Film Materials Preservation Guidance

Preservation aims

Under the FIAF Code of Ethics

- “Archives will store material, especially original or preservation master material, in the best conditions available to them. If those conditions fall short of the optimum, archives will strive to secure better facilities.” (1.3)
- “When copying material for preservation purposes, archives will not edit or distort the nature of the work being copied. Within the technical possibilities available, new preservation copies shall be an accurate replica of the source material.” (1.4)
- “Archives will not unnecessarily destroy material, even when it has been preserved or protected by copying.” (1.8)

This guidance is limited to the matter of preserving the primary masters. How an archive defines the primary masters depends on circumstances; primary masters may include anything from the original printing elements to original release prints. In most cases, archival films are presented to audiences using elements that are *derived from* the primary masters; therefore the aim of this guidance is to examine ways of preserving the information held by the primary masters in order to retain the possibility of recreating the original viewing experience through any current or future technology. This means that, if at all possible, the primary film elements themselves should be preserved. A ‘preservation copy’ can only be an inferior substitute for the original film element.

Film degradation

Cellulose-based film materials, principally cellulose nitrate and cellulose acetate, but also other cellulose esters such as cellulose butyrate, are subject to decomposition over time. The rate of decomposition is very strongly influenced by temperature and moisture, and the life-expectancy of a film can vary by orders of magnitude (from less than 10 years to well over 1000 years) depending on the conditions.

The decomposition of these plastics is also affected by the products of the decomposition, most notably acetic acid from decomposing cellulose acetate: this volatile material can not only increase the rate of decomposition of the affected film, but also is thought to promote decomposition in other films in the same storage area.

Because these decomposition reactions are autocatalytic (i.e. the reaction products accelerate the reaction), cellulose film plastics generally follow a similar pattern of decomposition over time: a slow degradation stage leading to an increased rate of decomposition once the acid reaches a certain level. Researchers[1] have identified an ‘autocatalytic’ point (figure 1) beyond which the rate of decomposition becomes

[1] Stability of Cellulose Ester Base Photographic Film; Adelstein, Reilly, Nishimura, Erbland; SMPTE Journal

significantly greater. Evidence suggests that films which have passed this point cannot be preserved for the long term[2] even in the most stringent storage conditions.

For cellulose acetate film, the decomposition is usually signalled by the odour of vinegar long before any visible sign of deterioration is noted. For cellulose nitrate film, there may be no external signs of decomposition until the film has visibly begun to decompose (figure 2).

Film is also prone to damage mould growth promoted by excess moisture: this is a serious problem because the mould primarily attacks the emulsion itself, causing indelible damage. High moisture levels can also result in the gelatin layer softening and sticking to the adjacent film layer, a condition sometimes known as 'blocking' because the film becomes a solid block which cannot be unwound without damage. Polyester film is equally prone to these types of damage resulting from excessive moisture levels.

Image fading is another serious form of film deterioration. Normal black and white film with a silver image is relatively stable provided it has been properly processed, but most types of colour image are prone to fading, especially 'chromogenic' colour film (i.e. where the colour has been produced by development during processing, eg in Eastmancolor and similar film types). Again, the rate of fading is heavily dependent on temperature and moisture conditions, but many colour dyes are also seriously affected by the presence of acid produced by cellulose plastic decomposition.

Assessment

The more information the archive has about the condition of the films in a collection, the more effective the preservation strategy is likely to be.

The level of acid in the film provides a reasonable prediction of its life-expectancy. For cellulose acetate film, the level of acid in the air inside the film can will provide a reasonable guide to the level of acid in the film; this can be simply measured using acid indicator papers. This test works because of the volatility of acetic acid; it does not work for cellulose nitrate film, and there is no simple non-destructive acid-level test for nitrate film. Visual condition checks can provide useful information about the current state of the film but will be less useful for predicting its stability.

Assessing the state of the films in a collection might be confined to acid-level testing of acetate reels, or might include a more detailed examination for damage and deterioration, depending on circumstances. If there is a need to determine the general state of a film collection, a random survey will provide this information a with a good degree of accuracy and confidence. An assessment can be broken down into separate surveys of different parts of the collection (such as Store A, Store B… or Acetate reels, Nitrate reels… etc), but the reels selected for checking in each part of the survey must be a truly random selection. This can be done by assigning a number to each reel, and then using a random number generator to select the reels to be checked. (Selecting the first reel from each shelf, for instance, is NOT a random selection.)

It is not necessary to select a huge number of reels in order to get a reliable overview of the whole collection. The percentage of reels that need to be checked decreases as the total size of the collection increases, so if surveying a collection of 10,000 reels or more, it is only necessary to check around 400 reels to achieve an accuracy within 5% and a confidence level of 95%. A smaller collection of 1,000 reels will need around 300 reels

[2] 'Long term' in this context is considered to be at least 100 years.

checked for the same level of accuracy and confidence. For a very small collection of 100 reels or less, virtually all the reels will need to be checked.

A random survey is useful for determining the overall picture and for planning budgets and storage requirements and so on, but unless the strategy is to build and maintain a single store operating at the most stringent environmental conditions for all reels, more granular information will ultimately be needed.

Another important aspect of assessing a collection is to identify which copies are the most important for the future preservation of the film. Note that even if the original printing masters exist, it is usually important to preserve original projection prints as a record of how the film was presented to an audience.

Safety

Decomposing film can be a significant health hazard.

Acetic acid is often the most evident decomposition product because it is volatile and the smell can be easily detected. The regulations in most countries stipulate a maximum level of exposure for safe working of up to 8 hours at 10 ppm (parts per million) of acetic acid. This is above the level at which the smell can be detected, so a slight smell of vinegar in a film store should not be considered a hazard. For handling degrading acetate reels however, effective ventilation or fume extraction should be employed.

The less volatile decomposition products such as nitric acid and plasticisers can be considerably more toxic. Protective gloves should therefore be worn when handling decomposing films of any sort.

Fungus and bacteria are another type of hazard. Handling fungal reels can release huge quantities of fungal spores, many of which can be dangerous. Fungal spores are tiny and will pass through basic dust masks, so protective masks fitted with filters suitable for trapping fungal spores should be used whenever handling mouldy film.

Storage conditions

The **ISO** recommendations for long-term storage of fresh film are:

Cellulose nitrate film:

2 ˚C (36 ˚F)
20 to 30 %RH

Cellulose acetate black and white film:

2 ˚C (36 ˚F)	or	5 ˚C (41 ˚F)	or	7 ˚C (45 ˚F)
20 to 50 %RH		20 to 40 %RH		20 to 30 %RH

Chromogenic colour film:

-10 ˚C (14 ˚F)	or	-3 ˚C (27 ˚F)	or	2 ˚C (36 ˚F)
20 to 50 %RH		20 to 40 %RH		20 to 30 %RH

However, note that these recommendations are for *fresh* film. All nitrate film is now at least 65 years old, and most acetate film is far from fresh, so these recommendations must be considered as a set of minimum requirements.

Predictions of the life-expectancy of Cellulose Nitrate film are hampered by the wide variations in manufacturing, by uncertainty about past storage conditions, by the higher sensitivity of nitrate decomposition to elevated temperatures, by the rapid speed of the later stages of decomposition, and by the lack of a simple, non-destructive test for acid levels in nitrate film. Existing information indicates that:

- Storage nitrate below-zero Celsius will afford nitrate film a good archival lifetime provided it is not visibly decomposing.
- Storing nitrate at higher temperatures will lead to a steady loss of reels due to decomposition.
- Visibly decomposing nitrate reels will continue to decompose at an appreciable rate at below-zero Celsius.

For these reasons **it is strongly recommended that all nitrate film is stored at below-zero Celsius**.

The degradation of both fresh and slightly degraded Cellulose Acetate and of Colour film can be predicted using the calculators at FilmCare.org, a web resource provided by the Image Permanence Institute. These calculators should be used with a clear understanding of what they show:

- The Acetate calculator is intended to inform the planning of storage for film in reasonable condition, based on the assumption that once a film has reached the 'autocatalytic point', it is too late for it to be preserved for the long-term.
- The calculators do not attempt to indicate life-expectancies per se, but rather how long before a film is no longer viable for normal usage; it is understood that the image and sound on even badly degraded film can often be saved, albeit with difficulty.
- The figure for Fresh Acetate is an estimate of the time taken for new film to reach the autocatalytic point, not the end of its life.
- The figure for Degraded Acetate is an estimate of the time taken for film at the autocatalytic point (A-D Level 1.5) to reach an arbitrary point of greater degradation (A-D Level 2).
- The figure for how long Colour will last is an estimate of the time taken for new colour film to suffer a 30% density loss.
- The apparent precision of the numbers is misleading – the figures should be considered as broad approximations.
- The calculators do **not** provide any prediction of the rate of degradation of film already in an advanced state of degradation (ie A-D Strip level 2 or more).
- The calculators assume the film is not taken out of controlled storage; time spent out of storage will have a disproportionate impact on the life-expectancy of a film.

Reliable data about the continuing rate of decay of significantly degraded Cellulose Acetate film is sparse. Anecdotal evidence strongly suggests that even at -20 ˚C (-4 ˚F), badly degraded acetate will continue to decay at an appreciable rate. Based on the available evidence, **the table below sets out the expectations from storing acetate film at different stages of degradation at 40 %RH and four different temperatures**:

	A-D Level: 0.0 - 1.0	A-D Level: 1.5	A-D Level: 2.0 - 3.0
+10ºC 40%RH	Long term	Short term	Very short term
+5ºC 40%RH	Long term	Medium term	Very short term
-5ºC 40%RH	Very long term	Long term	Short term
-18ºC 40%RH	Very long term	Very long term	Short term

Very short term	Less than 5-10 years	Emergency action needed: find freezer storage plus urgent preservation copying
Short term	Less than 30 years	Start planning new stores and/or preservation copying programme
Medium term	Less than 100 years	Start planning new stores
Long term	More than 100 years	No action except regular condition checking
Very long term	More than 1000 years	No action

Extending lifetimes by other means

Although moving the film to cold, dry storage is by far the most effective method of prolonging its lifetime, other methods can be used to buy some time for degrading film if it is impossible to move it to recommended storage in the short term. Most of these methods are based on reducing the moisture content of the film by the use of desiccants and acid-scavengers (molecular sieves), or by removing the decomposition by-products (principally acetic acid) by venting.

Periodically rewinding decomposing film to allow moisture and acid to disperse is known to help slow the pace of decomposition. This practice has been employed systematically in some archives with some success, but it is not possible to provide unequivocal figures for the degree of effectiveness.

Placing the most seriously decomposed acetate films next to the air exhaust in the store coupled with effective air filtration will both help to ventilate the films and prevent the acetic acid affecting other films in the store, although the effect of acetic acid in the store on other films is not well studied and is often exaggerated.

The use of vented film cans which are intended to allow acetic acid to be flushed is sometimes advocated. However merely exchanging conventional film cans for vented ones is unlikely to affect the life expectancy significantly. Well-designed vented cans suitably stored to allow a free airflow through the can will undoubtedly have a beneficial effect, but it can only be a partial solution.

Adsorbent materials such as desiccants and molecular sieves can be used to help extend the lifetime, primarily by reducing the moisture content of the film. In practice this means creating a micro-environment (see below) by sealing each individual reel with the desiccant or molecular sieve in an enclosure such as a bag or taped film can. Desiccants function by taking up moisture until equilibrium is reached; molecular sieves will scavenge moisture and acid from the film. Because molecular sieves will aggressively adsorb moisture, only the recommended amount for the weight of the film reel should be used in order to ensure that the film reaches the desired moisture content. If the sealed enclosure is not completely impermeable to moisture (such as when conventional polyethylene bags are used), the moisture content of the film will increase as water vapour diffuses through the packaging.

Without lowering the temperature, the above approaches can only improve the life-expectancy by a relatively small factor. IPI estimates that life-expectancy can be increased at room temperature by up to 3 or 4 times by a large reduction in moisture content of the film; depending on the condition of the film, this may buy some time but is unlikely to be a long-term solution.

Micro-environments

The use of sealed micro-environments in **low temperature** storage can be a very effective long-term solution. The advantage is that no humidity control is required in the store; the disadvantage is that each film has to be sealed in its own package at the right moisture level.

There are two ways of achieving the recommended moisture level, either by pre-conditioning or by using a desiccant. For pre-conditioning, the film is kept in a low-humidity environment for sufficient time to allow it to reach equilibrium: typically this should take about 2 weeks at room temperature, rising to around 2 months at low temperature. If accurate scales are available, the film can be weighed before and during the conditioning process to observe the progress towards moisture equilibrium: the weight will drop fairly rapidly initially and then tail off as the film approaches the equilibrium level. Obviously if the film has already been stored in a low-RH environment for sufficient time, this conditioning process is not necessary. An RH of between 30 and 50 % is recommended if the film is destined for storage below 0 ˚C (32 ˚F).

If a desiccant such as silica gel is used instead to dry the film, this should be sealed inside the package with the film. A 'molecular sieve' can also be used to reduce the moisture content, but care should be taken to use the right amount so that the film is dried out the to the appropriate degree. (IPI recommend 5% by weight of film.)

The method used to seal up the film must ensure that the amount of moisture within the package does not change. Ideally, a heat-sealed bag made from a composite PET/aluminium foil (as commonly used in the food industry) will remain impermeable to moisture for the very long term. If cheaper polyethylene (polythene) bags are used, this should only be for the short term as this material is permeable to moisture, and depending on the circumstances, the film may need re-conditioning and repackaging within a few years. If this method is chosen as an emergency solution, it may be worth putting a moisture indicator card in each package: this will change colour when the moisture in the bag reaches too high a level.

Using this micro-environment approach means that there is no need for any humidity control in the store. However, because every film must be packaged separately in a sealed enclosure, any saving has to be offset against the resources (staff, time, packaging) needed to create the packages.

Film stores

Designing a film store should involve much more than just drawing up a specification for a target temperature and relative humidity, and then awarding a contract to the lowest bidder. All the factors should be carefully considered first. These include:

- The overall strategy for the preservation of the film collection
- The condition of the film collection, based on surveys
- Experiences of other archives in similar situations
- Input from experts in designing stores for archives
- Local climate
- Availability of suitable locations
- Expected continuity of funding
- Reliability of power supplies
- Expectations for long-term maintenance and support
- Staff resources

The right solution for the archive may range from a small-scale freezer unit containing pre-conditioned and sealed films, to a mass store running at controlled temperature and humidity. The solution might include a number of stores operating at different temperatures according to the type and condition of the film.

The requirements for film stores differ in some respects from other controlled-storage environments, particularly in the food industry, and there are a number of potential cost-saving measures which can be employed.

Temperature and humidity fluctuation: Because of the way a film is wound up in a reel, its response to changes in temperature and RH is relatively slow. This means that minor, daily changes in temperature and RH will make little change to the actual temperature and moisture content of the film itself. The more tolerance allowed around the set conditions, the simpler the design of the machinery and the cheaper it is to run. However, too much fluctuation across the seasons of the year is undesirable. The time a film spends at higher temperature and RH will have a disproportionate effect on its life-expectancy because of the higher rate of degradation in these conditions, so it is important to limit the amount of time a film spends out of store (or in a store with failed air-conditioning equipment awaiting repair). The cumulative effect of fluctuating conditions is given by the average rate of degradation, not by the average life-expectancy[3].

Access: Master films in deep storage are not expected to require frequent access. A store where the doors are kept closed for most of the time will be more economical that one which has a lot of traffic.

Air infiltration and conditioning: The store should be constructed to eliminate even small pathways allowing air to leak into the building, especially around doorways which must be as tight-fitting as possible. The entrance must have a lobby, and the inner and outer doors should never be open at the same time. However, film stores do not need a conditioning room for the films even where there is a large difference between the inner and outer environment. Films are not susceptible to damage from rapid changes of temperature, so the only requirement when moving film in and out of a cold store is that they are not subjected to moisture condensation. Where there is a danger of condensation, this can be

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[3] The rate of degradation is the reciprocal of the life expectancy as given by IPI's online tools. It can also be predicted directly using a formula provided in an appendix on page 2 of this paper from Tim Padfield: The Preservation Index and the Time Weighted Preservation Index

avoided by using insulated containers to move the films both in and out of store, allowing the air in the container to reach equilibrium overnight before the container is opened.

Air flow: An effective airflow throughout the store is advisable, particularly if there are degrading acetate films releasing acetic acid. The ideal flow from the air inlet to the air exhaust should be from all the way across one side to all the way across the opposite side, and from the top to the bottom. For maximum efficiency it may be worth considering installing a gas sampler to monitor the level of acetic acid in the exhaust air, which is then used to control the level of air change or filtration.

Location: Stores should be located if possible where there is no risk of flooding, away from pollution and heavy road traffic, and in a cool, shady location. It may be advantageous to plant trees in order to keep direct sunlight off the store because solar radiation is a major source of heat energy. In countries where there are large daily or seasonal variations in temperature, there may be a benefit from siting a store partially or wholly underground, but ground temperatures are generally higher than recommended for film storage, so the store will still require insulation, and there may be an increased risk of water ingress.

Insulation: Good insulation is essential for an efficient store. The thermal conductivity of insulation is given by the U-value (or R-value[4]), and should be as low as feasible. Where there is a large temperature difference between the inside and outside of the store, the U-value of the insulation will need to be very low, and even the most efficient insulating material will need to be very thick. The insulation must cover the entire inner walls and ceiling with no gaps or thermal bridges. Careful consideration must be given to the floor design as this must also be insulated, but has to be strong enough to support shelving. Film stores must not have windows – glass is a very poor thermal insulator, and also transmits thermal radiation from the sun. If converting an existing building to a film store, all windows should be covered internally with insulating panels as with the rest of the walls. If the glass is to be left in place, a reflective covering should be applied to reduce the heat transmitted through the glass.

Some examples of recent low-temperature film stored in FIAF archives are listed in the appendix.

Copying

As discussed above, good storage is not always able to guarantee a long lifetime to a film reel if degradation is already advanced, in which case it may be necessary to make a preservation copy. Although FIAF ethics state that 'preservation copies shall be an accurate replica of the source material', this is not possible in practice. Neither photochemical copying nor digitisation will create an 'accurate replica', and archives must decide whether the ultimate goal is to adhere to the original photochemical production pathway, or is to capture a perfect description of the original film in the form of an electronic file. The former is really only achievable if original printing elements survive, otherwise the duplication will be compromised; the latter will only become a reality when film capture has vastly improved. At present, photochemical copying and digitisation operate at a similar level of quality (that is, the resolution and dynamic range are of a broadly similar scale), and therefore both options are compromises as means of preserving film images. It can be argued that film soundtracks, particularly magnetic tracks, can be digitally captured to full preservation standards, but this is highly dependent on the type of original, the equipment available, and the expertise of the operator.

[4] The R-value is the reciprocal of the U-value.

Duplication for preservation purposes, whether photochemical or digital, is not a routine operation, and requires the highest possible standards and quality control. It is common for duplication programmes to greatly underestimate the resources and effort needed. However, while photochemical technology has now reached an evolutionary end-point, it can be expected that digital technology will continue to evolve, and that making preservation copies using digital (or post-digital) means will generally become cheaper and easier over time.

In either case, any preservation copying programme can be expected to take a long time and substantial resources.

Strategies

To summarise the discussion above, when devising a preservation strategy these key points should be considered:

- The most authentic way to preserve a film is to preserve the original elements.
- A survey of the condition of the collection will greatly enhance planning; a statistical survey can be carried out with minimum effort.
- It is not difficult to estimate the life-expectancies of different areas of the collection in different storage environments using easily-available predictive tools.
- Once an acetate film has reached the 'autocatalytic point' the battle to save it through good storage is already partially lost.
- Film store design has improved along with cost- and energy-saving strategies.
- Preservation copying is only second-best and is a laborious process.
- Photochemical copying is now widely unavailable and is unlikely to be subject to improvement.
- Technology for capturing film electronically will improve, making digitisation ultimately better, easier and cheaper.
- Preserving film is necessarily different from preserving cinema: a separate (but linked) strategy is required for access and presentation.

From this, it can be seen that any strategy must be based on two key elements:

1. Prevent film in good condition from degrading.
2. Make preservation copies of degraded films while they are still viable.

If the preservation copying is to be by digitisation, a third element can be added:

3. If possible, delay digitisation to allow time for the technology to improve.

To illustrate this, some examples are given in the following scenarios:

Archive 1

Situation

> All the film is in storage appropriate to its type and condition. There is a small proportion of acetate film which has passed the autocatalytic point.

Action

> In this archive a detailed survey has been carried out and the degraded acetate has been moved into very stringent storage conditions (below-zero °C). Only magnetic soundtracks and the most seriously degraded film masters are currently being

digitised to the best possible standards. A future copying programme is planned for the remainder of the degrading film which will be guided by the perceived rate of degradation.

Archive 2

Situation

All the film is in ISO recommended storage conditions for fresh film regardless of its condition. There is an undefined proportion of acetate film which has passed the autocatalytic point.

Action

ISO recommended conditions for fresh acetate film (around 5 °C, 35 %RH) will offer a long life-expectancy for film in good condition, but the degrading acetate will continue to degrade in these conditions. The archive might choose to carry out a comprehensive acid-level check to determine which reels are in the most serious condition, moving these degraded reels to below-zero °C storage in order to delay the need to make preservation copies, and only digitising magnetic soundtracks and the films in the most serious condition. If the scale of the problem is not too great, storing the degrading films in sealed, pre-conditioned packages in freezers might be an effective solution. If it is not feasible to determine the condition and status of all the reels in the collection in reasonable time, the only safe option is to create below-zero °C storage for every reel.

Archive 3

Situation

The collection is in storage which does not meet ISO recommendations. There is a large proportion of acetate film which has passed the autocatalytic point.

Action

In storage which fails even to meet ISO recommendations for fresh film, even non-degrading film is at risk. A survey to establish the general state of the collection will determine what improved storage is required so that films in good condition have a long-term future and that preservation copying for degraded reels can be carried out in a controlled manner. If there is no inventory, a full survey of all reels may be needed to identify the primary masters. All efforts must be made to implement a well-informed storage strategy because with passing time the film will become more degraded and ultimately more expensive to rescue. Emergency copying may have to be carried out on the most degraded reels using any technology available.

Archive 4

Situation

The collection is in very poor storage. The majority of film is badly degraded.

Action

This is an emergency situation. The bulk of the collection will ultimately have to be copied for preservation, but copying an entire collection will be a very lengthy and complex process, particularly if there is no adequate inventory. In very poor storage, there is a high probability that much of the collection will reach a state beyond rescue before it can be copied, so the first priority is to get the collection into better storage, ideally below-zero ˚C, so that a copying programme can be prioritised on the most vulnerable and the most important films. There is no time to wait, and if the film is already the victim of very moist conditions, suffering from 'blocking' and fungal growth, then for these reels it is already too late.

Archive 5

Situation

A large nitrate collection in moderate storage conditions.

Action

In the past nitrate storage was primarily designed to protect against fire, with environmental conditions a secondary consideration. Because of the difficulty of predicting the life-expectancy of nitrate film through condition-checking and testing, it is necessary to assume that every film is vulnerable. The long-term preservation of nitrate can therefore only be guaranteed by storage below-zero ˚C, so the archive should be making an urgent case to upgrade its storage – it is no longer considered acceptable for nitrate reels to be 'preserved' through safety film duplicates.

These scenarios show that unless the storage is already optimal, improving film storage rather than rushing into preservation copying is likely to be the better preservation strategy, even if a significant proportion of the collection has already degraded. In emergency situations, digitisation using any available equipment will be better than losing the content of the films entirely, but if the degradation of the films outpaces the speed of digitisation, then emergency low-temperature storage will be necessary to save the collection.

Appendix

The following are some examples of recent low-temperature film stores in FIAF archives

Archive	Type of building	Type of film	Year	Capacity/Size	Conditions
North West Film Archive, UK	Part of renovated historical building	Safety	2014	ca. 450 m of shelving	3 ˚C 30 %RH
Irish Film Archive	Purpose-built	Safety	2018	ca.1000 m of shelving	4 ˚C 35 %RH
Danish Film Institute	Converted warehouse	Safety	2005	250 m^2	-5 ˚C 35 %RH

Danish Film Institute	Converted bunker	Nitrate	2007	1200 m^2	-5 ˚C 35 %RH
Swedish Film Institute	Purpose-built	Nitrate	2006	15,000 reels	4 ˚C 30 %RH
Austrian Film Archive	Purpose-built	Nitrate	2010	70,000 reels	1 ˚C 35 %RH
National Film and Sound Archive, Australia	Converted building	Safety	2013	8570 m of shelving	4 ˚C 35 %RH
BFI National Archive, UK	Purpose-built	Safety and nitrate	2012	190,000 reels nitrate 240,000 reels safety	-5 ˚C 35 %R`H

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