CHAPTER 21

NONIONIZING RADIATION

21-1 THE ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation is arranged in a spectrum of wavelengths; see Figure 21-1. Wavelengths range from long (3×10^8 m) and very low frequency (1 Hz) to short (3×10^{-15} m) and very high frequency (10^{23} Hz). The spectrum is divided into several bands: gamma rays, x-rays, ultraviolet, visible, infrared, microwave, television, and radio waves, induction heating, and power waves.

There are many sources of radiant energy. Some, like the sun and fires, are natural sources. Others, like microwaves, radio transmission, atomic reactors, lamps, and lasers, are manufactured sources. Some sources have energy levels high enough to ionize atoms or molecules or break the bond of molecular elements. Approximately 10 to 12 eV or more are needed to break these bonds. Because photon energies of electromagnetic radiation are proportional to radiation frequency and inversely proportional to wavelength, wavelengths in the lower portion of the spectrum generally are below this minimum energy level.

Some effects of electromagnetic waves that are dependent on frequency include visibility, penetration, and heating of materials, including human tissue. Some properties apply across the spectrum; for example, energy from a radiation source diminishes as a function of the distance squared (refer to Chapter 22).

Although energy levels for nonionizing radiation do not affect molecular structure, nonionizing radiation can affect biological tissue by changing energy levels in tissue molecules, often producing heat. Heat most easily affects certain tissue, like that of the eye, because the eye has little blood circulation and little ability to remove heat through blood movement. Tissue absorbs some wavelengths, but for other wavelengths, tissue is essentially transparent. The depth of penetration for absorbed wavelengths varies as well. Figure 21-2 illustrates the general absorption properties of the eye for electromagnetic radiation.

Because of the increase in radiation in products and equipment, Congress enacted legislation to control radiation emissions.[1] Today, several government standards (OSHA, Consumer Products Safety Commission [CPSC], and the Food and Drug Administration [FDA]) and consensus standards apply to equipment, exposures, and measurement.

21-2 MICROWAVES

Microwaves have wavelengths from approximately 1 mm to 10 m and frequencies from approximately 30 MHz to 300 GHz. Microwaves are used in communications, navigation, medical diathermy, microwave ovens, in drying equipment, and other applications. A variety of devices produce microwaves.

Safety and Health for Engineers, Second Edition, by Roger L. Brauer

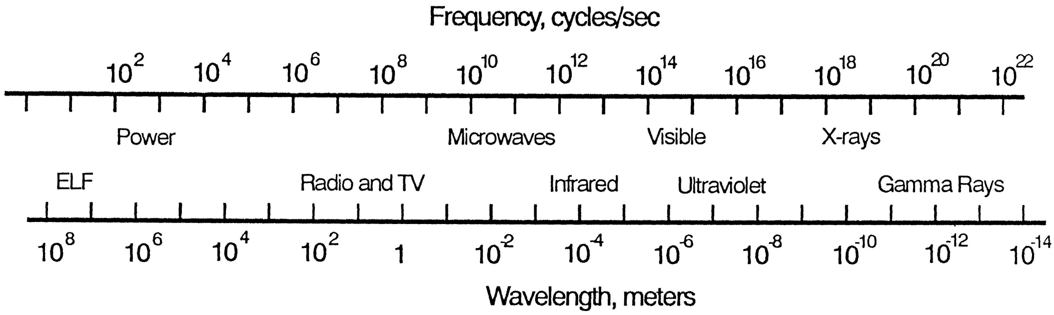

Figure 21-1. Electromagnetic spectrum.

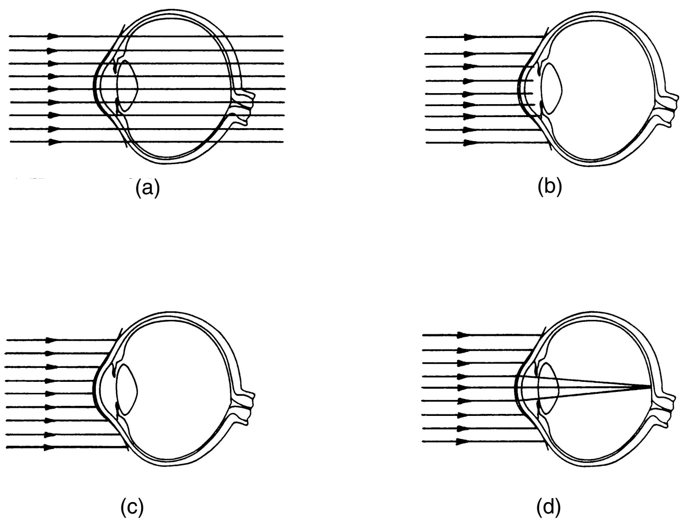

Figure 21-2. General absorption properties of the eye for electromagnetic radiation. (a) X-ray and gamma ray. (b) Ultraviolet A. (c) Ultraviolet Band C and infrared Band C. (d) Visible and infrared A.

Hazards

Microwaves less than 3 cm are absorbed in the outer skin, 3 to 10 cm wavelengths penetrate from 1 mm to 1 cm into the skin, and 25 to 200 cm wavelengths penetrate to deeper tissue and organs. Human tissue is essentially transparent to microwaves with wavelengths of more than 200 cm.

Absorbed microwave radiation is primarily converted to heat. Tissue and body temperatures rise, depending on exposure and location exposed. Temperature increases in deeper tissue may cause damage before one senses heating. Absorption by other materials also will produce heating, possibly raising temperatures high enough to be a hazard.

Because people may come into contact with microwave equipment and to avoid electric shock and burn hazards, grounding is essential, particularly if power densities are near acceptable limits. Objects near power sources, such as fences and vehicles, also must be grounded because they may couple to radio frequencies.

The greatest danger from microwaves is to the eyes, where microwaves seem to have a cumulative effect on the lens of the eyes, ultimately producing cataracts. The onset of cataracts depends on frequency, power density, duration of exposure, and intervals between exposures. There is some evidence that microwaves also affect the central nervous system in various ways. They also affect the performance of some types of cardiac pacemakers.

For a time, a beneficial use of microwaves on humans was diathermy. Diathermy is a therapeutic means of generating heat in body tissues. Localized application of levels up to 100 mW/cm^2 helped promote healing in joints, tendons, muscle, and other tissue. Diathermy devices operate in shortwave radio frequencies and ultrasonic frequencies in addition to microwave frequencies. If not applied carefully for limited times, the treatment can burn skin and injure deeper tissues. In addition, diathermy can cause severe injury or even death when used on patients with implanted leads or other objects or devices.

Controls

One control to prevent microwave injury is limiting exposure. This is accomplished by limiting the intensity of microwaves (the frequency or wavelength one is exposed to) or limiting the duration of exposure. Distance from a source and shielding also can control intensity of exposure. Table 21-1 lists attenuation of various shielding materials. Before implementing controls, one must determine what potential exposures exist through analysis, measurements, or both. These are compared with exposure standards to determine if controls are needed.

Other controls are signs to warn about radiation hazards or dangers (see ANSI C95 for details), special protective clothing that uses metallized fabric to provide some shielding, and protective eyewear that has a closely woven screen for shielding. Workers should handle equipment near microwave sources with insulated gloves to minimize shock and burn hazards.

High-power microwave equipment must be grounded to reduce electrical hazards. Access to hazardous microwave locations can be protected by interlocks on doors and regular inspections, and testing ensures that the interlocks are working. During servicing of microwave equipment, lockout and tagout procedures are important.

Standards

Microwave exposure standards appear in several publications. One source is OSHA standards,[2] which limit power density to 10 mW/cm^2 for exposure periods of 0.1 hr or more. For exposures shorter than 0.1 hr, energy density is limited to 1 mW-hr/cm^2, with limited excursions higher than 10 mW/cm^2.

TABLE 21-1 Microwave Shielding Attenuation Factors

	Frequency (GHz)			
Material	1–3	3–5	5–7	7–10
60 × 60 mesh screening	0.01	0.003	0.006	0.01
32 × 32 mesh screening	0.016	0.006	0.006	0.016
16 × 16 window screening	0.016	0.01	0.01	0.006
1/4-in mesh (hardware cloth)	0.016	0.032	0.06	0.1
Window glass	0.63	0.63	0.50	0.45
3/4-in pine sheathing	0.63	0.63	0.63	0.45
8-in concrete block	0.01	0.006	0.006	0.001

TABLE 21-2 Electromagnetic Field[a] Radio Frequency and Microwave Threshold Limit Values[b,c]

Frequency	Power Density (mW/cm^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Averaging Time E^2, H^2, or S (min)
30 kHz–100 kHz	614	163	6	
100 kHz–3 MHz	614	16.3/f	6	
3 MHz–30 MHz	1,842/f	16.3/f	6	
30 MHz–100 MHz		61.4	16.3/f	6
100 MHz–300 MHz	1	61.4	0.163	6
300 MHz–3 GHz	f/300			6
3 GHz–15 GHz	10			6
15 GHz–300 GHz	10			$616{,}000/f^{1.2}$

[a] The exposure values in terms of electric and magnetic field strengths are obtained by spatially averaging over an area equivalent to the vertical cross section of the human body (projected area).
[b] f = frequency in MHz.
[c] *2004 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH. (Note: This publication is updated annually and standards may change. Refer to the current edition for additional details.)

The American Conference of Governmental Industrial Hygienists (ACGIH) publishes exposure limits based on power density, electric field strength, and magnetic field strength for particular frequency bandwidths.[3] This standard includes radio and microwave frequencies. Table 21-2 lists the ACGIH threshold limit values (TLVs), which should be used as guides in the evaluation and control of exposure to radio frequency and microwave radiation and should not be regarded as a fine line between safe and dangerous levels. Radio frequency radiation exposures should be kept as low as reasonably possible.

The FDA sets standards for microwave ovens (21 CFR 1030.10). Included in the standard is a limit for the amount of microwaves that can leak from an oven throughout its lifetime. The limit is 5 mW/cm^2 at approximately 2 in from the oven surface.

Measurement

One can measure microwaves with thermal or electrical detector instruments. Thermal detectors assess temperature rise in a material, whereas electrical detectors convert microwaves into direct current. Instruments are usually factory calibrated to particular microwave frequencies and intensities.

21-3 ULTRAVIOLET RADIATION

Ultraviolet (UV) radiation of significance to safety falls in the region between 200 and 400 nm. In this region, photon energy levels range from 4.4 to 3.1 eV. Air, water, and window glass are transparent for wavelengths in the 300- to 400-nm range, and ordinary window glass and skin absorb wavelengths from 200 to 320 nm. The ozone layer absorbs much of the UV energy from the sun in the wavelengths less than 290 nm, and although UV wavelengths extend below 200 nm, these wavelengths are poorly transmitted or fully absorbed in air.

One classification scheme for UV radiation has three spectral bands:

1. UV-A or near UV includes wavelengths from 315 to 400 nm
2. UV-B extends from 280 to 315 nm
3. UV-C extends from 200 to 280 nm

Wavelengths from 200 to 315 nm are of greatest concern in safety and health. This band is called the actinic UV region.

The sun is the most notable source of UV radiation. Other sources include heliarc welding, mercury and xenon discharge lamps, certain lasers, and full-spectrum fluorescent lamps.

Hazards

One hazard of UV exposure is skin burns or erythema (reddening). With extended exposure, blistering can occur. Skin does not absorb all UV wavelengths the same, and the erythemal effects vary across the absorbed spectrum. Wavelengths less than 280 nm are absorbed in the most outer layer of the skin (stratum corneum of the epidermis), wavelengths between 280 and 320 nm are absorbed in deeper layers of the skin (dermis), and those between 320 and 380 nm are absorbed in the outer layer of the skin (epidermis). Thus, exposures to wavelengths at or near 300 nm are most likely to produce erythema. Erythema has a latent period of 2 hr or more, depending on the degree of UV exposure. Some people expose themselves to UV to get a "tan." Such exposures cause the pigment in the skin (melanin granules) to migrate toward the surface (tanning). The likelihood of erythema is reduced with increased natural or conditioned (tanned) levels of pigmentation.

Other hazards of extended UV exposure are skin cancer and skin aging (photoaging). Skin cancer is more prevalent among people who spend considerable time in sunlight and it occurs more readily among those who have little skin pigment. People with a history of severe UV burns, particularly if severe burns occur in childhood (young skin), have a higher incidence of skin cancer, as do people with occupations requiring extensive work in sunlight and those who live in sunny regions.

Another hazard of UV exposure is keratitis—inflammation of the cornea of the eye. As noted in Figure 21-2(b), UV in the 280- to 400-nm range and some UV in the 200- to 280-nm range is absorbed by the cornea. The threshold for injury is greatest at or near 280 nm. Initially, one has a sensation of sand in the eyes. In addition, the eyes may water and the eyelids may swell shut.

Controls

The primary controls for UV exposures are limiting exposure, particularly to most harmful wavelengths, and using absorbing materials. In some cases, it may be possible to limit the UV energy at the source.

Length of Exposure Limiting exposures to UV prevents erythema or keratitis. The duration depends on the intensity of UV irradiation. Limiting extended exposures seems to reduce the likelihood of skin cancer. However, there are other factors involved in skin cancer risks.

Selective Wavelengths All UV wavelengths can produce harm. However, the effects that are most likely to appear differ according to wavelength. Controlling exposure to the most harmful wavelengths can help reduce risks of skin burns and cancer. For example, informed selection of UV lamps, which differ in wavelengths emitted, will lessen risks. Similarly, protective coating for the skin, such as suntan lotions and creams, may filter certain wavelengths. They have a sun protective factor rating that rates filtering of UV rays in general. The ratings of products range from zero to more than 40. Some filtering ingredients are more effective than others, because each ingredient protects for different wavelengths.

Absorption of Ultraviolet Wavelengths It is quite easy to shield the skin and eyes from UV exposure. Shielding limits the energy level reaching the eyes or skin. Because UV radiation is readily absorbed by many materials, one should select those that eliminate or minimize harmful UV exposures. Tanning lotions have a sunscreen index and sunglasses have a UV absorption index, both of which indicate degrees of shielding. Workers, such as welders and other who may be exposed to high levels of UV, must wear appropriate eye and skin protection (see Chapter 28 on personal protective clothing). High-intensity mercury vapor discharge lamps have an outer protective glass envelope that absorbs UV wavelengths less than 320 nm. Protective eyewear must accompany sunlamp use.

Standards

There are several standards on UV exposures. The American Conference of Government Industrial Hygienists (ACGIH) maintains exposure standards based on wavelength, exposure time, and irradiance.[4] Table 21-3 lists the ACGIH TLVs. The FDA regulates sunlamp and UV lamps (21 CFR 1040.20) and high-intensity mercury vapor discharge lamps (21 CFR 1040.30).

Measurement

There is a variety of UV detection devices. They convert radiation arriving at a sensing device or medium to some form of display. Conversion methods include electrical (photovoltaic cells and phototubes), thermal (thermopile), and chemical (photographic plates). For most devices, selective filters determine what wavelengths arrive at the sensor.

21-4 INFRARED RADIATION

Infrared radiation has wavelengths from 700 nm to 1 mm and is characterized by smaller bands. IR-A (near infrared) is the spectral region from 701 to 1400 nm. IR-B includes wavelengths from 1.4 to 100 μm. The IR-C spectrum is 0.1 to 1 mm. Most radiative heat transfer involves the infrared region. Sources of infrared typically are sources of radiative heat, including fires and open flames, stoves, electrical heating elements, certain lasers, and many other sources.

Hazards

Near infrared radiation (700–1400 nm) passes through the lens of the eye to the retina or is refracted from other tissues (see Figure 21-2(d)). High energy levels can cause a variety of eye disorders, among which is scotoma. Scotoma is loss of vision in a portion of the visual field resulting from damage to the retina where radiation is absorbed. Other disorders range from simple reddening from low-level exposures to swelling of the eye, hemorrhaging, and lesions. Extended exposures to infrared radiation can cause cataracts.

TABLE 21-3 Sample Exposure Limits for Ultraviolet Radiation on Unprotected Skin and Eyes[a]

Wavelengths (nm)	TLV (J/m^2)	Relative Spectral Effectiveness S_λ
180	2,500	0.012
190	1,600	0.019
200	1,000	0.030
210	400	0.075
220	250	0.120
230	160	0.190
240	100	0.300
250	70	0.430
260	46	0.650
270	30	1.000
280	34	0.880
290	47	0.640
300	100	0.300
310	2,000	0.015
320	2.9×10^4	0.010
330	7.3×10^4	0.00041
340	1.1×10^5	0.00028
350	1.5×10^5	0.00020
360	2.3×10^5	0.00013
370	3.2×10^5	0.000093
380	4.7×10^5	0.000064
390	6.8×10^5	0.000044
400	1.0×10^6	0.000030

Note: for t_{max} = maximum exposure time in seconds = $0.003/E_{eff}$,
where $E_{eff} = \Sigma E_\lambda S_\lambda \Delta_\lambda$ and E_{eff} = effective irradiance relative to a monochromatic source at 270 nm in watts per centimeter squared.
E_λ = spectral irradiance in watts per centimeter squared per nanometer,
S_λ = relative spectral effectiveness (unitless), and
Δ_λ = band width in nanometers.
[a] *2004 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH. (Note: This publication is updated annually and standards may change. Refer to the current version for additional details.)

Common examples are glassblower's and bottlemaker's cataracts that result from looking into fire and heat sources. Iron workers who peer into furnaces extensively have a high incidence of cataracts.

High levels of infrared heat also can cause ignition of materials and fire. Refer to chapter 16.

Controls

To limit the danger from infrared radiation, limit the duration of exposure and the intensity of exposure. Because the danger is mainly to the retina of the eye, looking into infrared sources should be avoided. The intensity of exposure is most easily reduced by shielding. Eyewear that absorbs and reduces the amount of infrared reaching the eye should be worn. Lenses in glasses, goggles, or faceshields must have the correct shade to reduce harmful levels (see Chapter 28).

21-5 HIGH-INTENSITY VISIBLE LIGHT

Visible light occurs in the region from 380 (violet) through 750 nm (red). It passes through the cornea and lens and is focused on the retina (see Figure 21-2(d)). There are many sources of visible light, including natural light from the sun and artificial light sources. Most objects we see are reflected light.

Hazards

If energy levels for visible light are too high, they can cause injury to the eyes. Injury may involve the retina and other parts of the eye. Sources of high-intensity visible light are welding, carbon arc lamps, and some lasers.

Controls

Controls include enclosing the source, limiting source intensity, and shielding or filtering the source from the eyes. For example, portable panels screen welding operations so that the bright source does not reach people. Welders should wear protective eyewear with the applicable filter density for the type of operation (see Chapter 28). Carbon arc lamps are enclosed except for the aperture to direct the light where it is needed. Lasers with dangerous levels of visible light also have enclosures.

21-6 LASERS

The word *laser* is an acronym for light amplification by stimulated emission of radiation. A laser is a source of intense, coherent, and directional optical radiation. Lasers are usually composed of an energy source, a resonant cavity, and an active lasing medium. A laser system is an assembly of electrical, mechanical, and optical components that includes a laser.

Lasers and laser systems are becoming quite common in today's high-technology society. There are lasers for welding and machining and there are lasers for accurate measurement of distance and alignment of equipment. Lasers are used in mining and stress analysis and in holographic devices at grocery checkouts, and they have many medical applications. There are laser pointers for lectures and presentation. The military uses lasers in weapon systems to measure distance to targets or in guidance.

Hazards

Some lasers are dangerous, whereas others are not. The hazard depends on intensity and wavelength of light beams, duration of exposure, means of exposure, and the part of the body exposed.

Materials exposed to laser radiation can burn if energy levels are high enough and heat builds up sufficiently to start combustion. Lasers can cut or remove materials. Controlled local heating with laser beams in certain liquids causes the material to change state. Some machines apply this principle to create prototype plastic parts. In medical applications, lasers remove unwanted tissue or cut tissue.

The effects of lasers on people are essentially the same as for visible, ultraviolet, and infrared radiation. Lasers fall in these bands of wavelengths. Like other nonionizing radiation, the greatest danger is to the eye. Dependent on wavelength and the location where energy is absorbed, damage may be to the cornea, lens, retina, or other parts of the eye (refer to Figure 21-2). Dangers are greatest when a beam is viewed directly and may be reduced when a beam is reflected. As illustrated in Figure 21-3, properties of the reflecting surface may keep the beam essentially intact (specular reflection) or scatter the light (diffuse reflection). A polished, flat surface (like a mirror or window glass) reflects a beam with minimal absorption and little diffusion and poses the greatest reflected danger.

Damage ranging from erythema (reddening) to blistering and charring also may be inflicted on the skin. Compared with the region from 315 nm to 1 mm, effects to the skin are somewhat reduced in the 200 to 315 nm region.

A classification system for laser hazards divides lasers into five categories. Table 21-4 details this classification scheme.

Controls

The controls required depend on the class of laser. Where protection is heeded, controls may include enclosure of the laser source, control of potentially reflective surfaces, inter-

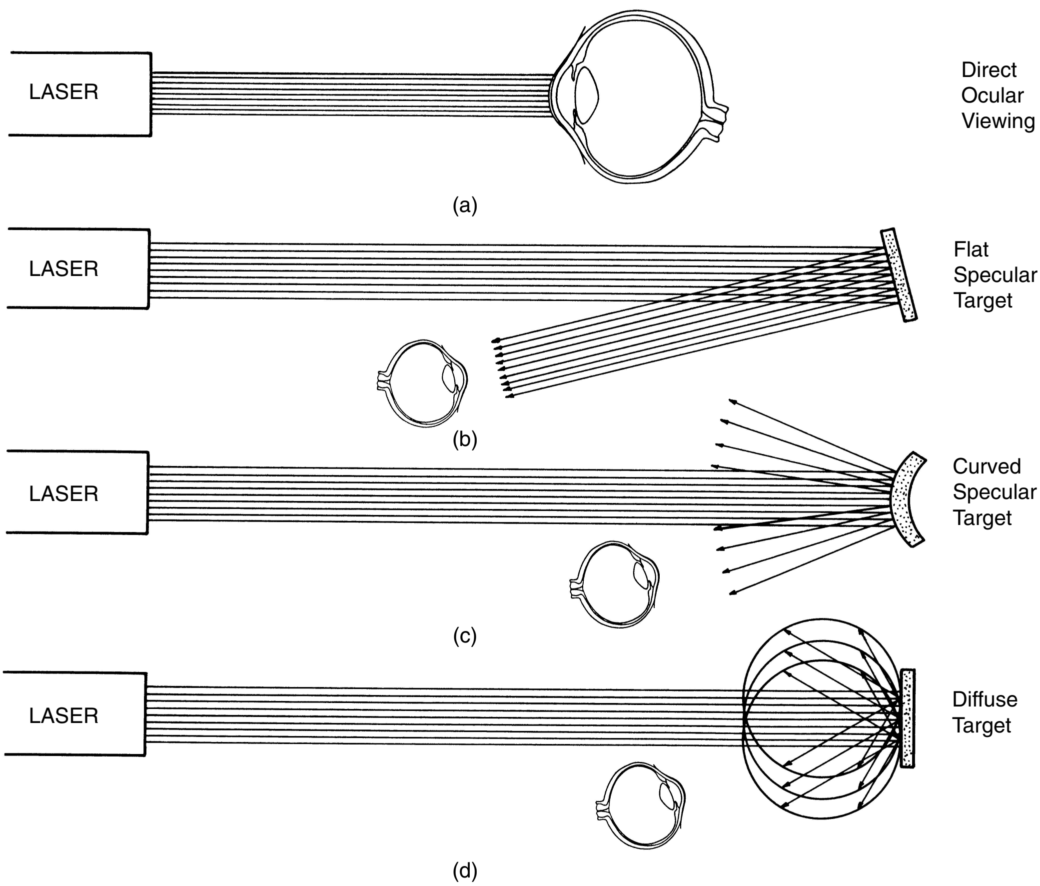

Figure 21-3. Laser radiation may be viewed directly (a) or reflected (b–d); (b) flat specular reflection; (c) curved specular reflection; (d) diffuse reflection.

TABLE 21-4 Laser Device Hazard Classification Definitions[a]

Category	Definition
Class 1	Any laser device that cannot emit laser radiation levels in (exempt) excess of the AEL for the maximum possible duration inherent to the design of the laser or laser system. The exemption from hazard controls strictly applies to emitted laser radiation hazards and not to other potential hazards.
Class 2	Visible (400–700 nm) CW laser device that can emit a power exceeding the AEL far Class 1 for the maximum possible duration inherent to the design of the laser or laser system but not exceeding 1 mW. Visible (400–700 nm) repetitively pulsed laser devices that can emit a power exceeding the appropriate AEL for Class 1 for the maximum possible duration inherent to the design of the laser device but not exceeding the AEL for a 0.25-s exposure.
Class 2a	A visible (400–700 nm) laser or laser system that is not intended for intrabeam viewing and does not exceed the exposure limit for 1,000 s of viewing time.
Class 3a	Lasers or laser systems that have (1) an accessible output power or energy between one and five times the lowest appropriate AEL for Class 2 for visible wavelengths and between one and five times the AEL for Class 1 far all other wavelengths or (2) do not exceed the appropriate exposure levels as measured over the limiting aperture (2.5 mW/cm^2) for visible CW lasers.
Class 3b	(1) *Infrared (1.4 μm–1 mm) and ultraviolet (200–400 nm) laser devices*. Emit a radiant power in excess of the AEL Class 1 for the maximum possible duration inherent to the design of the laser device. Cannot emit an average radiant power of 0.5 W or greater for T_{max} greater than 0.25 s or a radiant exposure of 10 J/cm^2 within an exposure time of 0.25 s or less. (2) *Visible (400–700 nm) CW or repetitive pulsed laser devices*. Produce a radiant power in excess of the AEL Class 1 for a 0.25-s exposure (1 mW for a CW laser). Cannot emit an average radiant power of 0.5 or greater for T_{max} greater than 0.25 s. (3) *Visible and near-infrared (400–1,400 nm) pulsed laser devices.* Emit a radiant energy in excess of the AEL Class 1. Cannot emit a radiant exposure that exceeds that required to produce a hazardous diffuse reflection (refer to standards for precise properties). (4) *Near-infrared (700–1,400 nm) CW laser devices or repetitively pulsed laser devices.* Emit power in excess of the AEL for Class 1 for the maximum duration inherent in the design of the laser device. Cannot emit an average power of 0.5 W or greater for periods in excess of 0.25 s.
Class 4	(1) *Ultraviolet (200–400 nm) and infrared (1.4 μm–1 mm) laser devices*. Emit an average power of 0.5 W or greater for periods greater than 0.25 s, or a radiant exposure of 10 J/cm^2 within an exposure duration of 0.25 s or less. (2) *Visible (400–700 nm) and near-infrared (700–1,400 nm) laser devices*. Emit an average power of 0.5 W or greater for periods greater than 0.25 s, or a radiant exposure in excess of that required to produce a hazardous diffuse reflection (refer to standards for precise properties).

Note: AEL (accessible emission limit) is the maximum accessible emission level within a particular class. The Class 1 AEL is that radiant power or energy of a laser under consideration such that no applicable exposure limit for exposure of the eye for a specified exposure duration can be exceeded under any possible viewing conditions with or without optical instruments, whether or not the beam is focused.

[a] From Technical Bulletin TB MED 524, Department of the Army, Washington, DC, June 1985.

locks on doors to locations where lasers are used, fail-safe pulsing controls to prevent accidental actuation, remote firing room and controls, use of baffles to limit locations of beams, and wearing of suitable protective eyewear and clothing. The FDA has standards for the classification and safety design features of lasers (21 CFR 1040.10 and 1040.11).

Other controls include warnings, training of users, and medical surveillance of users. Where lasers present dangers, warning signs and alarm systems are needed. Dangerous laser devices must have warning labels. Operators must learn how to operate laser systems correctly and safely. The training should include procedures to avoid pointing them where other people may pass or controlling access to the location where they are used. People who do not operate laser systems but work with teams using them must learn proper procedures. They must learn the hazards the systems present. If protective eyewear or clothing is required, users must wear them.

Medical surveillance includes eye and vision examinations and proper selection of protective eyewear and clothing.

The equipment itself and the operation for which it is used may present other hazards that must be controlled. Electrical hazards must be controlled with grounding, compliance with electrical codes, and lockouts for maintenance and servicing. Where lasers vaporize material in machining, often ventilation is required. If lasers cause materials to fly, such as in cutting and machining operations, guarding is needed to contain the flying particles. Ionizing radiation from some lasers requires proper shielding. Cryogenic systems to cool lasers must be properly designed, operated, and maintained to prevent injury from the extremely cold coolants.

Standards

Tables 21-5 through 21-7 give U.S. Army exposure standards for various wavelengths based on potential damage to the eyes and skin. ANSI publishes laser exposure standards, as does the ACGIH. There are some differences among standards.

Measurement

The measurement of laser radiation is expensive and difficult to make. Manufacturers normally certify the source energy and wavelengths emitted from lasers, and these data normally are adequate to recognize hazards and establish suitable controls for laser systems. Some apply a factor of safety in selecting and implementing controls.

21-7 OTHER NONIONIZING RADIATION

There are devices and systems that use or emit nonionizing radiation for which there are no consensus standards for safety. In some cases, little is known about the dangers to people, particularly over extended periods of exposure at levels that are less than immediate injury levels. Some devices are in wide use and have drawn public concern. An example is the widespread use of monitors or visual display terminals (VDTs) in office automation. Many manufacturers have reduced the emission levels in newer monitors and the change to flat panel displays reduces emissions even further.

Recent studies evaluated extended exposures to nonionizing radiation. Some report evidence that extended exposures to microwaves may be related to development of cancerous tumor in rats. Statistical studies suggest increased rates of leukemia among power station operators, aluminum workers, power and telephone linemen, and other workers chronically exposed to electric and magnetic fields. As yet, results of such studies are not conclusive regarding harmful effects to humans.

The current microwave standard is based mainly on thermal effects in tissue. Other biological effects are under investigation. Not all effects are harmful; some are beneficial. Incorporation of new information into exposure standards generally is a slow process.

TABLE 21-5 Exposure Limits[a] for Direct Ocular Exposures (Intrabeam Viewing) from a Laser Beam[b]

Spectral Region	Wavelength (nm)	Range of Exposure Times[c] (s)	Exposure Limit	Defining Aperture (mm)
UV-C	200–302	10^{-9} to 3×10^4	3 mJ/cm^2	1[d]
UV-B	303	10^{-9} to 3×10^4	4 mJ/cm^2	1[d]
	304	10^{-9} to 3×10^4	6 mJ/cm^2	1[d]
	305	10^{-9} to 3×10^4	10 mJ/cm^2	1[d]
	306	10^{-9} to 3×10^4	16 mJ/cm^2	1[d]
	307	10^{-9} to 3×10^4	25 mJ/cm^2	1[d]
	308	10^{-9} to 3×10^4	40 mJ/cm^2	1[d]
	309	10^{-9} to 3×10^4	63 mJ/cm^2	1[d]
	310	10^{-9} to 3×10^4	100 mJ/cm^2	1[d]
	311	10^{-9} to 3×10^4	160 mJ/cm^2	1[d]
	312	10^{-9} to 3×10^4	250 mJ/cm^2	1[d]
	313	10^{-9} to 3×10^4	400 mJ/cm^2	1[d]
	314	10^{-9} to 3×10^4	630 mJ/cm^2	1[d]
UV-A	315–400[e]	10^{-9} to 10	$0.56t^{1/4}$ J/cm^2	1[d]
	315–400	10 to 10^3	1.0 J/cm^2	1
	315–400	10^3 to 3×10^4	1.0 mW/cm^2	1
Light	400–700	10^{-9} to 1.8×10^{-5}	5×10^{-7} J/cm^2	7
	400–700	1.8×10^{-5} to 10	$1.8t^{3/4}$ mJ/cm^2	7
	400–550	10 to 10^4	10 mJ/cm^2	7
	550–700	10 to T_1	$1.8t^{3/4}$ mJ/cm^2	7
	550–700	T_1 to 10^4	$10\,C_B$ mJ/cm^2	7
	400–700	10^4 to 3×10^4	C_B μW/cm^2	7
IR-A	701–1,049	10^{-9} to 1.8×10^{-5}	$5C_AC_p \times 10^{-7}$ J/cm^2	7
	701–1,049	1.8×10^{-5} to 10^3	$1.8C_At^{3/4}$ mJ/cm^2	7
	1,050–1,400	10^{-9} to 5×10^{-5}	$5C_p \times 10^{-6}$ J/cm^2	7
	1,050–1,400	5×10^{-5} to 10^3	$9t^{3/4}$ mJ/cm^2	7
	701–1,400	10^3 to 3×10^4	$320C_A$ μW/cm^2	7
IR-B & C	1.4–10^3 μm	10^{-9} to 10^{-7}	10^{-2} J/cm^2	1, 11[f]
	1.4–10^3 μm	10^{-7} to 10	$0.56t^{1/4}$ J/cm^2	1, 11[f]
	1.4–10^3 μm	>10	0.1 W/cm^2	1, 11[f]

[a] Exposure limits are for maximum permissible exposure to laser radiation under conditions to which nearly all persons may be exposed without adverse effects. The values should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels.

$C_A = 10^{[0.002(\lambda - 700)]}$ for λ = 700–1049 nm
$= 1$ for λ = 400–700 nm
$= 5$ for λ = 1,050–1,400 nm
$C_B = 1$ for λ = 400–550 nm
$= 10^{[0.015(\lambda - 550)]}$ for λ = 550–700 nm
$T_1 = 10 \times 10^{[0.02(\lambda - 550)]}$ for λ = 550–700 nm
$C_p = 1/(F)^{1/2}$ for PRF (pulse repetition frequency) ≤ 100 Hz is determined from charts for PRFs from > 100 Hz ≤ 1,000 Hz
$= 0.06$ for PRFs > 1,000 Hz

These values of C_p only apply for $t \le 10$ μs. Determining C_p is more complex for $t > 10$ μs. Refer to standards.

[b] From Technical Bulletin TB MED 524, Department of the Army, Washington, DC, June 1985.

[c] The exposure limit at 1,540 (erbium) for a single pulse (<1 μs) is 1 J/cm^2.

[d] Or $0.56t^{1/4}$ J/cm^2.

[e] Or not to exceed 1 J/cm^2 over 24 hr.

[f] 1 mm for 1,400 to 105 nm; 11 mm for 105 to 106 nm.

TABLE 21-6 Exposure Limits for Viewing a Diffuse Reflection of a Laser Beam or an Extended Source Laser[a]

Spectral Region	Wavelength (nm)	Exposure Times[b] (S)	Exposure Limit[b]
Light	400–700	10^{-9} to 10	$10t^{1/3}$ J/cm^2 sr^{-1}
	400–550	10 to 10^4	21 J/cm^2 sr^{-1}
	550–700	10 to T1	$3.83t^{3/4}$ J/cm^2 sr^{-1}
	550–700	T1 to 10^4	$21C_B$ J/cm^2 sr^{-1}
	400–700	10^4 to 3×10^4	$2.1C_B$ mW/cm^2 sr^{-1}
Near	700–1,400	10^{-9} to 10	$10C_A$ t1/3 J/cm^2 sr^{-1}
Infrared	700–1,400	10 to 10^3	$3.83C_A t^{3/4}$ J/cm^2 sr^{-1}
	700–1,400	10^3 to 3×10^4	$0.64C_A$ W/cm^2 sr^{-1}

[a] From Technical Bulletin TB MED 524, Department of the Army, Washington, DC, June 1985.
[b] For C_A, C_B, and T_1, see Table 21-5.

TABLE 21-7 Protection Standards for Skin Exposure to a Laser Beam[a]

Spectral Region	Wavelength (nm)	Exposure Time[b] t(s)	Exposure Limit[b]
UV	200–400	10^{-9} to 3×10^4	Same as Table 21-5
Light and infrared A	400–1,400	10^{-9} to 10^{-7}	2 $C_A \times$ 10–2 J/cm^2
	400–1,400	10^{-7} to 10	1.1 $C_A t^{1/4}$ J/cm^2
	400–1,400	10 to 3×10^4	0.2 C_A W/cm^2
Infrared B and C	1.4 µm–1 mm	10^{-9} to 3×10^4	Same as Table 21-5

[a] From Technical Bulletin TB MED 524, Department of the Army, Washington, DC, June 1985.
[b] The limiting aperture for all exposure limits is 1 mm for wavelengths less than 0.1 mm. The limiting aperture for wavelengths more than 0.1 mm is 11 mm. Whole-body exposure should be limited to 10 mW/cm^2. The above limits refer to a laser beam having a cross-sectional area less than 100 cm^2.
[c] For C_A, see Table 21-5.

The rapid expansion in use of cell phones and their compact designs that place them against the head have raised some long-term health concerns related to high use levels. This concern has not been fully resolved, but the level of exposure for most low-frequency users does not seem to be significant. One can obtain radiation data for phone models.

Visual Display Terminals and Computer Monitors

When office automation exploded in the 1980s, there was controversy of many kinds related to computer equipment. Some believed that radiation emitted by computer monitors created risks to fetuses. Much of the concern arose from clusters of female office workers who miscarried or bore children with birth defects. One 5-year study found no effect on miscarriages for women who work on VDTs for fewer than 20 h per week and a 5% greater incidence of miscarriage for those who work at VDTs more than 20 hr per week. The controversy seems to have disappeared, because studies showed no strong link between VDT use and miscarriages and birth defects. In addition, manufacturers reduced the emission levels.

The attention on hazards of VDT workstations has had a number of beneficial effects. Researchers identified a number of problems with VDT workstations and environments that contribute to cumulative trauma, visual, and other disorders. Conventional furniture did not provide a suitable fit between worker and work stations for computers and VDTs. The quality of the visual image on VDT screens, glare, lighting, and other factors were identified as contributing to VDT workstation problems. Newer display technologies and designs and higher screen resolutions have reduced the visual problems considerably.

Low-Frequency Electric and Magnetic Fields

For a period in the 1980s, there was significant attention on low-frequency electric and magnetic fields. Power transmission frequencies (50–60 Hz) and below are called extremely low frequency (ELF) and most often occur around extra high-voltage (EHV) transmission lines. They also occur in special radio transmission frequencies that penetrate underwater for submarines. There are also many nontransmission sources for power frequency fields, such as wall wiring, appliances, and lighting fixtures.

Public concern over power transmission lines initially involved aesthetics of towers, property right-of-way issues, and nuisance effects, which include interference with radio and television reception, audible noise, and induced shocks that can occur when a person standing beneath an EHV line touches a large ungrounded metal object such as a truck or farm vehicle. Potential health effects were first noted in the early 1970s in scientific and medical literature. Under certain circumstances, the membranes of cells can be sensitive to even fairly weak externally imposed low-frequency electromagnetic fields, and biochemical responses can be triggered. A government-sponsored review of the ELF health effects literature found the existing information complex and inconclusive. However, effects are clearly demonstrated at the cellular level, and epidemiological evidence is beginning to provide a basis for concern about risks from chronic exposure. Some states have established limits on field strength in right of ways.[5]

EXERCISES

1. A worker is exposed to microwave radiation. Properties of the exposure are as follows: type of source, continuous wave; power density at worker location, 15 mW/cm^2; duration of exposure, 3 min. Is the exposure allowable under microwave radiation exposure standards?
2. A microwave oven has a 6-GHz source. If the energy incident on the inside of the door is 200 mW/cm^2 and the door has a 32 × 32 mesh screen, what is the energy level passing through this screen?
3. A worker with unprotected eyes and skin is exposed to UV radiation. The properties of the exposure are as follows: spectrum, 290 nm; duration, 6 h; irradiance, 8 mJ/cm^2. Does the exposure exceed recommended standards?
4. It is known that a work environment has a broadband ultraviolet source, uniformly distributed over the range 215 to 285 nm and having a uniform irradiance of 7 mW/cm^2 nm^{-1} over the range.
   (a) Compute the effective irradiance (E_{eff}), using bandwidths of 10 nm.
   (b) Determine the allowable exposure time.
5. A worker receives a direct ocular exposure to a laser. Determine if the TLV is exceeded for each of the following conditions:

Exposure wavelength	Time	Irradiance
(a) 307 nm	10 s	28 mJ/cm^2
(b) 410 nm	15 s	10 mJ/cm^2
(c) 800 nm	1.5 s	10 mJ/cm^2
(d) 560 nm	200 s	15 mJ/cm^2.

6. A worker receives skin exposure to a laser beam. Determine whether the TLV is exceeded for the following conditions: wavelength, 1,200 nm; exposure time, 1×10^{-8} s; irradiance, 0.5 J/cm^2.

7. Conduct a review of the literature to identify the current state of knowledge related to cellular phone use and identify any exposure standards that have emerged.

REVIEW QUESTIONS

1. Which forms of nonionizing radiation are
   (a) absorbed by the cornea of the eye?
   (b) pass through eye tissue?
   (c) absorbed by the lens of the eye?
   (d) absorbed by the retina of the eye?

2. Compared with other body tissues, why is the eye highly susceptible to damage from nonionizing radiation?

3. What are five effects of microwaves on humans?

4. What controls are used to limit exposures to microwaves?

5. What are the dangers of UV radiation?

6. What are the dangers from exposure to infrared radiation?

7. What controls can reduce or eliminate UV and infrared dangers?

8. What are the dangers of high-intensity visible light?

9. What controls limit these dangers?

10. What are the dangers associated with lasers?

11. What parts of the body are most susceptible to laser injury?

12. What controls reduce the hazards of lasers?

13. What are possible dangers associated with VDTs?

NOTES

1 Public Law 90-602, Radiation Control for Health and Safety Act of 1960.

2 29 CFR 1910.97.

3 *Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*, American Conference of Government Industrial Hygienists (ACGIH), Cincinnati, OH, annual update.

4 *Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, annual update. (Note: This publication is updated annually and standards in it may change.)

5 Nair, I., Morgan, M., and Florig, H. K., *Biological Effects of Power Frequency Electric and Magnetic Fields*, Office of Technology Assessment, Congress of the United States, May, 1989.

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C95.2 Standard for Radio Frequency Energy and Current Flow Symbol

C95.3 Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave

C95.4 Recommended Practices for Determining Safe Distances from Radio Frequency Transmitting Antennas When Using Electric Blasting Caps During Explosive Operations

Z136.1 Safe Use of Lasers

Z136.2 Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources

Z136.3 Safe Use of Lasers in Health Care Facilities

Z136.5 Safe Use of Lasers in Educational Institutions

Z136.6 Safe Use of Lasers in an Outdoor Environment

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