conservation), ALP (Advancement of Librarianship in the Third World.)

The Round Table on Audio-Visual Media is the main group specializing in matters relating to audio-visual materials. The Round Table is a small group and collaborates, where appropriate, with other sections within IFLA on specific matters. Its main function is to promote the use and availability of audio-visual materials and to advise and monitor developments.

As a result of an initiative by the late Guust van Wesemael, the International Round Table on audio-visual Records evolved from an exploratory meeting of IASA, ICA and IFLA held at the 1981 IFLA Annual Congress in Leipzig. The first meeting of the International Round Table took place the following year in Paris.

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