New Materials & Research

Using Risk Assessment Tools to Evaluate the Use of LEDs for the Illumination of Light-Sensitive Collections

Light Emitting Diodes (LEDs) have been gaining a great deal of attention over the last few years. This interest has been fueled by the need to find an energy efficient replacement for the incandescent lamp, a technology that has been around in various forms since the time of Edison. The rapid emergence of LEDs as a potential source for general lighting applications has also led to a great deal of confusion and concern about the appropriateness of the current generation of LEDs. These concerns fall into three categories:

- Risk to light sensitive artifacts
- Color rendering characteristics
- Reliability and cost-benefit of LEDs compared with alternative sources of illumination

This article focuses specifically on risk because it is of primary concern in considering the use of LEDs in a display setting.

Development of a Metric to Evaluate Risk from Light Sources

In order to evaluate the relative risk of different light sources, it is necessary to have an appropriate damage metric. This is the problem that confronted researchers from the National Bureau of Standards (NBS), now known as the National Institute of Standards and Technology (NIST) when they did a pioneering study on light damage in the early 1950s to protect the Charters of Freedom at the National Archives. At that time, they determined that the metric had to focus on the inherent spectral differences between light sources, not on the unique properties of any specific museum object:

> *The materials of museum objects are varied… it is all the more impossible to assign to a light source a rate of damage applying simultaneously to all museum objects. The best that can be hoped for is an evaluation of the radiation hazard associated with each light source, that is, the probable rate of damage to the average museum object associated with unit areal density of incident luminous flux from the source. (National Bureau of Standards Report #2254 cited in Harrison 1953)*

Scientists understood that for equal amounts of radiant power, shorter wavelengths of light (UV-blue region) should have more potential to cause damage than longer wavelengths (red-IR region) since longer wavelengths of light have less energy. The NBS team exposed low-grade paper to a full range of wavelengths in the UV and visible region, and measured damage to determine the relative damage potential of each wavelength.

In order to assess and compare the damage potential of different types of light sources, the NBS calculated an illuminant's "relative damage factor" as follows:

- Multiply the amount of power per wavelength for a light source by the NBS derived damage potential for that wavelength. This value describes the relative contribution to damage for each wavelength for a specific light source.
- Multiply this result by the relative visual intensity within the visible spectrum for each wavelength, defined as the photopic luminosity function $V(\lambda)$. This value describes the relative contribution to overall illuminance of each wavelength in proportion to its power and damage potential.
- Total up the values calculated in the previous step. This sum is the total damage potential for the source.
- Finally, by knowing the total illuminance (lux or foot candles) of the source, divide the sum by its luminous intensity to determine the relative damage per lux or foot candle for the source.

In the early 1950s, with the rapid growth of fluorescent lamps as a general light source, a great deal of concern was raised about potential damage to light sensitive museum collections from fluorescent lamps as compared to incandescent lamps or UV filtered daylight, not unlike today's concern about LEDs. In 1953, the Metropolitan Museum of Art hired a lighting engineer, Lawrence Harrison, to study this issue. He analyzed the potential hazard of different types of light sources, building on data and the method of analysis developed by the NBS.

Harrison's results were fascinating. It turned out that a high color temperature source like daylight, filtered to remove all UV radiation, had three to four times the damage potential of an incandescent lamp based on the NBS relative damage function per wavelength.

Revisiting the Relative Damage Factor

In the 1970s–1980s, a group led by Krochmann reassessed the NBS work. They used a large range of light sensitive materials, over 50 in total. Their results reconfirmed the NBS work for low-grade paper. For more photochemically stable materials, including rag paper, oil on canvas, textiles, and watercolors on rag paper, damage per radiant unit of light exposure increased with a decrease in wavelength, but at a slower rate compared to low-grade paper. Follow-up work by Saunders and Kirby in the 1990s reconfirmed that shorter wavelengths have more damage potential than long wavelengths. They also observed that damage is reduced in the wavelengths where the object has the highest reflectance value, since less radiant energy is absorbed in this region. All of these studies were assimilated and published by Cuttle in 1996 and were embodied within the Commission Internationale de l´Eclairage (CIE) Museum Report entitled *Control of Damage to Museum Objects by Optical Radiation* (CIE 157:2004).

In sum, the damage curves described in the CIE report provide the most universal method for assessing relative damage based on the spectral distribution of any light source. Because the probable rate of damage per wavelength is based on results from a broad range of materials, it avoids the inevitable problem of making general assumptions about damage based on unique photochemical sensitivity of a particular material. For now, these values provide the most useful means for calculating wavelength specific damage since they take into account the higher damage potential of shorter wavelengths. Although future research may result in modifications of current damage values, the general procedure for comparing relative risk from different light sources, first described by the NBS in the early 1950s, is correct.

Alternative damage metrics such as the British Blue Wool Standards and Light Check are useful and important tools when used as dosimeters for measuring cumulative damage over time. These tools have their own unique photochemical sensitivities, which is not a problem for their intended application, but are not appropriate for comparing the spectral damage potential of light sources.

Comparison of Relative Damage Potential of Full Spectrum Light Sources

Table 1: Relative Damage Potential for Different Color Temperatures

Color Temperature of Source	Relative Damage Potential	Example of Lamp Type
3000°K	1.04	Tungsten halogen
4000°K	1.37	Cool white fluorescent
5000°K	1.71	Sun + Daylight
6000°K	2.01	Daylight fluorescent

According to this data, a museum collection illuminated with daylight at 6000°K will sustain almost twice the damage compared to a tungsten halogen source at the same level of luminous intensity.

The CIE Report includes a table of relative potential damage for full spectrum sources ranging from 2500°K to 7500°K in 500°K increments. It did not include any discontinuous spectral sources such as fluorescent, metal halide, or LED lamps, since the emphasis was on the overall impact of color temperature on damage, rather than the unique damage potential of specific light sources. To simplify comparison, all values were normalized based on an assignment of a value of 1.0 for Source A (2856°K) and all wavelengths below 400nm were excluded. A summary of some of the values is listed in Table 1.

LEDs and Full Spectrum Light Sources: A Comparison of Relative Damage Potential

For purposes of this communication, Art Preservation Services analyzed six different lamp/filter combinations to assess the relative potential damage of LEDs compared to tungsten halogen sources and the results are tabulated in Table 2.

According to the results in Table 2, the two warm LEDs had the lowest relative damage potential and the unfiltered 4700°K Solux tungsten halogen lamp had the highest relative damage potential. These results are not surprising.

- A typical warm LED has a peak around 445–455 nanometers (nm).
  - It has very little power below 440 nm, a part of the blue region which is more damaging and provides less luminous intensity than the blue region at or above 440 nm.
  - A warm LED would be expected to do less or approximately the same damage as a conventional tungsten halogen lamp of an equivalent brightness, since neither source has a large amount of radiant energy in the blue region, especially in the most damaging portion below 440 nm.
- The Solux 4700°K tungsten halogen lamp has a relatively high proportion of short to long wavelengths compared with a normal tungsten halogen lamp, which is why it has a high color temperature.
  - The higher proportional amount of blue to red explains why this type of lamp has a higher damage potential than a warm LED or a conventional 3000°K tungsten halogen lamp.
  - The higher proportion of blue also results in a higher proportion of UV, which is why a UV filter has a bigger benefit for this lamp than for a 3000°K tungsten halogen lamp.

Table 2: Relative Damage Potential for Select Tungsten Halogen and LED Sources

Lamp and Filter*	Source	Color Temperature or CCT	Relative Damage Potential**
MR-16, No Filter	T-H	3000°K	1.00
MR-16, UV filter	T-H	-	0.96
Ledtronics, No Filter	LED	3200°K	0.86
Cree MP-L, No Filter	LED	3500°K	0.93
Solux, No Filter	T-H	4700°K	1.37
Solux, UV Filter	T-H	-	1.14

All measurements were done with an Ocean Optics 2000 USB spectrometer. All color temperature readings are based on manufacturer data. All calculations utilized the CIE published damage values.

* MR-16 Sylvania Tru-aim MR16 35/12; Ledtronics PAR 30 10w; Cree MP-L: XLamp MP-L EasyWhite at 700mA; Solux 4700°K; UV filter Optium Museum Acrylic

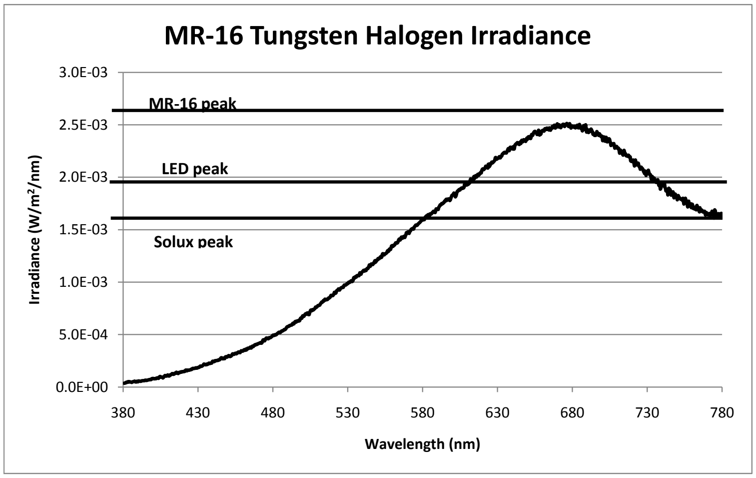
** All damage values were normalized based on the assignment of a value of 1.0 for an unfiltered tungsten halogen MR-16 lamp.

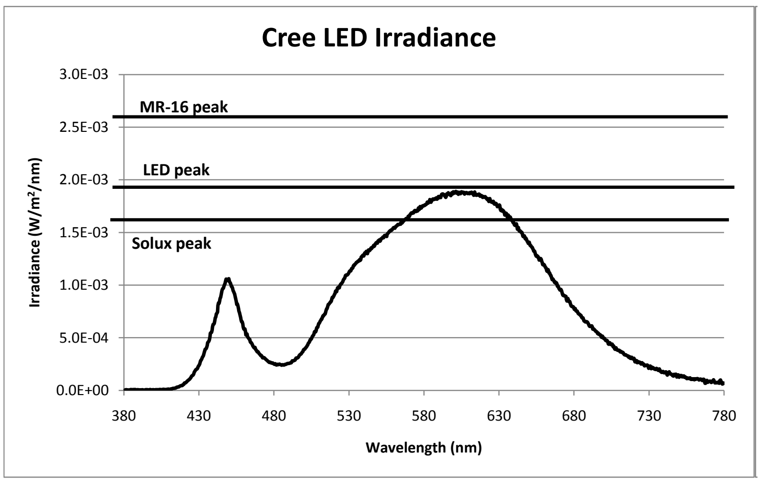
Alternative Methods for Evaluating Risk from Light Sources: Peak Power Output

An alternative metric for evaluating relative risk of light sources under recent discussion among conservators and conservation scientists compares the peak radiant output of different lamp sources, all measured at the same photopic level of intensity. This metric:

- Only takes into account the peak energy of the single wavelength with the highest output, not the overall spectral distribution of the lamp.

Diagram 1: Peak Power Output of Select Tungsten Halogen and LED Sources





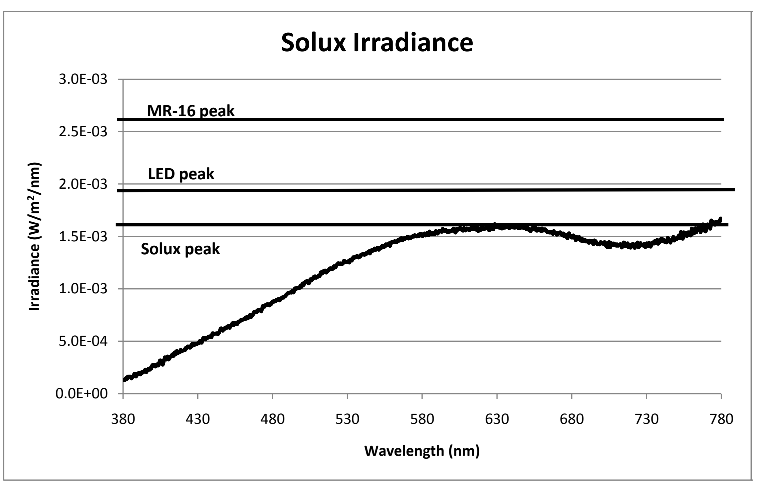


Diagram 1: Spectral power distributions of three lamps—3000°K Tungsten Halogen, 3500°K LED, 4700°K Solux. All lamps normalized to 1 Lux. Horizontal lines placed at 2.5^{-3} W/m²/nm for the MR-16 peak, 1.8^{-3} W/m²/nm for the LED peak, and 1.6^{-3} W/m²/nm for the Solux peak.

- Assumes that there is a one-to-one correlation between peak energy and damage.

The rationale for looking at peak energy rather than total energy is based on the phenomenon of "hole-burning," and assumes that isolated LED output peaks will cause accelerated damage.

It would be useful to put risk into perspective by comparing the results of this metric to the CIE damage metric. Three lamps previously analyzed in Table 2, a standard tungsten halogen lamp, a Solux 4700°K lamp, and a representative warm white LED are compared in Diagram 1, all at equal illuminance. According to the damage metric based on peak power output:

- The MR-16 tungsten halogen lamp would be the most damaging of the three light sources by a significant margin. Its peak wavelength is 130% greater than the narrow blue peak of the LED and 40% greater than the LED broad band peak.
- The Solux 4700°K lamp would be the least damaging of the three light sources since it is heavily filtered to reduce energy in the peak red portion of the spectrum in order to increase its color temperature.

These results are the opposite of the *relative damage potential* values from Table 2, which were based on CIE calculations. When the damage potential of the full spectral distribution curve is taken into account, an unfiltered tungsten halogen lamp was slightly more damaging then a 3500°K white LED, and considerably less damaging then the unfiltered Solux 4700°K lamp.

What is the cause of this significant discrepancy regarding relative damage?

- *Relative damage potential* deals with the entire UV through visible spectral output of a light source.
- Total photochemical damage cannot be calculated based on the comparison of the highest peak in the spectrum.

Does the risk of "hole-burning" warrant the adoption of an alternative damage metric based on peak power output? This phenomenon occurs in the unique case where a very high energy peak from a light source closely aligns with a region of high absorption by a light-sensitive material, referred to as its action spectrum. For warm and neutral white phosphor-based LEDs where the narrow blue "peak" is actually a lower value than the broad spectral band and is much lower than the peak of a tungsten halogen lamp, the risk of "hole-burning" damage at an illumination level of 5 to 20 foot candles is very small or non-existent.

Conclusion

Shorter wavelengths of light have more energy and therefore more damage potential than longer wavelengths for equal amounts of radiant power. An appropriate metric for comparing the relative damage from light sources must account for the damage potential of individual wavelengths.

Since each light sensitive object responds somewhat differently to light exposure, it is necessary to assign a damage potential per wavelength based on the average response of a broad range of light sensitive materials. The Krochmann/CIE damage values provide information that is supported by average wavelength-specific light sensitivity response and was based on testing that was performed on a large number and wide variety of materials. Using this method, it is reasonable to conclude that low to intermediate color temperature (2700–4000°K) white phosphor-based LEDs and UV-filtered tungsten halogen lamps are safe for the illumination of light sensitive materials if used at an appropriate light level for museum applications.

Alternative damage metrics such as British Blue Wool standards and Light Check are useful as general dosimeters but are not appropriate for comparing light sources. Other metrics such as peak power output are inappropriate because they don't take into account the contribution to damage from the entire spectrum. The CIE method for calculating relative damage of light sources provides a valuable tool for making critical decisions about the impact of light on collections.

Note

A detailed description of how to calculate spectral damage is available as a downloadable document on the Art Preservation Services website (www.apsnyc.com).

Sources

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Acknowledgment

Elyse Canosa for assisting with the spectrometer readings and preparation of the graphs.

—*Steven Weintraub*

Art Preservation Services, Inc., sw@apsnyc.org

New Publications

Les arts graphiques: restauration/recherche: Journée d'études en l'honneur de Carlo James, publishes the papers given at a colloquium held in 2005 in honor of Carlo James, conservator of prints and drawings for the Fondation Custodia. Paris: Fondation Custodia, 2008.

Conserving Outdoor Sculpture: The Stark Collection at the Getty Center, by Brian B. Considine, recounts the acquisition, treatment, installation, and maintenance of the Stark collection of outdoor sculpture from the point of view of its conservators. The project commenced in December 2005 and continued until June 2007, when the installation of all 28 sculptures was completed. Los Angeles: Getty Conservation Institute, 2010.

Issues in the Conservation of Photographs, edited by Debra Hess Norris and Jennifer Jae Gutierrez, gathers 72 texts from the nineteenth century to the present day, covering the history of photograph conservation, practical approaches to the preservation of specific photograph types, and criteria for collection management and treatment, among other topics. Los Angeles: Getty Conservation Institute, 2010.

Witnesses to History: A Compendium of Documents and Writings on the Return of Cultural Objects, edited by Lyndel V. Prott, compiles documents concerning various aspects of the repatriation of cultural objects, including their history, philosophy, and ethics; legal issues; and procedures for requests. Paris: UNESCO, 2009.

Contesting Knowledge: Museums and Indigenous Perspectives, edited by Susan Sleeper-Smith, is a collection of essays dealing with the relationships between museums and nation-states. Lincoln: University of Nebraska Press, 2009.

Installing Exhibitions: A Practical Guide, by Pete Smithson, presents practical information on how to put up an exhibition, from the initial considerations (e.g., risk assessment, health and safety) to basic construction, fixing, lighting, and other topics. It includes separate chapters on two-dimensional work and audio-visual materials. London: A & C Black, 2009.

People

Kelly Ciociola, a recent graduate of Clemson University/College of Charleston's Historic Preservation program, is joining Kreilick Conservation LLC as Architectural and Sculptural Conservator.

Dr. Christina Cole has been named the first Andrew W. Mellon Fellow in Conservation Education at the Department of Art Conservation Department of the University of Delaware.