

Non-destructive microfade testing at the National Museum of Australia

Bruce Ford

National Museum of Australia
Bruce.Ford@nma.gov.au

Abstract

Limiting light-induced colour change of displayed objects to an acceptable degree is an important but difficult task for conservators, who are required to make exposure decisions which have fundamental consequences for access and display, usually without adequate rate data. The NMA's early experience with an accelerated fading technique known as microfading, which uniquely allows the relative rates of colour change of actual museum objects to be estimated, is described. The technique is rapid, essentially non-destructive and highly cost-effective, allowing the museum to identify and concentrate its resources on protecting the most vulnerable objects, rather than applying blanket rules to very broad classes of colourants.

Keywords: microfade testing, accelerated light ageing, lightfastness, nondestructive, colour change.

Introduction

A recent review of the National Museum of Australia's lighting guidelines highlighted the lack of reliable fading rate data for the majority of the National Museum of Australia's collection and the impact this has on the high cost of light-driven exhibition changeovers. As part of a strategy to address this situation we acquired an Oriel Micro-fading Test System (O-MFT) developed in the late 1990s by Dr Paul Whitmore at the Carnegie Mellon University Art Conservation Research Center (Whitmore et al. 1999, Whitmore 2002). We have subsequently made minor alterations to the equipment, developed methods for testing a wide range of surfaces and objects represented in the collection, and incorporated micro-fade testing into the routine exhibition and loans program. The data has allowed us to identify objects at most risk of fading and to better target resources otherwise expended on object replacements which were based on what have proven to be systematically conservative light-fastness estimates, and is providing interesting insights into the diverse materials represented in the collection and their colourants.

The instrument

The instrument, assembled from mostly off-the-shelf optical and spectrophotometric components, is marketed in a complete form by the Newport Corporation (Newport Corporation, n.d.). It is very simple in principle; comprising a 75W stabilised xenon source; filters to remove UV and IR; an optic

fibre and lens assembly which project a 300 μ m spot of very intense visible light onto the surface of the object for which fading rate data is required. A second lens assembly collects reflected light at 45° to the source from where it is directed to a photodiode array spectrophotometer via optic fibre (Fig. 1).

Output from the xenon lamp is held constant by an exposure controller and filtered to 400–700nm using a water filter, near infrared hot mirror, and UV long pass filter. The spectral distribution, similar to UV filtered daylight, has a higher colour temperature than the usual museum mid-range lighting, which will tend to systematically overestimate fading rates. The IR filtering delivers a measurable temperature rise at the sampled surface of less than 5°C, precluding either thermal damage to objects or influence on fading rates and mechanisms (Fig. 2). The source intensity is equivalent to approximately 10Mlx over the area of the 300 μ m spot diameter; sufficient to fade ISO BW1 to more than 10 ΔE_{ab} within 15 minutes (Fig. 4). Assuming reciprocity holds, this is equivalent to 15–20 years on continuous display at 50 lux (UV filtered).

Similar equipment has been developed independently elsewhere (Pretzel 2008), and other laboratories have built on Whitmore's basic design, with the addition of video cameras or borescopes which allow precise location and a magnified view of the surface being tested (Fig. 1c and Fig. 3), motorised focus (Lerwill et al. 2008), and substitution of achromats for the standard lenses to improve focus and the uniformity of illumination. Very small

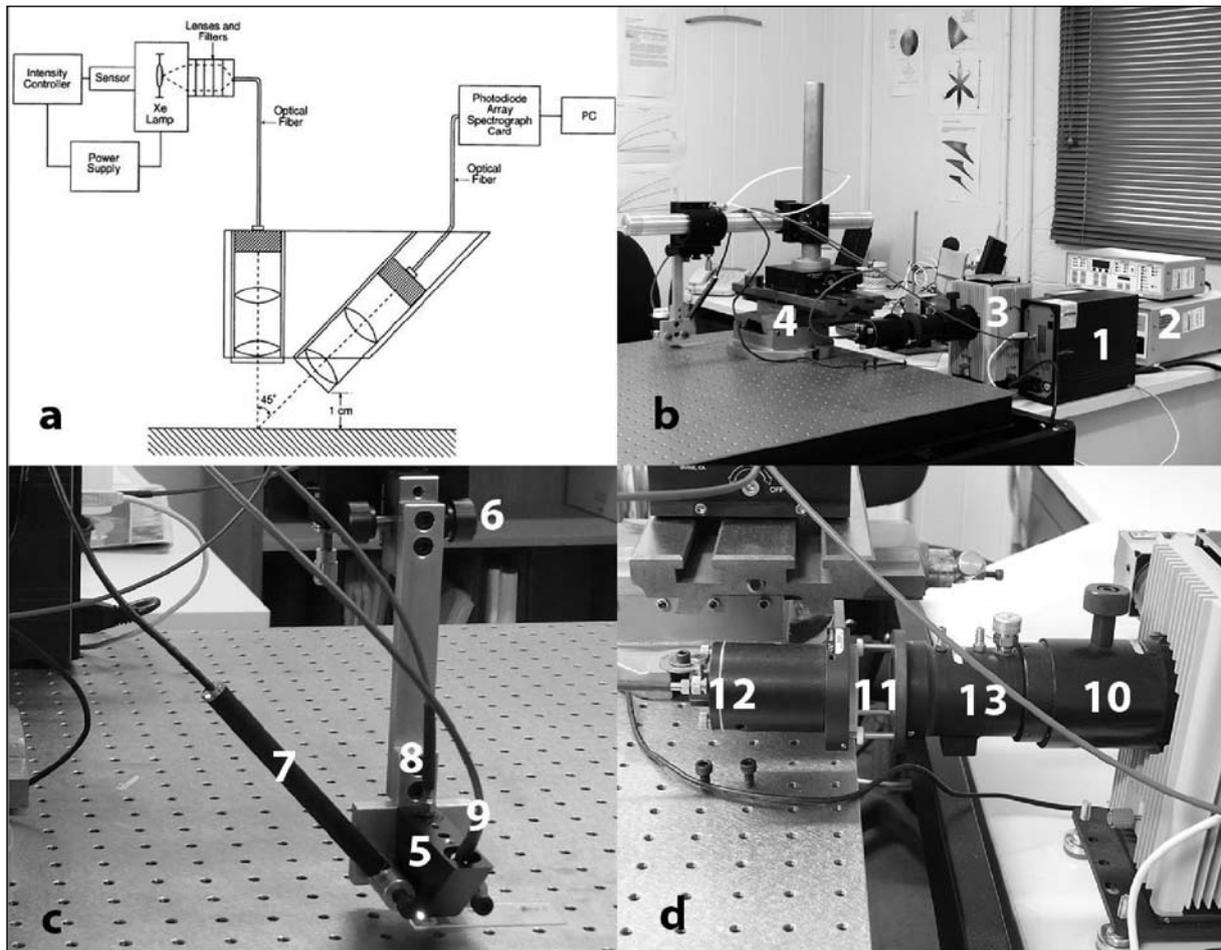


Figure 1 (a) Schematic diagram of O-MFT; (b) Spectrophotometer (1), power supply (2), xenon (3), x-y stage (4); (c) lens holder (5), focus (6), pen-cam video camera (7), delivery optic fibre (8), collection optic fibre (9); (d) condenser focus (10), filter holder (11), fibre optic exit (12), water filter (13). (Fig. 1a reprinted from the Journal of the American Institute for Conservation, Vol. 38, No. 3, with the permission of the American Institute for Conservation of Historic and Artistic Works, 1156 15th Street, NW, Suite 320, Washington, DC 20005)

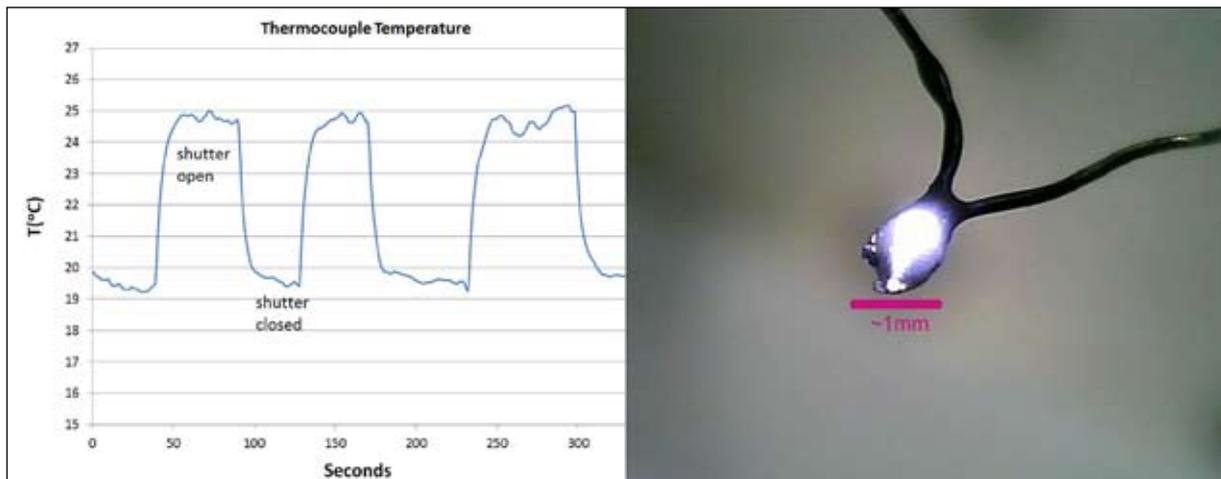


Figure 2. Temperature rise (left) of black thermocouple illuminated by the test beam (right). This was confirmed independently using a liquid crystal thermochromic thermometer, but both methods may underestimate actual heating because of thermal conductivity and emission differences to real samples.

physical movements of the object during testing, for example, the relaxation of a recently moved textile or book, defocus the incident beam and alter the intensity of the reflected light, producing an apparent colour change. For this reason we have mounted the measuring head support on a standard milling machine x–y translation stage (Fig. 1b) which, with the pen-cam (Fig. 1b), allows the head rather than the object to be shifted rapidly and precisely to a new test location. The O-MFT is bulky but still moveable in its present form (see Fig. 4), but hand-held spectrophotometers, much smaller xenon lamp housings with fixed focus and integrated power supplies, and direct delivery of light through an optic fibre without focusing lenses will undoubtedly ensure much greater portability and reduce set-up times in the future.

Averaged spectra at 1nm resolution are typically recorded at 1 minute intervals for 10–15 minutes. The software provided with the spectrophotometer converts spectral into CIELAB $L^*a^*b^*$ and CIEDE 1976 ($\Delta E_{ab}(1976)$) values which can be imported into a spreadsheet or the GCI Spectral Viewer program written specifically for the Newport spectrophotometer by Dr Lionel Keene of the Getty Conservation Institute. We report fading rates relative to the fading of the ISO Blue Wool swatches (Fig. 5), however they can be expressed as $\Delta E_{ab}/Mlx\ hr$, with the reservation that there are several reasons, including the colour temperature of the source, to regard with some skepticism the direct translation of micro-fading cumulative exposures into exhibition exposures. The source spectrum is normalised using a standard reflectance white tile after the machine has warmed up and settled down to an acceptable drift (about an hour). The CIELAB colour coordinates are similar, but not the same, as those obtained using a dedicated incident colour meter such as a Minolta Chroma Meter, partly because the light source is not matched to a standard illuminant. Although this does not affect the validity of colour change data during a micro-fading run, it does mean that the instrument is not suitable for measuring absolute colour coordinates.

Sampling and data collection

Provided it is small enough, the object to be tested is placed on a table and supported or stabilised as necessary to prevent any subsequent movement. The measuring head is positioned about 1cm from the surface at the confocal point of the light delivery and collection lenses, and rough focusing is carried out

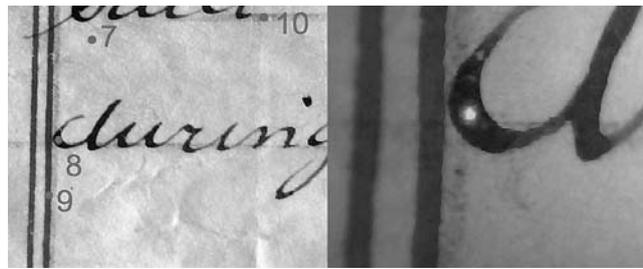


Figure 3. Test fading handwriting, record of sample positions (left) and pen-cam image of sample beam (right). The intensity of the sample beam has been reduced by 99% for positioning with a neutral density filter.



Figure 4. Test fading painted Peace Bus (left), and thylacine pelt (right).

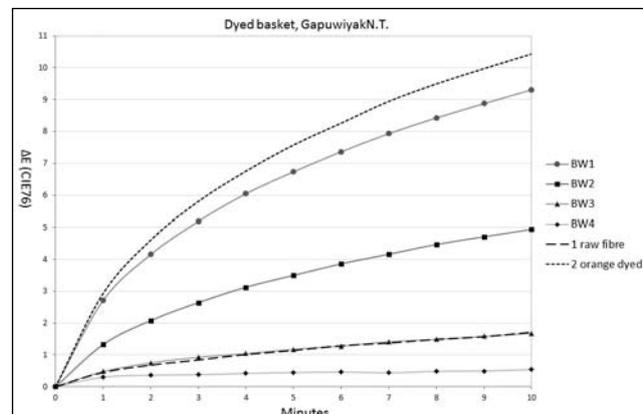


Figure 5. Fading curves of BW1-BW4, and orange-dyed and undyed natural basket fibres from Gapuywyiak, NT. The undyed fibre fades at a rate approximately equivalent to BW3 and the orange-dyed fibre between BW3 and BW2.

through the pen-cam with a 99% neutral density filter in place. Once this is removed, final focus is achieved at full power by adjusting the fine focus knob (Fig. 1c) until the reflectance spectrum is maximised, and data collection is then initiated. With practice, this is a rapid and relatively reproducible process.

Calibration of the instrument is carried out by

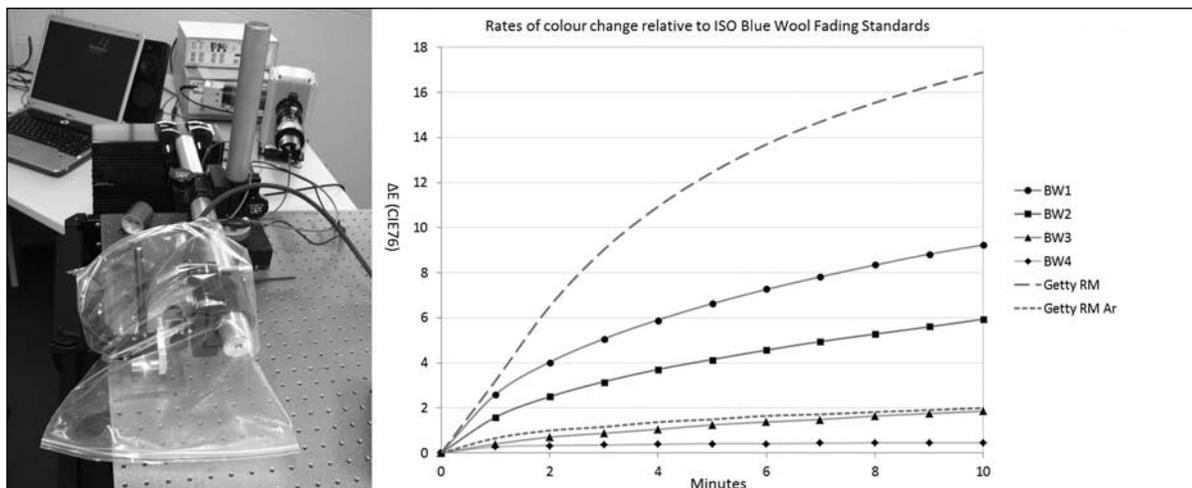


Figure 6. Measuring head inside plastic bag filled with argon (left); fading of Winsor & Newton Rose Malmaison gouache in air and under argon (right).



Figure 7. Testing thylacine hair clamped under glass using a modified mousetrap.

test-fading ISO Blue Wool Fading Standard (BWFS) cloths 1–4, with which the fading of samples will be compared (Fig. 5). The effective intensity and spectral distribution of the light source vary with the age and alignment of the lamp as well as a number of other variables that affect between-sample, between-setup and inter-laboratory results. These include the specific filters and lenses, uniformity of the illuminated spot, and sample surface topology which, at the scale of the test area, effectively modifies the intensity of illumination across it (Fig. 8c).

The 10–15 min test runs are often repeated and extended to 20–30 minutes if the shape of the fading curve is atypical or cut short where the small test-faded spot might become visible at high ΔE_{ab} values on very uniform surfaces (see below).

It is very easy to adapt the apparatus to test materials under specific conditions, for example at high or low relative humidity or in the absence of oxygen, by enclosing the measuring head and sample in a plastic bag (Fig. 6), within which the desired conditions are

established and maintained. A preliminary study showed no significant fading rate change in an oxygen-free (argon) environment for the iron gall and red inks or parchment of a 19th century document. If replicated this would raise questions about the benefit of expensive argon capsules for similar documents, since neither fading nor the iron catalysed oxidative corrosive reactions require molecular oxygen to proceed. On the other hand the fading rate of a sample of Winsor & Newton 'Rose Malmaison' Designer Gouache (rhodamine lake), which does undergo photo-oxidation in air (Whitmore 1999) dropped by a factor of 10 under the same conditions (Fig. 6).

The measuring head may be used in any plane normal to the surface being tested and it is possible to use the instrument outside the laboratory, for example on the hand-painted murals on the side of the double-decker bus in Fig. 4. Hair and fur, which otherwise scatter light and easily move, may be clamped flat under a glass microscope slide through which the readings are taken (Fig. 7) and compared to ISO Blue Wool standards run under the same conditions.

Destructive or non-destructive?

Although the technique does fade the 300 micron diameter probe area, it is effectively non-destructive in the sense that it is very difficult or impossible to relocate the faded spot on most textured and/or unevenly coloured materials at colour changes as high as 10–15 ΔE_{ab} . At worst, Lerwill et al. (2008) found that observers could relocate the faded spot on very smooth, evenly coloured surfaces down to about 2–3 ΔE_{ab} and in such cases, care is taken to limit fading to that extent. In practice, evenly coloured, smooth surfaces that fade rapidly are quite rare in our collection. It is likely that future models will feature even smaller test areas, however, as with any analytical technique, there is a trade-off between sampling size and representativeness.

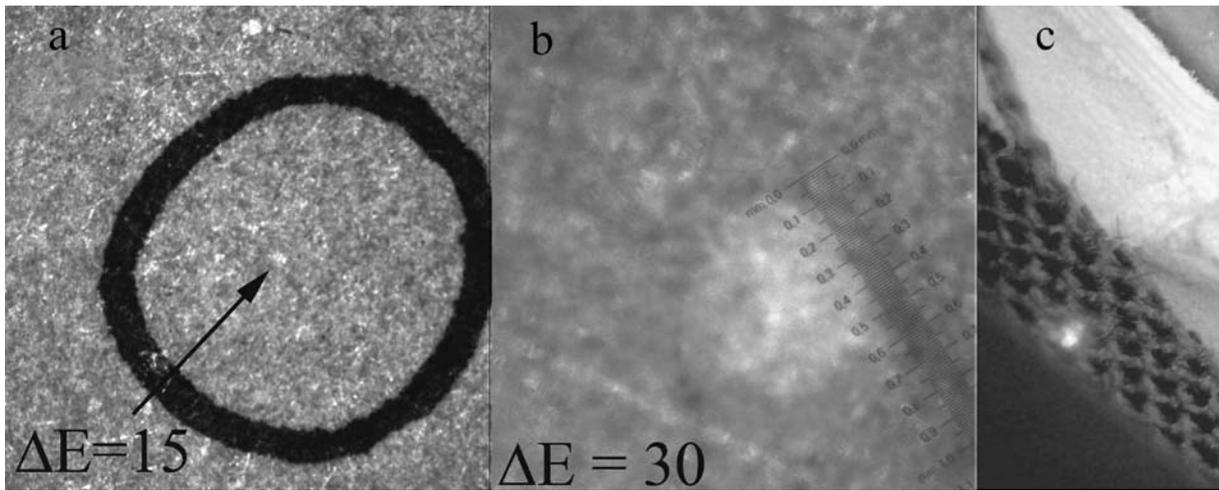


Figure 8. Test spot visibility and scale (a) Faded spot, turmeric on photocopy paper faded to $E_{ab} = 15$. Circle is a ballpoint pen line. (b) Micrograph of faded spot with scale in mm, turmeric on paper $E_{ab} = 30$ (c) Attenuated (99% neutral density filter) and focused test spot on ISO Blue Wool fading swatch.

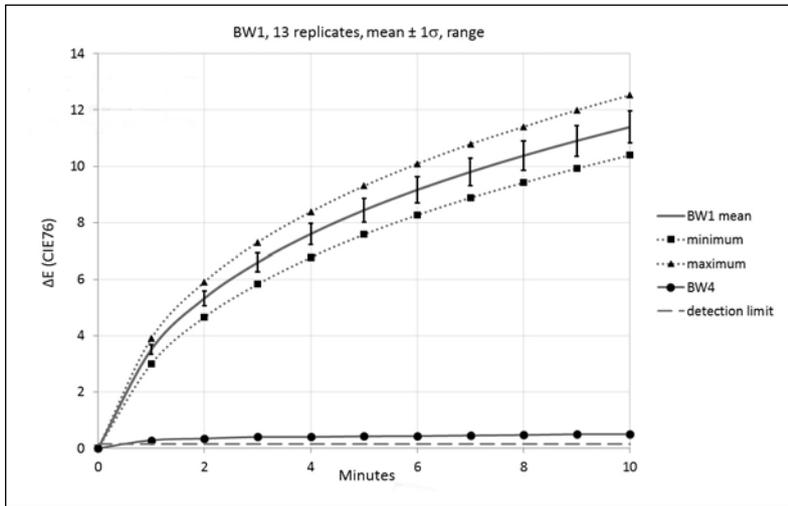


Figure 9. Typical replicates for BW1, $n=13$, $\sigma = 5\%$, range 10% of mean.

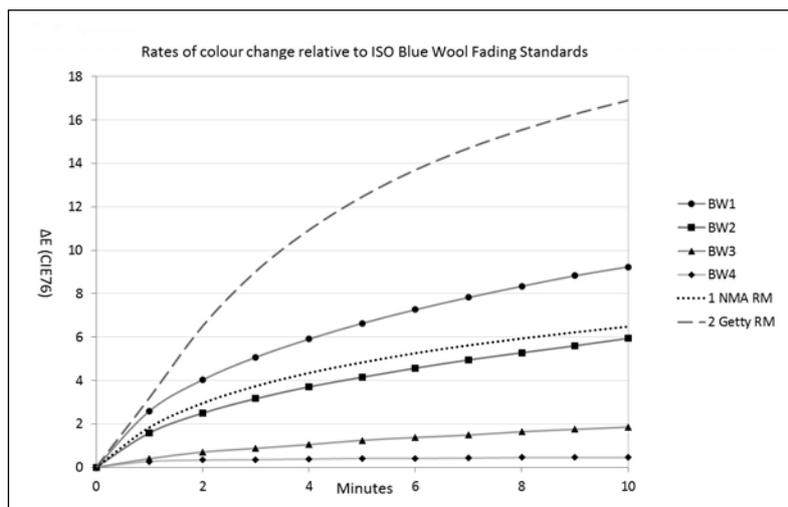


Figure 10. The so far unexplained difference in fading rates of two tubes of identically labeled Winsor & Newton Rose Malmaison Designer's Gouache, one purchased in Los Angeles and the other in Canberra. Winsor & Newton gives the rhodamine based paints a 'C' permanence rating (fugitive).

Detection limits and reproducibility

Tests on white tiles over a typical 10–30 minute run have established that for our instrument source and instrument drift result in a detection limit of about $0.1-0.2 \Delta E_{ab}$ or effectively BW4–5. For reasons that are not clear, we have found that BWs 5 and 6 consistently undergo a rapid initial fade which places them at or slightly above BW4, however, after the early burst their curves flatten out below the $0.2\Delta E_{ab}$ detection limit.

It is known that the ISO Blue Wool standards are sensitive to quite minor spectral changes (Zhang et al 2008) and differences between machines and changes in blue wool values over time may reflect lamp ageing as well as the (non-achromat) condenser focus. Known and suspected sources of variation between consecutive runs include: accuracy of focus; how quickly focus is achieved and the reference spectrum is acquired once the shutter is opened; texture at the scale of the probe spot for samples and BWFS; variability of light-fastness within and between samples and standards due to uneven tint strength, dyeing, and prior exposure; and operator skill. In general, standard deviations for BW1 replicates are about 5% with ranges in the order of $\pm 10\%$ (Fig. 6). Occasionally there are

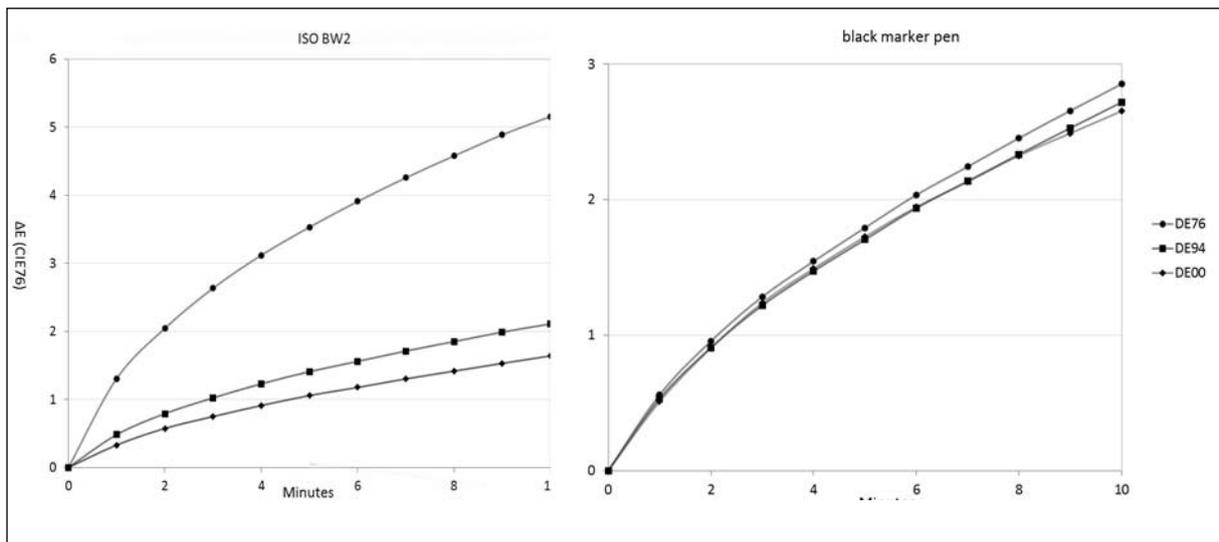


Figure 11. Comparison of different CIEDE calculations for Eab from the same data. Changes to black are perceived similarly in all three perceptual CIEDE models, but this is not true of blues.

outliers, which usually turn out to be sample or measuring head movement (Fig. 15).

So far there have been no organised ‘blind’ trials between laboratories where samples have been swapped, but the results are encouraging. There are hints, however, that ISO Blue Wool Fading Standards themselves might be subject to batch to batch variation or uneven dyeing, and experience has shown that one may not even assume that examples of exactly the same product from the same manufacturer—for instance two different tubes of a manufacturers paint—will necessarily fade similarly, even if they are supposed to share common ingredients (Fig. 10). All this means that inter-laboratory trials will require the distribution of identical blue wool standards and samples and, incidentally, underlines the inadequacy of generic fading rates on which lighting guidelines are usually based.

Interpretation of data

Although we use the CIEDE(76) colour difference equation, ΔE_{ab} values may be calculated using the more recent CIE equations (CIEDE 1996 & 2000) based on improved perceptual models, or other specialised but potentially relevant non-CIE models, such as the

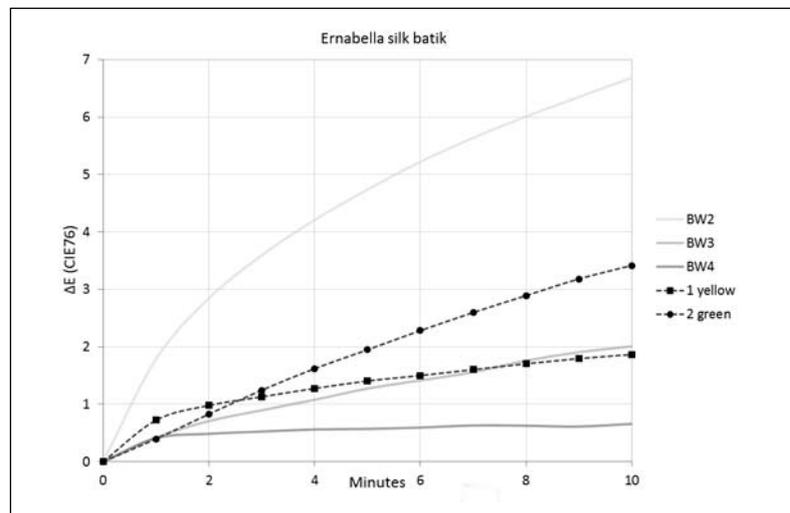


Figure 12. Different shaped fading curves of dyes in an Ernabella batik.

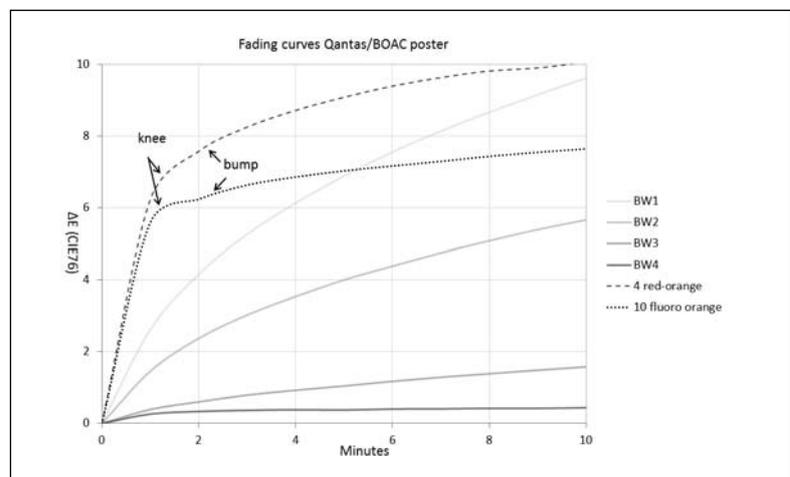


Figure 13. Unusual fading curves for 1950s fluorescent poster inks.

I^* metric developed specifically for evaluating the 'retained image' appearance of photographs (McCormic-Goodhart 2007). CIEDE(76) is convenient, however, because most accelerated fading data exists in this form, and it is not possible to retrospectively convert from one model to the other without the original $L^*a^*b^*$ values. Although there can be quite marked differences between the older and newer ΔE_{ab} calculations, we have found this does not affect the sorting of objects into our quite broad relative lightfastness categories (Table 1) often enough to outweigh the advantages of reporting CIEDE(76). Probably the worst-case scenario is illustrated in Fig. 11 below, where the different perceptual models are similar for black, but very different for blues, including the BWFS used to calibrate the instrument. In fact all three models may be considered unsatisfactory within a range of different perceptual contexts (Kuenhi 2008).

The shapes of colour change curves themselves provide insights into colourants and dyeing processes. For example, in Fig. 12 there are at least three different kinds of curves: the sooth exponential decrease of BWFS 2 and 3; the early knee followed by a flattening out in the yellow textile dye and BW4; and a more or less linear progression for the green dye. Based upon earlier research by Giles (1965), research by Cox-Crews (1987) relates curve shapes to different dispositions of dye molecules and aggregates within the fibre. The first, which Cox-Crews calls Type I, is ascribed to dyes molecularly dispersed throughout the fibre; the second (Type II) is supposed to be typical of mostly aggregated (e.g. mordanted) dye molecules with a proportion of exposed dispersed molecules rapidly mopped up early in the fading process; and the third (Type III) 'pigments and fast dyes that form large aggregates inside the fiber' with concomitantly reduced accessibility to light, as well as water and oxygen where relevant. Whether or not the explanations are generally valid is open to question; for example, in this case the green dye is more fugitive than most of the other synthetic dyes found in Ernabella batiks.

In Figure 13, the fading curves of the fluorescent inks on a 1950s advertising poster under consideration for inclusion in the National Historical Collection (NHC), appear to have the early knee characteristic of Type I with a second Type II curve (the bump) superimposed just as the first abruptly flattens out. It seems likely that the fluorescent inks contain two colourants with quite different fading rates—the more stable of which is initially swamped by

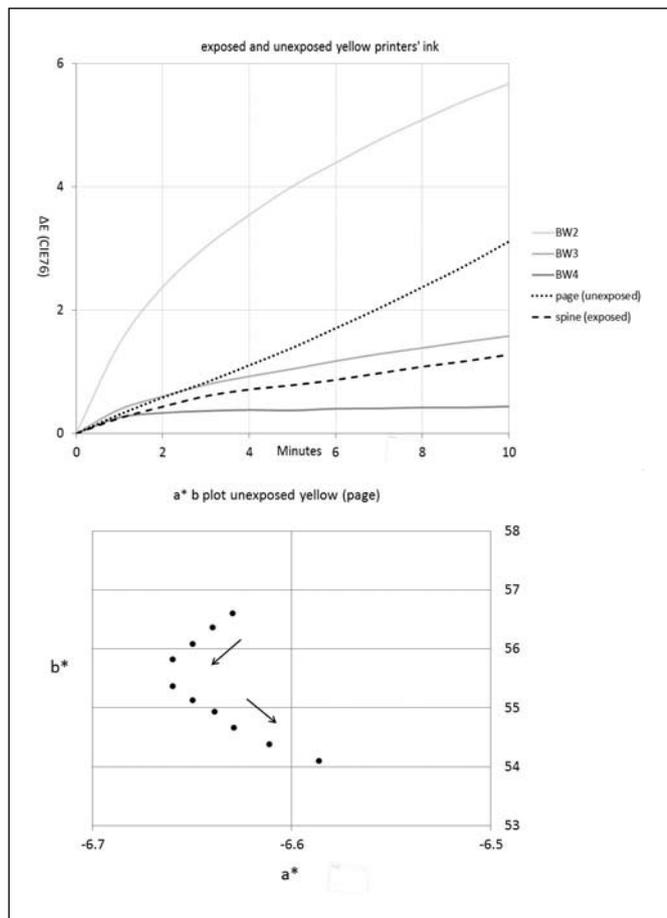


Figure 14. Fading curve (top), $b^* a^*$ (bottom) of a yellow printers' ink.

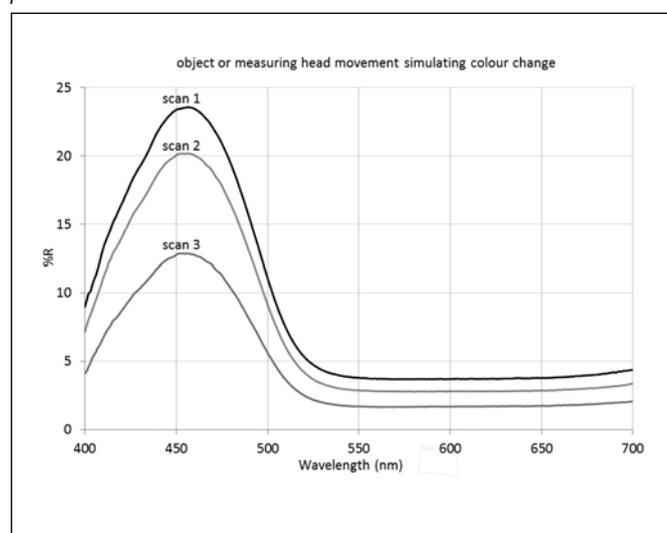


Figure 15. Spectral change typical of sample movement, for example, the relaxation of a fibre basket during testing.

the rapid and almost complete destruction of the most fugitive. If this is true, the colours following initial fading will be those of the more stable components, which will presumably proceed to fade at the much slower rate of the flat part of the curve. The rapid early colour change, which would be expected to have already occurred with

significant prior exposure, confirmed that the poster is in remarkably good—perhaps pristine—condition for its age, and helped inform the decision to include the poster in the NHC. The results also led us to recommend a very short display period and to further investigate colour changes in fluorescent dyes with the inclusion of a test strip containing a number of (modern) fluorescent cardboards in a display cabinet with other works containing similar fluorescent materials as a long-term check on the micro-fading information.

While fading rates are important, the spectral and derived $L^*a^*b^*$ data contain a great deal of other information because they describe the trajectory of the colourant within the colour solid rendered by the particular perceptual model. One can tell, for example, whether a colourant darkens or lightens (L^*) or becomes more or less yellow-blue (b^*) or red-green (a^*). The type of change can be relevant to display options; for example, if a plain yellowed cotton fabric bleaches (L^* increase), the change might not be considered detrimental if the yellowing had no particular historic significance.

Figure 14 (top image) records the fading of yellow paper from a doctor’s prescription pad which exhibits typical as well as some unusual colour change characteristics. It is typical in that the spine, which would have been exposed to light, fades more slowly than the previously unexposed pages of the closed pad. In principle it is possible to estimate prior exposure by extrapolating the fading rates of areas protected from light to the faded portion, but like all absolute extrapolations or predictions based on an estimate of cumulative exposure during micro-fading, this could only be regarded as an approximation. The unexposed page is unusual, however, in having a convex fading curve (Type V) at least over the test period, after which it must, according to the behavior of the spine, eventually revert to a more normal curve. Cox-Crews claims that Type V behavior is rare, but occasionally observed for azo dyes on cellulose, which is plausible in this case. It is also interesting that the colour change initially proceeds in the green (a^* decrease) direction and then doubles back towards red, perhaps signaling a greenish intermediate. Whether the reaction is photo-

oxidative or reductive (both mechanisms exist for azo dyes) could be easily determined by repeating the test under anoxic conditions. Thus a 10-minute fading run not only informed the display decision but also provided a testable hypothesis as to the identity of the colourant and evidence of a multi-step photochemical process.

Spectra and spectral changes are in themselves informative and also an essential check on the plausibility of fading curves. For example a spectral change like Fig. 15, in which the reflectance of the entire 400-700 nm range decreases in equal proportion, is often indicative of measuring head or sample movement masquerading as colour change, whereas genuine colour changes usually affect some regions of the spectrum more than others. Although reflectance spectroscopy has been used to identify pigments and dyes (Leona & Winter 2001), visible spectra are usually fairly non-specific. However, spectra combined with object provenance, colour coordinate shifts, fading rates, and sensitivity to oxygen and water, as well as other analytical methods, is likely to be a powerful tool for the non-destructive identification of dyes and pigments as more data is accumulated and shared.

Reliability of micro-fading

It is reasonable to ask how much weight to give the results of a new technique still in its development phase and for which there are both known and unknown sources of uncertainty and a number of simplifying assumptions involved. The answer to this important question depends to a large extent on the context in which the results are used and the availability and applicability of existing fading rate information.

Part of the answer is that there is no realistic alternative to micro-fading. In addition to its rapidity, the enormous advantage of micro-fading over conventional accelerated exposure of surrogate samples is that it is unnecessary to know or assume anything about the identity and prior exposure of colourants and their substrates. Long-term colour monitoring of objects on display is feasible in some situations (Ford 1991) and should be carried out where possible as an independent check on accelerated methods, but is really only suitable for fairly fugitive

ISO (BW#)	< about BW2	about BW2–BW3	about BW3–BW4	> about BW4
Light level	about 50 lux	50-100 lux*	50-150 lux*	100 -250 lux*
Exposure of high significance (high use) objects	individually decided	2 years/decade	5 years/decade	life of exhibition
Exposure of average significance (lower use) objects	Individually decided	5 years/decade	life of exhibition max 10 years	life of exhibition max 10 years
	As low as possible consistent with good display			

Table 1. Example of a simplified significance-based lighting framework. Until the NMA agrees on workable significance criteria, we are treating all works as if they are highly significant.

materials with large enough areas of uniform colour to accommodate the test footprint of machines like the Minolta Chroma Meter (8mm²). It would be impossible to assess the lightfastness of the iron-gall ink handwriting in Fig. 3 except by analogy to surrogate samples, which will not necessarily reflect real fading rates of objects with their complex and idiosyncratic compositions (including other colouring agents in this case), histories of use, and prior exposure to chemical and environmental influences and light. There are other reasons, apart from prior exposure and mordants, why the same dyestuff might behave very differently in diverse physical systems, including the presence of light stabilisers and blocking agents in polymers and coatings and the synergistic or antagonistic effects of other photochemically or thermally active ingredients and their breakdown products. Except for natural products and synthetic polymers of common commercial or artistic significance, it would be very unusual to find useful information about the effect of substrates and other components on the fading of colourants or discolouration of polymers in the literature.

One of the important assumptions is that 15 minutes exposure to 10Mlx really is equivalent to approximately 15 years museum display at 50 lux. Known as reciprocity, this assumption is the basis of all accelerated ageing methods and also of lighting guidelines that rely on cumulative exposure limits. Where reciprocity failure occurs it is probably specific to the colourant rather than the accelerated exposure method and usually arises from limitations on the rate of diffusion of reactants or intermediates to or from the reaction site. Apparent reciprocity failure is said to be more often a temperature effect due to test-lamp heating (Feller 1994), which does not appear to be a significant problem for the O-MFT. Although it is a different question, Whitmore (1999) has shown that for a limited number of fugitive colorants, including BWFS 1, micro-fading and conventional xenon cabinet test results are comparable.

Other approximations and sources of uncertainty associated with the application of micro-fading results to the museum situation include the fact that the filtered xenon source does not at present replicate contemporary lighting (although it could easily be filtered to do so), let alone novel filtered and LED tri-band solutions now being developed (Druzik & Eshøjment n.d.) and various scale effects associated with the small size of the test area including representativeness and the effect of surface topography on the evenness of illumination across the spot. For these reasons, and because the fading of real objects in real museums depends on a host of other variables, quantitative predictions based on cumulative exposure under micro-fading or any other accelerated conditions will almost certainly be inaccurate.

Order of magnitude estimates of deterioration

processes are normal for risk-management purposes—that is, whether the adverse events in question take effect over a few hours, a month, a year, a decade, a century or a millennium (Waller & Michalski 2005). Smaller measurement and interpretive uncertainties, for example $\pm 10\%$ or even 50%, while undesirable, do not invalidate the use of accelerated ageing results for managing the lighting risk. It is in this context that we use the results of micro-fading, where its first and primary role is as an early warning device for very fugitive colourants (with fading rates greater than about BW2) that can easily be damaged under normal museum conditions, and secondarily to allocate objects to the broad comparative fading rate categories in Table 1 below, which cover rates differing by much more than an order of magnitude. We had found that the previous strategy of lumping all potentially unstable colourants and materials into the V&A's single 'sensitive' (or the similar CIE157 'high responsivity category' (CIE 2004)) with an averaged fading rate equivalent to about BW2, was un-necessarily restrictive and expensive to implement for objects containing colourants below that average, and logically overexposed those that faded faster (Ford & Smith 2009).

The final result of our use of micro-fading data, along with other relevant considerations soon to include significance, is that objects are allocated to one of four exposure categories. We are able to focus our attention on individual objects assessed as fugitive and—like the poster containing fluorescent inks—consider their exhibition requirements very carefully, while the rest are distributed between the two- and five-year changeover categories or remain on display for the duration of a typical permanent exhibition. There is no *a priori* reason or evidence so far to suggest that micro-fading systematically underestimates real fading rates, although much work remains to be done on correlating accelerated testing with 'real' fading. Any risk of overexposure in a particular case is, in our opinion, outweighed by a reduction in overall risk to fugitive objects in particular and more informed and rational decisions about the rest of the collection at an affordable cost. Our implementation of the lighting framework is not dogmatic and we believe that because concern about fading is most often expressed in relation to the importance of specific objects, they will be mostly addressed when we systematically introduce significance as an additional decision-making filter.

Summary

The NMA acquired the O-MFT primarily as a screening tool for fugitive colourants and to better target expensive light-driven changeovers during permanent exhibitions. It was always intended to be part of a revised exhibition lighting framework within which

allowable exposures will be based on the significance of objects as a measure of demand for exhibition, as well as estimates of fading rates. While the significance criteria have yet to be finalised and implemented, the amount of time and money we have already saved on exhibition changeovers as a result of testing alone is considerable and far outweighs costs, including the purchase and maintenance of the instrument and labour.

Along the way we have accumulated a great deal of fading rate data, some specific and some with more general applicability to classes of natural, processed, and industrial materials found in traditional and modern Indigenous artefacts and works of art; industrial coatings; modern and historic textiles and prints; books and letters; leather, fur, and hair; insects; botanical samples; coloured plastics; and even formalin-preserved anatomical specimens. While the list of unknown colourants for which there is little or no reliable fading data in collections is literally endless, we anticipate that with the accumulation of data the requirement for testing will decrease. In fact much of the uncertainty and cost involved in managing an institution's light risk could be mitigated by testing a relatively small group of the most important and (suspected) vulnerable objects along with a survey of broader classes of materials characteristic of the rest of the collection. The individual testing of significant and suspected fugitive objects will remain important because experience has shown that assumptions about 'typical' fading behavior can be very wide of the mark.

Currently there are only a few O-MFT users worldwide, most of whom met for a symposium at the Netherlands Institute for Cultural Heritage (ICN) in Amsterdam in March 2009 to discuss experiences, applications, and problem areas, and to consider the future development of the instrument and its place in materials conservation and research. This group included representatives from the Getty and Canadian Conservation Institutes, the Netherlands Institute for Cultural Heritage, the National Gallery of Art in Washington, the British Museum and the Tate Gallery, who are collaborating with the Imaging & Optics for Art Conservation and Archaeology group at Nottingham Trent University, and Carnegie-Mellon University, where the machine was developed by Paul Whitmore.

It is clear, even from the few examples above, that the value of micro-fading is far from confined to screening for exhibition risk-management purposes. In addition to the identification of colourants, and providing photochemical information which may be used, for example, to assess the value of anoxic display enclosures, applications discussed at the ICN meeting included testing the fading rate compatibility of in-painting pigments and textile repairs; studies on photo-bleaching of yellowed paper and stained canvases; the effect of

relative humidity on fading; the fading of lake pigments; and the use of band-pass filters to determine activation spectra (the wavelength ranges within the visible spectra of sources of most photochemical potency for a particular colourant) which will directly influence filters for exhibition lighting and the adoption of different light sources, including a return to filtered natural light as an aspect of energy conservation.

There is undoubtedly room for technical improvement and a great deal to learn about the relationship between accelerated and real-time colour change, however, it is difficult to imagine that the main elements of direct testing of this kind are not already in place with this instrument, which we have found to be an invaluable component of our light exposure decision making process.

Acknowledgements

I wish to thank Jim Druzik at the GCI, Season Tse (CCI) and Paul Whitmore (Carnegie-Mellon) for their invaluable assistance and advice, and also my colleagues at the National Museum of Australia for their support and encouragement for the micro-fading project, in particular Eric Archer, Nicki Smith and David Hallam, and also Sharon Towns for prioritising and arranging access to a wide range of objects in current exhibitions.

Biography

Bruce Ford is a consultant Conservation Scientist. He has a background in chemistry and has worked for a number of national cultural institutions over the last 20 years. Areas of specialisation include Rock Art Conservation. Since 2006 he has been working with NMA Conservation staff to develop a risk management approach to exhibition changeovers.

References

- CIE, 2004, 'Control of damage to museum objects by optical radiation', International commission on illumination, ISBN 3 901 906 27 4.
- Cox-Crews, P 1987, 'The fading rates of some natural dyes', *Studies in Conservation*, vol. 32, no. 2, pp. 65–7.
- Druzik, J, Eshøjment, B, 'Museum lighting: its past and future development', <www.natmus.dk/graphics/konferencer_mm/microclimates/pdf/druzik.pdf>, viewed 6 September 2009.
- Feller, R 1994, 'Accelerated aging: photochemical and thermal aspects', the J Paul Getty Trust, USA, <www.getty.edu/conservation/resources/aging.pdf>, viewed 6 September 2009.
- Ford, BL, Smith, N 2011, 'The development of a significance-based lighting framework at the National Museum of Australia', *AICCM Bulletin*, vol. 32.
- Ford, BL 1991, 'Monitoring colour change in textiles on display', *Studies in Conservation*, vol. 37, no. 1, pp. 1–11.
- Giles, CH 1965, 'The fading of colouring matters', *Journal of*

- Applied Chemistry*, vol. 15, pp. 541–50.
- Kuenhi, RG 2008, 'Colour difference formulas: an unsatisfactory state of affairs', *Color Research and Application*, vol. 33, pp. 324–6.
- Leona, M, & Winter, J 2001, 'Fiber optics reflectance spectroscopy: a unique tool for the investigation of Japanese paintings', *Studies in Conservation*, vol. 46, no. 3, pp. 153–62
- Lerwill, A, Townsend, JH, Liang, H, Thomas, J, Hackney, S 2008, 'A portable micro-fading spectrometer for versatile lightfastness testing', *E-Preservation Science*, vol. 5, pp. 17–28, viewed 15 December 2008, <www.morana-rtd.com/e-preservation-science/2008/Lerwill-22-01-2008.pdf>.
- McCormic-Goodhart, M, Wilhelm, H, Shklyarov, D 2007, 'A "retained image appearance" metric for full tonal scale, colorimetric evaluation of photographic image stability', viewed 12 September 2009, <www.aardenburg-imaging.com/documents.html>.
- Newport Corporation, 'The Oriel fading test system', viewed 17 September 09, <www.newport.com/Fading-Test-System/378064/1033/catalog.aspx?Section=Pricing>.
- Pretzel, B 2008, 'Now you see it, now you don't: lighting decisions for the Ardabil Carpet based on the probability of visual perception and rates of fading', preprints of the 15th Triennial Meeting, New Delhi, 22–26 September, vol. 2, pp. 751–7.
- Waller, R, Michalski, S 2005, 'A paradigm shift for preventive conservation, and a software tool to facilitate the transition', preprints of the ICOM Committee for Conservation, 14th triennial meeting, the Hague, 12–16 September, vol. 1, pp. 733–8.
- Whitmore, PM 2002, 'Pursuing the fugitive: direct measurement of light sensitivity with micro-fading tests', *The Broad Spectrum: The Art and Science of Conserving Colored Media on Paper*, Archetype Publications, London, HK Stratis and B Salvesen eds, pp. 241–3, ISBN 1873132573, viewed 9 September 09, <www.cmu.edu/acrc/Publications/LightSensitivity.pdf>.
- Whitmore, PM, Pan, X, Bailie, C 1999, 'Predicting the fading of objects: Identification of fugitive colorants through direct nondestructive lightfastness measurements', *Journal of the American Institute for Conservation*, vol. 38, pp. 395–409, viewed 9 September 09, <<http://www.cmu.edu/acrc/Publications/lightfast%20measures.pdf>>.
- Zhang, H, Cookson, P, Wang, X 2008, 'Comparative study on accelerated weathering tests of wool fabrics', *Textile Research Journal*, vol. 78, no. 11, pp. 1004–7.