16 UV Radiation Safety

Ultraviolet radiation (UV) is electromagnetic radiation covering the range of wavelengths 40 - 400 nm (30 - 3 eV). It is divided into 3 ranges (see Table 1). The direct potential radiation hazards to health arise from UV with wavelengths greater than 180 nm. UV of lower wavelength is readily absorbed in air and only exists in a vacuum.

For most people, the main source of UV exposure is the sun. Other sources include tanning booths, black lights, curing lamps, germicidal lamps, mercury vapor lamps, halogen lights, high-intensity discharge lamps, fluorescent and incandescent sources and some types of lasers (e.g., excimer lasers, nitrogen lasers, and third harmonic Nd:YAG lasers). Unique hazards from these sources depends on the wavelength range of the UV radiation.

Generally, the shorter the wavelength, the more biologically damaging is the UV radiation. UV-A is the least damaging (longest wavelength) form of UV and reaches the earth in great quantities. While UV-B can be very harmful, stratospheric oxygen and ozone absorbs 97 - 99% of the sun’s light with wavelengths between 150 and 300 nm. Factors affecting exposure to sunlight include:
- Latitude - at high latitudes (e.g., the poles), the sun is low in the sky and sunlight passes through more atmosphere, so UV-B exposure at the poles is over 1000-times lower than at the equator.
- Elevation - on mountain tops the air is thinner and cleaner, so more UV reaches there than at lower elevations.
- Cloud cover - clouds significantly absorb UV-B.
- Time - UV intensity is higher in the summer and daily between 10 AM and 2 PM.
- Air pollution - industrial processes produce smog and ozone which absorb UV-B.
- Surface material - snow reflects up to 85% of the UV, sand and concrete up to 12%, water and grass only 5%.

16.1 Physical / Health Effects

Because of the limited penetration of UV into the body (Figure 16-1), the main tissues affected by UV are the skin and eye. Excessive short-term UV exposure to the skin causes sunburn and to the eye it can cause acute damage to the cornea and conjunctiva. Certain individuals have abnormal skin responses to UV exposure (i.e., photosensitivity) because of genetic, metabolic or other abnormalities, or show photosensitive responses because of intake or contact with certain drugs or chemicals. There is also experimental evidence in animal models and human subjects of suppressive effects of UV on the immune system, however their significance for human health is unclear.

UV-C, far UV and vacuum UV are almost never observed in nature because they are completely absorbed by the atmosphere. Germicidal lamps are designed to emit UV-C because of its ability to kill bacteria. In humans, UV-C is absorbed in the outer, dead layers of the skin. Accidental exposure can cause corneal burns (e.g., welders’ flash, snow blindness) or severe sunburn to the face and, although UV-C injuries usually clear up in a day or two, they can be extremely painful.

UV-B is typically the most destructive form of UV. It has enough energy to cause photochemical damage to cellular DNA and is not completely absorbed in the atmosphere. UV-B effects include erythema (sunburn), cataracts, and development of skin cancer. Individuals working outdoors are at greatest risk for UV-B effects.

UV-A is the most commonly encountered type of UV light. Initially UV-A exposure has a pigment-darkening effect (tanning) where the skin produces melanin to protect itself from exposure. This is followed by erythema if the exposure is excessive. The atmosphere absorbs very little UV-A and UV-A is needed for synthesis of vitamin D. Overexposure to UV-A has been associated with toughening of the skin, suppression of the immune system, and cataract formation. UV-A, often referred to as black light, is commonly found in phototherapy and tanning booths.

DNA absorbs UV-B and the absorbed energy can break bonds in the DNA. Most of these breakages are repaired by proteins present in the cell's nucleus, but unrepaired genetic damage can lead to skin cancers. One method that is used to analyze the amount of genetically-damaging UV-B is to expose samples of DNA to light and then count the number of DNA breaks.
Ninety percent of the skin carcinomas are attributed to UV-B exposure and the principle danger of skin cancer is to light-skinned peoples. It is estimated that a 1% decrease in the ozone layer would cause an estimated 2% increase in UV-B irradiation, leading to a 4% increase in basal carcinomas and 6% increase in squamous cell carcinomas. There appears to be a correlation between brief, high intensity exposures to UV and eventual (i.e., a 10 - 20 year latent period) appearance of melanoma. Twice as many deaths due to melanomas are seen in the southern states of Texas and Florida, as in the northern states of Wisconsin and Montana. Long-term sun exposure is undisputedly linked to premature aging of the skin. Even careful tanning kills skin cells, damages DNA and causes permanent changes in skin connective tissue which leads to wrinkle formation.

Eye damage can result from high doses of UV light. The cornea is a good absorber of UV light (Figure 16-1). High doses can cause temporary clouding of the cornea (i.e., snow blindness) and chronic doses, particularly exposure to UV-B at 300 nm, have been tentatively linked to cataract formations. Higher incidences of cataracts are also found at high elevations (i.e., Tibet, Bolivia) and at lower latitudes (i.e., near the equator).

The photochemical effects of UV radiation can be exacerbated by chemical agents including birth control pills, tetracycline, sulphathiazole, cyclamates, antidepressants, coal tar distillates found in antidandruff shampoos, lime oil, and some cosmetics. Protection from UV is provided by clothing, polycarbonate, glass, acrylics, and plastic diffusers used in office lighting. Sun-blocking lotions offer limited protection against UV exposure.

### 16.2 Protective Measures

Accidental overexposures can injure the unaware victims because the UV is invisible and does not produce an immediate reaction. Labeling on UV sources usually consists of a caution or warning label on the product or the bulb packing cover, or a warning sign on the entryway. Reported UV accident scenarios often involve work near UV sources with protective coverings removed, cracked, or fallen off. Depending on the intensity of the UV source and length of exposure, an accident victim may end with an injury causing lost-time. Hazard communication is helpful in preventing accidental exposures in the workplace.

The National Toxicology Program (NTP) has listed broad spectrum ultraviolet radiation as a known human carcinogen while UV-A, UV-B, and UV-C are listed as reasonably anticipated to be human carcinogens. The FDA Center for Devices and Radiological Health (CDRH) has promulgated regulations concerning sun lamp / tanning products including the use of labels stating, "DANGER -- Ultraviolet radiation."

The intensity of UV is measured by the amount of energy deposited (mW/cm² or J/cm²) and the dose rate indicates the instantaneous amount of incident radiation. A total dose value is obtained by integrating the dose rate over time. While scientifically this is easy to do in an experimental setting, in real life, it is not practical.

The American Conference of Governmental Industrial Hygienists (ACGIH) has set threshold limit values (TLV) for skin and eye exposure of occupationally exposed persons. The TLVs are determined by these parameters:

- For the near UV spectral region (320 - 400 nm), total irradiance incident upon the unprotected eye should not exceed 1.0 mW/cm² for periods greater than 10³ seconds (about 16 minutes) and for exposure times less than 10³ seconds should not exceed 1.0 J/cm².

- Unprotected eye or skin exposure to UV should not exceed 250 mJ/cm² (180 nm) to 1.0 x 105 mJ/cm² (400 nm) for an 8-hour period (Table 16-2). The TLVs in the wavelength range 235 to 300 nm are 3.0 (at 270 nm) to 10 mJ/cm².

### Table 16-2. UV Exposure Limits (EL)

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
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<th>Wavelength (nm)</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
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<td>190</td>
<td>200</td>
<td>205</td>
</tr>
<tr>
<td>210</td>
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<tr>
<td>297</td>
<td>300</td>
<td>303</td>
<td>308</td>
</tr>
<tr>
<td>EL (J/m²)</td>
<td>EL (J/m²)</td>
<td>EL (J/m²)</td>
<td>EL (J/m²)</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>1 min</td>
<td>4 hours</td>
<td>1 hour</td>
<td>30 min</td>
</tr>
<tr>
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<td>10</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>510 min</td>
<td>0.5 sec</td>
<td>10 sec</td>
<td>1 sec</td>
</tr>
<tr>
<td>1.7</td>
<td>3.3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>1 sec</td>
<td>0.5 sec</td>
<td>0.1 sec</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>6000</td>
<td>30,000</td>
<td></td>
</tr>
</tbody>
</table>

1 principal emission line of low-pressure quartz-mercury lamps

### Table 16-3. Limiting UV Exposure Duration

<table>
<thead>
<tr>
<th>Duration</th>
<th>μW/cm²</th>
<th>Duration</th>
<th>μW/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 hours</td>
<td>0.1</td>
<td>5 min</td>
<td>10</td>
</tr>
<tr>
<td>4 hours</td>
<td>0.2</td>
<td>1 min</td>
<td>50</td>
</tr>
<tr>
<td>2 hours</td>
<td>0.4</td>
<td>30 sec</td>
<td>100</td>
</tr>
<tr>
<td>1 hour</td>
<td>0.8</td>
<td>10 sec</td>
<td>300</td>
</tr>
<tr>
<td>30 min</td>
<td>1.7</td>
<td>1 sec</td>
<td>3000</td>
</tr>
<tr>
<td>15 min</td>
<td>3.3</td>
<td>0.5 sec</td>
<td>6000</td>
</tr>
<tr>
<td>10 min</td>
<td>5</td>
<td>0.1 sec</td>
<td>30,000</td>
</tr>
</tbody>
</table>
Effective irradiance for broad-band sources must be determined with a weighing formula.

For most white-light sources and all open arcs, the weighing of spectral irradiance between 200 and 315 nm should suffice to determine the effective irradiance. Only specialized UV sources designed to emit UV-A radiation would normally require spectral weighing from 315 to 400 nm.

The permissible UV exposure for unprotected eye and skin exposure (Table 16-3) may range from $0.1 \mu W/cm^2$ (8 hours/day) to $30,000 \mu W/cm^2$ (0.1 sec/day).

The UV hazard potential of a source cannot be judged solely by its brightness. For example, germicidal lamps emit only a faint visible glow, but do emit a large amount of UV. The hazard potential can only be judged by doing a careful hazard assessment. When a source constitutes a hazard, protective measures include engineering and administrative controls and personal protection.

Engineering control measures are preferred to protective clothing, goggles and procedural safety measures. Glass envelopes for arc lamps will filter out most UV-B and UV-C. For lengthy exposures at close proximity to high power glass-envelope lamps and quartz halogen lamps, additional glass filtration may be necessary. Light-tight cabinets and enclosures and UV absorbing glass and plastic shielding are the key engineering control measures. Interlocks (Figure 16-2) should be used where the removal of a cover could result in hazardous exposure. Surfaces which are reflective can be painted with appropriate non-UV reflective material. UV-C is capable of producing ozone. TLVs for ozone range from 0.05 ppm for heavy work to 0.1 ppm for light work. For working times less than 2 hours, the TLV is 0.2 ppm. If ozone is a potential product, ventilation may be needed to reduce concentrations.

Administrative controls are directed toward persons working with UV sources. These persons should be provided adequate training to understand the need for hazard control and methods to work safely. Access to the areas should be restricted to workers directly concerned with its operation. Time, distance and shielding are suitable protective measures for all types of radiation. Workers should reduce the time of exposure and increase the distance (i.e., UV follows the inverse square law) to effectively limit exposure. Hazard warning signs (Figure 16-3) should be used to indicate the presence of a potential UV hazard when exposures are likely to exceed exposure limits, indicating restriction of access and need for personal protection, if appropriate. Warning lights may also be used to show when the equipment is energized. When maintenance/service requires the removal of shielding, great care must be exercised to prevent hazardous exposure.

For occupational exposure to artificial sources, the areas of the skin usually at risk are the backs of the hands, the face, the head and neck. Hands can be protected by wearing gloves with low UV transmission (e.g., nitrile). The face can be protected by a UV-absorbing face shield or visor which also offers eye protection. Suitable head gear will protect the head and neck (Figure 16-4). Goggles, spectacles, visors or face shields which absorb UV should be worn where there is a potential eye hazard. If retinal damage from intense visible light is also a possibility, appropriate tinted lenses should be worn.
16.3 Practical Hazard Assessment and Control

The aim of hazard assessment is to assess equipment emissions and possible personnel exposures. While there have been exposure limit values recommended by different groups, there is no current exposure limit standard adopted by OSHA or the State of Wisconsin. Another complicating factor is that suggested exposure limits include radiant exposures from all sources of UV, not just from processes involving UV. Exposures to different sources, including lighting, may contribute to the individual's total UV exposure. In the workplace, a person's exposure is determined by the UV emissions of equipment (which vary with location relative to the equipment) and the exposure duration. In the future, individual devices capable of measuring irradiance may be available just as ionizing radiation dosimeters are available, but there are some techniques available that do not involve measurements. Because UV exposure can cause both short and long term injury and as there are no established federal exposure level standards, the worker should take precautions when working with any UV source. The steps involved in this assessment are:

1. Determine the type of UV source (e.g., UV-A, UV-B, UV-C). This can be obtained by from the manufacturer or it may be listed on the equipment. The type of UV determines the type of risk (e.g., skin, eye, etc.).
2. Determine the intensity of the source. Many UV bulb suppliers provide the bulb intensity in \( \mu \text{W/cm}^2 \) at a specific distance (e.g., 0.75 inch, 3 inches, 12 inches, etc.).
3. Determine the exposure duration. As opposed to industry where workers may do the same task repeatedly, most people working in laboratories (excepting certain clinical tasks) will be performing a random series of tests and both exposure and exposure durations will be sporadic. Attempt to determine whether exposure will be hours per week or minutes per week.
4. Use proper protective equipment. Lab coat, protective gloves (e.g., nitrile), safety glasses, face shields provide a significant level of protection.
5. If your equipment comes with protective devices (e.g., interlocks, shields, etc.), do not defeat or remove them. If you must remove them for maintenance, put a note on the control panel informing others not to use the equipment until you have replaced the safety devices.

A review of some of the most common sources found in medical / research institutions may better enable you to apply the assessment principle.

Germicidal Lamps

The most common UV lamps, low-pressure mercury ("quartz") lamps, are used for germicidal control in hospital hallways, intensive-care wards, operating rooms and biological laboratory hoods. In some cases these lamps have been installed in fixtures to insure that exposures of personnel will be indirect. Sometimes these fixtures are not very effective and direct skin and eye exposure can occur. The paint near these fixtures may be reflective, causing increased exposures and even erythema in some workers.

Effective germicidal action in a room or laboratory hood requires such high UV levels that personnel in the area must always be protected. The glass shield in the laboratory hood (i.e., lime glass) sash filters out most UV radiation with wavelengths below 320 nm. Protective clothing in operating rooms and other such rooms consist of gown, face shield and gloves to protect the skin and eyes. Some companies sell specialty face shields and goggles, however almost any plastic face shield or goggle will be equally effective. Many transparent plastics transmit a significant fraction of UV-B, but manufacturers often add UV absorbers to deter aging.

If germicidal lamps are used in air ducts, laboratory pass boxes, toilets, etc., interlocks (Figure 16-2) should be installed to insure that workers are not injured. Special warning labels can be used to assure that users of UV equipment are adequately informed.

Figure 16-5. High-Intensity Light Warning Labels
Phototherapy Lamps and Sunlamps
Dermatologists often use UV lamps for special phototherapy treatments. The use of these lamps is regulated by the FDA and the State of Wisconsin. The lamps are usually vertically arranged in treatment booths and have several tubular UV fluorescent sunlamps and UV fluorescent "black lights." Normally only one set of lamps is used for any one treatment (e.g., UV-A lamps used for treating psoriasis).

Dermatologists are well aware of the hazards of excessive exposure and normally employ timing switches to limit exposure. The protective booths are often open at the top for ventilation. While there may be some reflection from the ceiling, this is generally below the 8-hour hazard limits for personnel standing outside the booth. Additionally, a variety of high-pressure and medium-pressure, mercury, quartz lamps (i.e., "hot quartz") are used for localized skin treatment.

Because of the high potential for injury, most clinics employ detailed precautions and patient instruction. An example SOP:

Serious and painful ultraviolet induced eye and skin irritation may result to unprotected personnel if these units were improperly used. The following precautions reduce needless occupational exposure:

- Only authorized personnel familiar with the potential hazards and control measures shall use the unit.
- The unit shall be used in a designated area with limited access which affords added protection to passers-by. Operation from within a closed well-ventilated room or draped area reduces the risk of exposure.
- Operator protective measures include the usage of dark glasses with side shields, long sleeved shirts, gloves and long pants. Although these devices may not completely eliminate the ultraviolet radiation, they lessen the risk of severe burn.
- Avoid needless exposure even when skin or eyes are covered.
- Never look directly at the lamp. Cover eyes and skin of patients which do not require exposure. Avoid an overdose. Time carefully. Know the erythemic reaction of the patient. Avoid needless exposure to patients.

"Black Light" Lamps
The "black light" or UV-A lamp (sometimes called a "Wood's Lamp") has applications with fluorescent powders in testing, for special effects in entertainment and medical fields. These lamps are normally not considered hazardous since the UV-A radiance at the lamp surface is only about 1 - 5 mW/cm² and the skin or eye would not normally be exposed to levels exceeding 1 mW/cm². However problems can arise if the lamp envelope does not filter all UV lines of the mercury spectrum (i.e., 297, 303, and 313 nm) or if the person using the lamp is photosensitive.

Additionally, persons who have worked with black light for many years can develop sensitivity to the light and persons taking some medications (e.g., tetracycline) may be photosensitive.

Some small portable black light units used for fluorescence studies may have a "shortwave" (UV-C and UV-B) mode as well as a "longwave" (UV-A) mode. For these devices, procedures should consider the type of radiation being used and proper precautions employed.

Black lights should be positioned so that individuals are not exposed to UV irradiances exceeding 1 mW/cm². As an added precaution, the eyes should not be chronically exposed to that level. When looked at with the naked eye, black light appears fuzzy. This is primarily the result of UV-A interactions in the cornea and lens. Special glasses which filter out UV-A will eliminate the distortion.

Transilluminators and UV Sterilizers
Labs working in the biotechnology field often deal with UV light sources as transilluminators and sterilizers. As discussed in assessment, above, the first step is to determine the type of UV light. UV transilluminators provide an optimum platform for visualization of agarose and polyacrylamide gels. Samples are placed on the illumination window and are illuminated by the UV light. These devices seem to operate at one or several bands depending upon the type of sample. The standard bands are: 254 nm, 312 nm and 365 nm.
Transilluminators usually come with an adjustable UV blocking cover to protect the user from harmful UV. These UV blocking covers should not be removed since viewing fluorescently labeled DNA unprotected can cause damage to the face and eyes. There have been reports of injuries to researchers who did such viewing without wearing protective eye wear or using a face shield. Some simple laboratory rules for UV transilluminator work:

- The acrylic shield / UV blocking cover supplied should be closed while the UV light is on.
- If the work requires the shield to remain open:
  - All persons in the room must cover all exposed skin.
  - Face and eyes must be covered by wearing an appropriate UV absorbing full face shield.
  - Heavy duty rubber gloves should be worn on the hands, standard laboratory gloves are not suitable for hand protection from UV.

Some small (bench top) UV sterilization devices (Figure 16-8) are also available. Among other uses, these cabinets are designed to decontaminate reagents and equipment prior to carrying out PCR reactions using UV lamps to denature nucleic acids in only 5 to 10 minutes. The cabinet is equipped with interlocks on the cabinet doors to protect the user from accidental exposure. The 1 cm thick acrylic material also works as a shield with radioactive material.

16.4 Review Questions - Fill in or select the correct response

1. UV-B effects include __________ (i.e., sunburn) and __________.
2. Germicidal lamps are designed to emit __________.
3. The National Toxicology Program has listed broad spectrum ultraviolet radiation as a known human carcinogen while UV-A, UV-B, and UV-C are listed as reasonably anticipated to be human carcinogens. true / false
4. The UV exposure limit (J/m²) for a transilluminator emitting light at 254 nm is __________.
5. Three protective measures for UV radiation are time, distance, and shielding. true / false
6. Engineering controls include interlocks, non-UV reflective surfaces, and glass envelopes. true / false
7. UV personal protective equipment includes face shields, gloves with low UV transmission. true / false
8. If your equipment comes with protective devices (e.g., interlocks, shields, etc.), do / do not remove them.
9. Low pressure mercury (“quartz”) lamps are used for __________ control in hospitals and laboratory hoods.
10. The use of sun lamps and phototherapy lamps is regulated by the __________.
11. A black light or "wood's lamp" emits __________ radiation.
12. Persons who have work with black light for many years may develop sensitivity to the light. true / false
13. Some small black light units may have a “shortwave” (UV-C and UV-B) and "longwave" (UV-A) mode. Safety with these devices requires that the user consider the type of radiation being used. true / false
14. Transilluminators may operate at one of several bands, these are: ______ nm, ______ nm and ______ nm.
15. When using a UV transilluminator, insure that the acrylic shield / UV blocking cover is closed while the UV light is on. true / false
16. If work with a transilluminator requires the shield to remain open, cover exposed skin, wear an appropriate UV absorbing full face shield, and wear heavy rubber gloves (latex gloves are not suitable). true / false

16.5 References
National Radiological Protection Board, Advice on Protection Against Ultraviolet Radiation, NRPB, Oxfordshire, 2002
Sliney, David and Wolbarst, Myron, Safety with Lasers and Other Optical Sources, Plenum Press, New York, 1980