Preservation and Reuse of Motion Picture Film Material for Television: Guidance for Broadcasters

TECH. 3289-E: Supplement 1 April 2004

This supplement to EBU Technical Document 3289 (2001) is in the nature of an addendum. As such it should be interpreted as providing updated information to portions of the original document, or, in the case of digital cinema, bringing new material to the discussion.

There is no direct correlation between the chapter headings of Tech Doc 3289 and those of the present document as it was considered important to maintain the readability of this supplement.

TABLE of CONTENTS

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1. Introduction

EBU Technical Document 3289, "**Preservation and Reuse of Film Material for Television"**, produced in March 2001, has been widely quoted in many publications. It continues to provide a valuable and accurate resource on film storage, progressive decay of film and film images and the techniques for transferring film images to preservation and access formats. It is directed at broadcasters and as such is generally confined to broadcast uses.

Every film collection is unique, with its own (largely unrecorded) handling and storage history. For this reason alone every collection needs to be checked frequently to estimate its continuing value and to allow decisions to be made about its future. That having been said, it must be noted that the life expectancy of film, even very old film, that is properly stored in the right climatic conditions far exceeds that of any current video, data or digital format. Regular checking ensures this.

Today we increasingly worry about the consequences of the past. In all film collections there is decay and image impairment that we cannot explain. The vinegar syndrome is the only degradation variable that continues to be studied and there is a great deal of useful technical literature on the vinegar syndrome in relation to the climatic conditions of vaults. Dye fading is still a relatively unresearched phenomenon and it varies considerably from one manufacturer to another, and between film stocks of a single manufacturer.

Since 2001 a number of world-wide investigations and research programmes have marginally changed some thinking on existing preservation programmes, supporting some, challenging others and developing existing ideas into more tangible and realisable philosophies. This document is an attempt to encapsulate this recent thinking.

It must be noted that in estimating the remaining life of film material the term "expected lifetime" is often used to indicate the remaining lifetime based on its chemical and physical decay up to the point where the film can no longer be used. In terms of a broadcast production chain the expected remaining "usable lifetime" of a film might be rather different, as it will additionally depend on the properties and capacities of the individual processes in the production chain. In a broadcast production chain the telecine is the bottleneck that will restrict the usable lifetime of archival film. Since most telecines are not designed to handle archival film their individual properties and capabilities will affect the usable life of film

Using the information in this document, each broadcaster should undertake their own management investigations to formulate their plan to maximise the life expectancy of their film archive.

Other sources of useful Information

FIAT/IFTA (www.fiatifta.org) and EU projects such as FIRST [1] and PRESTO [2] have useful information on their websites.

2. Dye Image Degradation, Base Decay and Storage Conditions

2.1 Dye fading

Film images are either silver, or are dye combinations. Today all the dyes in film images are produced by dye coupling during processing, although this was not always so. EBU Tech 3289, 2001, presents information from Eastman Kodak on the stability of dyes, concentrating on "dark fading", dye fading occurring in the dark and accentuated by high temperatures and to a lesser extent by humidity, and that different film stocks fade to different extents.

Table 1
General effect of temperature on dye fading rate at 40% constant relative humidity.

Storage temperature	Relative dye fading rate	Relative storage time
30°C	2	½
24°C	1	1
19°C	½	2
16°C	¼	3½
12°C	1/5	5
7°C	1/10	10
-10°C	1/100	100
-26°C	1/1000	1000

Table 2
General effect of humidity on dye fading rate at constant temperature.

Relative humidity %	Dye fading rate	Relative storage time
60%	2	½
40%	1	1
15%	½	2

Table 3
Examples for dye fading of older film stocks at 18°C and 50% RH (since 1976).

Type	Film Stock	ΔD = 0.1 .	ΔD = 0.2 .	ΔD = 0.4
Reversal	Ektachrome Commercial, 7252	3 years	7 years	18 years
Reversal	Gevachrome II T 700	6 years	14 years	-
Negative	ECN II 7247	20 years	-	-
Print	ECP 7381	4 years	11 years	18 years

*Where D**D** is the loss of the density value at an original starting density of 1.00.* *Source: Eastman Kodak*

Eastman Kodak predicted in 1987 that both camera negative originals and print films kept in the dark at 7°C and 40% RH would take 200-400 years for the loss of **yellow dye** to diminish by 0.1.

Modern film stocks after, say, 1980 are considered to be more stable and some old film stocks (such as Eastman Colour Reversal Intermediate (CRI)) are known to be considerably worse.

Eastman Kodak publication No H-23X "The Book of Film Care" sets out this data on yellow dyes and although it is still widely valued it is becoming generally accepted that some of the information should be regarded with caution.

Examples from reality do not seem to provide such precise data, or such long dye lives, and many archives report anecdotal evidence of far worse degrees of fading. While there is much information about the decay of nitrate film and the vinegar syndrome decay of acetate film there is no authoritative research on these dyes.

Collections, archives and broadcasters alike can expect that dye fading will be more severe than the currently available information implies. Reports from Hollywood suggest that all pre-1980 camera negative and all pre-1985 print is faded, however it is stored.

It is uncertain why the emphasis was placed on yellow dye fading as this is of minor importance in comparison with the dark fading of cyan dye, which is far greater in all colour films (resulting in the characteristic magenta images of faded prints and reversal originals).

Restorers know that cyan is the principal problem, with yellow a secondary problem in some stocks, which often exhibit an uneven yellow staining rather than fading. Huge budgets have been needed to restore some of these cyan-faded originals.

2.2 Vinegar Syndrome

The **Image Permanence Institute** in Rochester NY has been an important source of impartial data on film decay for many years. It continues to educate archivists and broadcasters in the factors that they can use to control decay. Their most recent assistance is the **Prescalc [3]** software that is available from their website. Prescalc uses the film storage humidity and temperature to estimate the expected lifetime of fresh film base.

If 7°C and 40% RH are entered (the Kodak conditions to keep the loss of yellow dye to just 10%) the film base lifetime is 317 years. Experience from collections suggests that the cyan dye will be long gone by this time!

If the 18°C and 50% RH storage conditions used in the dye-fading table are used, Prescalc indicates a likely lifetime for the film base of only 56 years.

Most film collections are not kept under these conditions of low temperature and humidity partly due to cost but in some broadcast collections, because the organisation requires the film to be accessible without long warm-up times. This puts some print collections at considerable risk as a vault at 20°C and 40% RH puts the life of fresh film at only 58 years, and many films approach or exceed this age now. Film stocks are still on the market and the negative master (perhaps kept in better conditions) can still be used to make a new print. This will not continue to be the case indefinitely and eventually a new print will not be possible. Thus the only source of the image will be the negative master (or a digital copy, having a considerably shorter lifetime than any film).

Freezing film to temperatures as low as -5°C and 30% RH puts the life expectancy of fresh film at thousands of years.

IPI have also analysed the effects on film of fluctuating storage conditions and this has produced a number of important lessons.

Low RH and temperature reduces the vinegar syndrome decay, as measured by acid increase, and freezing conditions bring decay to a virtual standstill. There is also good reason to believe that a similar reduction occurs to the rate of dye fade (although research is badly needed). This provides the possibility of arresting all decay by freezing. It has also become clear that film at the end of its useful life, either due to base decay or image fade, can be maintained in this perilous state by freezing while, hopefully, decisions are made for its rescue.

In conclusion it is becoming more and more obvious that the potential lifetime of film, both in terms of base decay and image fading is far longer than has been believed, providing archives with the knowledge that the format with the greatest image information has the longest life. On the other hand this longevity can be jeopardised by poor storage conditions.

IPI research has crystallised attitudes to film storage. The IPI Prescalc software should be seen as an essential management (and accountant’s) tool. In the future it is hoped that more research will support its development for the analysis of faded dyes as well as decaying bases.

2.3 Recent Strategic Plans for Film Storage for Maximum Life Expectancy

The use of carefully controlled low temperatures and low humidity to extend the life of both film base and dyes **even if severe vinegar syndrome has already begun** is best illustrated by the papers published on the research and planning that was carried out by both IPI and DFI staff for the Danish Film Institute’s new storage vaults for acetate (and nitrate) film.

This research includes the extent to which vinegar syndrome could be arrested by lowering storage temperature and freezing, and the effect of cycling storage temperature and humidity.

The proposed strategic plan looked both at fresh film and at film with an unknown storage history. The following table shows the degree to which it was possible to significantly increase the life span of acetate base films that had already started to decay and were approaching, or were at, the vinegar syndrome autocatalytic point. The table compares the existing Danish Film Institute's vaults with a new cold store and a freezer vault, based on IPI's accelerated ageing tests.

Table 4
Estimated Time to Reach Acidity 1 (A-D Strip Level 2) based on Average Temperature and RH Conditions

	VAULT 1 14°, 61% RH	VAULT 2 6°, 68% RH	VAULT 3 5°, 35% RH	COLD STORE 2°, 20-30% RH	FREEZER STORE -5°, 20-30% RH
Fresh Acetate film	75 years	190 years	500years	>1,000 years	>2,000 years
Degrading film at A-D level 1.5	<15 years	<50 years	<200 years	<350 years	>500 years

From this the DFI and IPI created a film storage strategy and a new film access policy. Some of the key objectives were:

1 Conserve the film originals and film duplicates for as long as possible (Life Expectancy goal: minimum 100 years).

2 Make duplication and restoration masters and prints of most important works (national film heritage).

3 Create access duplicates (35 mm, Digital Betacam) for presentation and standard to low-resolution access copies (DVD, VHS, MPEG) to serve external and internal demand.

Prior to 2000, storage was at 10°C/80% RH, giving a Life Expectancy of 70 years for fresh film and 10 years for decaying films (the annual budget needed for film duplication to keep up with deterioration was 10 M€).

After new vaults were commissioned, decaying films (and all nitrate) were stored at 5°C/35% RH, giving a Life Expectancy of 500 years (and the estimated annual budget needed to keep up with deterioration fell to 750.000 €).

References to this and other recent research and experimentation are available in [4], [5], [6] and [7].

2.4 Acetate film base shrinkage

Linear shrinkage is a well-known phenomenon. Some specialist film printers have been designed to handle films shrunk to a linear maximum of about 4% whereas current telecine designs cannot achieve this.

It had been widely assumed that the lateral shrinkage was more or less similar to the linear shrinkage. However it seems that lateral shrinkage is frequently in excess of the linear shrinkage by 20 - 40%. Optical film printers and telecine units have zoom or image controls, which can resize the frame.

Many factors can affect how acetate will shrink and there seems to be no consensus of opinion as to the main reason for shrinkage. The chemical composition of the film base is fundamental, but various factors appear to interact in different ways. These include the original film dimensions, perforations, film emulsion, presence of a magnetic pre-striped track, processing, tightness of roll wind, conditions of storage, orientation of the roll in storage, storage temperature and humidity cycles. The container used for storage, how or whether it was sealed, the material it was made from, whether it is in contact with magnetic tape, whether there is paper or cardboard in the can (and of what sort) also seem to be factors.

The life history of the film seems to have a bearing on shrinkage. How many times the material has been taken out for printing, how often it has been ultrasonically or otherwise cleaned or re-washed, the number of times it has been de-shrunk and processes such as waxing, Vaccumate, Photoguard or lacquering all seem to factor.

Shrinkage generally tends to be greater across the width in a wound roll simply because the plasticiser "leaks out" faster from a surface in contact with the air or around the perforations.

In manufacturing the film base is slit to width and perforated. Under controlled conditions the film dimensions will fall within the specified standards. From that moment on it will never be the same again because of all the environmental factors involved. With processing (developing), film always shrinks slightly below the original dimensions of the unexposed film. Most measurements show values of linear shrinkage of approximately 0.5%.

It is clearly important that broadcasters are aware both of the worst-case scenarios they could meet in their collections and of the general average. Extreme cases of 5% and, exceptionally, 10% linear shrinkage have been known with a film image that is still worth viewing, but this is exceedingly rare. Many major archives report that small proportions (< 2%) of their collections have intact images on 4% shrunk film support.

In general, any film shrunk by more that 3% is already decayed and the image useless, or so brittle due to plasticiser or water loss that it cannot be handled at all. Film archives record that most of their films are shrunk by abut 0.5-0.8% (the expected range for any processed film), and less than 2% of their collection are beyond 3% linear shrinkage (probably equating to 5-10% lateral shrinkage).

There are several proprietary methods of de-shrinking film but these are not widely used as they are regarded as shortening the eventual life of the film. Techniques used include prolonged exposure to acetone vapour and water vapour, separately or together. These techniques can be tried but it is suggested that they should only be done in extreme circumstances by experienced specialist film laboratories (with the correct safety procedures in place).

In telecine, shrinkage has been noticed on Super 16 mm gates that are now in widespread used on telecine units for the transfer of shrunk *standard* 16 mm material, and it is now thought to be a common problem. The film may have shrunk to an extent that the film edge falls into the open gate aperture, severely losing frame edge sharpness, creating unsteadiness, and ultimately wearing the film gate, resulting in poor quality 16 mm transfers. ***It is recommended that for standard 16 mm transfers a standard 16 mm gate aperture be used.***

Film printers do not suffer from these problems to such an extent, as the gate aperture is almost always the same width as the film frame, even on continuous printers.

Two useful, if rather old papers on the subject of shrinkage are [8] and [9].

2.4.1 Checking a film for defects

Any film collection should be checked for possible chemical decay and physical degradation.

The danger signs to look for in any broadcast collection are:

1. Rusting cans, - since rust auto-catalyses the vinegar syndrome
2. Sepmag stored in the same can as acetate picture film,
3. Commag film, - since the presence of iron has been found to catalyse VS
4. Any film which is sticky or distorted in the roll
5. Any roll which smells of vinegar is almost certainly beyond the autocatalytic point
6. The use of a plastic bag (that will trap acid released from the picture or sound film).
7. Film cores of less than 75 mm and of a material that is of harm to film material (recommended materials are High density Polyethylene or Polypropylene).
8. Dye fading, which can be clearly seen in positive images; usually this is an increasing magenta cast.
9. Negative dye fading. This can only be recognised by display on a telecine at a telecine alignment setting (using a TAF negative). Usually (not always) a faded negative looks low in blue contrast, and visually blue.
10. Linear shrinkage, which can be estimated with a commercial shrinkage meter. 1% to 1.5% is the limit for most continuous transport telecines.
11. Width shrinkage, which should be measured with a vernier calliper and logged, 2% should be regarded as having an increased risk of damage in handling. But see our specific information about the use of Super 16 gates.
12. Buckle and curl (irregular shrinkage), which will affect the transfer. Telecines vary in their ability to handle these defects and in future new devices will be needed on telecine equipment to handle this. (These devices already exist on specialist film printers and on some specialist data scanners).

Any film showing any of the above symptoms should be prioritised for examination and treatment or transfer.

3. The term "preservation"

The EBU and other broadcast organisations come into contact with archives and cinema technologists, and mismatching terminology is a common discussion point.

The term **PRESERVATION** is widely used by broadcasters, film archivists and museum curators (more broadly, in natural history, geology, archaeology and fine art), but in each case it has a different meaning. This disparity is at risk of becoming a barrier to proper understanding and the useful sharing of ideas.

A dictionary definition of PRESERVATION is:

1. [n] the activity of protecting something from loss or danger

2. [n] the condition of being (well or ill) preserved

Museum curators define **PRESERVATION** as the proper care of an original artefact, artwork, specimen or object, in order to limit or prevent its decay by time, environment or climate.

Archivists, including film archivists, use the term **PRESERVATION** to mean the creation of a copy of an original work in the highest quality that retains all the characteristics and informational data present in the original. **Archivists,** including film archivists, use the term **DIGITAL PRESERVATION** to describe the ability to display, retrieve, and use digital collections in the face of rapidly changing technological and organisational infrastructures and elements. **(In other words the preservation of collections of digital material).**

Broadcasters use the term **PRESERVATION** to mean **the transfer of images to useful formats (today's digital formats) for exploitation or use.** Broadcasters use the term **DIGITAL PRESERVATION** to mean the transfer of analogue formats to digital formats.

(These formats are what film archivists, and commercial collection managers call **Access formats).**

Already these differences in meaning are causing strains, in particular where broadcasters have film collections, and where broadcast engineers, film collection managers and their archivists come together.

Archivists are dedicated to retaining the entire film image content and quality content, and believe that broadcasters risk sacrificing the life of their originals by being overly concerned about exploitation and by creating preservation formats with short lives and at a low quality.

Broadcasters believe that archivists are over protective of their collections, and think only of posterity, to the extent that the images are not easily available to anyone who wants to see or use them.

In the spirit of mutual coming together, both, of course, are at once right and wrong.

Broadcasters do need to consider what their future market may be. New higher quality broadcast standards will benefit from the increased image quality on film (HD is already mentioned in EBU Tech 3289). Film in broadcast collections may be used for digital cinema programmes where very much higher resolutions are needed for large screens (already 2k projection is available and 4k has been proposed). The current broadcast and standard definition access formats have short lives and uncertain futures, so keeping the film to return to for later reuse, or making the highest quality digital version as a long-term preservation strategy makes good sense.

Film archivists and many commercial collections are suspicious of digital technology because it isn't film and it isn't currently able to achieve anything like the longevity of film (bearing in mind that even decaying vinegar syndrome film can be frozen to arrest the process). They point to the cost of short-lived access formats, and prefer to keep the original film, knowing that it will continue to be the highest quality image that will have the greatest value.

However the end of film as we know it is coming for film collections, cinemas and broadcasters alike, and digital technology is all that is available to take its place.

As a footnote to this subject, **Migration** can be another contentious term. Broadcasters (particularly in EBU documentation) use the term to include the initial transfer of film to digital formats. Archivists always use the term to mean the protection of an existing digital format (original or made from a film image) from loss or obsolescence by transfer to another medium or format.

4. Scanning, digitisation and restoration

In 2003 several broadly new items of equipment, techniques, ideas or concepts entered the market, or were shown and tested:

1 Two manufacturers demonstrated high-resolution (4k or more), high bit-depth (16 bit) fast (frames per second not seconds per frame) scanners at exhibitions. Both are operated without controllers, the grading being carried out at workstations after scanning, reducing the film running time and film wear. Unfortunately both were delayed to market while essential modifications were carried out to permit a wider range of film conditions to be scanned and to fit the existing post-production technology. It is understood that similar products from other manufacturers should also become available in 2004.

2 Workstations for grading and image control, some entirely software based others hardware-software combinations also made an impact this year, continuing the trend to scan at higher bit depths and to grade later.

3 Plans to introduce digital cinema projectors to conventional cinema circuits progressed in 2004. In the UK, funding has been found for up to 250 screens, mostly for small or "art" cinemas. In Scandinavia several conventional distribution chains extended their coverage, using Texas Instruments' DLP (Digital Light Processing) technology.

4 A 2k DLP digital projection engine became available and immediately appeared in a commercial product. JVC showed their 2k D-ILA projector widely. The Japanese Digital Cinema Consortium toured Europe and the US with a demonstration using a prototype 4k projector.

5 Digital intermediate post-production dominated the major (and many minor) feature films in the cinema. Most were recorded back to film for commercial release, but some were also software converted to HD for parallel digital cinema release, particularly in Scandinavia.

6 Graphics data originated animation features were released on film and HD versions for digital cinema. Many of these have shown extraordinary quality due largely to the precision of graphics edge detail, which easily exceeds any lens-and-camera shot images.

7 Highly successful digital restorations made more impact in the cinema this year than in the past. Several US majors entered this field with back-to-film versions and in the case of Warner Bros. with three digital cinema versions of feature films shown at both 1.3k and 2k in a range of European sites using DLP-based projectors. This sector is clearly growing very quickly.

8 Kodak announced it was altering its philosophy towards digital imagery (and presumably away from film) in September 2003.

4.1 Migration and digital storage

Little has changed in the last year in terms of new products or new concepts in either of these fields. There was a presentation at the FIAF Conference in Brussels in November 2003 of an optical tape format that might prove interesting as a high-density long life digital "preservation" format.

4.1.1 The Information Content of a Film Image

A processed film image is a complex, often multi-layered (even in some B & W films) three-dimensional structure.

The images we see in the cinema are rarely projections of the original camera film. They are positive images transferred to a release print from the camera film using a range of equipment sometimes involving lenses similar to those in the original camera. Current release prints seen in the cinema are usually at least the fourth generation of film stock and some effects sections will be up to eight generations of film stock. Digital techniques are reducing the number of effects generations, however.

Many old films are far less sharp, are grainier and less consistent than modern films, and as the film degrades with time its images fade or decay, greatly diminishing their image quality.

The question arises as to whether it is really necessary to record every structural detail of a film (the image and its base support from perforation to perforation) in order to retain its information for the foreseeable future and to contribute to future restorations (or our understanding of the format). Other than this, there may be a basic minimum that is required to adequately preserve the information content.

To some extent the urgency in finding answers to this issue is diminishing. Film will keep, and it is already widely recognised amongst archivists that it is more economic to use restricted funds to conserve films in optimum conditions (even in freezing conditions for the most vulnerable) instead of transferring the images into digital formats when scanning, maintenance or migration cannot be funded. The technology too is hardly ready for scanning, retrieving and maintaining large collections at high resolutions and bit-depths.

4.1.2 Scanning resolution and bit-depth

There are many opposing views on the resolution and bit depth needed to record film images, and the areas of contention may be summarised by reference to a number of different philosophies. These range from concepts that originate from intrinsic film characteristics (the nature of film and processed film emulsions themselves) to others that take more pragmatic approaches.

4.1.2.1 Estimates from intrinsic film characteristics

One view (supported in EBU Tech 3289) is that the optimum resolution and bit depth can be calculated from published characteristics of a film stock together with knowledge of display systems and the human eye.

Kodak (and other manufacturers) publishes the Modulation Transfer Function (MTF) of their film stocks as a graph. From this the % response of a film to fine image lines can be inferred, leading to an estimate of the resolving power of a film stock in lines (or line pairs) per millimetre. The overall resolving power of the film system is reduced by lenses and by subsequent printing steps (to obtain cinema release prints) to finally result in a measure of the film system's ability to record fine detail, in lines per mm (l/mm) of film image. From these concepts Max Rotthaler (IRT Munich) estimated the resolution of film in digital terms **[10]** as follows:

A 90% MTF response of a film demonstrates the resolution of a film in line pairs per mm. Applying this to a film frame of 22 mm Academy frame-width gives a 1990 Kodak colour negative film a resolution of **160 lines per mm**. The dimension of the narrowest line is therefore 6 µm. If one pixel = 6 µm x 6 µm this corresponds to 2,860 pixels for the 22 mm horizontal dimension of the Academy frame. This can be described as 2860 pixels per horizontal line (p/l), also known in the industry as "2.86k".

- 16 mm requires less - about 1,310 p/l.
- Super 35 needs more - about 3,240 p/l.
- In a typical 35 mm camera the lens reduces the resolution to **130 pixels per mm**.
- The printing process reduces it yet again - to **110 p/mm**.

The procedure to produce a cinema release print involves four generations: lens + negative + intermediate positive + intermediate negative + Print = **100 p/mm** (and even less if an optical printer is used!)

Rotthaler assumed that no controller was used to grade the film negative prior to scanning (these are now used for restoration but might not be used for preservation mastering). He assumed 14-bit colour depth for the negative and 10 bit for a print (because a print required no grading, and the negative did).

Rotthaler produced a table showing the different file sizes for scans of negatives and prints from different routes for different film formats. The largest file size was achieved with Super 35 mm negative, which required 5.5 Tbyte per 90-minute feature film. The smallest file size was achieved with 16 mm print from a standard 16 mm negative, which required 0.4 Tbyte per 90-minute feature film.

Table 5
M. Rotthaler, 1990; EBU Tech 3289, 2001 Information Content of Film Images

File Format	Image area	Pixels/frame Negative		Pixels/frame 4th. Generation Release Print	
	Mm	k x k	Mp x l	k x k	Mp x l
Standard 16 mm	10.05 x 7.42	1.32 x 0.96	1.26	1.06 x 0.8	0.85
Academy 35 mm	22 x 16	2.88 x 2.08	5.95	2.3 x 1.68	3.87

Pixels/mm at 90% MTF response	
Original camera negative + Lens	130 pixels/mm
Original camera negative + Lens + Print	110 pixels/mm
Original camera negative + Lens +Intermediate positive + Duplicate negative + Print	100 pixels/mm
1990 Film Stocks	Eastman Colour Negative 7/5245
	Eastman Colour Print 7386/5384
	Eastman Colour Intermediate 5253
Lenses	16 mm zoom
	35 mm 50 mm prime

Academy 35 mm Negative	2,860 pixels per horizontal line
Academy 35 mm Print	2,300 pixels per horizontal line

Data per 90-minute feature

Academy 35 mm Negative scanned at 14 bit	4.2 Tbyte per feature
Academy 35 mm Print scanned at 10 bit	2.0 Tbyte per feature

Rotthaler's method is still widely used for quick estimates of resolution, although his actual results are not so widely accepted today. There are several problems with his approach.

1 The film stocks Rotthaler used are no longer available but his simple calculations can be applied to any film stock where the MTF values are shown in the manufacturer's data sheets in graphical form.

2 MTF value estimates give slightly higher values than empirical experiments suggest.

3 MTF values do not exist for many film stocks, early camera lenses, or for most printing systems.

4 No account is taken of aliasing artefacts created by scanning resolutions close to the film image resolution (which can be minimised by "over-scanning").

5 Scanners are not identical, and there is no doubt that files resulting from ostensibly the same resolution vary in the quality of the image they yield, either due to maintenance or handling practice (even to focussing!) or to design differences.

The EBU has investigated the issue of scanner frequency response, and it has produced a telecine/scanner test film that extends to higher resolutions than those needed for standard definition broadcast.

4.1.2.2 Estimates from pragmatic opinions

Another view, at the other extreme, holds that film images are complex structures and that they must only be digitised at the highest possible resolutions and bit depths to ensure that no information is lost. Some views extend to always scanning the entire film from edge to edge, not simply the image and sound track, and even that film is a three dimensional structure and that this in itself needs to be recorded.

A resolution of 14k p/l and 20-bit per channel has been suggested as being necessary for a 24 mm wide Academy film image but this has never been substantiated by experiment or measurement. It can be demonstrated that 4k/line is certainly better than 2k/line for 35 mm film by visually inspecting the resulting images, but beyond that it is difficult to demonstrate that these high resolutions are needed.

On the other hand, pragmatic methods of using different resolutions of and looking at the results that have yielded the best images produced the following table, widely used by restorers, never published, but passed from hand to hand, is widely used.

Table 6
Resolution of some films in “Scanning” terms.
Pragmatic estimates from discussions, 1997 - 98

RESOLUTION REQUIREMENTS IN PIXELS Estimates from discussions FILM SYSTEM and frame size	RESOLUTION REQUIRED Height x Width pixels Approximations	Total Pixels Millions
35 mm Eastman Colour Academy frame 1997	2057 x 3656	7.52
35 mm Eastman Colour full frame 1997	2664 x 3656	9.74
35 mm Eastman Colour Vistavision 1997	3456 x 6144	21.23
35 mm Technicolor print Academy frame 1950	1000 x 1750	1.75
35 mm Black & White nitrate negative Academy 1935	2057 x 3656	7.52
35 mm Black & White nitrate print Academy 1935	2057 x 3656	7.52
35 mm Black & White nitrate negative full frame 1920	1140 x 2000	2.28
35 mm Black & White nitrate negative full frame 1915	1140 x 2000	2.28
35 mm Prussian Blue toned full frame 1925	761 x 1354	1.03
35 mm Cinecolor [2-colour] print Academy 1940	1000 x 1750	1.75
16 mm Eastman Colour frame 1997	900 x 1575	1.4
16 mm Ektachrome EF News film	761 x 1354	1.03
16 mm Eastman Colour Print 1960	761 x 1354	1.03

All these resolutions were judged by creating data files from two very different scanners (the 2k Spirit and the 2k - 4k Genesis). Estimates of "quality" were from a projected colour print, made by contact from a colour negative film re-recorded on a 2k Celco in 1997 (widely distributed information from joint tests by Soho Images, London and Digital Film Lab, Copenhagen). These resolutions, or values very close to them, are still widely used for restoration purposes. However problems 4 & 5, above, still apply.

4.1.2.3 Pragmatic research programmes

Several papers by Morton, Maurer and Du Mont **[11]**, **[12]**, **[13]** published in the last two years have altered the way this issue is judged. They compared HD files created by different routes from scanning 35 mm negatives with those obtained from HDTV cameras, and evaluated the quality of the digital images using a series of methods of their own devising.

They concluded that the visual result in terms of resolution and visual sharpness is better from a film scanned at 4k and then digitally enhanced with a sharpness tool before saving as an HD file, than any HD camera image, or a film scan made at 2k. This implies that film suitably over-sampled plus digital enhancement will result in the optimum image at a defined resolution. The authors also stress that the result is an empirical one and could not be easily pre-determined.

"Over scanning", a widely accepted technique, has several benefits. Some are easy to define (and calculate), such as the minimisation of visual aliasing artefacts, and some image improvements are not so easily explained. This has sometimes been described as a synergy where the visual improvements are more than the sum of the expected individual gains - a further reason for pragmatism.

4.1.3 Resolution requirements for digital cinema projection

There are lessons to be learned from a rapidly expanding digital cinema technology. Digital cinema places the highest quality demands on any digital version of a preserved moving image. Film archivists have repeatedly defended their ethical standpoint that only a film duplicate in the original dimensional format can be considered to be a preservation master because of this. This is still enshrined in the Code of Ethics of FIAF (International Federation of Film Archives).

The original film represents the maximum image content available. At present 35 mm Academy images on Eastman or Fuji colour negative films exceed the capabilities of digital cinema although it is clear that given optimum projection specifications and high quality original material, digital versions can exceed most multigenerational film duplicates in terms of viewing quality.

Digital cinema of the highest quality has created an outlet for some of the most interesting and elaborate restorations of feature films over the last year (2003). Digital reconstruction of Technicolor classics, early silent tinted and toned films, great black and white cinema images from the 1940 and 50's, and faded film restorations (which would be beyond an archive's budget if done on film alone) were all shown recently in London. Many were re-recorded back to film for projection but the restorations digitally projected from HD files were not obviously different except where the restorer had deliberately chosen to move away from the original film image.

Digital cinema is similarly trying to settle on projection resolutions and specifications. Just as there are several approaches to this issue in digital preservation of film images so there are different philosophies in digital cinema. Exactly where the upper quality level of digital cinema will finally settle (if it ever does) is uncertain but it is widely felt that resolutions will continue to increase as digital camera resolutions increase. Projection at 1.3k and 2k is commonly used now, whilst 4k is being deployed and it is clear that "IMAX digital" would need even greater resolutions to extract satisfactory images from the 15-perforation pull-down 65 mm negative film images.

The principles of digital cinema are based on complex technology with a substantial dose of pragmatism.

4.1.3.1 Projection resolution estimated from human visual response

One way of proceeding is to take into account that the required resolution is limited by what the eye and brain can perceive in a cinema location.

The resolving power of the human eye has been variously estimated, but the most widely accepted figure is that the eye can resolve an object that subtends 1.5 minutes of arc at the eye.

The maximum angle of view permitted in a cinema is 90° (by a viewer in the front row), and the minimum is not defined, but is frequently 10°. The eye’s resolving power implies that it cannot distinguish two points less than 1.5 minutes of arc apart, so that the viewer in a digital cinema with a horizontal 90° angle of view will require at least 90/1.5minutes (= 90 x 60/1.5) horizontal pixels to see a smooth unstructured image. This corresponds to 3,600 pixels across the screen width. To provide a safety margin, about 4k pixels will be required. Any viewer further away from the screen will require fewer horizontal pixels to see a smooth image.

IMAX uses higher angles of view, from 90° to 110°, corresponding to a maximum of 4,400 pixels per horizontal line.

Bearing in mind that aliasing can be seen at any resolution, and that this can be minimised by over-sampling, it seems likely that for optimum 4k cinema projection resolutions, the original film will need to be scanned at 8k. If the film edge definition were low (due to film MTF, lens, printing and other factors) the aliasing will be correspondingly low and there would be no gain from higher scanned resolutions. It should be noted that IMAX images are more than 20 times the area of a Super 35 frame.

These estimates are not intended to be recommendations as considerably more research and practical testing is needed, but it indicates the need for high-resolution film scanning to provide the optimum film image to the cinema screen.

4.1.3.2 Resolutions for digital cinema projection - empirical estimates

The Japanese Digital Cinema Consortium (amongst others) takes a more pragmatic approach over choices of technology for digital cinema projectors. It points out that the technological factors that contribute to the eye’s appreciation of an image are now so great that calculation of benefits is not as satisfactory as viewing the image.

The JDCC has a very graphic demonstration using a test-bed 4k projector which projects 4k scanned files from a number of different film formats (35 mm, 65 mm and the 4"x5" still format). The larger the format, the more image details are visible on screen suggesting that 4k pixels per horizontal line is enough for formats larger than 35 mm (and by implication 4k is more than sufficient for 35 mm Academy frames). The JDCC however emphasise that these experiments are empirical, and pragmatic - their files are 4k and 10-bit sampled, but in order to display them in real time they are heavily compressed (using JPEG 2000).

Table 7
POST-1950 ACETATE ARCHIVE FILM STORAGE, SCANNING AND TRANSFER ISSUES FOR BROADCASTERS

ISSUE	Scratches and damage	Dye fading	Vinegar syndrome	Film shrinkage
Storage conditions, Temp./RH etc.		1 Yellow dye "light" fading well documented by Kodak. Effect probably uncommon and restricted to well used prints. 2 Cyan dye "dark" fading more significant. 3 Dark fading probably stopped by freezing. Exact relationship with VS not known. Assumed to be similar. 4 Research needed.	IPI references and Prescalc allows precise storage and life expectancy planning based on VS risks (and on fading risks by implication only).	Shrinkage caused by various storage conditions: 1 High temperature/low humidity causes plasticizer and water loss. 2 Vinegar syndrome decay 3 May be other factors 4 Uneven shrinkage causes buckling, accentuated by poor winding and storing on roll edge.
Scanning	1 Minor surface defects correctable by some exposing techniques (e.g. IR "mask" imagery), semi-automatic software during scan, or in stand-alone workstations. 2 Wet gate very effective for scratch minimisation, but rarely used; disliked by engineers. 3 Semi-automatic image repair systems ("noise reducers") effective for fast access work, but may create new artefacts.	1 No information on threshold density values of faded images available from TK manufacturers. 2 No relevant dye characteristics available from manufacturers in a useful format. 3 Research needed. 4 Operator who corrects pragmatically may not notice minor fading. 5 TKs rarely permit the degree of fading to be measured. 6 Use of TAF settings often the only guide to degree of fade. 7 Secondary correction channels necessary for extreme faded film correction. 8 Unfaded dye references for calibration not available. 9 No TK controller is specifically designed for fade correction	1 Reduced film stiffness of VS film is a well- known factor reducing the ability of a film to lie flat in the film gate, take up badly, or be subject to damage or stretching during scanning. 2 Severe VS film may have plasticizer crystals on film surface and require cleaning before scan. Requires a specialist service. 3 Plasticiser crystals are also a risk to TK mechanisms as well as obscuring the film image.	1 Lateral shrinkage is more than linear effecting Super 16mm gates in particular. 2 Step transport and pin register scanners poor for archive film, increasing damage risks. 3 Uneven shrinkage causes buckling and uneven focus, unless special adaptations to gates. 4 In general TKs are not designed for archive film. Only Kinoton scanner intended for shrunk film. 5 XY zoom can correct for mage shrinkage.

ISSUE	Scratches and damage	Dye fading	Vinegar syndrome	Film shrinkage
Restoration / correction after TK scanning	1 Several specialist standalone workstations available. 2 Alternatively "sparks" for effects hardware/software devices. 3 Always time consuming 4 Almost always some manual retouching needed as well as specialist algorithm based techniques.	1 Visual correction required even after automatic software. 2 Secondary correction channels necessary for extreme faded film correction. 3 Unfaded dye references for calibration not available. 4 14-16 bit scans needed to allow severe fade correction at post-scanning stage.	Some persistent surface crystal shadows may be re-imaged by specialist workstations.	1 Image shrinkage and anamorphism can be corrected on some workstations, although the effect rarely obvious. 2 No effective device for dealing with image distortion from buckle.
Useful life of film for transfer		1 Dye fading is not considered as critical as the film support degradation 2 Different telecine and scanner concepts will have different ability to analyse and separate the image dye information	The vinegar syndrome will cause active decay and effect the life of film and sound, but it is no relation between the amount of acidity and the consequent effect on the useful life for film to be transferred. There are several variables beside the vinegar syndrome that affects the film and the usable lifetime for transfer. Research needed.	Restricted to the capacities and performance of the telecine or scanner to be used Critical film degradation variables are: • Shrinkage beyond 1% • Buckle and curl Improvements required
Checking archival film for transfer			Check for any of the following symptoms: • Rusting cans • Sepmag stored in same container as acetate film • Commag striped film • Any sticky or disordered roll of film • Any roll that smells of vinegar • Film or Sepmag stored in plastic bags	Measure the shrinkage. The simple method is measuring the width, which can be as much as 40% more than length. Use a vernier with a digital window. Log the values for later checking Inspect visually for excessive buckle and curl. Any departure from flatness might be a problem

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