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Measurement of Ultraviolet Radiation – Canadian Conservation Institute (CCI) Notes 2/2

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Ultraviolet (UV) Radiation

Minimizing the exposure of UV on a collection is important due to the cumulative damage it can cause to the colour and structure of materials. This Note discusses different ways to measure UV and provides guidelines to estimate its potential impact on a collection. Refer to CCI Note 2/1 *Ultraviolet Filters* for further information about UV damage and how to filter UV from a light source.

The Quantification of UV

There are two common ways to measure UV radiation: compare the amount of UV energy relative to the light emitted by a source, or measure the absolute amount of UV energy an object receives over its surface.

Relative measurement

The relative measure of UV is primarily used in heritage preservation and is almost unknown to professionals in other fields. It is the ratio of the amount of UV energy that a surface receives to the amount of visible radiation (lumens) from the same light source. Note that, while taking these measurements, it is preferable to have the UV meter facing the light source. The relative value enables a quick comparison of UV content between illuminants, independent of light intensity.

Table 1 shows the possible ranges of UV emitted by different sources in units of microwatts per lumen (μW/lumen). The sources of light with the highest UV content are the sun and high intensity discharge lamps, while the lowest is the light-emitting diode (LED) (blue pump type). In the last few decades, the amount of UV from fluorescent lamps has reduced significantly due to advances in technology. The UV range indicated in Table 1 includes values from both old and new fluorescent long tubes.

Table 1. Typical relative UV levels from different light sources (updated and adapted from Michalski 2011 and Saunders 1989).

Light Sources	**Relative UV levels (µW/lumen)**
Incandescent, traditional (tungsten lamp)	60–80
Incandescent, quartz halogen	100–200
Fluorescent, long tube	30–150
Fluorescent, compact	70–150
HID (high intensity discharge) such as metal halide lamps	160–700
White LED, blue pump	usually below 1
Daylight (light from outside entering the room)	300–600

Absolute measurement

Absolute measurement gives the amount of UV energy on the object per unit area, expressed in milliwatts per square meter (mW/m^2). This is useful to determine the UV dose that an object receives, which can help predict its future state (i.e. in a manner similar to calculating light dose). While taking an absolute measurement, the UV meter must be parallel to the object surface. Proper alignment allows the instrument to measure UV radiation received from multiple sources.

Correlation between the relative and absolute UV levels

Converting between relative and absolute UV values is simple to perform. The UV and light measurements are taken with the instrument sensor parallel to the object surface, and the light intensity measurement is expressed in lux. A relative UV value is converted to the absolute form using the relationship

$$UV_{Ab} = \frac{L \times UV_R}{1000}$$ **Equation 1**

where L is the light intensity (lux) in lumen/m^2, UV_R is the relative UV measurement in µW/lumen, and UV_{Ab} is the absolute value in mW/m^2.

Example:
If the surface of a painting is illuminated at 100 lux with a relative UV measurement of 75 µW/lumen, the absolute UV radiation that the painting receives is 100 x 75/1000 = 7.5 mW/m^2.

Recommended maximum UV levels

Relative UV (UV_R)

Thomson (1978) reported that the amount of UV emitted by a typical tungsten lamp is about six times lower than daylight. He then suggested the UV content of a tungsten lamp (~75 µW/lumen) as the upper threshold for a museum light source, below which filtration is not required. He did not recommend a lower value primarily to avoid people mistakenly placing plastic filters over hot lamps and causing a fire risk.

He also made a strong argument for keeping light levels low for objects with high and medium light sensitivity, specifying 50 and 200 lux respectively. Saunders (1989) later suggested a lower limit of 10 µW/lumen for UV_R based on good performance of UV filters available on the market, with higher heat resistance. While it is preferable to use the lowest UV possible, both accepted limits are found in the conservation literature with a general preference for the 75 µW/lumen value. Note that efficient filters are also very important to reduce UV from daylight (consult CCI Note 2/1 *Ultraviolet Filters*).

Absolute UV (UV_{Ab})

It is also beneficial to define the maximum level of absolute UV exposure for collections. Table 2 shows different UV_R recommendations followed by scenarios converted to the absolute form based on two typical light levels in museums. The UV_R quantities are independent of light intensity and give a simple comparison of the UV content of each illuminant as a fraction of the light (lumens). As the lux level is increased, the absolute UV rises proportionally, which is evident between the 50 lux and 200 lux scenarios (i.e. increasing lux by a factor of four will increase UV_{Ab} by the same factor). A UV_{Ab} value of 10 mW/m^2 could be considered an allowable maximum since it is close to the amount of UV an object would receive from a tungsten lamp. More importantly, this is also similar to daylight at low light intensity with an efficient UV filter.

Table 2. Relative and absolute UV levels from different recommendations and scenarios.*

Recommendations and light sources	UV_R (µW/lumen)	UV_{Ab} at 50 lux (mW/m^2)	UV_{Ab} at 200 lux (mW/m^2)
Thomson's recommendation	75	3.8	15
Saunders' recommendation	10	0.50	2.0
Daylight (blue sky[1])	500	25	100
Traditional tungsten lamp	75	3.8	15
Daylight, 90% UV cut **	50	2.5	10
Traditional tungsten lamp, 90% UV cut **	7.5	0.38	1.5

* UV values from an Elsec UV meter.
** The 90% efficiency is based on the UV reduction performance measured with an Elsec UV meter.

In heritage preservation, measurements of the relative and absolute UV values are commonly taken with an Elsec UV meter manufactured by Littlemore Scientific in the United Kingdom. The sensitivity of the UV photodiode is specific to the range of ~340–380 nm. Values obtained from other instruments may need adjustments for comparison with the recommended values. The limited UV measurement band of the portable Elsec is not ideal; however, it is quite convenient for practical purposes and is widely used.

Absolute weighted UV (UV_{AbW})

To perform a more detailed risk assessment for UV exposure, it is possible to consider the potential reactivity of different wavelengths (λ) on materials. This is worth considering before purchasing a substantial quantity of glazing materials for vulnerable objects. Shorter wavelengths are known to have the potential to cause more damage to the structure of organic materials. By 1951, the National Bureau of Standards had assessed photochemical damage caused by different wavelengths on acid papers. Michalski (1987), Feller (1994), Andrady et al. (1998) and the International Commission on Illumination (CIE 2004) later compiled the relationship of damage and wavelength for different materials, including colourants. Each material reacts with radiation in its own specific way due to different energy absorption characteristics; therefore, the damage predictions are very generalized.

A damage function, D(λ), was adopted by CIE (2004) and the International Organization for Standardization (ISO 2003) as an empirical representation of the reactivity of UV and light on objects, based on measured colour changes of some watercolours and oil paints. The function is defined in such a way that the damage is weighted to unity at λ = 300 nm, using the relationship

$$D(\lambda) = \exp[-0.0115(\lambda - 300)] \qquad \textbf{Equation 2}$$

Calculating the weighted UV value involves integrating the product of the damage function, and the measured absolute UV at each wavelength, $UV_{Ab}(\lambda)$. The damage function has been normalized in such a way that the damage is 1 at 300 nm. This allows the total weighted absolute value that an object receives to be defined as

$$UV_{AbW} = \sum_{\lambda=300}^{400} UV_{Ab}(\lambda)D(\lambda) \qquad \textbf{Equation 3}$$

with units of mW/m^2. The form of Equation 3 is given for UV_{Ab} measurements in wavelength intervals of one nanometer. Glass and many plastic materials effectively block wavelengths shorter than 300 nm; therefore, the integration is most important over the UV range from 300 nm to the beginning of the visible at ~400 nm. Several UV_{AbW} values from different scenarios are shown in Table 3. By comparing the UV_{AbW} of daylight to that of the tungsten lamp with the same conditions (light intensity and UV filtration), it is evident that daylight is approximately 10–13 times more damaging than the tungsten lamp.

Table 3. Weighted absolute UV levels (mW/m^2) for the UV range from 300 to 400 nm for different scenarios based on the CIE (2004) damage function.

Light sources	**UV_{AbW} at 50 lux**	**UV_{AbW} at 200 lux**	**UV_{AbW} at 500 lux**
Daylight*	23	92	230
Daylight*, 30% UV cut** (regular glass)	17	67	170
Daylight*, 90% UV cut **	2.9	12	29
Daylight*, 99.5% UV cut**	0.051	0.2	0.51
Traditional tungsten lamp	1.9	7.7	19
Traditional tungsten lamp with regular glass, 30% UV cut**	1.3	5.3	13
Traditional tungsten lamp, 90% UV cut**	0.29	1.2	2.9
Traditional tungsten lamp, 99.5% UV cut**	0.0044	0.018	0.044

* Daylight: north blue sky[1] in Ottawa, early afternoon, May 2013.
** The 30, 90 and 99.5% efficiencies are based on the UV reduction performances measured with an Elsec UV meter.

To build upon the reviewed recommendations for relative and absolute UV in museums, a maximum level of 10 mW/m^2 for UV_{AbW} is proposed. If the concern is primarily related to the degradation of the material structure, rather than the fading of the colourant, a modified damage function may be considered in place of Equation 2:

$$D(\lambda) = \exp[-0.03(\lambda - 300)]$$ **Equation 4**

The degradation of many different types of materials such as newspaper, wood, rubber and paint better follow this function since the far UV (toward 300 nm) affects the physical structure more than the near-visible wavelengths. Fortunately, the far-UV radiation is easy to filter by common materials. The empirical damage function in Equation 4 is based on the compilation of different sources in the literature (Tétreault 2013). When it is unclear which function to use, consider the damage function for colourants (Equation 2) since it is the most commonly used and also the most conservative.

An evaluation of the overall reactivity of UV radiation based on wavelength is probably the most appropriate method to assess its impact on objects; however, it is also the most difficult to perform due to the need for special instruments (a spectrophotometer equipped with an integrating sphere). Access to this technology may become easier in the future, but in the meantime some shortcuts are possible. If the goal is to determine the impact of UV from solar radiation, the normalized relative solar spectral distribution provided in ISO 9050:2003, *Glass in Building – Determination of Light Transmittance, Solar Direct Transmittance, Total Solar Energy Transmittance, Ultraviolet Transmittance and Related Glazing Factors* can be used (available in Table 2 of the standard, “Normalized Relative Spectral Distribution of Global Solar Radiation”). Equation 2 can be modified to the form

$$UV_{AbW} = \cos\varphi \sum_{\lambda=300}^{400} S(\lambda)D(\lambda)T(\lambda)$$ **Equation 5**

where S(λ) is the daylight spectral power distribution and T(λ) is the UV transmittance of the glazing material provided by the manufacturer. If there is a significant angle of incidence, φ, a reduction of radiation intensity should be considered. Note that $\varphi = 0$ indicates that the energy approaches normal (perpendicular) at the surface, giving cos(0˚) = 1. It is also possible to request the spectrum of a particular light source from the manufacturer, taking care to adjust to the correct number of lumens (e.g. 50 lux = 50 lumens per square meter). For comparison of weighted absolute UV levels with data from the Ottawa blue sky[1] distribution at 200 lux (Table 3), the solar distribution $S_{(\lambda)}$ (from ISO 9050) needs to be multiplied by 31.

Minimizing Damage From UV Exposure

There are two main methods for reducing the damaging effects of UV energy on objects. The first approach is to reduce the level of UV exposure that an object receives at a given time. This is achieved by selecting a light source with low UV content (Table 1 above), by reducing the light intensity and by filtering out the UV energy (consult CCI Note 2/1 *Ultraviolet Filters*). The second method is simply to reduce duration of exposure. Both approaches aim to minimize the total UV dose (UV dose = **UV energy received** x **exposure time**), in a manner commonly used to manage light fading (light dose = **lux** x **exposure time**).

It is possible to record the UV level using a data-logger that helps keep track of the light and UV doses that an object receives over time. Recording the radiation over time is quite useful if the illumination fluctuates. This would result from a combination of daylight and electric lighting, with time intervals where the light levels are reduced or turned off.

Remember that solar radiation, even from a blue sky[1], emits a lot of UV. In contrast, common white LEDs do not emit significant amounts of UV. For other types of lamps, inspect the technical literature before buying a large quantity. Look for a colour rendering index (CRI) of 90 or above and low to moderate colour temperature (CCT below 3500 K) for most applications. Obtain a few different lamps to verify the quality of the illumination and UV received on the object surface in a specific context. In the end, the true test is the measurement of what UV exposure the object is receiving in its specific environment.

Conclusion

The maximum UV recommended, expressed as either a relative, absolute or weighted absolute value, can guide the museum professional to minimize the impact of UV on the collection. These values may evolve in the future based on new knowledge about the sensitivity of objects to radiation, new technology and a balance between preservation and sustainable practices. In terms of risk assessment, there is interest in quantifying the potential reaction of UV radiation with objects in a more advanced approach. This can be achieved by measuring the weighted absolute UV or by measuring the UV received by the objects, which can provide information about the damage potential. In both cases, it is preferable to keep levels below 10 mW/m^2 for organic materials.

End Note

[1] The term "blue sky" refers to mid-day clear sky opposite the sun. In the northern hemisphere, this will be on the north side when the sun is on the south side. Alternatively, for the southern hemisphere, the blue sky would be on the south side of the sky when the sun is on the north side.

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