MUSEUM LIGHTING - PURE AND SIMPLE
Jack V. Miller and Ruth Ellen Miller

THE MUSEUM MISSION STATEMENT

The missions of a museum are:
1) Collect and exhibit art and historic artifacts for public education and enjoyment,
2) Protect the collection from damage, and
3) Do this all as efficiently as possible.

That’s it, Pure and Simple... preserving and presenting our art and heritage. Anything that detracts from this is artistic or architectural nonsense and a violation of a museum’s stewardship.

If the "public" (young or old) cannot see, understand and enjoy the exhibits, the building is not a museum, it is an archive. If items are not preserved, whatever it may be, the building is not a museum. Without both good presentation and effective preservation, a museum won’t be able to continue. Funding is directly proportional to both the quality of art or artifacts and the quality of presentation.

The Dilemma

The problem is that exhibition always increases the risk of damage. The more visible and more accessible an artifact, the higher the risk. For our purposes, exhibition increases the dangers of light damage, both photochemical damage (fading) and photomechanical damage (structural damage). The safest place for a collection is in a vault, stored away in the dark, but that defeats the museum mission.

The light energy hitting an artifact either reflects off or it is absorbed. Reflected energy hits our eyes where it causes chemical changes. We call that vision. Absorbed energy causes chemical changes in the artifact. We call that photochemical damage. Eyes recover fairly rapidly from light-induced chemical changes. Artifacts do not.

Museums can minimize light damage by minimizing the energy absorbed by artifacts. First, we do this by using good lighting design to lower the overall light levels. Full visible spectrum lighting with all colors represented and none over or under-represented can double visibility without increasing intensity. Eliminating shadows, glare and reflections, lighting artifacts and not areas, and keeping backgrounds subdued also increase visibility while letting us lower overall light intensity. On top of that, it is easy to greatly reduce total absorbed energy without reducing any of the reflected energy that we see. We do this by choosing the proper light sources (following IESNA guidelines), eliminating non-visible radiation (UV and IR), and filtering lighting to match colors.

All this is simpler than you might suspect. We cover the basics here in under ten pages.

Only visible light helps you see.
IR and UV only cause damage.
Light energy is either absorbed or reflected.
Only absorbed energy causes damage.
Minimize absorbed energy to minimize damage!

N O U V I R
20915 SUSSEX HIGHWAY 13
PH. (302) 628-9933
RESEARCH
SEAPORD, DELAWARE 19973
FAX (302) 628-9932
THE WAR OF THE PHOTONS

It is impossible to understand museum lighting without understanding light and its interaction with materials. It is equally impossible without understanding how people see in a museum.

Every museum is engaged in a continuing war against the damaging effects of light. The war begins as light rays (photons) cut through atoms of fragile color molecules and organic materials. The casualties are rare historic documents, sensitive textiles, fragile watercolors, fragile printed materials and organically dyed native arts. Damaged artifacts are given a quiet burial in the archives, never to be displayed again. Even the merchandise in the museum gift shop; clothes, books, posters, videos, can end up light damaged, discounted and sold at a loss.

Priceless (or at least, costly) artifacts are set up like targets in a shooting gallery. The attacking weapons are the recessed lights and track fixtures you bought and paid for. The ammunition is the electrical power on every monthly electric bill. Those lights magically convert electrical power (electrons) into photon bullets. They are shot at 186,000 miles per second (that’s seven times around the world every second) and spin at 10^14 revolutions per second.

Visible light along with invisible ultraviolet and infrared radiation shoot deep into materials, past and through the open spaces in and between many thousands of atoms. "Reflective" materials need to be 50,000 atoms thick to reflect just half of the photons of a beam of light. Even then, they only reflect photons of certain colors of light. The rest of the photons in the light beam bore into the material to seek out and cut the atomic bonds that hold the molecules together. The more light, the more photons. The more photons, the more damage. That’s quantum physics, pure and simple.

Light Meters Lie

Conservators establish limits for measured levels of illumination to limit damage. Lighting designers over-light exhibits to provide a margin for future changes. Conservators then dim the lights to the specified light level using a "color-corrected" light meter. **Everything is "correct"... but the collections continue to fade.** No one considers the fact that dimming just moves the light energy towards the red and infrared wavelengths, where a light meter is nearly blind. Most of the light is still there, but no one (the viewer or the light meter) can see it... and the damage continues.

2. Jack Miller, Optics and Physiology of Human Vision in a Museum Environment (Seaford, DE: NoUVIR Research, 1994).
MUSEUM LIGHTING - PURE AND SIMPLE

The graph below shows the complete spectral output of a quartz halogen track light at 3000°K. Most of the energy (95%) is outside the visible spectrum. About 1% is ultraviolet, below 380 nm. Roughly 94% is infrared, above 770 nm. None of that energy is visible to you or your museum light meter. Lighting manufacturers almost never give you full spectrum data. Now you know why.

A light meter is filtered to the sensitivity of the human eye, the CIE3 curve. As you can see from this curve, eyes (and light meters) see none of the energy outside the visible spectrum (and then only about half of the energy actually present). Take the filter out of your light meter and you will find that a measured ten footcandles of quartz halogen light is actually somewhere above 200 equivalent footcandles of full spectrum radiation (ultraviolet through infrared). Because NoUVIR is limited to a spectral output matching the CIE curve, ten footcandles of NoUVIR lighting remains ten footcandles.

Dimming Doesn’t Help

The dashed line in the graph shows the same lamp dimmed to 50% intensity in the visible spectrum. The actual result is to shift the peak of the curve toward the infrared, lowering the total energy hitting the exhibit by just 10%. Your light meter shows half the light, but your artifacts still experience 90% of the damage. This is why dimming incandescent tracklighting is not an effective preservation tool.

Who’s Looking Anyway?

The orange-yellow color of dimmed lighting also makes it harder to see, especially for older patrons. We need to remember that over one-half of all museum visitors are over 55. They have about half the focal adjustment of someone college age and about one quarter the blue and violet sensitivity. While the color shift of dimmed lighting will effect the appearance of all art and artifacts, this will be especially apparent and distracting to older adults. In terms of presentation, it is much wiser to use lower wattage lamps or fewer lamps at full voltage than to consider dimming.

Older people have significantly slower reaction times to lowered light levels. Glare sources (discussed in detail later) can leave an older person “snow blind” for 10 to 15 minutes. A great many older Americans wear glasses. Plan graphics, signs, and exhibits so that they are in the focal range of people wearing bifocals or progressive lenses. Plan lighting for those with the mild vision problems common to older Americans. People over 55 control over 75% of the wealth and discretionary income in this country. Few college students have large collections, leave bequests or are interested in estate planning. Support the people who support you.

3. CIE stands for Commission International de l’Enclairage, the agency that developed this curve.
MUSEUM LIGHTING - PURE AND SIMPLE

EXHIBIT LIGHTING ELEMENTS

The elements of exhibit lighting match the three goals of any museum:

1. **PRESENTATION:** Showing the true beauty of art and historic artifacts
2. **PRESERVATION:** Protecting exhibits from fading and damage, and
3. **CONSERVATION:** Conserving energy, resources, manpower and funds

These three elements of exhibit lighting (and the three museum goals) are dependent on the things we’ve discussed above, understanding what light is, how people see it, and what happens when it hits something. Once you understand these fundamentals, you can control the light, protect the collection, and save money in the process.

Presentation

Presentation is an easy term to understand. It is simply the visitors’ view of an exhibit... good or bad. Turn off the lights, what do you see? Nothing. You can exhibit the most wonderful masterpieces or historical treasures, but without light, who will know? Who will come?

When you realize that people only see what the lighting reveals, it turns exhibit design upside down. You can have the most beautiful objects in the world, but only light transmits beauty to a viewer. When you walk into a museum, you experience just the lighting. It is the only communication link between the objects and the people. If colors are not present in the illumination, or if they are too strong or out of balance, it distorts that communication link. Poor lighting always creates poor exhibits!

Ignoring good lighting design, glare and reflection can make even wonderful artifacts difficult to see. Bad lighting will make artwork or exhibits dull, lifeless, or distorted. The bottom line is that any exhibit is only as good as what the visitor sees. And the visitor only sees the light you provide.

NoUVIR fiber optic systems produce a full, balanced color spectrum very close to that of sunlight, but with No UV or IR. Thus, there is nothing more dramatic than seeing the change when you switch off ordinary lights and turn on this remarkable fiber optics system. The result of doing that has been very consistent. There is usually a moment of total silence, followed by a gasp. Then someone says, "I never knew that was so beautiful!"

A Side-by-Side Study in Color Balance

The human mind has a unique ability to correct color-distorted light coming through tinted glasses or from off-color lights. The mind corrects the colors to somewhat normal vision in a process called "chromatic adaptation". As you adapt, you will still mis-identify colors, lose details and miss variations in hue, but you stop noticing how bad the lighting really is.

Typical museum incandescent and halogen lamps (particularly when dimmed) have poor color balance. There is too much energy at the yellow/red end of the spectrum and too little energy in the blue/violet hues. This is functionally identical to seeing through yellow shooting glasses. Your mind will adapt to the world turned yellow. The blue hues are suppressed and the violets are missing from your perception. But, when everything in a gallery has the same distortion, your mind conceals it. You start to think washed out colors and no blues look normal.
Side-by-Side Comparisons of Light Sources

Fluorescent spectral output shows both missing and overrepresented colors.

NoUVIR’s spectral output closely matches sunlight (with zero UV or IR)

Halogen has all colors present, but with a poor color balance (4 times the red of sunlight)

HID (metal halide) sources have more spikes than fluorescents and slightly more color distortion.

“White” LED (Nichia NSPW500BS) sources show poor color balance with a major blue component

What about non-visible light energy?

NoUVIR fiber optics, three fibers = 12 watts

Par 20 Halogen spot with glass lens, 40 watts
The three photographs on the left were made under identical conditions; the same teacup, exactly the same light level, even the same roll of film. Only the light sources changed. In a gallery, without this side-by-side comparison you might not realize the extreme blue emphasis of fluorescent and LED lighting, the green tint of HID's or the way tin-can parlamps steal the "purple mountains' majesty" from landscapes. Color adaptation interferes. But poor color balance will show on your art and artifacts. Colors shift. Skin tones turn lifeless. Subtle hues disappear. People think we exaggerated the color shifts in these photographs. We didn’t need to. You can do this same comparison yourself with a colorful artifact or print and a pair of desk lamps with various kinds of lamps.

Since we first did this testing, new sources have become popular. We’ve added the spectral outputs for HID and LED sources. The graphs clearly show the color distortion. You can calculate the area of spectral mismatch (the area above and below the sunlight curve) of any source and come up with a number that represents the variation from sunlight. This is called Correlated Color Imbalance. The higher the number, the greater the distortion. You can also call this number the “Coefficient of Ugly”.

Another number that helps judge color balance or distortion is Color Rendition Index (CRI). To get this number, test subjects sort colors under specific light sources (picture sorting a box of crayons). CRI is the percentage of correctly identified colors. A CRI of 80 sounds good, but what it really means is that 20% of all of the colors were misidentified. Anything less than 100 CRI shows distortion.

As you can see, HID sources have very similar output to tri-stimulus fluorescent. While they have more spikes and valleys, the total area of missing colors (below the sunlight curve) and over-represented colors (above the sunlight curve) is even greater than of fluorescent lights. As with fluorescent lighting, the missing reds make everything look blue-green.

“White” LEDs also have strong blue tint. In LEDs it is because of the huge blue spike in their output. LEDs are naturally mono-chromatic (one color). Just as fluorescent lamps generate UV to excite a phosphor coating to emit “white” light, “white” LEDs generate blue light at 450 nm to excite a “white” phosphor. The spectral output makes this distortion obvious.

NoUVIR is a visual duplicate of sunlight (with all the UV and IR removed). Thus, objects reflect their true colors. The coefficient of ugly is almost zero. Color Rendition Index, CRI, is 100. You get perfect color with no distortion.

But distortion is only part of the story. The chocolate under NoUVIR’s pure-white, stone-cold light is unchanged. But halogen light’s effect, side-by-side at the same light level for the same time shows the impact of its 94% IR and 1% UV. The cherry becomes a melted candy puddle. This demonstrates not only the poor presentation (loss of true color and beauty), but the degraded preservation (increased damage). This is also a demonstration of poor conservation because every watt of heat added to a space takes 3 to 4 watts of air conditioning to remove. (But, we’re getting ahead of ourselves.)

Watercolors, oil paintings, textiles, ancient glass, minerals, documents, photographs, etc., are all sensitive to bad lighting. The more complex the coloring and the finer the details, the greater poor lighting interferes with true perception. On top of this, for every 10°C rise in temperature the rate of chemical reactions double. The question is not, will bad lighting damage your artifacts? but, when? When will your plates or ceramics thermally craze? When will the background fabrics fade and need replacement? When will your textile, watercolor, etc., be damaged by UV, IR or both?

Just like your computer’s "GIGO", "Garbage-in" light creates "garbage-out" vision. That, in turn, damages collections and degrades the conservation of resources, man-hours, and money. The true bottom line is that presentation, preservation, and conservation are all interdependent. Bad lighting will have severe and inevitable consequences... it’s just a matter of time.
Preservation

Preservation is also an easy term to understand. It is simply the protection of the collection from the damage (remember the chocolate?) By the way, protection can extend to case linings, carpets, graphics and even the merchandise in our museum stores. As we've seen above, light is either reflected by an object, helping you see, or it is absorbed by the object, causing photochemical and/or photomechanical damage. Ultraviolet and infrared don't help you see. They can only cause damage, so the first task is to remove all light energy that doesn't help you see.

Getting information on energy outside the visible spectrum is sometimes difficult. It's even harder when you understand that most UV meters only read UV above 300 nm. But UV emissions below 300 nm are found in almost all sources. Few manufacturers bother to filter sources in UV ranges where no one has measuring tools. Fewer still give you accurate data. It's a matter of “what you don’t know won’t hurt me”. Here are full spectrum outputs (UV through IR) most people won’t show you.
MUSEUM LIGHTING - PURE AND SIMPLE

Removing all UV and IR dramatically retards fading and damage. Both laboratory and museum testing have proven that lighting systems with no UV or IR extend the exhibit life a minimum of 3 to 5 times, compared to typical museum lighting. Tests of various lights with both widely-used ISO blue wool and fugitive dye samples in assorted colors showed some surprising results:

1) Fluorescent lamps faded the ISO samples only 10% less than sunlight.
2) Dimmed incandescent and halogen lamps caused fading within 4% of fluorescent lamps.
3) UV filters on fluorescent lamps only reduced fading by 30%.
4) Adding glass IR filters to halogen lamps only reduced fading by 10%.
5) Fiber optics with no UV and IR reduced fading by 80% (five times the exhibit life) compared to fluorescent, incandescent or halogen lamps.
6) Lightly tainting fiber optics to match artifact color reduced fading by 91% (twelve times the exhibit life) compared to fluorescent, incandescent or halogen lamps.
7) Color filtering fiber optic lighting to exactly match the color of an artifact reduced fading by 99% (increased exhibit life by 100 times). Color-matched lighting stops fading.

This testing led to the science of Reflected Energy Matching. Remember, you only see reflected light and only absorbed light causes damage. Matching light color to artifact color does not change appearance. Again, you only see what is reflected. What does is eliminate absorbed energy (and damage). Hundreds of fading tests show that NoUVIR fiber optic lighting with color matching filters, can virtually stop photochemical damage!

Conservation

Conservation is simply stewardship of a museum's materials, personnel, and financial resources. The whole idea is in the old saying, "Waste not, want not." And in an era of tight budgets, it can be a matter of museum and personal survival.

Bad lighting results in more than poor presentation and destructive preservation. It also means that the lighting is inefficient. It wastes power. It generates heat. And every watt of power put into lighting takes 3 to 4 watts of air-conditioning to pump out.

Each NoUVIR projector powers up to 32 individual fiber optic luminaires. It is not unusual for a single projector (i.e., one light bulb) to illuminate two or more cases. NoUVIR installations require less energy and far fewer light bulbs. With the added saving in HVAC load, NoUVIR installations can provide 50% to 70% overall gallery energy savings.

Energy savings are only one way NoUVIR reduces operating costs. Case linings, signs and graphics last longer. IR driven case breathing and associated dust problems are eliminated. Exhibit rotations and cleaning cycles are extended. Maintenance and labor costs drop, all the result of good lighting.

4. We started teaching the need to eliminate UV and IR in the early 1990’s. By 2000 the Illuminating Engineering Society of North America (IES) established guidelines recommending filtering all UV and IR in museum (and commercial) environments. You’ll find these guidelines in the IESNA Lighting Handbook.


6. Los Angeles Department of Water and Power documented 70% gallery energy savings after they funded one museum’s NoUVIR installation as a power conservation program.
MUSEUM LIGHTING - PURE AND SIMPLE

THE ABCs of EXHIBIT LIGHTING DESIGN

*Museum lighting design must follow basic lighting principles:

A – LIGHT ARTIFACTS, NOT AREAS

People come to a museum to see the art and artifacts. Except for historic sites, people don’t visit museums to see walls and ceilings. Good lighting design will make each artifact a center of interest.

One of the most important features of the NoUVIR system is control, the ability to put an exact amount of light precisely where you want it. In lighting a painting, don’t splash light all over the wall around it. Instead, illuminate the painting evenly and uniformly from top to bottom, to show exactly what the artist painted. Conventional lighting can’t do that because the light on the top of the painting will always be several times brighter than the light on the bottom. That’s the $1/r^2$ law at work. NoUVIR’s adjustable beams let you control intensity on each part of the painting top to bottom. You’ll see color and details you never knew were there!

Lighting a small artifact, such as an Egyptian faience or ancient jade sculpture, doesn’t require flooding an entire case with light. Just zoom the fiber optic luminaire’s beam to the size of the artifact, and let light scattered from the object add a little soft glow to the interior. Now the case lining is not visually competing with the object. Similar objects can be grouped and lit with a single beam, showing the viewer the items are related, something impossible if you are lighting areas.

Lighting artifacts instead of areas lets you place artifacts made of different materials in the same case or on the same wall. Now each object can have a lighting intensity and effect that specifically fits the individual size, color, and importance of each item. Fragile papers can be displayed next to engraved silver; gemstones may be displayed on fugitive costumes. Watercolors and oils may be exhibited on the same wall. Your imagination chooses the placement and emphasis for each artifact and for each light pattern. The moon behind the hawk on the right is simply a beam of light from a NoUVIR spotlight.

Lighting artifacts not only gives you more effective presentation, it is more efficient as well. One NoUVIR gem and geology exhibit used 40 NoUVIR projectors (40 light bulbs) to replace 700 halogen light fixtures (and their 700 light bulbs). This took 60,000 watts off line; quadrupled the light levels on the individual gems; and improved the color, appearance, and depth of the specimens. The exhibit not only looked better, but the museum dramatically cut its operating costs. As a matter of fact, the savings are funding doing it all again in another gallery!

B – BACKGROUNDS MUST BE SUBDUED

Exhibits should always be brighter than the background and graphics around them. Exhibits should be on stage, the center of attention. Two-to-one is a good rule. Artifacts should be twice the intensity of the background. On top of that, nothing in view should be more than twice as bright as the dimmest lit exhibit in a gallery. This includes windows, banners, large lightly colored graphics and video presentations. More museum vision problems are caused by glare than low light levels.

N o U V I R
20915 SUSSEX HIGHWAY 13
PH. (302) 628-9933
RES E A R C H
SEAFORD, DELAWARE 19973
FAX (302) 628-9932
MUSEUM LIGHTING - PURE AND SIMPLE

Your eye sees the entire scene - artifact, background and any visible light sources. Then your eyes set the iris diameter like the f-stop of a camera, adjusting to average the total light present. A window, a bright background or an over lit graphic will cause your iris to contract. The result is a mild case of “snow blindness”. Direct glare from overhead lights does the same thing, only to a greater degree. You can read quite well at 2 to 3 footcandles given a few minutes to adjust and no bright visual distractions.

If the gallery or lighting design draws a visitor’s attention and gaze to a light source, they can be effectively blinded to the exhibit for up to fifteen minutes. A unique advantage of fiber optic lighting is that the light sources can be kept completely from view; often hidden entirely inside a display case behind door reveals and mullions. This allows the iris of the eye to open up to a larger f-stop, admitting more light and information to create a quality image on the retina.

C – CONTROL GLARE and CASE REFLECTIONS

A museum must protect exhibits from things like dust, contamination, visitors' hands, breath, sneezes, etc. Usually that means a case or “window” between the artifact and the visitor. But windows reflect.

The case “window” acts like a "one-way" mirror in a police line-up. The witnesses (museum visitors) are in a darkened room and the suspects (museum artifacts) are in a well lighted room. If there are no lights in the witness’ room, the viewers see the suspects (artifacts) very clearly. But if the lights are bright in the viewers’ gallery; the viewers will see the lights, the walls, their own images, and every illuminated item in the room reflected in the window.

You can demonstrate this with your TV, as the photo on the right shows. In the upper portion of the photo the “case” is dark. Room lights create reflection and glare. The bottom portion shows the same scene, in the same room with the same lighting. But now the “case” is lit. The reflections are still there, they have just faded to insignificance. Your ability to see into a display case is directly proportional to the ratio of the interior and exterior light levels.

A museum gallery should have the lowest ambient light levels possible. Low ambient lighting minimizes damage to both artifacts and furnishings. Conceal lighting. Use draperies over “historic” windows. (Draperies were common and important insulation in winter.) Use reversed graphics to avoid large white areas. Light artifacts to conservation levels and then control ambient light to about half of that level. You'll be amazed at the result.

7. Jack Miller, Optics and Physiology of Human Vision in a Museum Environment (Seafor, DE: NoUVIR Research, 1994)

A Final Note -

I hope that you have found Museum Lighting, well... Pure and Simple. If you have any questions, please feel free to call us. We invented museum lighting. We teach these subjects in seminars. We work with museums every day. We'd like to help. And, like I said in my introduction to this catalog, I'm on a crusade to save the world... one artifact, one exhibit, one museum, one building at a time.