Exhibition Lighting Guidelines for Robert Rauschenberg's *Cardbird I-VII* Series

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ABSTRACT

In 1971, Robert Rauschenberg collaborated with Gemini Graphic Editions Limited (G.E.L.), an innovative printmaking studio in Los Angeles, to produce a series of seven prints titled *Cardbird I-VII*, each in an edition of 75. Although the series appears to be made from assorted found cardboard, many components are meticulously printed to imitate found materials. Each *Cardbird* within this series features elements which include a five-color offset lithograph background designed to mimic a found cardboard surface. It has previously been observed and noted by conservators and the Robert Rauschenberg Foundation (RRF) that the lithographic printing found in the *Cardbird* series can shift from light brown to blue-gray. This report includes a literature review, summary of collaborative discussions, input from stakeholders, overview of prior analysis, and referenceable lighting guidelines tables. Values-based lighting guidelines are discussed as a method to clarify the conceptual beliefs and cultural meanings that inform lighting guidelines more broadly. Prior accelerated aging and material characterization tests are summarized and contextualized, with an emphasis on how these analytical investigations characterize the rate, extent, and underlying mechanisms of the Cardbird light sensitivity. Building on this research and literature review, the lighting guidelines can be used for exhibition and long-term risk management planning by the RRF, collections, and private collectors.

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1. INTRODUCTION

1.1 RRF, VoCA, and WUDPAC Collaborative Partnership and Project Overview

This project was conducted as the seventh year of a collaborative partnership between RRF, VoCA, and WUDPAC. This partnership provides a new educational model for contemporary art conservation, while addressing the specific needs of an artist endowed foundation. Through the technical study of selected works, Research Fellows develop conservation guidance to support the long-term care of Rauschenberg's work (Robert Rauschenberg Foundation). The *Cardbird I-VII* series was selected as the research focus to address Foundation concerns. Through the course ARTC-673, scientific analysis was conducted to investigate the material composition and rate of light-induced change. Through the course ARTC-667, these insights were translated into brief lighting guidelines. This report chronicles associated research for this project.

1.2 Robert Rauschenberg (1925-2008)

Robert Rauschenberg embraced collaborative and experimental approaches, transforming printmaking, photography, drawing, sculpture, and performance into cross-disciplinary practices that blurred the boundaries between art and life. Rauschenberg notably incorporated found and commercially reproduced objects and images into his work, beginning with his education at Black Mountain College in 1948 and continuing after he established a studio in New York City. In 1970, Rauschenberg moved to Captiva Island off the Gulf Coast of Florida. He was increasingly drawn to the aesthetics and conceptual possibilities of found materials–particularly sand, rope, and cardboard–materials that became central to his work (Bois and Elliott 2007, 10-11). It was during this period that Rauschenberg completed the series *Cardbird I-VII*.

1.3 Rauschenberg's Cardbird I-VII series (1971)

In 1971, Robert Rauschenberg collaborated with Gemini Graphic Editions Limited (G.E.L.), an innovative printmaking studio in Los Angeles, to produce a series of seven prints, each in an edition of 75 (fig. 1). Although the series appears to be made from assorted found cardboard, many components are meticulously printed to imitate found materials. Each *Cardbird* within this series features elements which include a five-color offset lithograph background designed to mimic a found cardboard surface.

Figure 1. *Cardbird I-IV*, from left to right. Image source: Gemini G.E.L, 1971.

1.4 RRF: Statement of Need

Figure 2. *Cardbird IV.* The image on the left shows a museum piece displayed under controlled lighting conditions (source: Seattle Art Museum), while the image on the right features a work from a private collection, where light exposure appears less regulated (source: Bukowskis).

Exposing collections to light is essential for education and accessibility. However, this exposure transmits energy to the material, leading to cumulative and irreversible changes. Artworks that are highly vulnerable to light damage, such as those made of paper, textiles, or sensitive colorants, require more frequent rotation. It has previously been observed and noted by conservators and the Robert Rauschenberg Foundation that the lithographic printing found in the *Cardbird* series can shift from light brown to blue-gray (fig. 2). This change is confirmed to be accelerated by exposure to high light levels, typically found in non-museum display settings (Diamond, Grayburn and Warda 2025). The primary concern is how to honor Rauschenberg's intent while incorporating his perspective on the ephemerality of his work as best understood. If the *trompe l'oeil* effect was central to his intent, what is the significance of works with components that have a noticeable blue hue? The inherent vice of the series may either convey or obscure its central message. As fading and color shifts are irreversible, it is essential for stakeholders to reach consensus on the acceptable degree of change, and determine what extent of change, if any, signifies that the object has reached the end of its lifetime. Considering this change in condition, lighting guidelines will be paramount to the foundation's ability to maintain accessibility of this series and answer questions regarding the long-term preservation of *Cardbird* works from private collectors and international collections.

2. METHODS

As a result of this investigation, lighting guidelines were created for the *Cardbird* series (Table 1).

Table 1. Methodology Overview for developing exhibition lighting guidelines.

Component	Purpose	Method
Values-based significance	Clarify the values that inform the lighting guidelines more broadly.	Reviewed literature.
Contextualize scientific analysis	Contextualize material characterization and fading tests to provide a brief overview of the sensitivity of the *Cardbird* series.	Overview of completed analytical methods (Diamond, Grayburn, and Warda 2025).
Lighting guidelines	Create referenceable exhibition light guidelines for the *Cardbird* series for collections, private collectors, and the RRF.	Developed referenceable tables.

3. LITERATURE REVIEW

3.1 Photo-Sensitive Colorants

Commercial offset lithograph printing inks exhibit varied lightfastness. Complex degradation processes occur when these inks exhibit color shifts in hue and lightness due to environmental conditions. The chromophores of dyes or pigments absorb light and can undergo radiative (e.g. fluorescence) and non-radiative processes (e.g. bonds break, bonds form, or reactions occur) (Del Hoyo-Meĺendez and Mecklenburg 2011, 53, 55, 61; Lackner 2024). Light parameters–such as the presence or absence of ultraviolet light, the spectral power distribution (SPD), lux hours of exposure, and the condition of the colorants–influence the photodegradation of dyes and pigments. Additional parameters contribute to photodegradation independently of or in conjunction with light, such as specific printing ink components, atmospheric pollutants, oxygen, pH, relative humidity, and temperature (Giles 1965, Groeneveld et al. 2023, King 1928, Lackner 2024, Pirok et al. 2019, Salvin 1963). Integrating the effect of light with other photodegradation factors can be challenging. Groeneveld et al. (2023, 3-5) provide a broad overview of recent research on the photodegradation of dyes and pigments, with a particular emphasis on the intensity, exposure time, and spectral distribution of the irradiation source. The photochemistry of dyes and pigments, including direct and indirect photodegradation pathways, has been extensively studied and is dependent on the chemical structure and quantity of pigment or dye used (Lackner 2024; Groeneveld et al. 2023; Hird 2000, 424; Cesarrato, Lombardi, and Leona 2017).

3.2 Lighting Guidelines for Photo-Sensitive Colorants

The goal of lighting guidelines is to minimize changes in condition while maximizing accessibility, supporting the transition from a perspective where highly light sensitive objects are "feared," to one where nuanced understandings of change, its timelines, and risk management approaches inform decision making processes (Michalski 2018; Beltran 2018, 6).[15] As stated by Ford and Smith: "[i]t is not generally understood that risk avoidance itself is a counterproductive and potentially dangerous [behavior] precisely because it discourages systematic risk assessment, and in practice delivers rapidly diminishing returns at high marginal cost, diverting attention and resources from competing priorities." The ideal approach of light management at museums involves identifying the most vulnerable works and concentrating resources on protecting them, rather than applying blanket rules to colorants or materials that allow for little opportunity for deviation or nuance (Ford and Smith 2011, 80, 85).

The International Organization for Standardization (ISO) Blue Wool (BW) reference standards (eight in total) fade at a known rate and are commonly used to classify the light sensitivity of collections in the context of lighting guidelines. BW1 is the most light-sensitive, and BW8 is the most lightfast. Each progressive BW standard within the series requires twice as much light exposure as the preceding

[15] Additional measures to minimize light damage to collections can encompass blocking light through exhibition design (UV filters, screens, motion-activated lighting systems, curtain or drawer systems that require visitor interaction to reveal the work) as well as ongoing light monitoring and visual investigation of fading. Additionally, installation with a darker wall to make colors more vivid in a work on display, replication, or more frequent rotation can be considered (Michalski 2018; Brokerhof, Kuiper and Scholten 2018, 28). However, some of these approaches may negatively impact accessibility, collections engagement, and the total expenses associated with exhibitions (Ford and Smith 2011).

standard to fade to the same degree (CAMEO 2022).[16] Guidelines may include the following information: assumed exposure per day (visible, UV, and IR), cumulative hours of display, approximated duration of exposure to reach quantified Just Noticeable Fade (JNF) (1 JNF = 1-1.6 ΔE), and established useful color lifetime based on object significance (Light Damage Calculator. The lower light limit of 50 lux is considered the minimum light level for viewing conditions. However, 50 lux is often inadequate for older visitors and those with vision impairments. Additionally, 50 lux inhibits the ability of all viewers to closely observe fine details or objects with low reflectance, low contrast, large size, at long viewing distances, and with limited viewing time (Ford and Smith 2011, 81, 84). Adaptation of established guidelines can inform the development of lighting guidelines for a specific work or series (BW1-3) (table 2).

Table 2. Reference lighting guidelines for sensitive colorants from varied international organizations.

<table>
<tr><th>Institution</th><th>Lighting Policy for Sensitive Colorants (BW1-BW3)</th></tr>
<tr><td>Canadian Conservation Institute (CCI)</td><td>For BW 1, 2, 3 at a daily exposure of 8 hours, each year 3,000 hours:
<table>
<tr><th>Exposure amount</th><th>Just noticeable fade</th><th>Almost total fade</th></tr>
<tr><td>50 lux</td><td>1.5 - 20 years</td><td>50 - 600 years</td></tr>
<tr><td>150 lux</td><td>0.5 - 7 years</td><td>15 - 200 years</td></tr>
</table>
* “The ‘almost total fade’ is based on a conservative estimate of 30× the ‘just noticeable fade,’ although fading often slows down, so that an estimate of 100×, the just noticeable fade is probable for many colours” (Michalski 2018).</td></tr>
<tr><td>Conservation Center for Art and Historic Artifacts (CCAHA)</td><td>50 lux of visible light, <75 microwatts/lumen UV light, 3 months (CCAHA 2011). These guidelines are now somewhat outdated, as LED and filters allow for the complete elimination of UV light in museum environments.</td></tr>
<tr><td>National Museum of Australia (NMA)</td><td>Goal of 1 JNF/50-year limit. High significance objects that are as sensitive as <BW2 standards should have 50 lux with an “individually decided” years/decade exhibition exhibition total. High significance objects that are as sensitive as BW2-3 standards can have 50-100 lux lighting, with lower conditions as possible, with 2 years/decade exhibition exhibition total.</td></tr>
<tr><td>Netherlands National Museum of Ethnology</td><td>Subdivided “sensitive” into “sensitive 1” (BW1 or worse), “sensitive 2” (BW2–3) and “sensitive 3” (BW3–4), with an additional “vulnerable” category containing “sensitive 1’ objects which are also pristine.”[17] BW 2 or above are allowed a 2-year, 50 lux schedule (Ford and Smith, 2011, p. 82)</td></tr>
</table>

[16] Approximate correlation of an object with a specific BW standard is the result of microfade testing (MFT). MFT is often used as a general screening tool to collect fading information for the most photo-sensitive colorants. This is crucial for developing specific and appropriate lighting guidelines for the most sensitive materials (Ford and Smith 2011, 82). However, as an accelerated aging test, there is the possibility of reciprocity failure and results should be seen as estimates rather than prescriptive determinations of how an object will be impacted by light.
[17] This notion of “pristineness” is a feature of objects with low lightfast colorants (Ford and Smith 2011, 82).

Texas Historical commission	50 lux of visible light, 0-10 microwatts/lumen (ideally, 75 max, UV light, 3-month max display. When exhibiting collections with variable light sensitivity, choose guidelines for the most sensitive component (Texas Historical Society 2013). These guidelines are now somewhat outdated, as LED and filters allow for the complete elimination of UV light in museum environments.
Victoria and Albert (V&A) Museum	The V&A established a minimum useful colored lifetime for objects: 500 years, broken into 50-year blocks during which objects are allowed 1 JNF. After 10 JNFs, the object was considered no longer fit for museum display. Objects that correspond to the ISO Blue Wool (BW) standard of 1-4 could be displayed for a maximum of two years/decade at 50 lux (Ford and Smith 2011, 80).
Winterthur Museum	"Gallery lighting is on for approximately 295 hours per month. This is a slight overestimate, and the number of hours Winterthur recommends is used when considering cumulative exposure for objects on loan." Paper and organic colorants are generally exhibited at 50 lux (Winterthur Museum, 2016).

Although lighting guidelines may appear as straightforward quantifications to follow, there are many subtle nuances that inform lighting guidelines and limit their universality. Ford and Smith (2011) bring address the limitations of using supposedly objective criteria (i.e. JNF, cumulative dose calculations) in isolation to develop lighting guidelines. These criteria, although scientific, still do have a degree of uncertainty, assumptions, simplifications, and over-generalizations built into them. For example, viewer's perceptions of color changes are not uniform, cumulative dose calculations are overly prescriptive, experimental standards (i.e. Blue Wool standards) may vary, museums often have different established object lifetime periods over which they hope to preserve colorants (500 versus 1,000 years), and fading may not proceed at a constant rate and may be significantly altered by compounding environmental conditions (Brokerhof et al 2008, Richardson & Saunders 2007, Pretzel 2008, Kuenhi Rolf 2008, Zhang et al 2008). Scientific analysis can be contextualized with conceptual, institutional, and practical considerations to develop lighting guidelines for a particular object.

3.3 Value-Based Lighting Guidelines

The perception of color change is dependent on the function of an object, the role of color as a "character-determining feature," and the broader cultural importance of a specific work (Brokerhof, Kuiper and Scholten 2018, 32). The value of an object to stakeholders will inform the significance of light-induced color changes. This in turn impacts how light guidelines are developed to protect photo-sensitive colorants. Values are not necessarily stable or objective attributes: they are contextual, relational, and adapt with the zeitgeist of each moment. Therefore, values-based lighting guidelines require periodic review and collaborative partnerships to contextualize quantitative fading data (Ford and Smith 2011, 82-83). Conducting systematic significance assessments involves clarifying many qualities, some of which include the following attributes:

- **Interpretive significance**: Exploring the importance of a particular object in the context of the artist, material tradition, cultural context, local/regional audience of an organization, specific communities or groups with related knowledge or interests, and historic significance. This category emphasizes that the importance of a work does not solely lie in the tangible form (Ford and Smith 2011, 83; Henderson 2020, 196; Reed 2018, 16-17).

- **Color significance**: Determining the centrality of color to the meaning of a work. Considering the intrinsic value of physical material (Ford and Smith 2011, 83).

- **Distinctive significance**: Establishing whether there are duplicates or alternatives; whether a work is an exceptional/typical/substandard example of comparable collections (Ford and Smith 2011, 83; Reed 2018, 16). Should one object absorb most of the fading in order to preserve others, or should condition changes be distributed evenly across similar works?[18]

- **Anticipated significance**: Considering whether a work will be as important in the future as it is now; considering if it is possible, desirable, or ethical to control the impact of restrictions based on an unknown future circumstance. Relying on "future display history" to set exposure limits is inherently a speculative approach (Ford and Smith 2011, 83; Scaturro 2023, 94; Henderson 2020).

These attributes can be clarified through consultations, surveys, and historical research as described by varied significance assessment toolkits (Russell and Winkworth 2009; Reed 2018; Henderson 2020).

3.4 Summary of Photostability Investigation

The color shift of the *Cardbird* series was confirmed to be light-induced, with the most sensitive color–the magenta of the CMYK offset lithograph–corresponding to a BW1-2 in both actual before/after exhibition color measurements and accelerated aging tests (Diamond, Grayburn, and Warda 2025; Hark 2025).

4. LIGHTING GUIDELINES

4.1 Lighting Guidelines

These guidelines were created to encourage openness and agency for stakeholders hoping to exhibit this innovative series (table 3). For highly light-sensitive colorants, generally 50 lux is the recommended visible light level when exhibited. However, works of this scale would be very difficult to light evenly at 50 lux and would not be well enough lit to be visually accessible by most audiences. Therefore, light levels at or below 100 lux would be more realistic for accessible lighting conditions. These higher light

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[18] There is certainly not one "correct" answer from a conservation perspective for this question. In a unique research study conducted in 2015-2016 at the University of Amsterdam's Special Collections, public opinions were compared to those of professionals regarding this central question. In the context of this experiment, the public and professionals both valued spreading fading over a collection if works are not faded, and valued sacrificing one object to preserve others if a work is already faded (Brokerhof, Kuiper and Scholten 2018). Rotations are often considered the default ethical approach, but causing damage to all works can easily become undisputed policy without critical reflection. These questions may ultimately depend on the specific context or collection mission. Careful "rationing" of rarely displayed objects may be a financial waste and unnecessary restriction (Ford and Smith 2011, 82).

levels can be offset by less frequent exhibition, shorter duration of exhibition, or more frequent rotation of objects in an exhibition. The elimination of ultraviolet light is essential, as these works are observed to shift in color most rapidly in private collections where ultraviolet light is not eliminated. Previous guidelines indicate that small amounts of ultraviolet light exposure (0-10 microwatts/lumen) is acceptable, but filters and LED light sources allow for the complete elimination of UV light. As observed with actual color measurements before and after exhibition, 115,000 lux hours of exposure caused a ΔE^*00 of <0.5, indicating that color change does occur with each exhibition and eventually a just noticeable difference (JND, equivalent to $\Delta E^*00=1$) will occur, but that it is still safe to exhibit the work alongside a light management strategy (Diamond, Grayburn, and Warda 2025). Long-term risk management decisions by collections can be made with the support of a calculation of just noticeable fade and almost total fade based on exhibition frequency and annualized exposure estimates (table 4).

Table 3. *Cardbird I-VII* lighting guidelines summary for 50 lux exposure.

Visible light level	<100 lux
Ultraviolet light level	0 microwatts/lumen
Duration for UV-free illumination	~100,000 lux hours[19]

Table 4. *Cardbird I-VII* long term light management planning.[20]

Scenario	Annualized exposure[21]	JNF[22]	Almost total fade (30 x JNF)[23]
Every 3 years	33,333 lux hours/year	~10 years	~ 297 years (theoretical)
Every 5 years	20,000 lux hours/year	~16.5 years	~ 495 years (theoretical)
Every 7 years	14,286 lux hours/year	~23 years	~ 693 years (theoretical)

[19] This cumulative total can be used to calculate specific conditions for lighting exposure. For example, an exhibition where an object is displayed at 100 lux x 8 hours a day x 7 days a week x 12 weeks would have a total exposure of 67,200 lux hours. This can be easily adjusted to accommodate variations in duration of exposure.

[20] The following scenarios in this table are examples which can be adapted over time, and can include duration of spaced exhibitions that are not outlined here.

[21] Each exhibition is assumed to expose the *Cardbird* to approximately 100,000 lux hours. Therefore, the annualized exposure can be calculated by dividing 100,000 lux hours by the interval of exhibition. For example, 100,000 lux hours / 3 years = 33,333 hours / year.

[22] If 115,000 lux hours is observed to cause approximately $\Delta E^*00 \approx 0.5$, then 330,000 lux hours can be assumed to cause $\Delta E^*00 \approx 1$. 330,000 lux hours divided by the annualized exposure produces the number of years at which a $\Delta E^*00 \approx 1$ will occur (Diamond, Grayburn, and Warda 2025). For example, 330,000 lux hours / 33,333 lux hours per year = 9.9 years. **1 JNF does not indicate a work is unexhibitable.**

[23] The almost total fade is based on an estimate of 30 times the JND. However, this value is highly theoretical as fading often slows down (Michalski 2018). This value was calculated by assuming that an almost total fade occurs at 30 times the 330,000 lux hours estimated to cause 1 JNF. Therefore, 9,900,000 lux hours would cause an almost total fade. Therefore, dividing 9,900,000 by the annualized exposure will provide an estimated time for the almost total fade to occur.

4.2 Future Research

Formalizing a values-based lighting guideline reference may be of interest to stakeholders. Future research could identify different levels of sensitivity within the series based on previous exhibition history and observed color shifts (i.e. pristine, mild to moderate, and extensive) (fig. 3). However, the more nuanced lighting guidelines become, the less accessible they are to stakeholders and the more room for interpretive error.

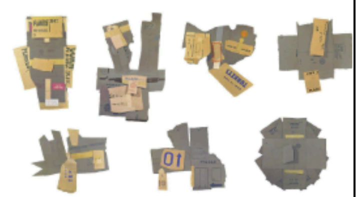
Sensitivity	*Cardbird* status	BW equivalent	Exhibition history	Visual representation
Sensitive 1	**Pristine**: No notable color difference between offset lithograph background and cardboard attachment; no blue hue notable.	< BW1.5 (approximate)	< ___ lux hours (approximate)	
Sensitive 2	**Mild to moderate color shift**: Mild to moderate color difference between offset lithograph background and cardboard attachment; slight blue hue notable, but the work is still legible as	BW1.5 - BW2.5 (approximate)	__ - __ lux hours (approximate)	
Sensitive 3	**Extensive color shift:** Extreme color difference between offset lithograph background and cardboard attachment; blue hue immediately notable.	> BW2.5 (approximate)	> ___ lux hours (approximate)	

Figure 3. Example of *Cardbird I-VII* classification of sensitivity based on the condition status.

5. CONCLUSION

Lighting guidelines for the preservation of contemporary art can be approached with a balance of accessibility and risk management. As Brokerhof, Kuiper, and Scholten (2018) emphasize, collections managers hold responsibility for the rationale behind decisions for future generations. Thoroughly considered exhibition policies, rooted in an understanding of both the scientific and ethical dimensions of preservation, are essential. Lighting guidelines can underscore the importance of evaluating potential losses in value, particularly in the context of significant cultural heritage, and further highlight that managing these risks requires careful consideration of the long-term effects on significance (Michalski's 2004, Ford and Smith 2011). By integrating risk assessment with informed decision-making, curators and conservators can safeguard the integrity of contemporary artworks, such as the *Cardbird* series, while ensuring their accessibility for future audiences.

PARTIALLY ANNOTATED BIBLIOGRAPHY

Barro, Lisa, Katherine Sanderson, Silvia Centeno, and Beth Saunders. 2020. "The Exhibition and Characterization of Seven Salted Paper Prints." *Journal of the American Institute for Conservation* 59, no. 3–4 (October): 171–85. https://doi.org/10.1080/01971360.2019.1696914.

Seven salted paper prints were investigated with XRF, Raman spectroscopy, spectrophotometry (before, during, and after exhibition measurements), and MFT. This paper connects the reciprocity principle, variability within multiple works of similar methods, material characterization and observed stability, and a literature review of perspectives on lighting guidelines for salted paper prints. This paper presents an approach to contextualizing MFT in broader contexts, including art historical research, material practices, and exhibition lighting guidelines.

Beltran, Vincent Laudato. 2018. *Advancing Microfading Tester Practice: A Report from an Experts Meeting Organized by the Getty Conservation Institute*. CA: The Getty Conservation Institute. https://hdl.handle.net/10020/gci_pubs/advancing_mft_practice.

Beltran, Vincent Laudato, Christel Pesme, Sarah K. Freeman, and Mark Benson. 2021. *Microfading Tester: Light Sensitivity Assessment and Role in Lighting Policy*. Los Angeles: Getty Conservation Institute. http://hdl.handle.net/10020/gci_pubs_microfading_tester.

Chapter 5, "Lighting Policy Framework and Role of MFT," provides nuanced and thorough discussions of best practices for assessing value at risk of being damaged by light, quantifying light risk, and managing light risk associated with display. Of particular interest is "Formulating Display Recommendations" on page 78. Table 5.7 effectively presents lighting recommendations in a way that empowers readers and collecting institutions to make informed decisions based on data, rather than assuming their needs and goals in advance.

Bois, Yve-Alain and Clare Elliott. 2007. *Robert Rauschenberg: Cardboards and Related Pieces*. Houston, TX: Menil Collection.

Brokerhof, Agnes W., Margrit Reuss, Fiona MacKinnon, Frank Ligterink, Han Neevel, Farideh Fekrsanati, and Graeme Scott. 2008. "Optimum Access at Minimum Risk: The Dilemma of Displaying Japanese Woodblock Prints." Studies in Conservation 53 (1): 82–87. https://doi.org/10.1179/sic.2008.53.Supplement-1.82

Brokerhof, Agnes, Pieter Kuiper, and Steph Scholten. 2018 "Spread or Sacrifice: Dilemma for Lighting Policies." *Studies in Conservation* 63, (1): 28–34. https://doi.org/10.1080/00393630.2018.1504439.

This article discusses the interpretation of lighting guidelines for light-sensitive objects: should the work be shown extensively or stored away and only viewed for restricted, periodic windows? Uniquely, this research connected public and professional opinions based on fading simulations with quantified changes in color value: "results show that while colour changes are hardly visible,

both public and professionals do not perceive them as damage and prefer to spread fading. Once fading becomes clearly visible in all maps, the preference shifts to sacrificing one map. The tipping point lies around five just noticeable changes" (Brokerhof, Kuiper and Scholten 2018, 28). Additionally, this paper includes a brief discussion of how museums reduce fading through installation decisions beyond duration of exhibition. The diagram and chart of how fading was visualized and interpreted (fig. 2 and fig. 3 on page 31-32) could be interesting to apply to this project. Strong insights in the conclusion included a discussion about how the function and value of an object determines the importance of color, as well as potential biases that may have affected results from the public and from museum professionals.

CAMEO (Conservation and Art Materials Encyclopedia Online). s.v. "Blue Wool Standard." Last modified May 8, 2022. https://cameo.mfa.org/wiki/Blue_Wool_Standard.

Cesaratto, Anna, John R. Lombardi, and Marco Leona. 2017. "Tracking photo-degradation of triarylmethane dyes with surface-enhanced Raman spectroscopy." *Journal of Raman Spectroscopy*, 48: 418–424. https://doi.org/10.1002/jrs.5056.

Conservation Center for Art and Historic Artifacts (CCAHA). 2011. *Light Levels for Storage and Exhibition*. Philadelphia: Conservation Center for Art and Historic Artifacts. https://www.connectingtocollections.org/wp-content/uploads/2011/08/hbcu-light-levels-for-storage-and-exhibition.original1.pdf.

del Hoyo-Meléndez, Julio M. 2024. "Physico-chemical characterisation and light stability of dyes and pigments found in cultural heritage objects: Insights from microfading testing for assessing light fastness." *Coloration Technology,* 1-26. https://doi.org/10.1111/cote.12788.

This article provides essential context on applying MFT measurements to real life, with an emphasis on the reciprocity principle of light, or the assumption that equivalent exposure doses obtained by brief, high-illuminance levels can cause similar degrees of damage to an object as prolonged, low-illuminance levels of light. Although focused on color standards and colorants not necessarily related to the *Cardbird* study, relevant equations and theoretical frameworks are presented in an accessible format. A key takeaway from this article is that "careful judgment should be exercised when establishing lighting parameters for museum exhibits which are based on accelerated light aging data since the reciprocity principle of light exposures generally holds only for the most stable artifacts, while deviations should be expected for materials with high light intensity" (61). In this article, MFT is framed as a useful tool for comparing the fading rates of several colorants, rather than establishing prescriptive notions of aging. Complementary analytical techniques are suggested for identifying the chemical process of degradation.

Del Hoyo-Meĺendez, Julio M. and Marion F. Mecklenburg. 2011. "An Investigation of the Reciprocity Principle of Light Exposures Using Microfading Spectrometry," *Spectroscopy Letters* 44, (1): 52–62, https://doi.org/10.1080/00387010903508572.

Diamond, Daisy, Rosie Grayburn, and Jeffrey Warda. 2025. "On the Light Stability of Robert Rauschenberg's Cardbird I-VII Series." Internal unpublished document. New York: Robert Rauschenberg Foundation.

Ford, Bruce and Nicki Smith. 2011. "The Development of a Significance-Based Lighting Framework at the National Museum of Australia," *AICCM Bulletin* 32, (1): 80–86. https://doi.org/10.1179/bac.2011.32.1.011.

In this progressive and holistic exploration of lighting guidelines in museums, the nuances of the assumptions, simplifications, and uncertainties in light data (i.e. JNF, cumulative dose calculations, etc.) are explored at the National Museum of Australia (NMA). This paper describes how contextual approaches to lighting guidelines are essential, particularly for the most sensitive materials (BW 1 or 2). This paper is particularly helpful for determining the overlapping and diverging practices of international institutions. Approaches taken by conservators at varied cultural heritage organizations are described. The authors also provide context on how to pursue systematic significance assessments.

Gemini G.E.L.. 1971. "Cardbirds" brochure. Los Angeles, CA: Gemini G.E.L.

Giles, C.H.. 1965. *The fading of colouring matters*. Journal of Applied Chemistry, 15: 541-550. https://doi.org/10.1002/jctb.5010151201.

Groeneveld, Iris, Maria Kanelli, Freek Ariese, and Maarten R. van Bommel. 2023. "Parameters That Affect the Photodegradation of Dyes and Pigments in Solution and on Substrate – An Overview," *Dyes and Pigments* 210: https://doi.org/10.1016/j.dyepig.2022.110999.

Hark, Richard. 2025 "Microfade Tests on Cardbird I-VI by Robert Rauschenberg [71.E004.AP1, 71.E004.AP2, 71.E004.AP3, 71.E005.AP3, 71.E006.AP1, 71.E007.AP1, 71.E008.AP1, 71.E009.AP1, 71.E010.AP1, 71.E010.AP2, 71.E010.AP3]." Internal unpublished document. New York: Robert Rauschenberg Foundation.

Henderson, Jane. 2020 "Beyond Lifetimes: Who Do We Exclude When We Keep Things for the Future?" *Journal of the Institute of Conservation* 43, (3): 195–212. https://doi.org/10.1080/19455224.2020.1810729.

Henderson's publication has many core concepts which will help establish values-based lighting guidelines. Through this article, Henderson describes and challenges a dominant narrative of risk management: keeping objects indefinitely is a fixed and ideal goal. She clarifies that extending "lifetimes" of objects is not inherently equivalent to extending the "life-experiences" generated by them. The overview of relevant theory in this article also contextualizes important significance assessment considerations that may be applicable to light guideline decision making processes. In conjunction with Reed 2018 as well as Russell and Winkworth 2009, these resources lay the groundwork for how to complete a significance assessment in collaboration with stakeholders.

Hird, Kenneth. 2000. *Offset Printing*. Tinley Park, IL: Goodheart-Willcox Co.

King, A.T.. 1928. “The Effect of Sulphur Dioxide on Azo Dyestuffs and A Proposed New Standard Test for Fastness to Stoving.” *Journal of the Society of Dyers and Colourists* 44, no. 1 (January): 14-18. https://doi.org/10.1111/j.1478-4408.1928.tb01461.x.

Kuehni, Rolf G. 2008. “Colour difference formulas: An unsatisfactory state of affairs.” *Color Research and Application*, 33: 324–326.

Lackner, Rachel. 2024. “Dye Chemistry” PowerPoint presentation, Properties and Structure of Art Materials I, Winterthur/University of Delaware Program in Art Conservation.

Light Damage Calculator. Canadian Conservation Institute. Accessed April 28, 2025. https://app.pch.gc.ca/application/cdl-ldc/description-about.app?lang=en.

This is a useful tool for collections stakeholders to estimate photo-induced fading of colorants. There are three calculators that can be used to assess the fading of a single colorant under a single set of conditions, compare side-by-side examples of fading caused by three different exposure scenarios, and present the fading of collections of colors. This user-friendly resource requires no complex math, and there is even an hour-long recorded presentation by Senior Conservation Scientist at CCI, Stefan Michalski, providing an overview of how to use the Calculator.

Michalski, Stefan. 2018. "Agent of Deterioration: Light, Ultraviolet and Infrared." *Canadian Conservation Institute.* https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html.Government of Canada+5Government of Canada+5Government of Canada+5

This website published as part of the CCI “Preventive Conservation and Risk Management” series covers core topics and examples related to lighting guidelines: the save vs. sacrifice dilemma (see also Ford and Smith 2011), quantifying light, accessibility and light, deterioration caused by light, controlling light, case studies and history of light management, key related readings, and a glossary. Tables 2a-b (“General Characteristics of Light Sources for Museums”) contain helpful information about voltage, common types, lifetime hours, cost per lamp, color temperature, UV output and filter needs, as well as advantages and disadvantages of fluorescent, incandescent, and LED bulbs.

Pirok, Bob W.J., Giacomo Moro, Nienke Meekel, Sanne V.J. Berbers, Peter J. Schoenmakers, and Maarten R. van Bommel. 2019. “Mapping degradation pathways of natural and synthetic dyes with LC-MS: Influence of solvent on degradation mechanisms.” *Journal of Cultural Heritage* 38: 29-36. https://doi.org/10.1016/j.culher.2019.01.003.

Pretzel, Barbara. 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.” In *Preprints of the 15th Triennial Meeting of the ICOM Committee for Conservation*, vol. 2: 751–757. New Delhi: Allied Publishers.

Reed, Caroline. 2018. “Reviewing Significance 3.0.” UK: Collections Trust.

Richardson, Clare, and David Saunders. 2007. "Acceptable Light Damage: A Preliminary Investigation." *Studies in Conservation* 52, (3): 177–87. http://www.jstor.org/stable/20619500.

In this article, Richardson and Saunders establish how to define tolerable levels of light-induced change to museum collections. They propose that instead of solely minimizing exposure, institutions can balance display needs with controlled, acceptable risks of change. Importantly, this paper goes beyond simply using the JND unit in support of risk management. The authors attempt to explore how acceptable change can be defined, and they problematize some of the arbitrary nature of broadly applicable acceptable degrees of change. This study examines the extent to which perception of color difference is affected by the context in which these differences appear. This research supports the idea of developing more flexible, evidence-based lighting guidelines tailored to specific collection needs.

Russell, Roslyn, and Kylie Winkworth. 2009. *Significance 2.0: A Guide to Assessing the Significance of Collections*. 2. ed. Rundle Mall: Collections Council of Australia.

In this guide, Russell and Winkworth present a framework for assessing the significance of collections based on a range of values, including historical, aesthetic, scientific, and social significance. Rather than focusing solely on material preservation, they emphasize the need to balance conservation with the broader meanings and uses of collections. This guide encourages stakeholders to consider how significance assessments can shape decision-making, including exhibition practices like lighting. Russell and Winkworth offer a model for integrating values-based reasoning into conservation strategies, supporting the development of lighting guidelines that are more flexible, context-specific, and aligned with the intended experiences of collections.

Salvin, V.S. 1963. "The Effect of Atmospheric Contaminants on Light Fastness." *Journal of the Society of Dyers and Colourist*s, 79: 687-696. https://doi.org/10.1111/j.1478-4408.1963.tb02529.x.

Scaturro, Sarah. 2023. "Towards a New Consideration for the Wearing of Historic Costume." *North American Textile Conservation Conference*Texas Historical Commission. 2013. *Light Level Recommendations for Museum Collections*. Austin: Texas Historical Commission. https://www.thc.texas.gov/public/upload/publications/Light%20Level%20Recommendations%202013.pdf.

Winterthur Museum, Garden & Library. 2016. "Environmental Management Policy: Galleries Building." Internal unpublished document. Wilmington, DE.

"Winterthur/University of Delaware Program in Art Conservation in conjunction with Voices in Contemporary Art: Conservation Fellowships, 2018-present." Robert Rauschenberg Foundation (RRF). Last accessed April 28, 2025. https://www.rauschenbergfoundation.org/collaborations/wudpac-and-voca-2018-present.

Zhang, Hu, Peter Cookson, and Xungai Wang. 2008. “Comparative Study on Accelerated Weathering Tests of Wool Fabrics.” *Textile Research Journal* 78, (11): 1004–1010. https://doi.org/10.1177/0040517507087857.AGRIS+2