# 1-0 DANGERS TO MUSEUM COLLECTIONS

> ***"…art objects in storage, as on exhibition, are susceptible to damage from fluctuating temperature and humidity, dust, insects, mold, light, and accidents…"***
>
> ***– Marjorie Shelley*** [1]

Barring physical accidents and disasters, there are a number of common dangers to museum artifacts and exhibits. While the catastrophic damage of accident, fire or flood may be fearsome to consider (and well ought to be considered), the fact is that statistically the most extensive damage to collections is caused by the ordinary actions of things like light, heat, humidity and pollution.

Here are the real fearsome dangers to museum collections. This is what is responsible for the greatest majority of damage to the greatest number of objects. These are the forces and processes that every person concerned with conservation must understand. They are:

1) Light
2) Temperature
3) Humidity
4) Pollution
5) Infestation

They are listed in this particular order because they are interrelated and problems in one area actually create problems in the areas that follow. As an example, improper artifact lighting can cause photochemical damage and fading. Lighting can also affect temperature. Temperature in turn greatly affects humidity. Cycles in temperature and/or humidity cause physical damage to art and artifacts. Besides creating dangerous changes in relative humidity, temperature cycles also power case breathing. That directly increases case pollution. Dust, the simplest form of pollution, greatly increases the growth of mold and mildew. One problem leads directly to the next. These dangers can only be dealt with effectively if they are prioritized and addressed in order.

## 1-1 Buildings as Defenses

In dealing with these progressive dangers, we have several layers of defense. The first of these is obviously a building. That building should be designed so that it provides protection for the contents from each of the forces and processes listed above. This may sound elementary, but in actual museum design today it quite often it is not the case.

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[1] Marjorie Shelley, The Care and Handling of Art Objects: Practices in the Metropolitan Museum of Art, (New York: The Metropolitan Museum of Art, 1987), p. 9.

We often find that museum buildings are designed or built in ways that make it terribly difficult if not impossible for a conservator to adequately protect a collection. There is nothing wrong with an architect or a benefactor wanting to make an architectural statement with a building design. Good architecture should be pleasing to look at. It ought to involve art. A distinctive architecture is a strong identifier and marketing point for any organization.

Having said that, we need to be sure that the "statement" we make with our architecture is not, "We don't care about preservation." A fine art museum with a wall of floor to ceiling windows transmitting 10,000 footcandles on a bright day or design features like internal water curtains, ponds or waterfalls that make humidity control impossible make just exactly that statement. These are not hypothetical design features. Anyone with any experience will immediately think of museums with just these problems right now.

We have been told repeatedly and in a number of ways by a number of different museum professionals that their collection's worst enemy was their museum architect. This shouldn't be the case. A museum architect needs to understand the conservation issues of each of the five dangers listed above as well as they understand the dangers of fire, water damage and physical security.[2] A good architect either will understand or be willing to listen to your conservation needs and learn. If an architect does not understand these things (and the conceptual sketches will show you if they do or don't) ask yourself which is harder, finding another architect or finding another collection. Then do whatever is the easiest.

A museum architect's first priority should be to design a safe environment for the collection. If we add the word "viewing" to make the design goal a safe viewing environment, we have really covered the museum mission. Everything else is extra. Office space, staff facilities, retail spaces, meeting rooms, even aesthetic interests are desirable and necessary requirements for a building design. But, they should never, never detract from the primary goal of a viewing environment safe from light, temperature, humidity, pollution (contamination) and infestation.

## 1-2 Galleries and Exhibits as Defenses

Within the building we have our next level of defense in the gallery or exhibit area. The purpose of the gallery or exhibit design is to provide an educational and historical context for the collection. A secondary, but very important, purpose is to provide additional protections for the collection. Quite often it is at the gallery and exhibit level that conservators are first able to mitigate problems of building design.

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[2] Museum architecture is a specialized field. It involves special considerations and specialized knowledge. I know of no architectural firm that is dedicated to or specializes in museum design. There is a wonderful market waiting for an architect willing to focus attention on this field and spend some time building a reputation.

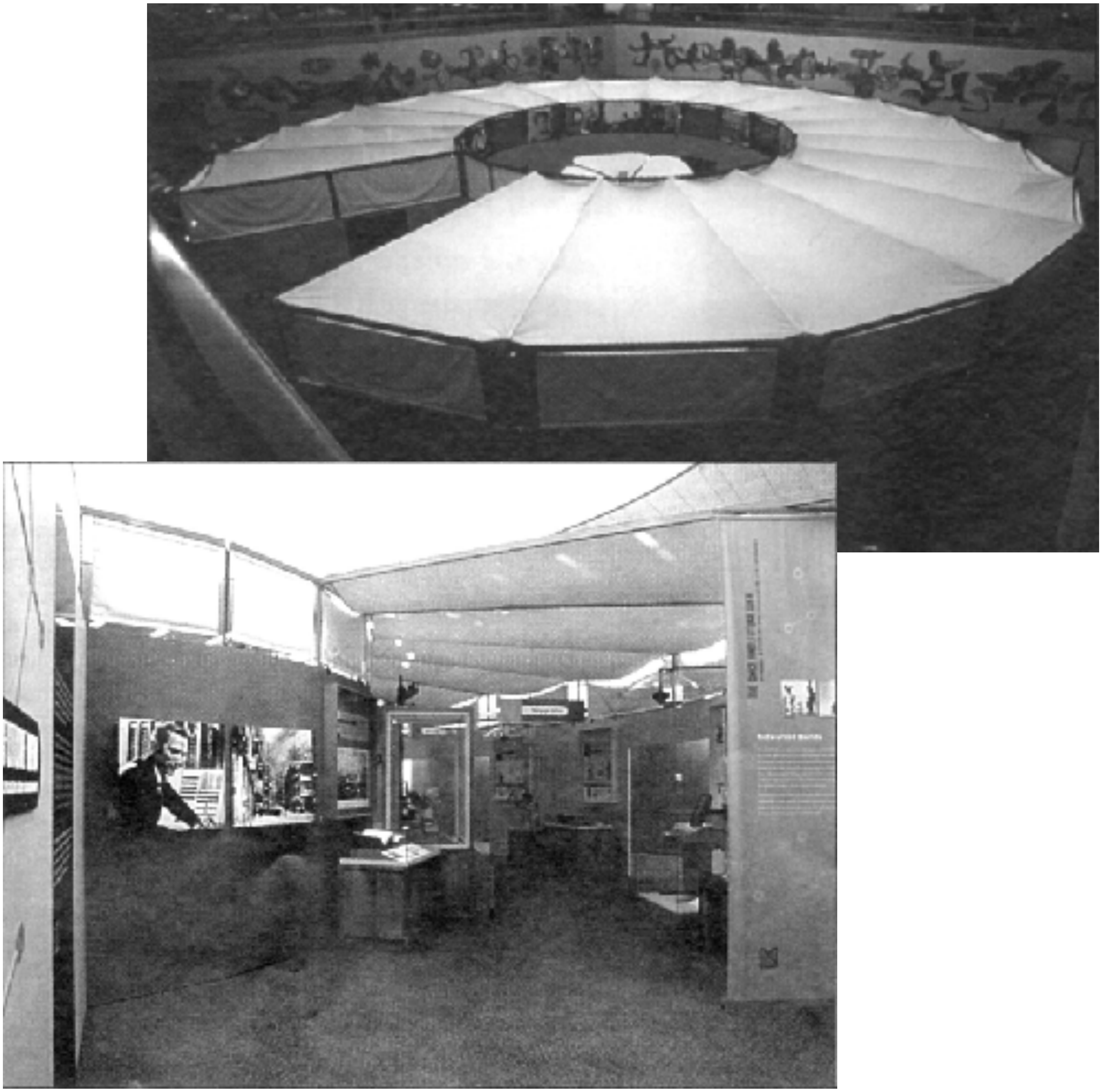

Figure 1-1. A striking example of gallery level protections used to compensate for building problems. The National Library of Medicine in Bethesda, MD was forced to build a tent structure for this exhibit to protect artifacts from excessive and unfiltered light from clerestory windows and the high UV of the building's truss mounted HID lighting.[3]

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[3] Kristy Ogg, "Round Exhibition - - Square Gallery," Exhibit Builder, March/April 2002, pp. 6-7.

It is often impossible or impractical to change or correct problems with a building after construction. This is especially true with historical structures where the building is actually a part of the collection. In these cases the interior design of the gallery space or the design of an exhibit space within the structure can offset design problems with the building. A good gallery or exhibit design will increase the protections against the dangers of light, temperature, humidity, pollution and infestation.[4]

## 1-3 Cases as Defenses

The third level of defense is the display case. The obvious duty of a display case is to protect objects from handling, theft and physical damage. It can be argued, however, that the most important duty of a case is as Michael Belcher writes:

> "…to provide a microclimate in which constant levels of temperature, relative humidity and light can be maintained, to protect objects from ultra-violet light, humidity, dust, insects, etc."[5]

The major purpose of this book is to demonstrate the effectiveness of museum display cases equipped with a properly engineered protection system in providing just such a microclimate. As Toby Raphael of the United States National Park Service writes:

> "Providing a microclimate in a well-sealed case is a low cost alternative to controlling the entire exhibit space"[6]

This doesn't mean that cases make it unnecessary to control the entire space. What it means is that cases can be used in addition to the controls in the exhibit space to provide an environment that is significantly more controlled than that of the gallery. Toby Raphael goes on to say:

> "Because microclimates cannot be created in traditional museum casework, a specially designed, well-sealed, climate controlled case must be constructed."[7]

The answer to this ought to be, "Not necessarily" or "Not any more!" Technically, it is true that creating a microclimate requires some special design. It is not true that the case has to be specially designed. We will describe a "specially designed"

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[4] Where building design problems can be solved or corrected every effort should be made to do so. It is best to solve a problem at its source. The things that can be addressed and the things that must be lived with will either be fairly obvious or they will make themselves obvious as corrections are considered. Don't live with problems that can be corrected. Your collection is the reason for your existence. It is almost always more valuable and harder to replace than your building.

[5] Micheal Belcher, Exhibitions in Museums, Leicester Museum Studies Series, (Washington, DC: Smithsonian Institution Press, 1991) p. 122.

[6] Toby Raphael, Exhibit Conservation Guidelines: Incorporating Conservation into the Exhibition Process (Washington, DC: National Park Service, 1999), C:1, p. 1.

[7] Toby Raphael, B:1, p. 2.

but relatively inexpensive case air filtering and humidity buffering system that can be added to and will operate with any normally-sealed museum case.[8]

Before you consider replacing existing casework with "specially designed" casework, you must quantify the risks or dangers to your artifacts. Then you can consider each danger and its mitigation in sequence and determine which steps you must follow to create a safe environment. Remember that the dangers are sequential.

We will cover each of these dangers in detail as we progress through this study. As an example here we can state that removing the IR of conventional lighting will significantly reduce temperature and humidity cycles within a case. It will also significantly reduce case breathing and the resulting problems with dirt and pollution. When not exposed to external heat sources, a case will buffer temperature cycles in a gallery by roughly 60%.[9]

Depending on construction and contents, cases can buffer humidity cycles even more effectively than they buffer temperature. It may be that removing the IR from conventional lighting is all that is necessary to provide the desired protection for your particular artifacts. But, it is only when we truly understand the way that light, temperature and humidity affect artifacts and the ways that light and temperature drive humidity, pollution and even infestation that we can make intelligent evaluations.

The available literature on case design is filled with terms like "tight-fitting," "well-sealed" and "climate-controlled." These terms have been for the most part left undefined. We all understand the terms generally, but there have been no suggested testable standards. Climate-controlled can mean anything from the refrigerated air at the local motion picture theater to a very specific and tightly controlled range of temperature and humidity in a special sealed environment.

There have been general attempts to provide case air exchange rates for various "levels" of sealing. They are described in detail in a subsequent section. Again, for the most part they are not measurable, testable, or standardized. In this book you will find specific testable measures for case sealing.

The lack of clear definitions and the failure to understand the processes involving light, temperature, humidity, pollution and infestation, make it impossible to evaluate existing protections or casework. They make it equally impossible to specify testable standards for "specially designed" casework. Conservation can only be a "science" when it deals with uniformly understood processes and clearly defined terms. This material will describe these processes and present clear definitions.

One last note on defenses. While no new buildings, exhibit spaces or display cases should be created without taking into account the conservation needs of the collection; it does not follow that the existing spaces and casework must be replaced.

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[8] We have elected to treat "encapsulation" as a part of case defenses rather than as a separate level of protection for brevity. The principles, processes and problems are identical in all sealed enclosures.

[9] Actual test data of library cases lit internally with IR free NoUVIR fiber optic lighting showed that the cases buffered a ±3°F gallery HVAC induced temperature variation to less than ±1°F within the cases.

Windows can be filtered or blocked. Conventional lighting can often be easily replaced. Temperature and humidity can be buffered. It is just as possible to fit existing cases with "specially designed" lighting and environmental controls as it is to build special cases with these things. Casework represents a significant investment. It can also be a part of both the exhibit and even the collection. If you already have functional casework, it is foolish to replace it unnecessarily. As Michael Belcher wrote in Exhibitions in Museums:

> "Many a museum has regretted the speed with which it disposed of all its early showcases."[10]

## 1-4 Dangers and Defenses Summary

The determination, design and implementation of a new conservation system can involve a significant commitment of resources, time and effort. It is vital that the museum professional not only understand the physical processes that cause dangers to collections, but that they have clear, objective, scientifically supportable and testable standards for dealing with these dangers. Dangers to art and artifacts are interrelated. Finding effective protection solutions requires that these interrelated dangers be prioritized and addressed in order.

**Notes on Dangers to Collections:**

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[10] Michael Belcher, p. 124.

## 2-0 LIGHT (Radiation)

> ***"Objects do not 'recover" from light exposure, light induced damage is irreversible and cumulative."***
>
> ***– Toby Raphael*** **[11]**

A short review of the progress toward understanding light and photochemical damage is necessary so that we can emphasize the changing technology and developments in science leading to today's common knowledge and practice. Light is itself an environmental factor and a cause of damage. It is also a major component in all the other risks to art and artifacts. (Dim lighting is even a factor in accidents.)

While we will look at photochemical damage briefly, the primary focus of this material is the photomechanical damages associated with the heat of conventional lighting and that heat's effects on other dangers to museum collections. A complete and much more detailed treatment of light, fading and photochemical damage is given in other publications available from NoUVIR Research.[12] For the present purposes you need only to understand that light and radiation are synonymous terms; and that all light is comprised of photons, physical particles with mass that impact the atomic structure of any object they strike.

## 2-1 Ultraviolet Light (Radiation)

The understanding of light and its ability to cause damage to art and artifacts is a fairly recent development in museum and lighting science. As late as 1971 major lighting suppliers were stating authoritatively that the ultraviolet energy in fluorescent or incandescent light sources (and even sunlight) were "unimportant" factors in fading. Here is a quotation from the *1971 Westinghouse Lighting Handbook:*

> "The relatively small amount of ultraviolet energy in sunlight has been shown to be an unimportant factor in the fading of textiles. Since artificial sources contain only about one-tenth as much ultraviolet per lumen as sunlight, the effect of the ultraviolet in incandescent or fluorescent light is negligible."[13]

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[11] Toby Raphael, B:6, p. 2.

[12] A listing can be found in "About NoUVIR Research" in the introduction.

[13] Lighting Handbook (Bloomfield, New Jersey: Westinghouse Electric Corporation, 1971), p.9-12.

The same handbook goes on to relate that 25% of a representative group of fabric samples showed fading after 25,000 footcandle hours of exposure to fluorescent or incandescent light.[14] At a conservation lighting level of 10 footcandles, this is equivalent to only one year of display, 8 hours a day, 6 days a week. Having one quarter of your textiles fade under the equivalent of a single year of museum level lighting does not make the photochemical danger of this lighting sound "unimportant".

Figure 2-1. Detail of fading on silk dress after less then 30 days under fluorescent lighting.

We purchased the silk dress shown in the accompanying photograph (Figure 2-1) at a significant discount because of its damage. The fading shown occurred while the dress hung on a clothing rack under normal fluorescent store lighting for less than 30 days. As the UV output of a fluorescent lamp is roughly the same as that of a xenon lamp,[15] most people today would attribute this damage to the relatively high UV content of fluorescent lighting. They would be partially right. But, the other factors that caused damage, IR radiation and mismatched color visible light are significant and will be discussed in detail later.

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[14] Lighting Handbook, p. 9-12.

[15] Terry T. Schaeffer, Effects of Light on Materials in Collections, Research in Conservation (Los Angeles: The Getty Conservation Institute, 2001), p. 22.

You need to be aware of several problems associated with the protection of collections from UV radiation. The first problem relates to a definition of terms. UV is defined and described in several different and sometimes conflicting ways.

**ULTRAVIOLET RADIATION**

| **Wavelength in Nanometers** | **Terms** | **Comments** |
|---|---|---|
| **5-100** | **Vacuum UV** | **Effectively filtered by air** |
| **100-280** | **UV-C** | **Fluorescent UV at 180 & 250 nm** |
| **180-220** | **Ozone producing** | **Light energy creating pollution** |
| **220-300** | **Bactericidal** | **Roughly "Short Wave UV"** |
| **280-315** | **UV-B** | **Matches erythermal** |
| **280-320** | **Erythemal** | **Causes sunburn** |
| **315-400** | **UV-A** | **"Long Wave" or "Black light"** |
| **380-400** | **Visible Violet** | **UV-A overlaps visible spectrum** |

Figure 2-2 Ultraviolet terms and descriptions by wavelength

As you can see from the above chart (Fig. 2-2), UV can be described by letters, "A," "B," or "C", by "short" or "long" wave and by quite a number of other terms. When marketing types add in words like "dangerous" or "harmful," it can get quite confusing. As the quotation from the *1971 Westinghouse Lighting Handbook* shows, opinions of what might be harmful or dangerous can vary greatly. One person's cancer risk is another person's source of vitamin D.

Here is a place where it is important to stay with numbers and study spectral curves. Quite often advertising materials refer only to long wave UV or to a part of the spectrum that someone (usually in marketing, not research) has decided to call harmful or potentially damaging. A major archival materials company catalog describes UV fluorescent light filters as transmitting "practically none of the harmful ultraviolet light." This statement is on a par with the quote from the *Westinghouse Lighting Handbook* which started this section.

A conservator's immediate questions should be what does "practically" mean and what is the definition of "harmful ultraviolet light?" You need to know exactly what wavelengths a product will filter and how effectively they filter those wavelengths. Be sure that you get meaningful data on effectiveness. Insist on seeing spectral transmission curves or actual test data before purchasing "safe" lighting or UV filtering materials.

Beware of products that cannot promise specific reductions or limitations at specific wavelengths.[16]

Ask about product warranties. Make sure they include an adequate service life. The life of conservation materials has to be defined as the time that they are effective, not simply the amount of time that they will exist. How long can the filter material that you purchased to protect your artwork from the damage of UV absorb this UV before it becomes damaged itself? The same fluorescent light filters I described above are promised to "last indefinitely." Does "last" mean "remain effective?" You will hear lots of promises about life and effectiveness. Those that are true will be documented in a written warranty.

You must also be careful when purchasing UV monitors or meters. Again, look at the numbers. A major archival materials company sells an ultraviolet monitor for museum use for a little over $1400.00. The monitor "features high sensitivity (between 300-400 nm)." You will immediately ask, "What about the rest of the UV spectrum." Good for you! This meter won't measure short wave UV. It is blind to the major mercury emission spikes of fluorescent and HID sources at 250 nanometers.[17] The shorter the frequency, the deeper the photon will penetrate the surface and the deeper photochemical damage will occur. These meters ignore a major and very destructive part of the UV spectrum.

To be effective for conservation purposes a UV meter must be calibrated for and measure both long wave and short wave UV. In actuality this will mean a monitor that has at least two sensor heads.[18] It simply isn't possible to measure the entire UV spectrum with a single photo sensor head. Ultraviolet Products in Ontario, California makes a very good meter of this type.

You might also ask, "Isn't 400 nanometer energy visible light?" Again, good for you! Many meters including Crawford™ meters read violet visible light between 380 and 400 nanometers as UV. Visible violet is not UV. Depending on the color of your art, it might be important. It could well be the "purple mountain's majesty" in your paintings, the sheen in iridescent blue feathers or butterflies, or the depth of color in an amethyst. While Garry Thomson claims that "the residual sensitivity of the eye between 380 and

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[16] You must even suspect some spectral data. Quite often spectral output information for light sources or conservation materials is incomplete. In our study of UV output we found it quite common for spectral graphs to simply stop somewhere in the 2 or 3 percent range when they approached the UV end of the graph. A "floating" graph isn't showing all of the information. And, it isn't showing exactly the information that you, as a conservator, really need to know.

Much more often the spectral information you need just isn't there. Charts showing UV filtering performance in both Garry Thomson's and Barbara Appelbaum's books simply end at around 300 nanometers. They ignore the short wave UV spectrum.

[17] Mercury emission spikes occur at around 360 nanometers, 250 nanometers and again at 180 nanometers in fluorescent and gas discharge lamps. You must be able to measure all of these.

[18] The two heads must both measure UV, one long wave and one short wave. Some two-headed meters sold are dual purpose, measuring visible light with one and one type of UV with the other.

400 nm is too small to affect color rendering…"[19] the truth is that this depends entirely on the colors of the artifact itself.

There is one further item that causes confusion when we attempt to quantify UV. Again, it is a problem with the terms we use. Micro-watts per lumen have become somewhat of a UV measurement standard for conservators. Seventy-five micro-watts per lumen (75 µw/l) is often recommended as a maximum UV exposure. It is supposed to be roughly the UV output of a standard incandescent lamp. Because it is a percentage, not an absolute value, as visible light levels go up or down, so does the amount of UV. That makes it really hard to set any absolute standards. You might remember that the *Westinghouse Lighting Handbook* used "per lumen" measurements to unrealistically minimize the fading effects of UV.

When you consider the definition of a lumen, things get really complicated. A lumen is a measure of "visually effective radiation (i.e. light) for a standard human observer."[20] In simple terms, it is a measure of the light intensity that you can see across the visible spectrum. In other words it is the visible spectrum adjusted for the response of the human eye. It is a photometric term relating to vision, not a radiometric term relating to energy.[21]

This means that for any light source, lumens per watt will vary according to the efficiency of that source. It also means that lumens per watt vary in relationship to the color of a light source. By using micro-watts per lumen as a standard, we have attempted to set standards for UV, radiometric energy, which we can't see, in terms of photometric energy, which we can see. We are comparing apples and oranges. But, we have also based that standard on data that varies radically source to source. So, we are comparing apples to oranges using a constantly changing scale. No wonder it's confusing!

A lumen is equal to 1/683 light watts.[22] Simple math reduces this to .00146 watts or 1460 µw. Replacing the term "lumen" with this value in the expression 75 µw per lumen gives us 75µw divided by 1460µw. This equals .051 or 5.1%. A 75 µw per lumen standard for an artifact gives us UV energy equal to 5% of that artifact's illumination. This is a little simpler.

But this percentage only applies to an incandescent lamp at about 3000° K. Change the color temperature to 2750 ° K and the percentage drops to 1.5%. Use a fluorescent or a HID source and it changes again. We help avoid confusion and are much more accurate if we express UV conservation limits in the absolute term of micro-watts

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[19] Garry Thomson, p.17

[20] The IESNA Lighting Handbook: Reference and Application, ed. Rea, Mark S. (New York: The Illuminating Engineering Society of North America, 2000), p. 1-6.

[21] Understanding the difference between photometric data relating to what you can see and radiometric data relating to the total energy striking an artifact is vital to conservation science. The next section on IR energy continues to explain this vital distinction.

[22] The IESNA Lighting Handbook: Reference and Application, p. 2-2.

per square centimeter. This is a pure radiometric measurement and describes exactly the energy impacting an artifact.

There should be absolutely no UV in museum artifact lighting. The goal should be zero.[23] Today's lighting technology makes this a perfectly achievable goal. If budgets or building designs don't allow you to achieve zero UV, you should come as close as you can. An absolute measurement allows you to more easily evaluate lighting and more closely achieve this goal. It also makes it much more difficult for others to manipulate numbers or misrepresent UV dangers.

There is one more thing that you need to consider when you look at UV meters that express UV as a percentage of light output. The basic circuit used to measure UV as a percentage of visible light (micro-watts per lumen) is a Wheatstone bridge. Electrically it divides UV by the total light present. This process by itself creates inaccuracies at very low (museum) lighting levels.

Every school child learns that it is illegal to divide by zero. This is because as a denominator approaches zero, the numerator approaches infinity. What happens in UV microwatt per lumen meters is that as the number of lumens gets very small (most museum light levels are relatively low), the value of the micro-watts (the UV measurement) becomes unrealistically large. We have had indications of high levels of UV from such meters inside of a completely dark closet where there were no energy sources at all. The meter was actually reading a nearby FM radio station.

To be accurate, you should take UV measurements in absolute terms (micro-watts per square centimeter). Measure both long wave and short wave UV and add your measurements. If you must use meters that measure UV in µw/l, make measurements at or near sources where overall light levels are high. You can then calculate the UV exposure for your artifacts in absolute terms as a percentage of light intensity.[24]

## 2-2 Infrared Light (Radiation)

Our corporate understanding of infrared radiation (IR) is following the same learning curve we followed with UV light and damage, but about ten years later. Infrared (IR) radiation was long considered benign. In 1984, Garry Thomson, who might well be considered the father of modern conservation, wrote the following:

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[23] I am ignoring specialized displays of the fluorescence of minerals or perhaps glow-in-the-dark art from the 60's. Such displays should be designed to use the minimum intensity of UV of the longest frequency possible. They should also be designed so that UV from the display <u>never</u> impinges on other artifacts.

[24] 1 footcandle is 1 lumen over 1 square foot. As 1 lumen = 1460 µw; 1 footcandle = 1.57 µw/cm2.

> "One can confidently assume that in the museum red light never causes any photochemical damage (damage due to chemical change by radiation)."[25]

Early in the 1990's NoUVIR Research began teaching that any light outside the visible spectrum was unnecessary for vision and a cause of damage. By 2000, the Illuminating Engineering Society (IES) agreed:

> "Visible light contributes to both vision and damage; infrared (IR) and ultraviolet (UV) energy, which are not visible, contribute only to damage. Unless all artifacts in a display area are totally insensitive to exposure, UV and IR should be controlled…"[26]

Toby Raphael at the National Park Service Division of Conservation states, "Research attributes up to 40% of color loss in dyes to IR radiation."[27] Current science therefore attributes almost half of the damage to the silk dress in our earlier picture to IR rather than UV radiation. This represents a radical change in thought and conservation policy in a relatively few years.

IR radiation forms the major portion of conventional museum lighting. Incandescent sources (tracklights and downlights) are 90% or more IR.

> "Most of the electricity which passes through an ordinary tungsten lamp is converted into heat (94 per cent for a 100 watt lamp) not light."[28]

These numbers have a significant impact on museum conservation. More than 90% of the output of incandescent light sources is invisible, usually undetected, unmeasured and dangerous to artifacts! Fluorescent sources are slightly better in IR (70+ %), but significantly worse (2 to 5 times) in UV. HID sources share fluorescent problems, but with greater intensity and far worse color rendition. The tragedy is that today a great number of conservation references limit their discussions of radiation to UV and to visible light. They totally ignore the effects of the IR radiation that makes up over 90% of the output of our most common museum light sources.

The 94% IR for incandescent tungsten lamps cited above is total energy. It is a radiometric and not a photometric term. The 75 µw/l maximum for UV we discussed earlier calculated out to energy equivalent to roughly 5% of the CIE[29] corrected visible

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[25] Garry Thomson, The Museum Environment, 2nd ed. (London and Boston: Butterworths, 1986), p. 15. Note: We can confidently assume that the only light that causes no photochemical damage is reflected light. Any light energy that is absorbed by a surface will cause damage, even if that damage is limited to a simple rise in surface temperature. These ideas are covered in more detail later in this paper.

[26] The IESNA Lighting Handbook: Reference and Application, p. 14-4.

[27] Toby Raphael, B:1: p. 2.

[28] Garry Thomson, p. 7.

[29] CIE stands for Commission International de l"Enclairage. It represents the visible spectrum adjusted for the sensitivity of the human eye (about 1/2 the energy actually present).

energy present. The IR energy here is 20 times the CIE corrected visible energy, 2000%. Expressing it in the same terms commonly used for UV, this IR energy is 30,000 μw/l.

Clearly, an individual UV photon may be more destructive than an IR photon. But the huge amounts of IR present in conventional lighting make IR a photochemical danger equal to UV. IR, however, has been almost universally ignored.

There is one more idea necessary to understanding the photochemical dangers of IR. Current conservation techniques often depend on dimming lighting to conservation levels with rheostats. As the dotted line on the graph below demonstrates, dimming a halogen source sufficiently to cut the visible light by 50% shifts the peak of the curve further into the IR spectrum where the light meter cannot see it. The total energy reduction (and the real conservation value) is only about 10%. Dimming is not an effective conservation tool.

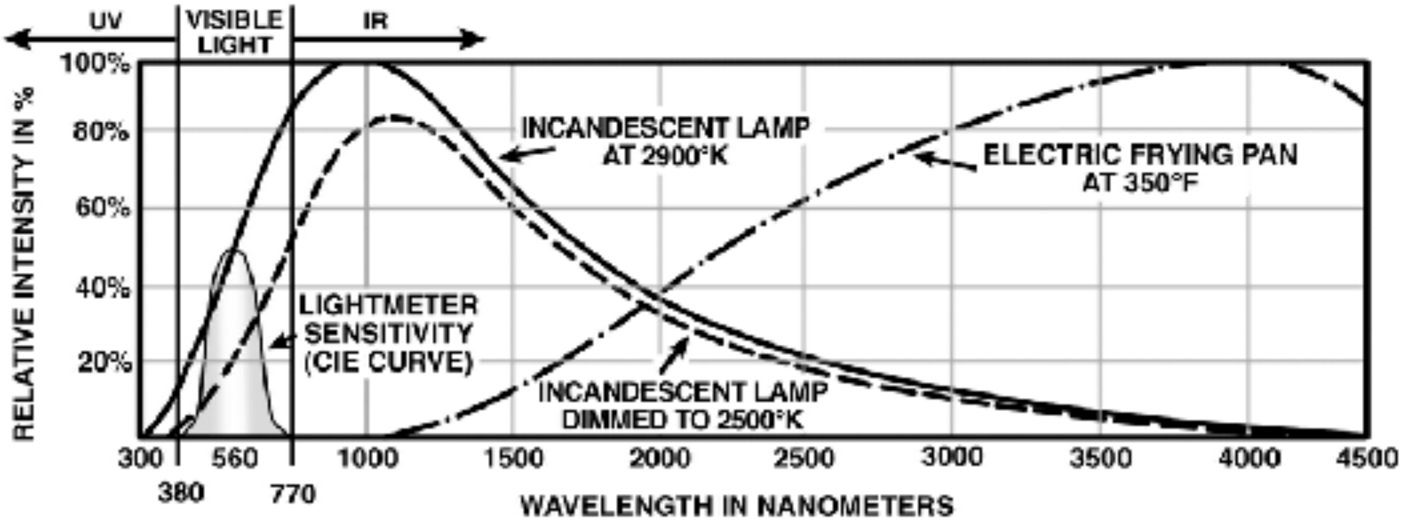


Figure 2-3. Typical output of a halogen lamp

The huge IR content of conventional lighting is responsible for much more than just Toby Raphael's 40% of fading and photochemical damage. As we look at temperature, humidity and pollution in subsequent sections you will find that the IR in conventional lighting is the major energy source driving cycles which endanger collections.

## 2-3 Setting "Safe" Light (radiation) Levels

Light meters read visible light only. In fact, as we have discussed, the sensors in a light meter are filtered to match the CIE curve, the sensitivity curve of the human eye. A light meter does not measure energy directly, but only as the eye sees it. A light meter gives you photometric data about what you see and not radiometric data about the total amount of energy present. A light meter only provides a part of the data you need.

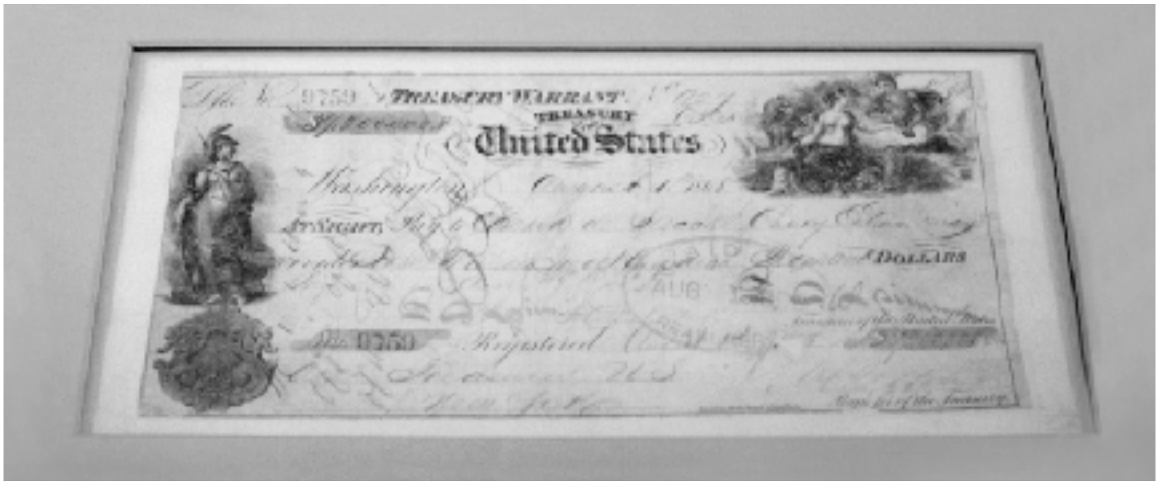
The CIE curve is shown in Figure 2-3 as "Lightmeter Sensitivity." You can see by the shape of the bell curve within the visible portion of the spectrum that light meters are weighted toward green light by about four times that of blue and red light. As a matter of fact, if you look at this filter in a light meter, you will see that it is dark green. (Figure 2-4 shows the darkness of the tint if not the color.) You can also see by comparing the areas under the curves that the CIE bell curve only represents about 50% of the energy present in the visible output of the halogen lamp. It only represents about 5% of the total energy present.

Figure 2-4. You can clearly see the dark CIE curve filter over the sensor head of this Weston light meter.

The CIE curve demonstrates that because of this filter, light meters are blind to both UV and IR. The meter sees no light energy below 380 nanometers and no light energy above 770 nanometers and only about half of the visible energy present between those wavelengths. Light meters are the conservator's primary tool for protecting against photochemical damage. It is quite a shock to realize that the light meter fails to register up to 95% of the total energy and roughly half of the of the visible energy of a conventional light source.

Until fairly recently this huge misrepresentation of energy had little practical impact. All light sources had very large IR components. The fact that a light meter showed only 4% or 5% of the actual energy impacting an artifact meant little because everyone was in the same boat and everyone's numbers were off by the same factor.

This is no longer the case. Museum professionals today are faced with a bewildering array of light sources; incandescent, quartz halogen incandescent, several types of fluorescent, HID, LED and fiber optic, again in several types. Each will have a different UV and IR component that is unmeasured by your light meter, from the 95% UV and IR of quartz halogen incandescent lights to the absolutely zero UV and IR in specific types of fiber optic lighting. The point to be made here is that without specifying the source and composition of the light, conservation footcandle recommendations can be misleading almost to the point of being meaningless.



9759 TREASURY WARRANT

TREASURY

United States

DOLLARS

9759

Figure 2-5. The Original United States Treasury Warrant
for the purchase of the Alaskan Territory.

Here is a practical example. Several years ago we had the opportunity to supply the lighting for a temporary exhibit showing among other things the original check that the United States used to purchase the Alaskan Territories (Figure 2-4). The National Archives specified a maximum light level of fewer than 3 footcandles for that particular artifact. They also specified no fluorescent light, due to the high UV content. Finally they limited the exhibit display to 30 days (roughly 700 footcandle hours) under normal halogen lighting.

A light meter reading of 3 footcandles of quartz-halogen track lighting (94% IR, 1% UV) would have exposed this fragile artifact to roughly 60 footcandles of total light energy. More energy-efficient fluorescent lighting at the same 3 footcandle light meter reading would still have a total energy level almost 5 times the recommended light level even had it been UV filtered. Because the NoUVIR fiber optic lighting used had absolutely no IR and no UV the artifact was lit with 2.7 footcandles of visible light and exposed to only 2.7 footcandles of total energy. Because of the quality of the lighting and the huge reduction in total energy, the National Archives extended the exhibit time to 120 days.

The point is that a light meter alone cannot give you enough information to safeguard your collection. You have to identify (and eliminate) any energy outside the visible spectrum. To do that you must know the exact spectral output of your light sources.

Even then, following the IES guidelines of no ultraviolet and no infrared may not be enough. The spectral output of the visible light is important. Your light meter only measures a portion of the energy in the red and blue parts of the spectrum. As we will see in the next section, light color is important not just for presentation but as a conservation factor.

## 2-4 Reflected Energy Matching

Knowing that light energy is comprised of photons that impact an artifact surface, we can assume (and testing proves) that the only safe light is light that will be reflected.[30] Any energy absorbed by a surface results in change. Photochemical damage then is a function of absorbed energy. Lighting a blue object with red light will greatly increase the absorbed energy and the damage. Measured data shows mismatching the color of light to the color of an object can increase damage 30 to 70 times.[31]

To return to the practical example of the Alaskan check used earlier, and to give credit to the National Archives, their current specifications for rare documents (like The Declaration of Independence, The Constitution and The Bill of Rights) require an absolute energy cut off at 500 nanometers. This not only eliminates all of the UV (380 nanometers and below), but also the very blue and violet visible light that would be totally absorbed by a sepia colored parchment. Unfortunately, National Archive's current (2002) specifications ignore the other end of the spectrum and the IR radiation of conventional light sources.[32]

Matching the color of lighting to the color of the object to decrease absorbed energy and photochemical damage is called Reflected Energy Matching. Ruth Ellen Miller at NoUVIR Research developed the theory of Reflected Energy Matching and

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[30] The mechanics of photon reflection and refraction are described in Light and Matter: The Dangerous Romance.

[31] Jack Miller, Evaluating Fading Characteristics of Light Sources (Seaford, DE: NoUVIR Research, 1993).

[32] As Figure 2-6 demonstrates, NoUVIR fiber optic lighting corrects this oversight by eliminating all energy above 770 nanometers (all IR). An accessory notch filter at the projector removes all the energy between 380 and 500 nanometers to absolutely meet National Archive standards.

demonstrated its effectiveness as a conservation tool. It is described in detail with actual fading test data in NoUVIR Research Publications.[33]

Because photochemical damage is a function of absorbed energy, we commonly think of it as being directly related to light intensity. This is true. Reflected Energy Matching is not so commonly understood, but is just as true. And, while Reflected Energy Matching helps explain the necessity of removing UV and IR from museum lighting, it goes much further than that.

Reflected Energy Matching also demonstrates that within the visible spectrum, photochemical damage is directly related to color. In particular, photochemical damage is related to the difference between the color of an object and the color of the light illuminating it. That difference determines the percentage of total energy of visible light absorbed by an object. In some cases this difference is more important to a conservator than the actual intensity of the light

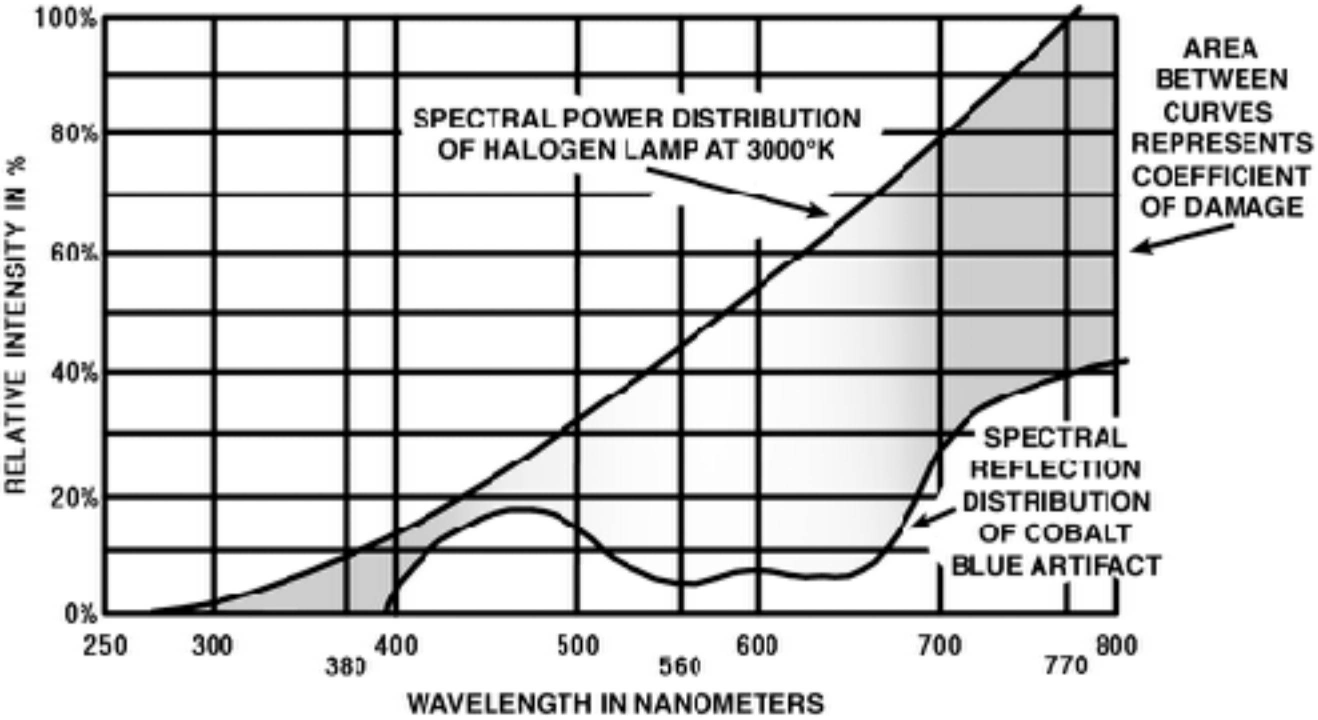

Figure 2-6. The difference between the spectral power distribution of a halogen light source and the spectral reflection distribution of a cobalt blue artifact demonstrates the coefficient of damage.

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[33] Ruth Ellen Miller, Jack V. Miller, Fading of Fugitive Colors By Museum Light Sources (Seaford, DE: NoUVIR Research, 1993).

Even partially filtering a light source to match the color of an artifact can extend its exhibit life 50 times or more. Interestingly, such filtering does not change the appearance of the object illuminated. This is because only the light that will be absorbed by an object is removed. There is no change in reflected light and therefore no change in what the eye sees. In demonstrations to conservation and museum professionals, they have been unable to guess which objects were lit with Reflected Energy Matching filters and which were not.

As shown in Figure 2-6, it is possible to determine the photochemical danger of any light source to any particular object. You do this by comparing the spectral power distribution of the light source to the reflection spectrum of the object.[34] The difference between the two curves identifies the percentage of light energy that will be absorbed by an object. We have identified this value as the coefficient of damage.

## 2-5 Defenses Against Photochemical Damage

The first priority in protecting your collection from photochemical damage will involve limiting overall intensity. Safe lighting automatically implies museum light levels. Once overall levels are controlled, focus on removing all light energy that does not help visitors to see. This means all energy outside the visible spectrum.

As discussed in Buildings as Defenses you need to make every effort to eliminate windows in exhibit spaces. The intensity of bright daylight is so far above museum conservation requirements and the natural variations of intensity in daylight so radical that it is almost impossible for a conservator to compensate for windows. Glass also transmits both UV and IR very efficiently. Tinting is possible, but tinting dark enough to protect the interior on a bright day will be almost totally black on an overcast day. Where protection is necessary in a historic building or because you already have windows and can't get rid of them, consider using shades, blinds or historic draperies to darken the exhibit area. Be sure that you have hard procedural rules for when and how such, shades or draperies are used. Having protections and not using them consistently is a waste of resources.

All recommended light intensities should take into consideration the spectral power distribution of the light sources. Figures 2-3 and 2-6 are examples of spectral power distribution curves. You need to be concerned with the total energy striking an artifact, not just the visible light. Whenever possible follow IES guidelines and use lighting with no UV and no IR.

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[34] Spectral power distribution curves should be available from any reputable lighting manufacturer. Spectral curves for the most common light sources can be found in the Illuminating Engineering Society North America Lighting Handbook, Mark Rea Editor. Reflectance curves can be found in sources like Artists' Pigments, A Handbook of their History and Characteristics edited by Robert L. Feller. Both of these books are listed in the bibliography.

Where it is not possible to use UV-free lighting there are a number of commercially available UV filtering case glazing materials. Most UV filtering materials include a slight yellow tint to filter the violet visible light from 380 to 400 nanometers that a Crawford meter mistakenly reads as UV. Clearer materials usually cost more. Generally, the thicker the filtering material, the more effective it will be. As mentioned above, insist on actual numbers for effectiveness and product life.

Actual testing at NoUVIR Research has shown that pmma (polymethyl methyacrylate) acrylic is an effective filter for UV. Measurements in direct sunlight showed 1/4" of pmma acrylic to remove 90% of the long wave and 75% of the short wave UV. At 1/2" these number rose to 96% and 80% respectively. Specially treated materials raise these numbers only a few percentage points and may or may not be worth the added expense.

With illumination under 100 footcandles in intensity, untreated pmma acrylic reduced UV, including short wave UV in the 250 nanometer range, to below measurable levels in any thickness of 3/8" or greater.[35] This filtering seems to be a function of acrylic's unique crystalline structure and is not true for polycarbonate materials like Lexan. Acrylic sheet like Plexiglass® can then be used as a window cover, in light attics or in fluorescent fixtures to reduce or eliminate UV. Objects lit with fiber optic lighting using pure pmma acrylic fiber where the thickness of the acrylic is measured in feet can be guaranteed to have zero UV.

Acrylic is also opaque to IR radiation. It will absorb IR up to its melting point. That is how they form aircraft canopies from acrylic. This is the reason it is not used as a communication fiber. (Communications applications use IR band lasers as signal sources. Glass fiber was originally designed for communications use and has its optimum transmission at 1400 nanometers, right in the middle of the IR band.)

Because acrylic absorbs IR it is very susceptible to heat damage. It is not an effective filtering material for the huge amounts of IR in incandescent lighting. Care should be taken when using acrylic as a filter for other conventional lighting. Acrylic should never exceed a continuous operating temperature of 70°C.

Great care should also be used in evaluating fiber optic systems using acrylic fiber. The IR must be removed from the light source *before* it is focused into the fiber. Failure to do this will result in yellowing, loss of transmission and fiber failure. Warranties are a good indication of actual performance. Fiber optic projectors available through NoUVIR research operate fiber ends at roughly 45°C enabling NoUVIR to offer a ten-year warranty against yellowing or any loss of transmission for their pmma acrylic fiber.

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[35] Testing was done using 40 watt T-8 fluorescent lamps with relatively high UV content at the electrodes where UV output is greatest using a dual head meter; one head with peak sensitivity at 250 nm (short wave) and the second head with peak sensitivity at 350 nm (long wave).

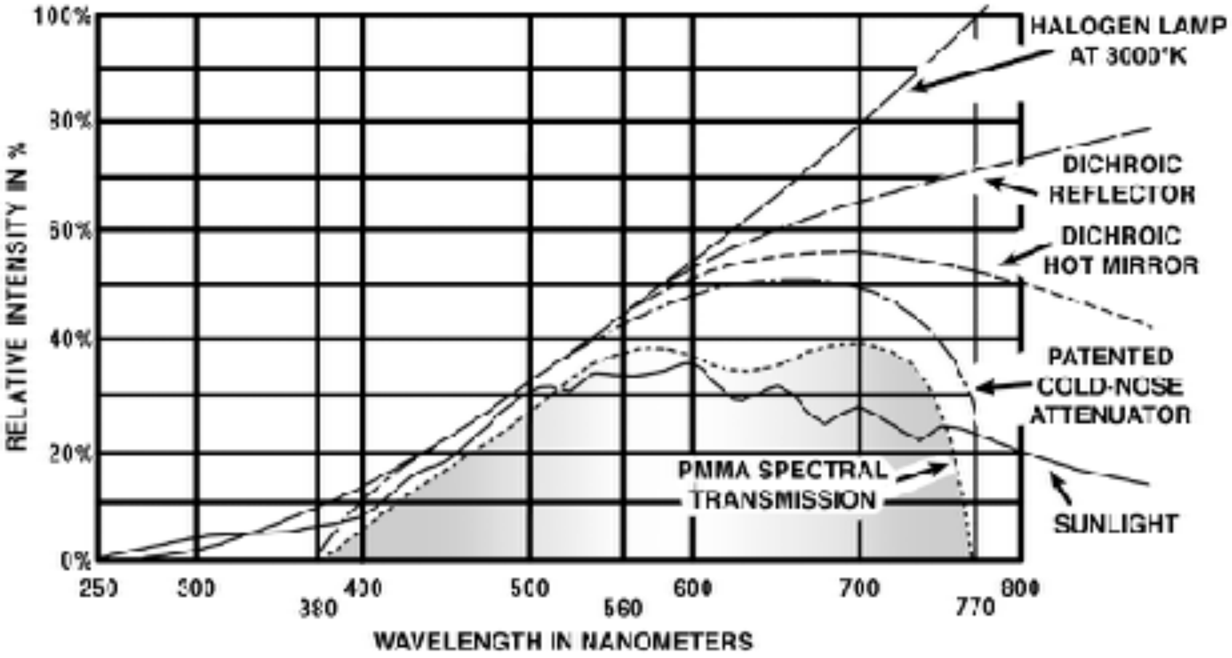

Figure 2-7. A portion of the spectral output of a halogen lamp showing the filtering stages of a NoUVIR projector. Note particularly that the transmission spectrum of pmma acrylic is zero both below 380 nanometers and above 770 nanometers.

As mentioned above, fluorescent lamps have relatively high UV outputs. The spectral output of a tri-stimulus fluorescent lamp shows a definite peak at about 250 nm. Meters that measure only long wave UV (300-400 nm) will not detect this output.

Most of the UV output from fluorescent lamps occurs at the ends of the tubes at the electrodes. You can purchase UV filtering sleeves for fluorescent tubes. Make sure that they completely cover the ends of the lamp, extending over the metal caps. This often makes installation of the tubes more difficult, so make sure that your maintenance department doesn’t shorten the filters slightly. Cutting off the tubes will make the job of replacing lamps easier, but destroy the effectiveness of the filters. Check such filters regularly for fit and filtering effectiveness. They do “wear out” and must be periodically replaced as they lose filtering ability.

We have already examined the standard practice of dimming incandescent lights by rheostat and seen that is not an effective conservation tool. Dimming simply shifts the spectral output of the lamps further toward the IR. It is startling to do the math and understand that reducing the visible light (what is shown on your light meter) by 50% may lower the total energy striking an artifact by 10% or less. This is graphed in Figure 2-3. Use lower wattage bulbs and operate them at higher voltage.

You must also understand that the common practice of moving light sources away from objects does nothing to effect the percentages involved. Ninety-four percent heat will remain 94% heat, no matter how far away the source. Tall galleries and long throws do not change these numbers at all.[36]

Screens on conventional incandescent lighting will lower the lighting intensity without the color shift of using a rheostat. They can, however, create moiré patterns in many applications. Screens have the advantage of being able to tolerate the intense heat close to incandescent fixtures. Like moving lights farther away, screens lower intensity; but do nothing to change the percentage of UV or IR present in the light. In fact all photons absorbed by a screen are re-radiated as IR. Know what is effective practice and choose wisely.

## 2-6 Additional Factors in Evaluating Light Sources

We cannot ignore the reasons we allow light into our gallery spaces in the first place. We have focused on preservation issues, primarily protecting museum artifacts from damage. While it is outside the scope of preservation, we need to touch on the subject of presentation, the way that an artifact looks or is presented. This is an important part of light and lighting. If it is done badly, it may make the preservation of your institution a problem.

There is a difference between a museum and an archive. The difference is the museum mission to present their collection to the general public. To fulfill its mission a museum has to be concerned about more than just the preservation quality of its lighting. It has to be concerned with the way things look. A museum professional has to be able to judge aesthetically between good and bad lighting. Often they have to do this before a system is purchased. Fortunately this too turns out to be a function of the spectral power distribution of a light source.

As we learned when we looked at the CIE curve, the human eye is designed to see the visible spectrum centered around green light at 560 nanometers. This roughly describes color balance. Light with perfect color balance will closely match the CIE curve, not too red, not too blue, and centered on green at 560 nanometers.

More specifically, the human eye is designed to see best in sunlight. That means a continuous, uninterrupted spectrum from red to blue. Sunlight gives a color rendition index (CRI) of 100. All of the colors of light are present in the correct proportions for the human eye.

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[36] Longer throws will lower intensity in fixed focus sources due to the inverse square rule of propagation. They do nothing to change spectral output or the percentages of UV or IR.

CRI is determined by having various subjects grade an assortment of colored samples by color under a particular light. A CRI of 70 (fluorescent light) means that the test subjects could correctly identify and sort 70% of the color samples they were presented. A museum, particularly an art museum, needs lighting with a CRI of 100. (Who wants to look at a Renoir and see only 70% of the colors he used?)

For more accurate measurement than CRI, we can calculate the variation from sunlight of any particular light source. We can do this by comparing the solar spectral power distribution to the spectral power distribution of a light source. We can then determine what colors are over exaggerated and what colors are missing. This can be calculated for any light source. We call the resultant value the CCI, Correlated Color Imbalance. CCI will give a mathematical value that includes both color balance (deviation from the CIE curve) and color rendition index (deviation from sunlight).[37] To be much less formal (but more accurate), we also call this the "coefficient of ugly."

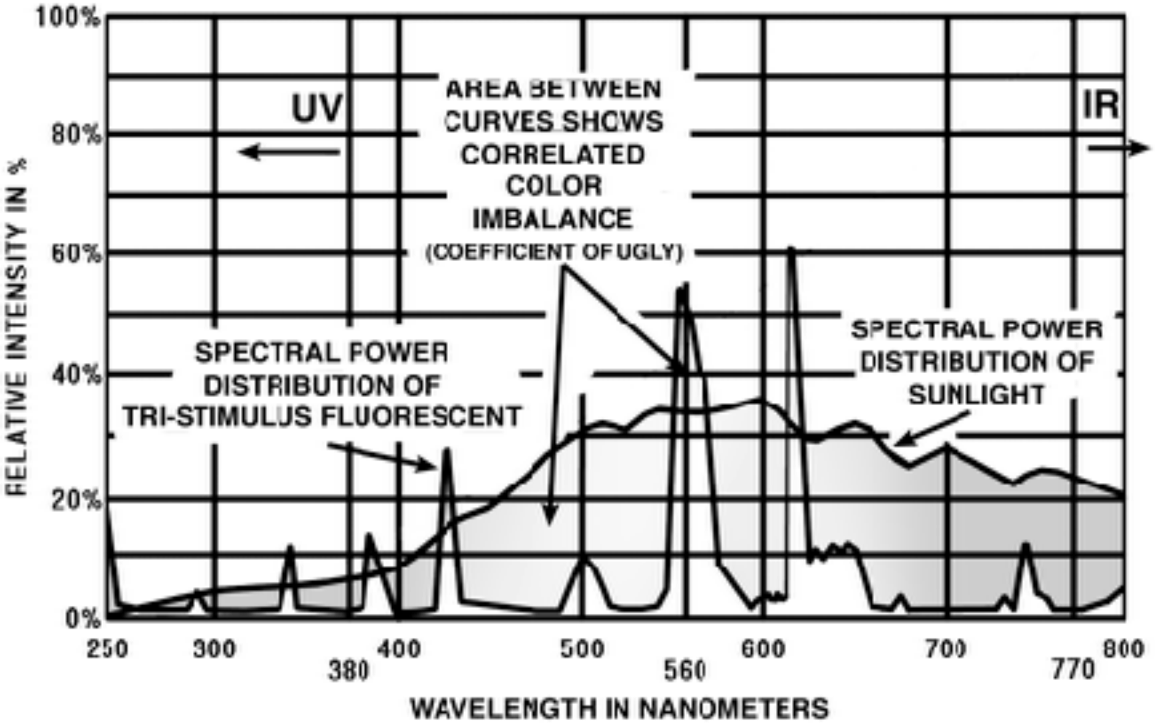

Figure 2-8. The difference between the spectral power distribution of sunlight and a tri-stimulus light source (fluorescent or LED) shows correlated color imbalance CCI or coefficient of ugly.

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[37] Correlated Color Imbalance (CCI) will also encompass CCT, correlated color temperature, a third and overlapping measure of light. Color temperature is a calculation of the radiation of a black body at a given temperature. Color temperature has a direct impact on both color resolution and color balance. A standard photo B studio lamp is 3200°K. Lower numbers are orange to red. Higher numbers a more blue.

## 2-7 Comparison of Various Museum Light Sources

Museum lighting needs to be evaluated on several different criteria. First and foremost we should consider the amount of radiation outside the visible spectrum, light energy that causes damage but does not help with vision. In this aspect the IES guidelines are correct. Museum lighting should have no UV and no IR.

Next we should consider the quality of the visible light. It should closely match the visible solar spectrum with very low (under 15%) correlated color imbalance (coefficeint of ugly). That means perfect color balance and perfect color rendition. Museum lighting should be adjustable in intensity without shifting color temperature or color balance.

Lastly, wherever possible, museum lighting should be filtered to match the reflected spectral distribution of the artifacts illuminated. In practice this means the lighting system must have very tight control over aim and focus. Beams must have clean edges without spill or scatter. And, each individual fixture must be able to accept a color filter.

The above criteria reflect the ideal museum lighting system. All of these criteria are technically possible and available on the market today. The cost of such systems is roughly equivalent to that of good quality tracklighting. The best of these systems provide energy and maintenance savings that by themselves justify installation.[38]

Today, there are thousands upon thousands of existing museum lighting installations and millions of dollars of impractical or obsolete lighting. Budget constraints are just one of the issues that slows the change to effective preservation lighting systems in museums. Unfortunately, protecting collections is sometimes a complicated muddle of conservation, economics, politics, practically and compromise. Things cannot change overnight.

But, they have to change. There is too much data, too widely desseminated and the solutions are too readily available to justify damaging artifacts with poor lighting. To know where you are and to evaluate the possible light dangers to your collection we will briefly review some of the common lighting sources in use in museums today.

### Incandescent Sources

Because they are so common, we have already described incandescent sources in some detail. They form a base line for comparison. Incandescent light has a huge IR component, roughly 94%. The IR in incandescent lighting is responsible for roughly 40% of the photochemical damage that occurs in museums today. As we will see later, this IR is the major energy source driving photomechanical damage through temperature and humidity cycles and case breathing.

Incandescent lighting has a UV component (1% to 1-1/2%) that is barely acceptable by today's conservation standards and completely unacceptable for long term

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[38] Appendix C briefly describes such a lighting system.

display. The UV output of an incandescent bulb is used by many conservation sources as the base for determining the maximum allowable UV in a museum setting. This is because until very recently there were no light sources available with any lower UV output and no light sources with absolutely no UV at all.

Incandescent lighting has roughly 4 times the red light of visible solar spectrum giving it poor color balance. It is full spectrum, so it has an acceptable color rendition index, but only because all of the colors are equally shifted toward the red. The coefficient of ugly (CCI) for a quartz halogen source is 45%.

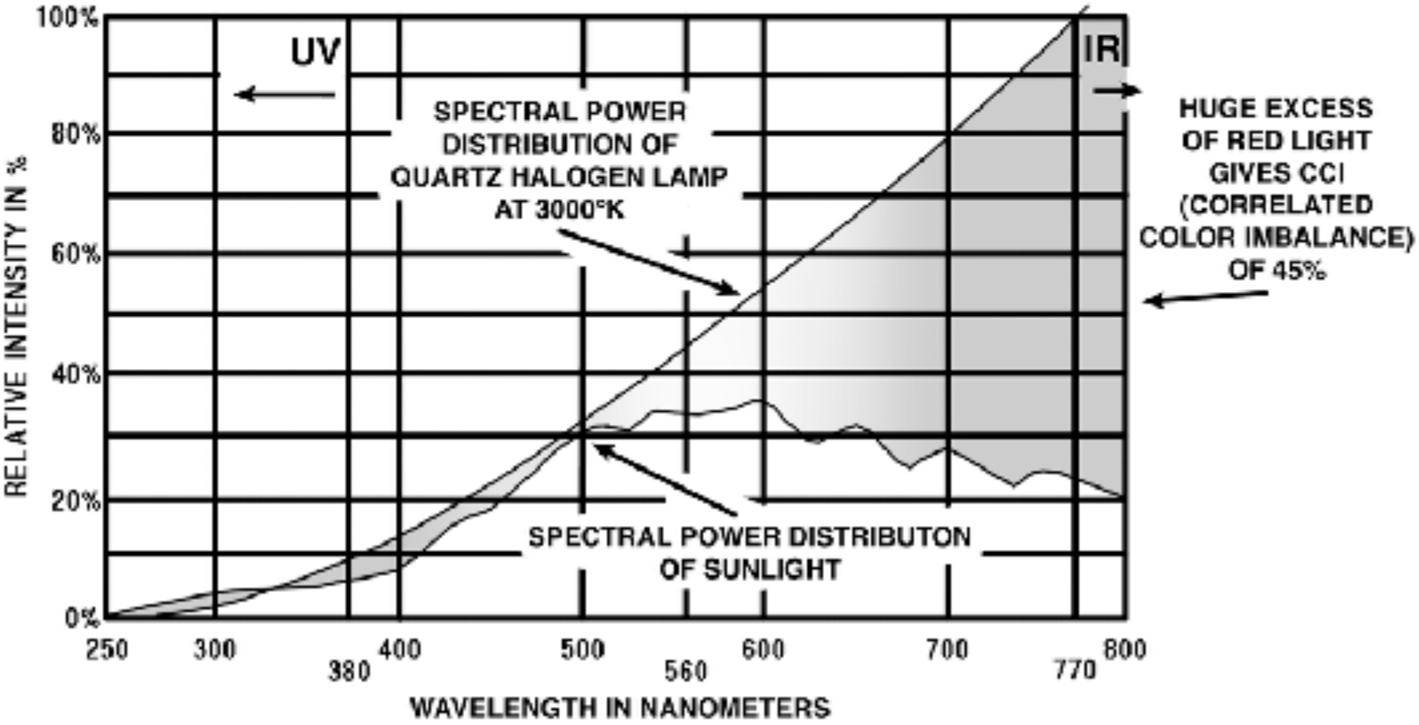

Figure 2-9. Spectral distribution of a quarts halogen lamp at 3000°K

### Tri-stimulus Fluorescent Lamps

Fluorescent lamps are roughly 3 to 4 times as efficient as incandescent lamps.[39] Their output is 22% to 23% visible light compared to the 4% of an incandescent source. As a result of this efficiency, only about 70% of a fluorescent lamp output is IR. Because fluorescent lamps cannot be focused effectively, their IR output may be less noticeable than that of incandescent lamps, but it is still large.

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[39] Lamp data will not address ballast efficiency. A fluorescent ballast will radiate about 10% of the electrical power as heat. At 40-watt fluorescent lamp in a fixture will then draw 44 watts of which 74% is heat.

Fluorescent lamps have a relatively high UV output (5% to 7%). A major part of this UV output is in the mercury emission lines below 300 nanometers. Most museum UV meters will not register these UV emissions.

Fluorescent lamps must be UV filtered. Remember that UV output is highest at the electrodes. Take care to see that UV filters completely cover the ends of the bulbs.

In the interest of energy reduction, fluorescent lamps (particularly cool-white lamps) now have a spectral power distribution consisting of 3 spikes of color; red, green and blue light. Together they form a metamer that the eye sees as white light much like the RGB in a computer monitor.

Fluorescent sources have a little too much blue in the output and large gaps between the color spikes. The ragged color spectrum brightly lights RGB colors, but looses all of the colors between these spikes. As a result they have poor color rendition and are rarely seen on paintings or textiles. They do show up fairly often on natural history dioramas. Fluorescent lamps have a calculated coefficient of ugly of 62%.

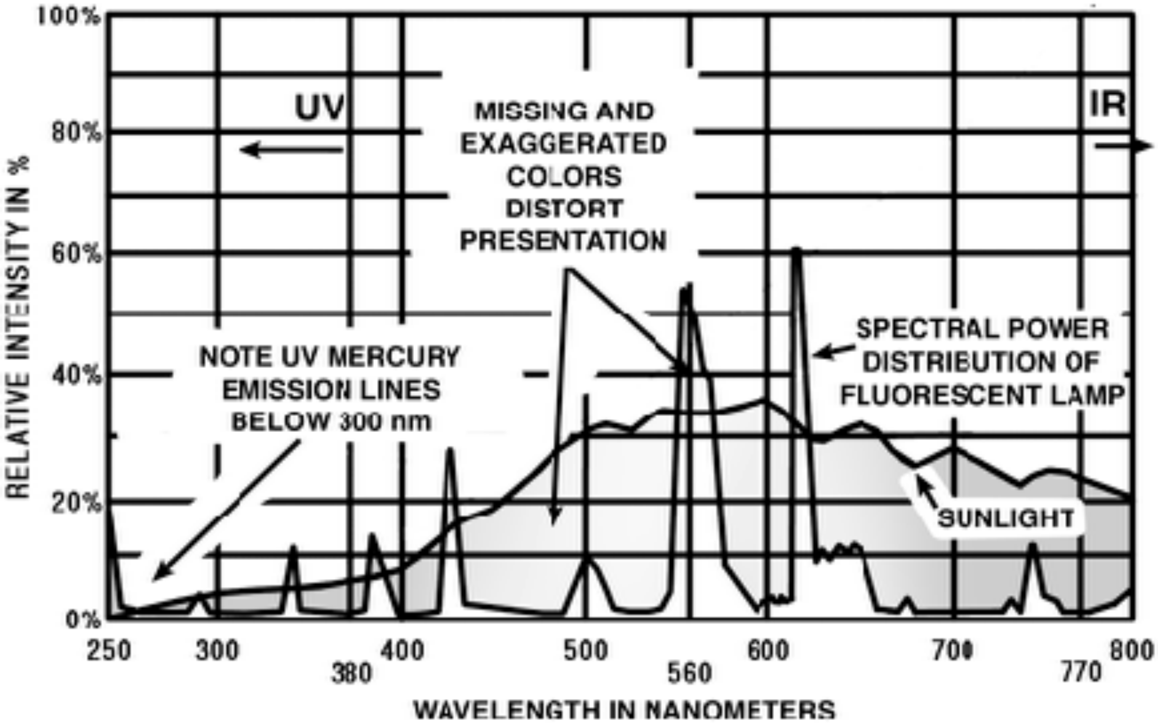

Figure 2-10. Spectral distribution of a tri-stimulus fluorescent lamp.

## Metal Halide Lamps

Metal halide lamps (also called high intensity discharge or HID lamps) have peak efficiencies that match fluorescent lamps.[40] Roughly 75% of their output is outside the visible spectrum. The UV output of metal halide lamps is 2 to 3 times that of fluorescent lamps. Like fluorescent lamps, most of this is below 300 nanometers and missed by the most common museum UV meters.

Because they are closer to being point sources and can be focused, metal halide lamps are difficult to filter for UV. The focused IR of the output melts or burns the filter materials. The high UV output alone makes metal halide sources unsuitable for museum use.

Like tri-stimulus lamps, metal halide lamps were developed in the interest of conserving energy. Also like fluorescent lamps, their spectral power distribution is made up of color spikes with gaps in between. In metal halide lamps, however, there are more than three spikes. Differing materials used in different types of metal halide lamps give widely different spectral distributions. Light color varies between individual lamps and will change as a lamp ages.

Metal halide lamps have a slightly lower CRI than fluorescent lamps, averaging around 65%. Their coefficient of ugly calculates at 70% to 75%. Their poor and constantly changing color and high UV content make metal halide lamps particularly bad choices for museum environments.

This includes uses as light sources for fiber optic systems where they are often used because of their high intensity. That very intensity, coupled with the high UV output, destroys plastic fibers and the epoxy resins that bond the ends of glass fiber. Glass fiber will transmit both the UV and the IR from these sources. All fibers will transmit bad color from a lamp. In computers the term used to describe this is” garbage in, garbage out.”

## Tri-stimulus Light Emitting Diodes (LEDs)

White LED sources are one of the latest developments in lighting. Like tri-stimulus fluorescent lamps they use RGB colors to form a metamer that the eye interprets as white light. It is not white light. Most colors are missing from its output. Like fluorescent lamps, LEDs use phosphors as a secondary emitter to even out the spectral distribution slightly.

The primary advantage of LEDs is their energy efficiency in terms of lumens per watt. Most of the energy of an LED is radiated as light, red, green or blue. But, LEDs do generate IR. This IR output limits the size and power of each individual LED because like computer chips, they are subject to damage by heat build up.

White LEDs (or combinations of red, blue and green LEDs used to approximate white light) will have roughly the same spectral output as fluorescent lamps, but shifted

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[40] <u>The IESNA Lighting Handbook: Reference and Application</u>, p. 26-2.

far toward the blue. White LEDs have a color temperature of 8000°K. (Remember that a standard photographic studio lamp is 3200°K.) Expect very poor color rendition and poor color balance. Also expect the color balance to change over LED life. The calculated Color Correlation Index (coefficient of ugly) will be around 80%.

Individual LEDs have very low output. Again, this is necessary because heat build up in any individual LED will cause damage. You will find most practical LED use today in intermittent lighting applications; signs, traffic signals, vehicle brake lights, even flashlights. The intermittent use, coupled with the separation of individual LEDs limits heat buildup.

It also allows most of these applications to run each LED roughly 50% above its design voltage. They do this to achieve acceptable intensity. Even then, it takes 10 white 3 mm LEDs to equal the light output of a single 3 mm fiber from a practical fiber optic light system.

A last attraction of LED light sources is their advertised 100,000-hour life. Recent data shows that LEDs loose 45% of their output within 4,000 hours and their effective life is more likely 10,000-hours than ten times that amount.[41] To make huge life claims even more suspect, you should assume that these tests were all done at design voltage with close temperature control. As with all lamps, actual field conditions will give significantly lower results.

## 2-8 Light Summary

Light is responsible for direct photochemical damage. Light is also responsible for direct photomechanical damage and indirect damage through its effect on artifact environment. Most of this damage is caused by non-visible radiation, both UV *and* IR. IR radiation is *the* major factor in heat induced damage in the museum environment. UV and IR can represent 90% or more of the output of conventional lighting. Both UV and IR should be eliminated from all museum artifact lighting. Doing so will extend exhibit life 5 to 10 times.

Once that is done, visible light can be balanced to match the color of an artifact, reducing or eliminating absorbed visible light energy that can cause fading. It is possible to calculate the amount of damage a particular light source can do a particular object or class of objects by calculating the color mismatch between the light and the object. This Coefficient of Damage is a mathematical expression of the amount of energy absorbed by an artifact. Reflected Energy Matching can extend artifact exhibit life 50 to 70 times.

It is also important that light sources be chosen for their ability to present artifacts in all of their beauty and detail. This requires good color balance and good color rendition. It is possible to calculate the visual distortion of any artifact by any light source by comparing the spectral power distribution of a source with the spectral reflection distribution of an object. This Color Correlation Index (coefficient of ugly) is a

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[41] Craig Dilque, "Are We There Yet? The Status of White LEDs in the Marketplace," Architectural Lighting, April/May 2002, p. 68.

mathematical expression of the colors in an object that are either missing or over represented in a light source.

Light meters are blind to light outside the visible spectrum. They are partially blind to visible light as well. Because 70% to 95% of conventional lighting energy is outside the visible spectrum, meters hugely misrepresent the total energy impacting an object. Ultraviolet measurement can also be terribly inaccurate or misleading. This includes the measurements some manufacturers use to certify their products.

You must be aware of all of these problems and carefully check technical data including full spectral output for all light and lighting materials. Knowing the general spectral output and color of the classes of light sources will let you evaluate existing installations and marketing claims. Good technical data on light sources, meters and conservation materials is vital. Reputable manufacturers will be able to provide you with clear, understandable technical data.

Understanding the science of light and photochemical damage will allow you to correctly assess lighting risks. It will also give you the tools you need to specify lighting and materials. Knowing how damage occurs and how to evaluate light and lighting data are the keys to protecting a collection from fading, photochemical and photomechanical damage.

**Reader’s Notes on Lighting:**