CHAPTER 11

ULTRAVIOLET RADIATION

1. **GENERAL**.

a. This chapter serves as a guide to industrial hygienists who are responsible for evaluating and making recommendations for the protection of workers from potential health effects of ultraviolet radiation.

b. The guidelines and the exposure limits are based on available knowledge and scientific research. The limits should provide a healthy work environment for the majority of workers exposed to ultraviolet radiation.

2. **PHYSICAL PROPERTIES**.

a. Physics.

(1) Radiation is energy in transit. Electromagnetic radiation is made up of oscillating electric and magnetic fields which are propagated in free space and in matter. Collectively, the electromagnetic spectrum includes: radiofrequency (radio, television and microwave transmission); infrared, visible and ultraviolet light; X and gamma radiations. Ultraviolet (UV) is part of the electromagnetic radiation spectrum with wavelengths from approximately 180 nanometers (nm) to 400 nm.

(2) Electromagnetic radiation can be classified by properties such as wave velocity, frequency or wavelength. These three parameters of electromagnetic radiation are related by the following:

$$c = \lambda \nu$$

Equation 11-1

Where:

c = velocity (light in vacuum); a constant 3×10^8 meters per second (m/s)

λ = wavelength; the distance occupied by one wave (in units of length such as meters, micrometers, or nanometers)

ν = frequency; the number of oscillations per unit time (expressed as oscillations per second using the unit Hertz (Hz))

(3) The electromagnetic spectrum can be represented by either frequency or wavelength as depicted in Table 11-1. All electromagnetic radiation, regardless of the medium, will exhibit certain attributes such as reflection, refraction and diffraction.

(a) Reflection takes place at an interface of materials. Two types of reflection occur, specular (mirror-like) and diffuse. Surfaces with irregularities or roughness produce diffuse reflections. Diffuse and specular reflections are wavelength dependent. A surface may produce a specular reflection at one wavelength but diffuse at another, due to the size of the surface roughness in relationship with the wavelength.

(b) Refraction takes place at an interface when a beam passes from one media to another having a different refractive index. It is responsible for the bending of the light near air-water, air-glass interfaces. Lenses and prisms are optical devices that use the principle of refraction.

(c) Diffraction of electromagnetic radiation occurs when waves pass around an object in their path and are deflected. This may occur when radiation passes through very narrow slits or small apertures.

(4) When radiation is transmitted through a material, it may lose energy to the medium by various processes (e.g., absorption). In a homogeneous material, the proportion of energy loss per unit length is constant.

b. Ultraviolet radiation is usually divided into several ranges based on physiologic effects:

UVA	(near UV)	315 - 400 nm
UVB	(middle UV)	280 - 315 nm
UVC	(far UV)	180 - 280 nm

UV radiation with wavelengths below 200 nm is not easily transmitted through air and usually does not pose an exposure problem.

c. Some important absorption properties of UV radiations are as follows:

(1) UVA radiation is easily transmitted through air and glass. There is penetration through the epidermis and the anterior ocular media.

(2) UVB and UVC radiation is transmitted through air and through quartz but is absorbed by ordinary glass. Absorption of these wavelengths by the ozone layer of the upper atmosphere is the reason why solar radiation on the earth's surface is almost devoid of wavelengths below 320 nm. UV radiation below 315 nm is primarily absorbed by the cornea or the top epithelial skin layer.

d. Of all the terms used to describe UV radiation, the power or energy per unit area, irradiance (E) and radiant exposure (H) respectively, are the most common. Irradiance (a dose rate used in photobiology) is described in watts (unit of power) per square meter (W/m^2) or watts per square centimeter (W/cm^2). Radiant exposure (H), is dose, and is described in joules (unit of energy) per square meter (J/m^2) or joules per square centimeter (J/cm^2). Note that a watt is a joule per second thus the dose rate (W/cm^2) multiplied by the exposure duration (seconds) equals dose (J/cm^2).

3. **BIOLOGICAL EFFECTS**.

a. The absorption of UV radiation can cause biological effects. The two primary organs of concern are the eye and the skin.

b. The UV spectral band of UVA (315-400 nm) is less photobiologically active than the rest of the ultraviolet; UVB (280-315 nm) and UVC (180-280 nm).

c. The adverse effects of UV radiation have been shown to be a result of photochemical reactions rather than thermal damage. This is shown by the rapid drop off of effects in the longer wavelengths of the UV spectrum. The effectiveness of the various wavelengths of UV radiation to produce a biological response is referred to as an action spectrum. The maximum sensitivity of the human eye occurs at approximately 270 nm and this wavelength is used as a reference for effectiveness of other UV wavelengths to elicit a biological response. The relative spectral effectiveness is the ability to produce a biological effect as compared to UV radiation at 270 nm (reference 11-1).

d. Acute effects.

(1) Erythema (i.e., redness) is a response to excessive exposure by UVB and UVC radiation. The dose required to produce erythema varies with skin pigmentation and the thickness of the horny layer (stratum corneum). There may be a latent period of 4-8 hours between the exposure and the effects. Effects may range from simple skin reddening to serious burns. Darkening of the skin and thickening of the stratum corneum offers some

protection against future exposures. Erythema production is dependent only on the total radiant exposure dose (i.e., product of irradiance and exposure duration).

(2) Skin photosensitization may occur when materials with photosensitizing capabilities (e.g., pitch, petroleum products, coal tar derivatives and some dyes or plants) are in contact with the skin during UV radiation exposure. Sometimes, photosensitizing substances are present as a result of a disease such as Lupus erythematosus, Xeroderma or Herpes simplex. Some therapeutic, diagnostic or cosmetic materials may elicit a response when present in the body or on the skin during UV radiation exposure. These include chlorpromazine, sulfanilamide, tetracyclines, salicylates, anti-bacteriostatic agents such as hexachlorophene, fungicides and oral contraceptives.

(3) Acute kerato-conjunctivitis is an inflammation of the cornea and conjunctiva after excessive exposure to UVB or UVC radiation. This is also known as snow blindness or welder's flash burn. Although the injury is extremely painful, it is usually temporary because of the recuperative powers of the epithelial layer. The latent period is usually 4-12 hours from the time of exposure and is spectral and dose dependent. There is a sensation of "sand" in the eyes, photophobia, blurred vision, lacrimation and blepharospasm (i.e., painful uncontrolled excessive blinking). Symptoms may last up to 24 hours with the corneal pain being severe. Recovery takes one to two days. The action spectrum and the threshold dose to cause kerato-conjunctivitis has been investigated. The peak of the action spectrum is 265-275 nm with the threshold for symptoms at approximately 4 mJ/cm^2. UV industrial sources (welding or germicidal lamps) may circumvent the natural defenses of the body and allow direct exposure to the cornea. This occurs when the sources emit UV radiation at angles unshielded by brow or eyelids.

(4) The lens of the eye has about the same sensitivity to UV as the cornea. The cornea however, is an efficient filter for UVC. The cornea allows substantial transmission of UVA while the lens has greater absorption. The actual effects of UV radiation exposure on the lens, such as cataract formation or photodegradation are, at best, speculative at this time. Arguments in favor of such effects are only supported by exposures to experimental animals at very high doses.

e. Chronic effects.

(1) Skin aging may occur prematurely in individuals exposed to UV radiation (UVB) for periods of many years. The skin appears as toughened, darkened and wrinkled especially in

outdoor workers and has been referred to as "Farmer's skin."

(2) Certain types of skin cancer may be induced by exposure to UV radiation, especially UVB. The cancer appears in individuals whose skin is exposed to solar radiation for a significant period of time (years) (reference 11-2).

f. Other effects.

(1) Exposure to some UV radiation is beneficial where a type of skin steroid (7-dehydrocholesterol) is converted to a form of vitamin D (an intermediate in cholesterol biosynthesis).

(2) UV radiation may interact with airborne compounds and produce harmful substances. UVC radiation below 240 nm interacts with oxygen (O_2) and may form ozone (O_3) or oxides of nitrogen (NO_X) in the atmosphere. The conversion of hydrocarbons to oxidants may occur and is the main cause of smog formation. UV radiation may also convert chlorinated hydrocarbons to phosgene.

4. **SOURCES**.

a. Sources of radiation can be grouped by the manner in which the radiation is originated. When the temperature of some material is elevated, many energy transitions occur and energy is emitted. A main source of UV radiation on the earth comes from the sun. However, when materials are heated to incandescence, some UV radiation may be emitted. The spectrum (wavelengths) emitted and the intensity is related to the temperature (absolute °K) of the material. Therefore, open arcs, fluorescent sources and incandescent sources can produce UV radiation with a wide variation of wavelengths. Depending on the source, the radiation emitted can be a broad band (so many wavelengths that it appears as a continuum) or narrow, specific wavelengths (i.e. line spectra from low pressure discharge lamps). The emitted spectrum is an important factor in evaluating the radiation.

b. Lasers have been developed which emit UV radiation. Lasers have specific characteristics which must be taken into consideration for adequate evaluation. This chapter does not address laser sources.

c. Besides the secondary production of UV radiation from arc and incandescent sources, specific lamps are manufactured to produce UV radiation in narrow spectral lines for germicidal control. These are usually low pressure mercury vapor sources that emit visible and UV wavelengths with 95% of the energy at 253.7 nm.

d. Some general lamp types are:

(1) Incandescent lamps, other than quartz-halide lamps normally have glass envelopes to keep UV radiation from being a hazard.

(2) Low-pressure discharge lamps if they have quartz envelopes may transmit UV radiation and may be of concern. Mercury low-pressure lamps can create a severe UV hazard.

(3) Fluorescent lamps usually have glass envelopes and may only present a UV hazard theoretically at the surface.

(4) High intensity discharge (HID) lamps may present UV hazards. If the envelope is glass, there may be only a concern for UV exposure at close distances. However, Quartz-Mercury HID lamps require UV hazard evaluation.

(5) Short arc lamps may produce a potential UV hazard because of the temperature of the arc and the quartz envelope.

(6) Carbon arc lamps may produce a potential exposure as with the short arc lamps. This is compounded when no glass lens or filter is present (a common situation).

5. **HAZARD ASSESSMENT AND STANDARDS**.

a. If enough information can be obtained, numerous measurements or calculations may be avoided. The following steps should be taken to evaluate any UV light source:

(1) Determine the Lamp Type - Categorizing the lamp can be useful to determine the potential UV hazard.

(2) Review the lamp manufacturer's data on radiometric specifications. This can be of great value to determine the hazard potential. Such data can be compared with data from sources previously measured. Spectral data is the most useful.

(3) Perform measurements when necessary if the above information is incomplete or lacking (see the Evaluation Section).

(4) Apply measurement results to the exposure limits.

b. The critical organs for UV exposure are the eye and skin. The thresholds for the observed effects vary significantly with wavelength. Therefore, "action spectra" have been developed to create a dose response relationship. Basically, the "action spectrum" refers to the relative spectral effectiveness of different wavelengths to elicit a biological effect (see references 11-1, 11-3). This is depicted in Table 11-2. Because some biological effects to the eyes and skin vary with wavelength, the human exposure guidelines express the efficacy of the UV spectrum normalized to the most effective wavelength (270-280 nm for the eyes). Acceptable exposure limits (Table 11-3) are based on an action spectrum that combines the spectra for erythema of caucasian skin with photokeratitis (i.e., a condition of the eye). The result is a smooth curve forming an acceptable criteria (Figure 11-1).

c. The limiting value of 3.0 mJ/cm^2 (30 J/m^2) is based on a 270 nm wavelength, where the eye appears to show the maximum sensitivity for acute effects on the cornea. A safety factor of 1.5 to 2 is applied for acute photokeratitis. Because the eye becomes more insensitive at other wavelengths, the exposure limits change (increase) due to the fact that it takes increasingly more UV exposure to elicit the same effects.

d. There has been much work to produce a basis to define a unified action spectrum or a single curve to use for occupational exposure evaluation which would apply for both the erythemic and keratotic effects, yet be simple enough for the available field instrumentation.

e. In reference 11-2, the National Institute for Occupational Safety and Health (NIOSH) published a recommended exposure limit (REL) for occupational exposure to UV radiation. The American Conference of Governmental Industrial Hygienists (ACGIH) has also produced a Threshold Limit Value (TLV®) for UV radiation very similar to NIOSH. In reference 11-1, these levels are depicted in Tables 1 and 2 in the "Ultraviolet Radiation" section. The protection limits are wavelength dependent in the spectral region of interest (200-315 nm) and are based on the action spectrum from thresholds of harmful effects in both animal and human studies. The relative spectral effectiveness values (Table 11-2) are basically a hazard weighting function. The action spectrum curve is presented in Figure 11-1. Proper use of the limits requires that the spectral irradiance of the source ($E\lambda$) be multiplied by the relative spectral effectiveness ($S\lambda$) in Table 11-2. Then the weighted irradiance values are summed in the wavelength range from 200-315 nm to obtain the effective irradiance (E_{eff}) in watts per square centimeter (W/cm^2). The allowable exposure duration is obtained from Table 11-3 or calculated by dividing 0.003 J/cm^2 by E_{eff}. Exposure to unprotected skin or eyes should not exceed these values within an eight (8) hour period. The use of a calibrated instrument that responds as the relative spectral effectiveness ($S\lambda$) eliminates the need to perform the weighting calculations.

f. The limit values represent situations where nearly all workers may be exposed without adverse effects. The limits are for exposures of the eye and skin to UV radiation from arcs, fluorescent, solar and incandescent sources but not lasers. Laser radiation must be treated separately and differently due to its coherent nature.

g. Such limits may not adequately protect individuals who are photosensitive or exposed to photosensitizing agents. Tanned or conditioned individuals may tolerate skin exposure in excess of the limits. Such conditioning does not, however, guarantee protection against skin cancer.

h. Aphakics (individuals with the crystalline lens of the eye removed) are a special problem where UVA radiation may affect the retina (such radiations are normally absorbed by the lens). Exposure limits do not apply to these individuals.

i. The exposure limits should be used as guides in the control of exposure to UV sources and are intended as upper limits for non-therapeutic exposure. The limits are not applicable to elective exposures such as tanning. The limits should be considered as absolute limits for ocular exposure. The exposure limits were developed considering a population with the greatest sensitivity and genetic disposition (i.e., lightly pigmented).

j. The ability to assess a hazard to UV radiation must be expressed or related to the relative spectral effectiveness as well as absolute radiometric aspects (descriptive units) of the radiation under study. The assessor must also recognize the variations of responses to insults from UV radiation exposure. That is, thresholds and latent periods from UV radiation exposure vary with individuals and great variations of the severity of effects are compounded with difficulties in attaining proper radiometric measurements.

6. **EVALUATION**.

a. Basic measurements may be performed using a calibrated broad-band radiometer with an actinic probe. The probe should be able to measure in the 200-315 nm range and have a response that accounts for the wavelength dependence of Figure 11-1 or Table 11-2.

b. Some probes may respond to wavelengths outside the UV range of interest (such as UVA and visible light), therefore, it is necessary to quantify or remove this contribution to the reading. This may be done by making measurements of the UV source using a blocking filter which absorbs the UV radiation below 315 nm, zeroing the meter, and then making the same measurement without the filter. This must be done for each measurement of a UV source under study. Some manufacturers state this is not necessary with their instrument because selective filtering is inherent with the probe. Contact the instrument manufacturer for specific details on this issue. It must be noted that the spectral range of the instrument is limited by the detector chosen.

c. Probe placement is important during measurements. The probe should represent the position of the critical areas (i.e. eyes and exposed skin) of the personnel in the occupational setting. Consideration should also be made for possible reflective surfaces contributing to the exposure of personnel (e.g., ceilings, polished table tops, etc.).

d. The number of readings depends on the size and number of the UV sources, occupiable areas and the workspace. Measurements may be taken to assess potential hazards during maintenance activities (such as close proximity to the source) not normally performed or conducted by the workspace occupants.

e. Attempts should be made to determine how long an individual is required to work in a given area when performing their duties. Such information is necessary to apply administrative controls and to compare the measurements with the limits of Table 11-3.

f. Allowable exposure durations at multiple work locations must be considered in determining the combined exposure level. The exposure at each work location are summed to obtain the combined exposure level, as follows:

$$\text{Combined Exposure Level} = \frac{T_1}{C_1} + \frac{T_2}{C_2} + \ldots + \frac{T_n}{C_n}$$

Equation 11-2

Where:

T_i = Total time spent at work station i
C_i = Allowable exposure duration at work station i

Any combined exposure level value greater than one would exceed the limits.

g. Steady state measurements can be made using the instrument’s “normal” mode. Average measurements can be taken on modulated or flickering light sources if the meter has the capability to measure with a fast function position. Meters with an integrating mode can measure flash exposures. Always consult the manual for the ability of the instrument to measure non-steady light (i.e., flickering or varying intensity light).

7. **EXPOSURE CONTROL**.

a. Control measures may be broken down into three areas: engineering, administrative controls and personal protection.

(1) Effective engineering controls may involve placing the light source or process within an opaque enclosure or providing a barrier where the UV output in habitable areas is below the exposure limits. This must be done without interfering with the operation. Devices such as key controls and cover interlocks are other examples of engineering controls. Shields or physical barriers may control exposure to individuals or prevent unsafe acts from occurring.

(2) Administrative controls consist of establishing standard operating procedures (SOPs) for the process, education and training of the user, maintenance and servicing training, warning signs such as Figure 11-2 and entry limitations. Limiting the access of personnel to exposure situations constitutes administrative control. However, reliable measurement data should be available to support this type of control decision.

(3) Personal Protective Equipment (PPE) is the least desirable control method, but may be applicable depending on the process. PPE may consist of eyewear, gloves or other apparel to protect the skin or eyes. The clothing (hoods, shirts etc.) should be opaque to the UV wavelengths encountered. UV absorbing eyewear should be fitted with UV absorbing side shields to minimize the likelihood of reflections hitting the eye.

(a) Protective eyewear is usually designed to greatly reduce or prevent particular wavelengths from reaching the eye. This information must be specified when purchasing such equipment. Optical density is the variable for determining the attenuation of the eyewear.

(b) Optical density (OD) is a logarithmic function of the incident radiation vice the transmitted radiation:

$$\mathrm{OD} = \log_{10}\left(\frac{E_o}{E}\right)$$

Equation 11-3

Where:

E_O = irradiance of the incident UV radiation
E = irradiance of the transmitted UV radiation

(c) Other considerations may be necessary when choosing eye protection. For example, in the protection from intense visible light with UV components (such as welding arcs), the eye protection also needs to be weighted to filter the blue light hazards.

(d) Topical screening materials have been developed that can provide partial or sometimes total protection of the skin to UV radiation. Most screening materials concentrate on filtering the actinic UV wavelengths. These are known as "sunscreens." Standard commercial sunscreens permit some UVA to be transmitted. Although less efficient than UVB, it can contribute to skin erythema.

(e) Normal work clothing provides adequate attenuation of UV radiation (OD > 4) produced by common welding operations. However, some man-made lightweight fabrics, such as nylon, may transmit significant amounts of UV. Welders should be instructed in the importance of wearing appropriate dense clothing. Long sleeve shirts and gloves which cover exposed skin are clearly indicated.

b. UV reflectance from aluminized fabrics may present an additional hazard. Such material should be avoided in the welding environment.

c. Hazard control methods must be chosen to reduce the risk sufficiently. Even though a method is used to adequately control the hazard, contingency methods (secondary interlocks) must always be available for possible circumventions of the establish methods.

8. **SPECIFIC SITUATIONS**.

a. General.

(1) High intensity discharge (HID) lamps (specifically the ones using mercury) are used in gymnasiums or high ceiling industrial areas. These may produce considerable UV radiation. Stringent manufacturing standards exist to assure that an outer jacket is installed to reduce the risk of UV radiation exposure. Most lamps are constructed to extinguish if the outer jacket is broken. Lamps not having this feature will have a warning

designating the potential for exposure. Maintenance personnel must be aware of the potential for UV exposure on these types of lamps if they operate with the outer jacket broken. A standard operating procedure (SOP) should be in place and followed by maintenance personnel during the replacement of HID lamps.

(2) Selection of paints in the work area can enhance or reduce the UV reflection to personnel. Check with the paint manufacturer for UV absorptive paints.

(3) For most applications, any plastic barrier face shield or goggle will be effective to protect occupants from UV exposures from these sources. This is because the manufacturers of these products add a UV absorbent to deter aging of the plastics. In situations where any measurable level is considered unacceptable, the spectral transmission of these materials should be checked.

(4) Interlocks should be installed where personnel have access to UV sources during maintenance. Appropriate labeling is necessary to assure that users are adequately informed.

b. Clinical.

(1) Low pressure mercury lamps are commonly used for germicidal control in hospitals, and biological laboratory hoods. In most cases, these lamps are housed in fixtures but may not always limit direct exposure to eyes or skin of personnel.

(2) Phototherapy and sun lamps are used by physicians to treat various conditions such as psoriasis. The physician should be well aware of the dangers of excessive exposure and assure that such devices are controlled. Ventilation openings may allow reflections from the source to exit the enclosure.

(3) Because of the potential exposure to individuals of high levels of UV radiation, therapy and sun lamps must be controlled and properly used. SOPs are essential and only personnel familiar with the potential dangers and control measures should operate the units. They should only be operated in designated areas which limit direct or reflected viewing bypersonnel not essential to their operation. Operators should utilize protective equipment such as shaded glasses and long sleeved shirts to lessen the risk of UV radiation exposure.

(4) Operating room lamps found in hospitals or dental operatories are designed to reduce the infrared loading to the patient and focus the visible light radiation. The glass over the surgical spotlight filters out UVB and UVC radiations.

(5) The phototherapy units for newborn infants who have hyperbilirubinemia use special blue lights. In addition to a potential blue light hazard (not covered in this chapter), the lamps may produce UV radiation. It is important that plastic or glass filters be used to protect the infant from UVB radiation. The nursing staff should not be at risk from these devices, however, the lamp should not be stared at directly. Operators should ensure the plastic or glass filter remains in place and that labels are in place to alert personnel to potential hazardous emissions.

c. "Black lights."

(1) "Black lights" are often used along with fluorescent powder for non-destructive test procedures. These lamps normally produce wavelengths in the UVA range. These lamps are normally not a problem unless the lamp envelope itself does not sufficiently filter out the actinic UV lines of the mercury spectrum (297, 303, 313 nm). Also, any individual who is photosensitive (such as the result of taking medication) may elicit a severe response when using such equipment.

(2) Some "black light" units have a mode to specifically produce UVC or UVB radiation. Such units should be evaluated or reference data from the manufacturer consulted to address potential hazards to personnel.

(3) Control methods include positioning the lights so that individuals are not chronically exposed. The lamps should also be used only in designated areas, free from reflective surfaces. Protective eyewear and long sleeve shirts or gloves may be necessary (see Hazard Assessment).

d. Curing operations. UV curing (photochemical curing) of special paints or plastic cast materials is sometimes used. One application is UVA curing of dental resins. Most systems are enclosed and when properly designed, have interlock systems and do not release the UV radiation to the workspace. Warning labels should be present however to adequately alert personnel of potential exposure.

e. Graphic arts and duplicating machines.

(1) In graphic art facilities, arc lamps or tungsten halogen lamps are used to make negatives and photo offset press plates. The glass platens will usually eliminate UVB or UVC radiations from the lamp. However, the units should be located away from traffic areas and employees should be cautioned to avoid staring at the exposed lamps. Most flip top platemakers reduce glare and eliminate safety concerns but the operator

should not stand over the slit that exists on the top of these units. It may be advisable to utilize UV filtration glasses if the operator must stand over the unit when it is in use.

(2) Photocopying machines that are often found in offices and print shops contain light sources that may produce UV radiation. The glass platen will almost always remove the UVB and UVC radiation. Operators are still cautioned not to stare into the light source when document covers are opened/removed. Manufacturers' light source emission data should be consulted on graphic arts and duplicating machines to assess hazard risks to maintenance personnel when the normal safety barriers are violated.

(3) Some selected sources of UV are provided as examples in Table 11-4. The irradiance values are provided as a relative indication of the hazard potential of the source. These values may vary considerably. The values also do not account for potential blue light hazards.

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Table 11-1. Electromagnetic Spectrum in Frequency and Equivalent Wavelengths.

Frequency (Hz)	Wavelength (meters)	Notes
10^0 (1 Hz)	3×10^8	
10^1	3×10^7	
10^2	3×10^6	Commercial Electrical Power
10^3 (1 KHz)	3×10^5	
10^4	3×10^4	
10^5	3×10^3 (3 Km)	
10^6 (1 MHz)	3×10^2	AM Broadcast (535-1600 KHz)
10^7	3×10^1	
10^8	3×10^0 (3 m)	FM Broadcast
10^9 (1 GHz)	3×10^{-1}	
10^{10}	3×10^{-2} (3 cm)	
10^{11}	3×10^{-3} (3 mm)	
10^{12}	3×10^{-4}	
10^{13}	3×10^{-5}	Infrared
10^{14}	3×10^{-6} (3 μm)	
10^{15}	3×10^{-7}	Visible Light
10^{16}	3×10^{-8}	
10^{17}	3×10^{-9} (3 nm)	Ultraviolet
10^{18}	3×10^{-10}	
10^{19}	3×10^{-11}	X rays
10^{20}	3×10^{-12} (3pm)	↓

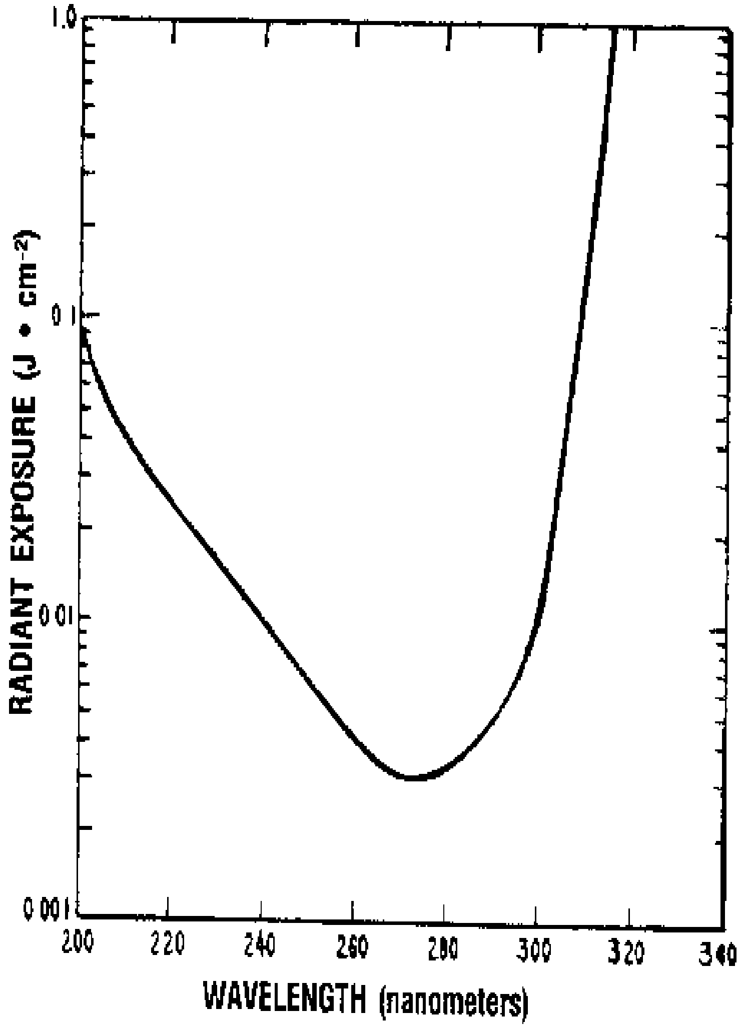

Figure 11-1. Action spectrum curve. (From American Conference of Governmental Industrial Hygienists (ACGIH), 1997, Reproduced with permission).

CAUTION

EYE HAZARD

Do Not Stare Into Light

OR

CAUTION

ULTRAVIOLET SOURCE

Eye and Skin Hazard

Authorized Operators Only

Figure 11-2. Sample warning signs

Table 11-2. Ultraviolet Radiation Exposure TLV and Spectral Weighting Function.

Wavelength (nm)	TLV (J/m^2)	TLV (mJ/cm^2)	Relative Spectral Effectiveness, S
180	2.5×10^3	2.5×10^2	0.012
190	1.6×10^3	1.6×10^2	0.019
200	1.0×10^3	1.0×10^2	0.030
205	5.9×10^2	5.9×10^1	0.051
210	4.0×10^2	4.0×10^1	0.075
215	3.2×10^2	3.2×10^1	0.095
220	2.5×10^2	2.5×10^1	0.120
225	2.0×10^2	2.0×10^1	0.150
230	1.6×10^2	1.6×10^1	0.190
235	1.3×10^2	1.3×10^1	0.240
240	1.0×10^2	1.0×10^1	0.300
245	8.3×10^1	8.3	0.360
250	7.0×10^1	7.0	0.430
254*	6.0×10^1	6.0	0.500
255	5.8×10^1	5.8	0.520
260	4.6×10^1	4.6	0.650
265	3.7×10^1	3.7	0.810
270	3.0×10^1	3.0	1.000
275	3.1×10^1	3.1	0.960
280*	3.4×10^1	3.4	0.880
285	3.9×10^1	3.9	0.770
290	4.7×10^1	4.7	0.640
295	5.6×10^1	5.6	0.540
297*	6.5×10^1	6.5	0.460
300	1.0×10^2	1.0×10^1	0.300
303*	2.5×10^2	2.5×10^1	0.120
305	5.0×10^2	5.0×10^1	0.060
308	1.2×10^3	1.2×10^2	0.026
310	2.0×10^3	2.0×10^2	0.015
313*	5.0×10^3	5.0×10^2	0.006
315	1.0×10^4	1.0×10^3	0.003
316	1.3×10^4	1.3×10^3	0.0024
317	0.5×10^4	1.5×10^3	0.0020
318	1.9×10^4	1.9×10^3	0.0016
319	2.5×10^4	2.5×10^3	0.0012
320	2.9×10^4	2.9×10^3	0.0010
322	4.5×10^4	4.5×10^3	0.00067
323	5.6×10^4	5.6×10^3	0.00054
325	6.0×10^4	6.0×10^3	0.00050
328	6.8×10^4	6.8×10^3	0.00044
330	7.3×10^4	7.3×10^3	0.00041
333	8.1×10^4	8.1×10^3	0.00037
335	8.8×10^4	8.8×10^3	0.00034
340	1.1×10^5	1.1×10^4	0.00028
345	1.3×10^5	1.3×10^4	0.00024
350	1.5×10^5	1.5×10^4	0.00020
355	1.9×10^5	1.9×10^4	0.00016
360	2.3×10^5	2.3×10^4	0.00013
365*	2.7×10^5	2.7×10^4	0.00011
370	3.2×10^5	3.2×10^4	0.000093
375	3.9×10^5	3.9×10^4	0.000077
380	4.7×10^5	4.7×10^4	0.000064
385	5.7×10^5	5.7×10^4	0.000053
390	6.8×10^5	6.8×10^4	0.000044
395	8.3×10^5	8.3×10^4	0.000036
400	1.0×10^6	1.0×10^5	0.000030

Source: American Conference of Governmental Industrial Hygienists (ACGIH) (1997). Reproduced with permission.

Wavelengths chosen are representative; other values can be interpolated.
* Emission lines of a mercury discharge spectrum.

Table 11-3. Permissible Ultraviolet Exposures.

Duration of Exposure Per Day	Effective Irradiance E_{eff} ($\mu W/cm^2$)
8 hours	0.1
4 hours	0.2
2 hours	0.4
1 hour	0.8
30 minutes	1.7
15 minutes	3.3
10 minutes	5
5 minutes	10
1 minute	50
30 seconds	100
10 seconds	300
1 second	3,000
0.5 second	6,000
0.1 second	30,000

Source: American Conference of Governmental Industrial Hygienists (ACGIH) (1997). Reproduced with permission.

Table 11-4. Selected Sources of Ultraviolet Radiation (does not account for potential blue light hazards).

Source	Conditions	Measured Levels[1]
Welding: GMAW	Al alloys at 1 m	0.18 - 3.7 mW/cm^2
GTAW	Al alloys	7.2 - 41 μW/cm^2
GTAW	Steel	0.1 mW/cm^2
SMAW	Steel	0.11 mW/cm^2
Hg-vapor Lamp	400 W, medium pressure, at 50 cm	1.0 μW/cm^2
	Germicidal	0.01 - 0.19 μW/cm^2
Photoflood Lamps		<0.01 - 6.9 μW/cm^2
Black Light	F4T5/BLB UV-B at 1.5 cm UV-A	0.13 μW/cm^2 3.7 mW/cm^2
Tanning	Fluorescent	0.16 - 1.6 mW/cm^2
Studio Lamps	Quartz Halogen at 50 cm FCV 1000W	2.6 - 3.4 μW/cm^2
	Quartz Halogen at 50 cm EHC/EHB/EGR 500W	1.7 - 5.7 μW/cm^2
Movie Lamp	With Reflector - FAE 550W at 100 cm	0.03 - 0.06 μW/cm^2
Photocopier Lamps	Q100073/CL at 100 cm Quartz Halogen 1000W	0.6 - 0.8 μW/cm^2
	BRH 1000W at 50 cm	7.7 - 8.5 μW/cm^2
Incandescent	Quartz-Tungsten Halide DXW 1000W at 50 cm	2.1 μW/cm^2
Sunlamp	Sylvania RSM 275W at 50 cm	510 μW/cm^2
Fluorescent Lamp	Cool White F40CW, Royal White F403K at 50 cm	0.14 μW/cm^2
	F48T12-CW-HO, F84T12-CW-HO, F96PG17-CW, 96T12UHO, F40CW/RS/WM at 100 cm general lighting use	<0.026 μW/cm^2
Xenon Short-Arc	Hanovia 976C1 at 50 cm	680 μW/cm^2
Medium Pressure Clear Jacket Mercury	400W at 50 cm	1 μW/cm^2

[1] These values may vary considerably. They are provided only as relative indicators of the source of UV radiation.