CHAPTER 14D

Ionizing and Non-ionizing Radiation

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The word "radiation" brings about certain feelings and responses in different people based on their past experiences and knowledge of the subject. Although humans evolved in an environment with background radiation for millions of years, mankind only became aware of this invisible energy in 1895, when Wilhelm Conrad Roentgen announced his discovery of x-rays. The following year, Antoine Henri Becquerel discovered that uranium emits another form of invisible energy, which was later given the name *radioactivity* by Marie Curie, who was also a pioneer in the field of radiation. Since 1895, these discoveries have led to thousands of beneficial uses of radiation in the medical, industrial, and agricultural industries, which have employed millions of workers. But perhaps the most common association with radiation today is the terror and images brought about through the nuclear weapons industry and the lingering adverse health effects of the workforce that fueled that industry. In addition, highly publicized negative events all too often are the basis from which populations judge the acceptance of radiation in society. The atomic bombings of Hiroshimi and Nagasaki (1945), nuclear power plant accidents at Three Mile Island (Pennsylvania, 1979) and Chernobyl (Soviet Union, 1986), the criticality at a nuclear fuels fabrication facility in Tokaimura, Japan (1999), the dispersion of a radioactive source from a teletherapy machine in Goiania, Brazil (1987), and the recently perceived terrorist threats with radioactive "dirty bombs" contribute to the fear associated with radiation.

The impact to the psychological, social, and economic sectors of society from these radiation events leaves little doubt that radiation could be an effective terrorist weapon. However, since September 11, 2001, the United States has placed a priority on preventing biological, chemical, and radiological attacks and, in doing so, created a new category of workers that not only defend against such attacks but are also exposed to radiation in the course of their work (Fig. 14D-1). These workers are categorized as "security-based" workers that use radiation technology to prevent terrorist attacks. They use computed tomography (CT) technology to scan checked baggage at U.S. airports for explosive materials, operate gamma-emitting equipment to detect illegal contraband, and use special backscatter and transmission technologies to view through clothing and body cavities.[1]

These workers join the ever-increasing workforce that uses radiation or radioactive materials in their jobs (Table 14D-1). In 1989, the National Council on Radiation Protection and Measurements (NCRP) published summary statistics on the average radiation exposures to various occupations in the United States.[2] Occupations that received the largest annual doses included underground uranium miners, commercial nuclear power plant workers, fuel fabricators, physicians, flight crews, industrial radiographers, and well loggers. Although these data are more than 15 years old, the general trends of an ever-increasing number of workers combined with a reduction of the average individual exposure likely continues today. Two exceptions to this statement exist for occupations in the commercial nuclear power plant industry and medical

FIGURE 14D-1 • Transportation Security Administration worker exposing his hands to x-rays while reaching into an explosive-detection system to extract a piece of luggage. (Photograph by John Cardarelli II.)

industry. The commercial nuclear power plant industry has had limited growth because no new plants have been built since the 1970s. Workers in health care may be exposed to higher radiation exposures due to a tremendous growth and use of new imaging technology, especially digital imaging.

The risk that all these occupations assume remains controversial among the radiation-control community because most of the recorded doses are well below regulatory limits, where the risks are not well characterized. The controversies were further enhanced when the United States enacted legislation to compensate workers in the nuclear weapons industry whose average doses were among the lowest when compared to other industries with radiation exposure.[3] According to a report recently published by the National Academies, the smallest doses are presumed to pose a potential risk of cancer,[3a] so it remains a priority of those in occupational and environmental health to anticipate, recognize, evaluate, and control exposures to prevent radiation injuries and illnesses.

IONIZING RADIATION

Ionizing Radiation Basics

The multiple units and scientific terminology used to define radiation do little to bring understanding to those outside the field. These problems have been around for decades and will continue to exist until scientific organizations, industry, and international governments work more actively toward harmonization. Scientific organizations are leading the way by publishing internationally recognized standards via the International Commission for Radiation Protection (ICRP) and the International Atomic Energy Agency (IAEA). Industry falls behind by continuing to produce instrumentation that provides results in the conventional units, and government regulations struggle to keep up with the changing recommendations due to lengthy legislative processes. As this field approaches more consistent use of units and terminology (Table 14D-2), those outside the field will begin to better understand the basics of radiation.

TABLE 14.9

Types of Workers Who May be Exposed Occupationally to Ionizing Radiation

Accelerator personnel	Manufacturing workers
Department of Defense (DOD) workers	Distribution workers
Department of Energy (DOE) workers	Well-logging workers
Contractor employees	Health care workers
Reactor facility employees	Other hospital workers
Weapons fabrication personnel	Veterinary workers
Office workers	Nuclear power plants workers
Uranium fuel cycle workers	Commercial workers
Miners	Naval (fleet and shipyard) workers
Millers	Transportation workers
Fuel fabricators	Screening personnel
Fuel processors	Trucking and other shipping workers
Uranium enrichment workers	Inspectors and other regulatory workers
Educational institution workers	Researchers
Radiographic (nondestructive testing) workers	

Adapted from National Council on Radiation Protection and Measurements. NCRP Report No. 101: Exposure of the U.S. Population from Occupational Radiation, NCRP, Washington, DC, 1989.

TABLE 14.10

Radiation Units

Parameter	Conventional Units	SI Units
Exposure	Roentgen (R) = 87.6 ergs per gram (air) = 2.58×10^{-4} Coulomb/kg (air)	Coulomb/kg
Dose	rad = 100 erg per gram (tissue) = 0.01 Gy	Gray (Gy) = 100 rad
Dose equivalent	rem = 1 rad $\times$ w_r[a] = 0.01 Sv	Sievert (Sv) = 100 rem
Activity	Curie (Ci) = 3.7×10^{10} decays per second	Becquerel (Bq) = 1 decay per second

[a] w_r = radiation weighting factor: a dimensionless number that depends on the way in which the energy of the radiation is distributed along its path through the tissue. In general, it is 20 for alpha particles, 1 for beta particles and gamma and x-rays, and 5 to 20 for neutron exposures.

Some of the most important concepts to understand in the field of radiation are ionizing and non-ionizing radiation, exposure and dose, half-life and activity, and risk. *Ionizing radiation* is caused when an electron is ejected from its atomic structure. *Non-ionizing* radiation does not eject electrons, but causes the molecules to vibrate. *Exposure* represents the amount of radiation that is absorbed in air. *Dose* refers to the amount of energy absorbed in a specified material other than air, usually tissue. The difference is due to the different densities of air and the specified material. *Half-life* is the amount of time it takes for half of the radioactive material to decay. *Activity* represents the decay rate or how quickly that radioactivity material decays. *Risk* is defined as the increment of some adverse health affect associated with a known amount of cumulative radiation dose.

Types of Ionizing Radiation

The various types of radiation and how they interact with matter can be described by our understanding of the atom. *Alpha radiation* (α) is a helium nucleus (contains only two protons and two neutrons) and is typically associated with heavy elements like radon, radium, uranium, and plutonium. It is a large, positive-charged particle and easily interacts with other atoms to quickly deposit its energy. Depending on its energy (measured in units called million electron-volts: MeV), an alpha particle can travel up to 10 cm in air, but most only penetrate 1 to 3 cm (less than 5 MeV) before being absorbed. Alpha particles with at least 7.5 MeV can penetrate the nominal protective layer of the skin (0.07 mm), but only 13.7 percent of all known alpha emissions (N = 1,999) occur above this energy and most of these are human-made. Therefore, alpha radiation does not pose an external hazard to humans because they are easily shielded (by air, skin, or paper) but can be hazardous if the emitting radionuclide is inhaled, ingested, or injected in the body where there is little protection to living tissue.

Beta radiation (β) is an electron emitted by an atom. Relative to the mass of a single proton, the beta particle mass is 1/1,836 the size and can penetrate further into materials or tissue.[4] Due to their smaller size and charge as compared to an alpha particle, beta particles can travel about 12 feet per MeV in air and need only 0.07 MeV to penetrate the skin. Most beta particles do not normally penetrate beyond the top layer of skin, but exposure to higher energy beta particles (>0.07 MeV) can cause skin burns. Beta radiation is easily shielded with plastic, glass, or metals, but layers of plastic materials are preferred in the occupational environment to reduce the production of x-rays. These characteristics make beta radiation both an external and internal hazard to humans.

Photon radiation (gamma or x-ray) is a form of electromagnetic radiation like light, except with energies high enough to cause ionization. There are several differences between these two forms of radiation with the foremost being their point of origin. *Gamma rays* originate from within the nucleus, and *x-rays* originate from surrounding orbital electrons. Gamma ray emissions are very specific and are often used to identify radionuclides with special instruments. X-ray emissions are generally not specific because they are produced artificially by the rapid slowing down of an electron beam (*bremsstrahlung radiation*). Because the rate of slowing is not specific, the various x-ray energies exist within a continuum of energies that peak at the maximum energy of the incident electron beam or beta particle. Characteristic x-rays are one exception where x-rays with specific energies are emitted due to the specific energy levels between electron shells. An electron shifting from a higher energy shell to a lower energy shell will emit an x-ray of a fixed energy equal to the energy difference between shells. Finally, gamma rays commonly encountered in the occupational environment (medical and industrial) are generally higher in energy than x-rays.

Neutron radiation is essentially zero for background radiation levels at ground level and is only an occupational concern at commercial nuclear power plants, research facilities, and high-altitude activities (airline industry and space exploration). Neutrons have no charge, therefore they are not influenced by other charged particles and can easily penetrate materials. Water or concrete are effective shielding materials because they contain many similar sized atoms close to that of a neutron (hydrogenous materials). As the neutrons penetrate these materials, they interact with the atomic nuclei of the material like billiard balls. Neutron radiation is also capable of creating radioactive materials through a process called *activation*. When a neutron is absorbed by an atomic nucleus, the atom becomes "excited" and often releases the excess energy in the form of other types of radiation, especially protons. Because atoms are identified by the number of protons in the nucleus, any change in this number will change the element and its chemical properties. The most common activation product encountered in various industries is cobalt-60. It is important to understand that alpha, beta, gamma, and x-radiation do not cause the body to become radioactive, but most materials in their natural state (including body tissue) contain measurable amounts of radioactivity.

External and Internal Exposures

External exposures occur when the body is irradiated by a radioactive source outside the body. Dose measurements from external exposures are relatively simple to measure using pocket ion-chambers (PICs); film; or thermolumenscent (TLD), optically stimulated luminescence (OSL), or electronic personal dosimeters (EPD). All these technologies can be arranged to differentiate between the types of radiation exposure (beta, gamma, or neutron) and their respective energies. Choosing the most appropriate dosimeter should be done by a qualified individual who can assess the advantages and limitations for the given application (Table 14D-3). Additional considerations include the type of radiation encountered, the monitoring frequency (immediate, hourly, weekly, monthly, quarterly), the required sensitivity, processing time, and cost.

Internal exposures occur when a radioactive material enters the body via inhalation, ingestion, injection, or absorption through the skin. Doses from internal exposures are more difficult to assess than external exposures because individual characteristics, such as diet, health status, and age, vary greatly within a population. In an attempt to standardize the dosimetry methodology, ICRP has developed sophisticated human reference models to estimate internal doses.[5,6] These models often govern the airborne radiation concentration limits, called derived air concentrations (DACs), for occupational environments. Internal dose estimates are determined

TABLE 14D-3

Advantages and Limitations of Dosimeter Types

Dosimeter Type	Advantages	Limitations
Pocket ion chambers	Immediate read-out Reusable Cost efficient Some can differentiate between gamma and neutrons	False positives (impact sensitive) Requires minor maintenance
Film	Provide a permanent record of dose (re-readable). Can differentiate between beta, gamma, and neutron exposures Provides integrated dose Can estimate energy level of radiation Simple design	Sensitive to light Higher limit of detection Measurement must be processed Variation from batch emulsions Chemical processing variables
Thermoluminescent (TLD)	Can differentiate between beta, gamma, and neutron exposures Provides integrated dose Can estimate energy level of radiation Lower limit of detection Simple design	Measurement must be processed Not a permanent record Some TLD materials subject to fading (result in under reporting of dose) Potential for false-positives
Optically stimulated luminescence (OSL)	Similar to TLDs Identify static vs. dynamic exposure conditions Provides a permanent record (reanalysis; dose verification) Quicker read-out (within seconds) Reduce potential false-positive	Measurement must be processed Sensitive to light
Electronic	Immediate read-out Can differentiate between beta, gamma, and neutron exposures Provides integrated dose Can estimate energy level of radiation Lower limit of detection Datalogging capabilities Some provide visual and audible warnings Telemetry	Cost (expensive) Requires calibration and maintenance Availability may be suspect Sophisticated design

by either direct measurements, biological sample analyses, or a combination of the two. Direct measurements of, for example, thyroid, whole body, or bone, employ very sensitive instruments that measure photon radiation (gamma rays or characteristic x-rays) emitted from within the body. Specific gamma energies identify the radionuclides while the measurement estimates the amount internally deposited. These data are then used with the knowledge of the initial time of exposure and the ICRP standardized models to estimate the dose. Biological samples, such as urine, feces, exhaled breath, sweat, and hair, are used when the type of exposure, chemical properties (soluble versus insoluble), and

radionuclide is known. The amount of radioactive material measured in these samples can estimate internal dose via the ICRP models. In the occupational environmental, both methods are used to refine internal dose estimates as more information on the individual's biological clearance process is obtained.

Background Radiation and the Environment

Background radiation levels vary all around the world from less than 0.005 milli-roentgen per hour (mR/hr) to more than 2.5 mR/hr. This results in an annual dose of about 0.4 mSv (40 mrem) to 220 mSv (22,000 mrem). This large dose range is due to various deposits of naturally occurring radioactive materials (NORM), altitude, and longitude positions on Earth. The Biological Effects of Ionizing Radiation Committee (BEIR V) reports an average annual background dose of about 3.6 mSv (360 mrem) to people living in the United States. Radon exposure is responsible for about 55 percent of background dose (about 2.0 mSv) and is highest where NORM material (uranium and thorium) is found. Cosmic radiation accounts for about 8 percent (0.27 mSv) of background levels and increases at higher altitudes and at longitude positions closer to the poles. Terrestial radiation (rocks and soil) also account for about 8 percent (0.28 mSv). Internal exposures (radioactive substances inside the body, particularly potassium-40) account for about 11 percent (0.39 mSv). Human-made radiation sources (medical procedures and consumer products) account for about 18 percent (0.63 mSv). Other sources (occupational, nuclear fuel cycle, fallout, and artificial sources) account for the remaining 0.3 percent (0.03 mSv).

Health Effects

Health effects from radiation exposures vary with the type, amount, and duration of exposure. When radiation exposes a cell, it may (a) pass through without doing any damage, (b) interact and damage the cell, with later repair by the cell, (c) interact and damage the cell in such a way that it continues to reproduce itself in a damaged state, or (d) kill the cell. The death of a single cell may not be harmful, but if many cells are killed within an organ then that organ may not function properly. The likelihood of damage is also related to the mitotic cycle of the cell. In 1906, the Law of Bergonie and Tribondeau concluded that the most radiosensitive cells have a high division rate, long dividing future, and are not of a specialized type. In general, tissues that are young and rapidly growing are most likely radiosensitive. Therefore, mature lymphocytes are more radiosensitive than (in order) intestinal crypt cells, mature spermatocytes, erythrocytes, and nerve cells.

Acute effects, sometimes referred to as *nonstochastic effects*, are those in which the severity of the effect varies with the dose and occur shortly (minutes to days) after exposure. If the dose is kept below a given threshold, usually about 0.25 Gy (25 rad), no effect will be observed. Above this value, especially above 1 Gy (100 rad), a group of clinical syndromes known as *acute radiation sickness* develop. These include the hemopoietic syndrome, gastrointestinal syndrome, and central nervous system syndrome. Another called cutaneous radiation syndrome may occur simultaneously with the others and often complicates the recovery process of the exposed individual due to an increase potential for infection. The hemopoietic syndrome occurs with penetrating gamma or x-ray doses ranging between 2 to 10 Gy (200 to 1000 rads) and is characterized by deficiencies of WBC, lymphocytes, and platelets. It consists of four phases: prodromal phase (nausea, vomiting, and anorexia lasting up to 48 hours); latent phase (asymptomatic but will begin to show changes in blood elements lasting up to 3 weeks); bone marrow depression; and recovery (Figure 14D-2). The gastrointestinal syndrome occurs with penetrating gamma or x-ray doses greater than 10 Gy (1,000 rads) and an immediate, prompt, and profuse onset of nausea, vomiting, and diarrhea, followed by a short latent period. Severe dehydration is caused by the massive denuding of the gastrointestinal tract. Most patients do not survive. The central nervous syndrome occurs with penetrating gamma or x-ray dose above 100 Gy (10,000 rads) accompanied by vomiting and diarrhea within minutes of exposures, confusion, disorientation, hypotension, and hyperpyrexia resulting in death within a short time. Cutaneous-syndrome severity is determined by the dose of beta radiation, the energy of the radiation, and the type of exposure (skin contamination, contact with contaminated clothing, or distant exposure). Effects depend on whether exposure is uniform or nonuniform and the location of contamination on the body. Most radiosensitive are moist areas (axilla, groin, and skin

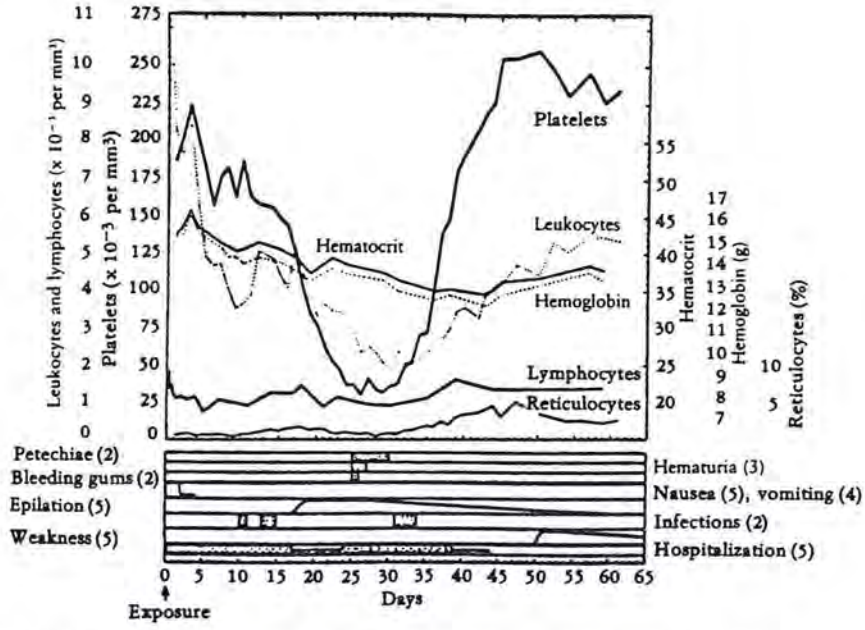

FIGURE 14D-2 • Hematologic values, symptoms, and clinical signs in five men exposed to whole-body irradiation in a criticality accident. The blood counts are average values for the five men; the figures in parentheses denote the numbers showing the symptoms and signs indicated. (From Andrews GA, Sitterson EW, Kretchmar AL, et al. Criticality accidents at the Y-12 plant. In: Diagnosis and treatment of acute radiation injury. Geneva: World Health Organization, 1961:27–48.)

folds), followed by the inner aspect of the neck, the antecubital and popliteal spaces, and the flexor surfaces of the extremities, chest, abdomen, face, and back. Least sensitive are the nape of the neck, scalp, palms, and soles. The larger the area irradiated, less dose is needed for adverse reactions. Likewise, the smaller the area irradiated, more dose is needed for a similar reaction. A temporal scheme proposed by Rubin and Casarett classifies the effects as *acute effects* (within first 6 months), *subacute effects* (second 6 months), *chronic clinical period* (2 to 5 years), and *late clinical period* (after 5 years). Depending on dose, the skin will experience several stages of response. These include erythema (3–10 Gy; 14–21 days); epilation (>3 Gy; 14–18 days), dry desquamation (8–12 Gy; 25–30 days), moist desquamation (15–20 Gy; 20–28 days), blister formation (15–25 Gy; 15–25 days), ulceration (>20 Gy, 14–21 days), and necrosis (>25 Gy; >21 days). The commercial nuclear power industry presents a unique skin hazard of highly localized, radioactive material (usually cobalt-60 or cesium-137) called "hot particles," "fleas," or "specks." These particles range from 1 to 100 μm in diameter, deliver very high doses to a local area, and are difficult to remove. In the event of a terrorist attack involving nuclear (involving fission) or radioactive (nonfissile) material, these particles may become a principal radiological concern but are not likely to result in whole-body doses leading to death.

Pregnancy Issues

Thousands of pregnant workers are exposed to ionizing radiation each year. The great anxiety and consideration of unnecessary termination of pregnancies are due to a lack of knowledge. These fears and concerns can be alleviated by understanding that the radiation risks throughout pregnancy are related to the stage of pregnancy and dose. Preconception irradiation of either parent's gonads has not been shown to result in increased risk of cancer or malformations in children. Radiation risks are most significant during organogenesis and in the early fetal period and become lower with each successful trimester. Malformations have a threshold ranging between 0.1 to 0.2 Gy (10 to 20 rad) and are typically associated with central nervous system problems. Fetal doses of 0.1 Gy are not reached even with 3 pelvic CT scans or 20 conventional

diagnostic x-ray examinations. Radiation has been shown to increase the risk of leukemia in adults and children. The embryo/fetus is assumed to be at about the same risk for carcinogenic effects as children. For an individual exposed *in utero* to 0.01 Gy, the absolute risk of cancer at ages 0 to 15 years is about 1 excess cancer death per 1,700. This suggests that the probability of bearing a healthy child is very high, even if the pregnant worker receives a radiation dose that exceeds the occupational dose limit for nonpregnant workers. These risks must be taken into context with the abnormal affects in a pregnant population that are not exposed to radiation (that is, spontaneous abortion, more than 15 percent; incidence of genetic abnormalities, 4 to 10 percent; intrauterine growth retardation, 4 percent; and incidence of major malformation, 2 to 4 percent).

The dose ranges mentioned above are extremely rare in the workplace, especially if the woman declares pregnancy to her employer. The dose to a declared pregnant worker is limited to 0.005 Gy (0.5 rad) per gestation period in the United States (a factor of 10 lower than the nonpregnant occupational dose limit). ICRP states that pregnant workers may work in a radiation environment as long as there is reasonable assurance that the fetal dose can be kept below 0.001 Gy (0.1 rad), above background, during the pregnancy. This is about the same dose that all persons receive annually from penetrating natural background radiation (excluding radon) and a factor of 50 lower than the nonpregnant occupational dose limit.

Termination of pregnancy is rarely contemplated from the perspective of an occupational exposure but may become a dominant concern after a nuclear or radiological terrorist attack. Despite the political or religious arguments, the scientific literature provides some guidance on this issue. High fetal doses (0.1–1.0 Gy; 10–100 rad) during late pregnancy are *not* likely to result in malformations or birth defects because all the organs have been formed, and there is less than 1 percent chance that the exposed fetus will develop childhood cancer or leukemia with a dose of about 0.1 Gy (10 rad). For this reason, termination of pregnancy at fetal doses less than 0.1 Gy (10 rad) is not justified based on radiation risk. As the fetal dose increases to above 0.5 Gy (50 rad), there can be significant fetal damage based on the stage of the pregnancy. At fetal doses between 0.1 (10 rad) and 0.5 Gy (50 rad), decisions should be based on individual circumstances.[7]

Chronic effects, sometimes referred to as *stochastic effects*, are those in which the probability of the effect increases with increasing dose without threshold. Any dose has a probability of causing the effect, but the severity of the effect remains unchanged. Cancer and heredity effects are examples of chronic effects. The international scientific community has adopted a linear no-threshold dose–response model to set occupational dose limits based primarily on the atomic-bomb survivors and medically exposed individuals. There is little controversy about the linear response between adverse health affects associated with high cumulative doses (>1 Gy; 100 rad). However, controversy continues as to whether the linear no-threshold model is appropriate for lower cumulative doses and dose-rate exposures as found in the workplace.[8] Recently, the National Academies published a report that concluded that the current scientific evidence is consistent with the hypothesis that there is a linear dose-response relationship between exposure to ionizing radiation and the development of solid cancers in humans. It also concluded that it is unlikely that there is a threshold below which cancers are not induced, but at low doses the number of radiation-induced cancers will be small.[3a] Over the past several decades, several response models have been studied and proposed in the scientific literature. These include the linear quadratic model, threshold model, supralinear model, and hormesis models (Fig. 14D-3).

Radiation Protection

Radiation protection standards have evolved since the discovery of x-rays in 1895 and continue to undergo changes, additions, and revisions today. International and national organizations recommend scientifically based protection standards, and governments promulgate legislation setting occupational dose limits (Table 14D-4). The latest scientific recommendations differ from regulatory standards because the regulatory process cannot keep pace with the recommended changes by scientific organizations due to a complex promulgation process. The BEIR VII report by the National Academies recently concluded that the magnitude of estimated risks for total cancer mortality or leukemia has not changed greatly from estimates provided in past reports, such as BEIR V (1990) and recent UNSCEAR and ICRP reports. BEIR V reported that the cancer risk estimates had increased

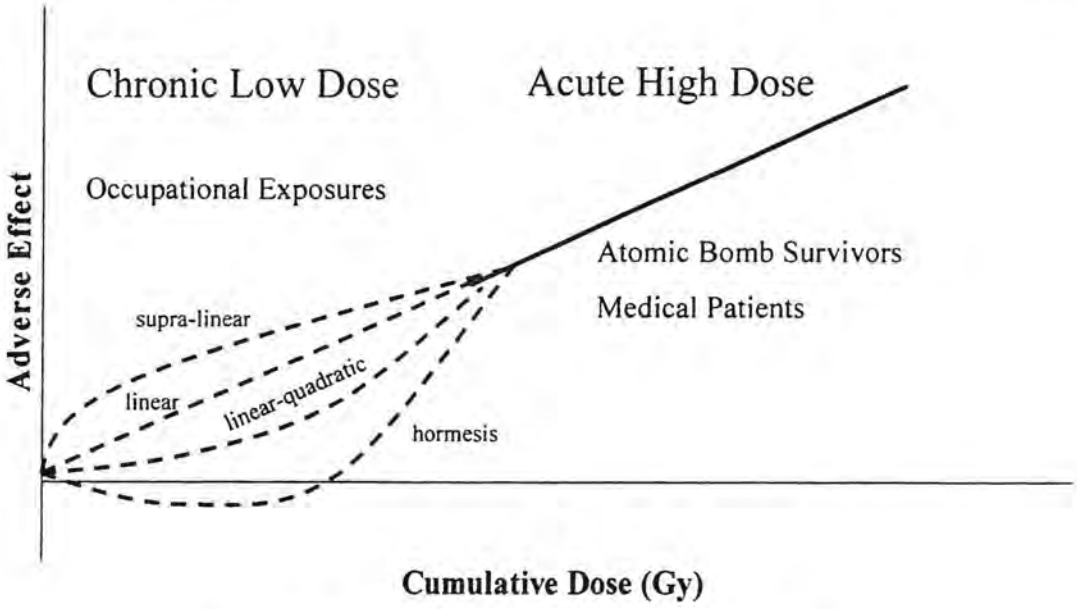

FIGURE 14D-3 • Health effects associated with radiation dose.

TABLE 14D-4

Occupational Dose Limits or Recommendations

Dose Limits	DOE	NRC	OSHA	NCRP (1993)	ICRP[a] (1991)
Occupational	**50 mSv per year** (external plus internal doses)	**50 mSv per year** (external plus internal doses)	**12.5 mSv per quarter** for the whole body (head and trunk; active blood-forming organs or gonads)	**50 mSv per year**	**20 mSv per year** averaged over 5 years (100 mSv in 5 years), with a further provision that the effective dose should not exceed **50 mSv in any single year**
Lens of eye	**150 mSv per year**	**150 mSv per year**	**12.5 mSv per quarter**	**150 mSv per year**	**150 mSv per year**
Hands and forearms; feet and ankles	**500 mSv per year**	**500 mSv per year**	**187.5 mSv per quarter**	**500 mSv per year**	**500 mSv per year**
Skin	**500 mSv per year**	**500 mSv per year**	**75 mSv per quarter**	**500 mSv per year**	**500 mSv per year**
Cumulative	None	None	**50 (N − 18) mSv** N = age (years)	**10 mSv × age (years)**	**100 mSv in 5 years**

DOE, Department of Energy; NRC, Nuclear Regulatory Commission; OSHA, Occupational Safety and Health Administration; NCRP, National Commission on Radiological Protection; ICRP, International Commission on Radiological Protection.

[a] The 2005 ICRP recommendations continue to endorse these limits.

by a factor of about 3 for solid cancers (relative risk projection) and about 4 for leukemia from its previous BEIR III (1980) report, on which many regulatory standards are based. The regulatory dose limits are based on BEIR III or earlier scientific reports and were set to be commensurate with the basic philosophy that radiation workers ought to have at least the same level of protection as those in safe industries (about 1 death per 10,000 workers per year).[9]

Radon

Occupational exposure limits for radon and radon progeny (also known as *radon daughters*) were derived to protect the health of underground miners over a working lifetime of 30 years.[10–12] When radon gas and radon progeny are inhaled, the radiation dose is primarily caused by the short-lived radon progeny rather than by the radon gas. Because it was not feasible to routinely measure the individual radon progeny, the concept of the working level (WL) was introduced and defined as 1.3×10^5 million electron volts (MeV) of alpha radiation emitted from the short-lived radon progeny in 1 L of air. An exposure of 1 WL for a working period of 1 month (170 hours) results in a cumulative exposure of 1 working level month (WLM). A WLM is the common unit of measure for human exposure to radon progeny and is the basis for the occupational exposure limits. More information about occupational radon exposures is available from the International Atomic Energy Organization (http://www.iaea.org) and the National Institute for Occupational Safety and Health (http://www.cdc.gov/niosh/).

Protection Programs

The objective of a radiation protection program is to reflect the application of the management responsibility for radiation protection and safety through the adoption of policies, procedures, and organizational structures that are commensurate with the nature and extent of the risks. Three principles of radiation protection and safety include justifying, limiting, and optimizing exposures. Radiation exposures may be justified if the activity produces sufficient benefit to offset the harm it might cause the exposed worker, taking into account social, economic, and other relevant factors. Dose limitation is necessary to limit the risk of stochastic effects from exposures considered to be unacceptable. Protection and safety should be optimized to ensure that the magnitude of worker doses, the number of workers exposed, and the likelihood of incurring exposure all be kept as low as reasonably achievable after accounting for social and economic factors. A "safety culture" is one key element that contributes to a successful radiation protection program. It depends on management commitment to encourage a questioning and learning attitude toward protection and safety and to discourage complacency. Studies have shown that a neutral or negative attitude toward radiological protection by management is one of six causes of unnecessary or excessive radiation exposure in the workplace. The other five are (a) inaccurate or incomplete radiation surveys, (b) inadequately prepared radiological work permits, (c) failure of the radiological technician to react to changing or unusual conditions, (d) failure of workers to follow procedures, and (e) lack of supervisor involvement. Whatever the situation, the basic structure of the radiation protection program should include the following:

1. Assignment of responsibilities to various levels of management.
2. Designation of controlled or supervised areas.
3. Local rules for workers to follow and the supervision of work.
4. Arrangement for monitoring workers and the workplace with appropriate dosimeters and instrumentation.
5. A system to record and report all relevant information to the appropriate decision makers.
6. Education and training programs on the nature of the hazards, protection, and safety.
7. Methods to periodically review and audit performance of the program.
8. Emergency response plans.
9. A health surveillance program.
10. A quality assurance and control program.

Emergency Response

Recent events have focused attention on preparedness to deal with large-scale radiological or nuclear threats and small-scale industrial accidents. In 2002, the United States established the Department of Homeland Security, consolidating many federal emergency response plans into a single national response plan and providing funding to states and local governments. Emergency response workers, such as police and firefighters, may be highly exposed to radiation at levels requiring additional precautions and medical intervention. Many of the

medical, public health, and public safety decisions may be made by a variety of individuals ranging from personal physicians to political leaders. All the decisions require consideration of several factors, including law enforcement issues, mass casualties and damage to infrastructure, psychosocial impacts, and environmental concerns, the details of which are beyond the scope of this chapter.[13] However, a key concept for those in occupational and environmental health regarding emergency response is to always treat life-threatening injuries first before measures to address radioactive contamination or exposure. Even if the patient has been heavily irradiated or contaminated, he or she must be evaluated for other forms of injury, such as mechanical trauma, burns, and smoke inhalation. One should be especially cautious of wounds containing metallic objects, as these could be very high source of radiation. The best way those in occupational and environmental health can protect themselves during a radiological or nuclear response is to seek additional training in the field of ionizing radiation. Most of the basic training materials can be found at the following Web sites:

GOVERNMENT WEB SITES

- Centers for Disease Control and Prevention <http://www.cdc.gov/nceh/radiation/default.htm>
- EPA Radiation Protection Programs <http://www.epa.gov/radiation/>
- FDA Center for Devices and Radiological Health <http://www.fda.gov/cdrh/>
- Federal Emergency Management Agency <http://www.fema.gov/>
- International Atomic Energy Agency <http://www.iaea.org/>
- Occupational Safety and Health Agency <http://www.osha.gov/SLTC/radiation/index.html>

WEB SITES OF SCIENTIFIC ORGANIZATIONS

- American Association of Physicists in Medicine (AAPM) <http://www.aapm.org/>
- American Association of Radon Scientists and Technologists (AARST) <http://www.aarst.org/>
- Conference on Radiation Control Program Directors (CRCPD) <http://www.crcpd.org/>
- Health Physics Society (HPS) <http://www.hps.org/>
- International Commission on Radiological Protection (ICRP) <http://www.icrp.org/>
- International Radiation Protection Association (IRPA) <http://www.irpa.net/>

NON-IONIZING RADIATION

Non-ionizing radiation exposes every person, every day, throughout the world. It is both naturally occurring and human-made. It can be both beneficial and detrimental to those exposed. Like ionizing radiation, one cannot see it (outside visible light: 400 to 760 nm), taste it, or smell it. But unlike ionizing radiation, one may be able to feel it via heat or shock sensations. It is the energy absorbed by any material without causing ionization (ejection of electrons surrounding the atoms within the material). It is the energy of television and radio signals, radar, transmissions for cordless and cellular phones and pagers, microwaves, visible light, infrared and ultraviolet light, lasers, and other examples.

Non-ionizing radiation is one of the most common and fastest growing environmental and occupational influences, about which anxiety and speculation are spreading. Levels of exposure will continue to increase as technology advances combined with societal demands for the conveniences it brings. The universal aspect of this subject is too voluminous to capture in this text, so a brief introduction will be given on the basics, how to interpret measurement data, the associated health effects, and how to protect those exposed in an occupational environment. It will focus primarily on extremely low frequency (ELF) and radio-frequency (RF) radiation, because ELF and RF comprise most of the electromagnetic spectrum and expose the most people. Ultraviolet radiation, infrared radiation, and lasers are briefly addressed by summarizing industrial applications and their associated adverse health effects.

Non-Ionizing Radiation Basics

The electromagnetic spectrum includes ionizing and non-ionizing radiation (Fig. 14D-4). All non-ionizing radiation presents itself in electric and magnetic fields called electromagnetic fields (EMFs). EMFs can be described by the frequency

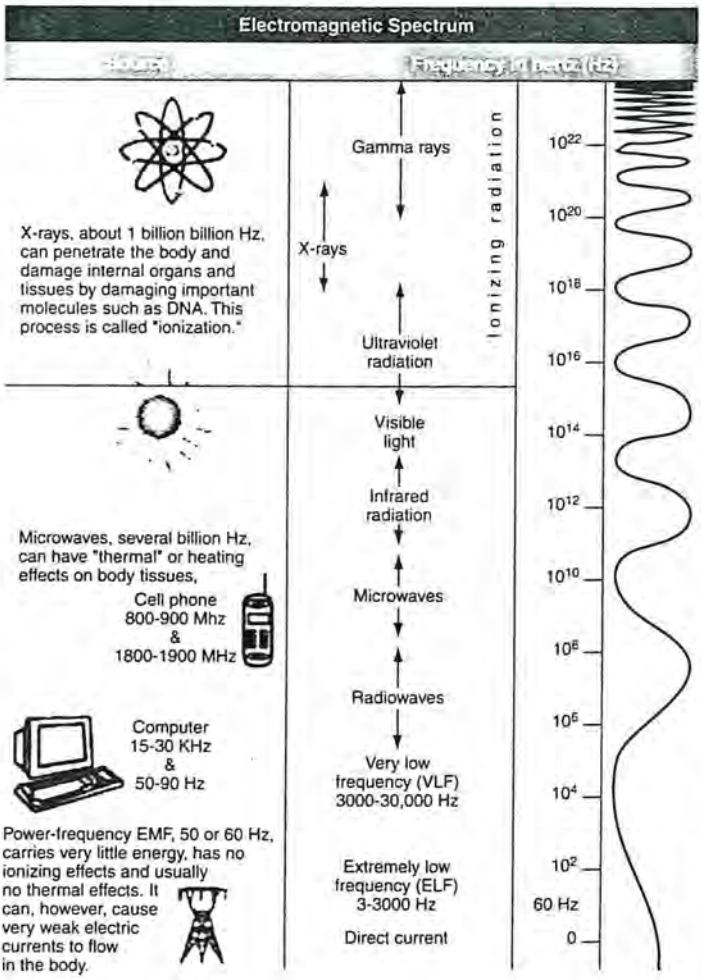

FIGURE 14D-4 ●
Electromagnetic spectrum. (From EMF in the Workplace. Department of Energy, National Institute for Occupational Safety and Health, and National Institute of Environmental Health Sciences, 1996. Note: ELF is defined as 3 to 300 Hz by NCRP Report 119.)

or the corresponding wavelength through the fundamental equation:

$$\lambda = c/f$$

where λ is wavelength in meters (m), c is velocity (usually the velocity of light, 3×10^8 meters per second; m/s), and f is frequency in cycles per seconds, commonly referred to as hertz (Hz), named after the German physicist Heinrich Rudolf Hertz.

Industrial applications span the entire EMF spectrum. For convenience, most of the nonionizing radiation spectrum is partitioned into specified radio-frequency bands. Hazards potentially associated with exposure to EMFs in the various bands may result in (a) currents being produced within the body via contact with energized sources or induced within the body without contact with sources or nearby metallic objects, (b) increased internal body temperature, or (c) increased body surface temperature (Table 14D-5). How efficient these fields interact with the body depends on several factors. For example, materials with a high water content (muscles) absorb EMF energy at a higher rate than dry materials. The absorption rate is higher when the incident electric field is parallel versus perpendicular to the body and higher when the incident magnetic field is perpendicular to larger cross-sectional areas versus smaller areas. Sharp corners, edges, and points concentrate electric fields. Depth of penetration decreases as conductivity increases and as frequency increases (shorter wavelengths).

Electric fields exist when electric charges exert forces on one another. *Electric field strength* describes the strength of forces on charges and has units of V/m. A good example of electric fields, their strengths, and shape is demonstrated in thunderstorms where the local build-up of electric charges in the atmosphere eventually reach a level that produce lightning. Lightning can illustrate the shape of the electric field but also provides the pathway

TABLE 14D-5

Frequency Bands and Their Associated Biological Impacts

Band		Frequency Range (Hz)	Wavelength Range (m)	Biological Impact
SELF (Sub-extremely-low frequency)		0 to 30	0 to 10^7	$0–10^5$ Hz 0–3,000 m
ELF (Extremely-low frequency)		30 to 300	10^7 to 10^6	Electrostimulation (primary dosimetric parameter is
VF (Voice frequency)		300 to 3,000	10^6 to 10^5	internal current density)
VLF (Very-low frequency)		3,000 to 3×10^4	10^5 to 10^4	
LF (Low frequency)		3×10^4 to 3×10^5	10^4 to 10^3	10^5 to 6×10^9 Hz
MF (Medium frequency)		3×10^5 to 3×10^6	10^3 to 10^2	3,000 to 0.05 m Specific absorption rates
HF (High frequency)		3×10^6 to 3×10^7	10^2 to 10	(heating effects)
VHF (Very high frequency)		3×10^7 to 3×10^8	10 to 1	
UHF (Ultrahigh frequency)		3×10^8 to 3×10^9	1 to 0.1	
SHF (Super-high frequency)		3×10^9 to 3×10^{10}	0.1 to 10^{-2}	Above 6×10^9 Hz
EHF (Extremely-high frequency)		3×10^{10} to 3×10^{11}	10^{-2} to 10^{-3}	Below 0.05 m Surface heating (Radiant)
SEHF (Supra-extremely-high frequency)		3×10^{11} to 3×10^{12}	10^{-3} to 10^{-4}	
Infrared radiation	**IR-C**		0.3 μm to 1 mm	Corneal burns, thermal skin
	IR-B		0.14 μm to 0.3 μm	burns
	IR-A		760 nm to 1,400 nm	Retinal burns, cataracts of lens, thermal skin burns
Visible light			400 to 760 nm	Retinal burns, thermal skin burns
Ultraviolet radiation	**UV-A**		400 to 320 nm	Cataract of lens, thermal skin burns
	UV-B		320 to 280 nm	Corneal injuries, cataracts of
	UV-C		280 to 200 nm	lens, photokeratitis, photoconjunctivitis, erythema

mm = millimeter (10^{-3} m); μm = micrometer (10^{-6} m); nm = nanometer (10^{-9} m).

for the electric charges to move through the atmosphere. Thus, an electric field can exist even when there is no movement, but once electric charges begin to move, magnetic fields also exert forces on charges moving through them.

Magnetic field strength has units of A/m and is associated with the strength of these additional forces on moving charges. The relationship between these fields is described by the term *power density*, defined as the power incident on a surface per unit surface area. It is given the abbreviation S and can be calculated from electric or magnetic field measurements by the following equation:

$$S = E^2/377. \text{ or } 377H^2$$

where S is power density in watts per square meter (W/m^2 or VA/m^2), E is electric field strength measurement (V/m) or H is magnetic field strength measurement (A/m), and the constant 377 is the impedance of free space (ohms, Ω or V/A). However, near RF sources where the highest exposures occur, the impedance cannot be assumed to be 377 ohms. Thus, for near-field exposures below 300 MHz, both E- and H-field strengths must be measured. Near-field exposures exist within one-half of a wavelength from RF sources or metallic objects illuminated with an RF field.

Exposure Limits

The transfer of energy from electric and magnetic fields in any material is described in terms of the specific absorption rate (SAR). "Specific" refers to the normalization to mass of the material exposed, "absorption" refers to the absorption of the energy, and "rate" means the time rate of change of the energy absorption. The SAR has been found to be the most reliable indicator or predictor of the potential for biological effects in test animals and a measure of what is happening inside the human body. It is expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). Because the SAR is difficult to evaluate or measure outside the laboratory, the measurable quantities of magnetic or electric field strengths and power density as well as induced and contact currents are used to define the RF environment and have been correlated with SAR to determine the maximum permissible exposure (MPE) levels (Table 14D-6). In the far-field (greater than one wavelength from RF source), measuring electric field strengths or power density provides reliable exposure assessments. In the near-field or in contact with RF sources and/or other metallic objects (where many occupational exposures occur), induced and contact current measurements provide the most reliable exposure evaluations. Measuring field strengths or power density is unreliable near or in contact with RF sources or other metallic objects. The MPE values provided are those from the Institute of Electrical and Electronics Engineers Standard, which incorporate the latest scientific findings and recommendations for occupational exposures.[14] Guidelines for limiting RF exposure have also been developed by several other scientific organizations and government agencies, but the differences are minor and efforts are underway to harmonize the various exposure limits.[15–20] In the case of exposure of the whole body, a human adult (height = 175 cm) absorbs RF energy most efficiently when the wavelength is 40 percent of the long axis of the body and parallel to the incident E-field vector. This occurs at a frequency of about 70 megahertz (MHz). The RF exposure limits reflect this dependency on frequency and were derived from a SAR of 4 W/kg for those frequencies associated with heating affects (100 kilohertz to 300 gigahertz). In terms of human metabolic heat production, 4 W/kg represents a moderate activity level, such as housecleaning. A safety factor of 10 was applied resulting in a RF exposure limit of 0.4 W/kg, virtually an indistinguishable heating effect from normal temperature variation, exercise, or exposure to the Sun. RF exposures below this level are intended to prevent adverse health effects. However, exposures in excess of the limits are not necessarily harmful, yet without intended benefit, such as lifesaving or medical benefits, these situations are not recommended.

Interpreting RF Measurement Data

Occupational limits—sometimes referred to as *controlled environment*—apply to persons exposed as a consequence of their employment, provided they are fully aware of the potential for exposure and can exercise control over their exposure. There are three fundamental concepts that one should understand when interpreting measurement data: (a) the difference between exposure and emission limits, (b) spatial averaging, and (c) time averaging.

Emission limits are the maximum power output authorized by government authorities for companies or individuals. However, these transmitting signals are often not emitted at the maximum power

TABLE 14D-6

Maximum Permissible Exposure for the Occupational Environments

Frequency Range (MHz)	*E*-Field[a] Strength (V/m)	*H*-Field[a] Strength (A/m)	Power Density (S) $(mW/cm)^2$	Averaging Time (min)
0.003–0.1	614	163		6
0.1–3.0	614	16.3/*f*		6
3–30	1,842/*f*	16.3/*f*		6
30–100	61.4	16.3/*f*		6
100–300	61.4	0.163	1.0	6
300–3,000			*f*/300	6
3,000–15,000			10	6
15,000–300,000			10	$616{,}000/f^{1.2}$

[a] Institute of Electrical and Electronics Engineers (IEEE) report C95.1 1999 Edition.

output. This is especially true for cell-phone base stations or towers, as the amount of power used is proportional to the number of calls handled. For this reason, the emission limit (maximum power output) may not be directly related to exposure potentials. Unlike the emission limits, the exposure guidelines apply to exposure limits, and they are relevant only to locations that are accessible by workers.

Spatial Averaging

The *exposure limits* are based on the concept that the exposures are applied to a whole-body averaged SAR. This means that spot measurements exceeding the stated exposure limits do not imply noncompliance or harmful exposure scenarios if the spatial average of RF fields over the body does not exceed the limits. A *spatial average measurement* may consist of three or more measurements averaged together that span a length of an adult.

Time Averaging

Another feature of the exposure guidelines is that exposures may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure. The averaging time for occupational (controlled environment) exposures is 6 minutes. To properly apply field measurements to the exposure limits, one must consider the length of time the individual is exposed. For example, with the occupational exposure, during any given 6-minute period, a worker could be exposed to twice the applicable limit for 3 minutes as long as they were not exposed at all for the preceding or following 3 minutes. Similarly, a worker could be exposed at three times the limit for 2 minutes as long as no exposure occurs during the preceding or subsequent 4 minutes.

Protective Measures

Engineering Controls

Protection of workers from unnecessary or excessive exposure to RF radiation is accomplished through engineering and administrative controls. Engineering controls are preferred because they eliminate or reduce the potential exposures at the source, but they require a sophisticated level of knowledge to install. Improperly installed controls may actually enhance worker exposures. Interlocks, shielding, bonding, grounding, and filtering are some of the more common controls employed. OSHA requires a lock-out/tag-out program for working with sources of hazardous energies, which may include installing many of the RF controls mentioned above.

The effectiveness of shielding materials varies with the material, geometry, frequency, and where the field reduction is measured. Some are more effective for reducing electric fields, whereas others are more suitable for reducing magnetic fields. One of the most recognizable types of shielding is that used on microwave ovens. The perforated

screen is designed to allow penetration of visible light (wavelength about 0.7×10^{-6} to 0.4×10^{-6} m. 430,000,000 to 750,000,000 MHz), but prevents leakage of microwave radiation (wavelength about 12 cm, 2,450 MHz). Perforated or continuous shielding materials reduce exposures by reflection, absorption (attenuation), and internal reflection. The proper selection of material is complex and should be done by qualified individuals.

Techniques that may supplement the use of engineering controls include prudent placement of RF sources, resonant frequency shift, and personal protective equipment. Consideration should be given to building construction materials and layout when installing RF equipment to reduce or prevent unnecessary enhancement of reflected energy at the worker's location. If the operating frequencies are around 10 to 40 MHz, the whole-body SAR may be reduced by separating the body from the ground plane by a small distance with electrically insulating materials. This is known as a *resonant frequency shift*. It reduces worker's absorption characteristics by reducing the flow of current from the body to a grounded surface. This may be especially useful for dielectric heater (plastic sealer) operators by having them stand on a nonconductive platform made of wood or rubber. For plant worksites, metal-reinforced concrete floors act as ground planes. Footwear that reduces the grounding effect achieves the same effect as resonant frequency shift. The level of RF exposure reduction is dependent on the RF frequency and the types of shoes and socks worn by the worker. Wool socks and rubber-soled shoes show the greatest reduction for frequencies below 100 MHz. RF protective suits may be helpful when work must be done in "hot" areas, such as continual radar, onboard naval vessels, and in some communication and broadcast environments. The suit material is typically wool, polyester, or nylon impregnated with a highly conductive threaded metal. Some are more effective than others depending on frequency, orientation of the worker in the environment relative to the incident electric fields, and construction of openings for feet, hands, and head. Washing these suits may reduce their protective capabilities. Some experts also recommend against use of RF-protective suits because the suits may present a potential hazard to individuals near the wearer and increase the hazard to the wearer by allowing closer proximity to open circuits that may act as secondary sources.

Administrative Controls

Administrative controls include increasing the distance between the source and workers, controlling the duration of exposure, restricting access, placing warning signs, providing training commensurate with the level of potential hazard, and real-time monitoring via dosimetry. Increasing the distance between the source and the worker is perhaps the most frequently used control measure and easiest to bypass. Horizontal and vertical distance should be considered when determining the appropriate distance, which is often the distance that results in a radiation level equal to the limit. This is referred to as the *hazard distance*. There are no simple means to calculate the reduction of field strength with distance because the calculation depends on so many factors; however, some researchers have suggested that field strengths are reduced by $1/r^5$ for induction heaters[21] and $1/r^3$ for video display terminals.[22] Controlling the duration of exposure is achieved by applying the time-averaging technique discussed earlier. Installing warning signs, restricting access, and providing training heighten the awareness of those potentially exposed to RF radiation, which may prevent harmful exposures. Finally, real-time monitoring devices, called *dosimeters*, are especially useful in identifying harmful exposures. Actions taken after identifying harmful exposures can reduce exposures. They provide an audible and visual alarm when exposures exceed a predetermined alarming level, giving the wearer immediate notification of a potentially hazardous environment. This equipment also allows the wearer to quickly identify if changes occur during their work activities.

Health Effects

Exposures to electric and magnetic fields (below 300 MHz) emanating from the generation, transmission, and use of electricity have been studied extensively over the past two decades. The current findings and recommendations by various scientific organizations and regulatory agencies continue to acknowledge controversy regarding the potential health effects of chronic low-level EMF exposures to children and adults; yet there remains no clear, convincing evidence of an actual health risk.[23,24] One of the most comprehensive reviews of the scientific literature was published by the International Agency for Research on Cancer (IARC),[25] which found that there is:

1. Limited evidence in humans for the carcinogenicity of ELF magnetic fields in relation to childhood leukemia.
2. Inadequate evidence in humans for the carcinogenicity of ELF magnetic fields in relation to all other cancers.
3. Inadequate evidence in humans for the carcinogenicity of static electric or magnetic fields and ELF electric fields.
4. Inadequate evidence in experimental animals for the carcinogenicity of ELF magnetic fields.
5. No data relevant to the carcinogenicity of static electric or magnetic fields and ELF electric fields in experimental animals were available.

As a result of these findings, IARC concluded that ELF magnetic fields are possibly carcinogenic to humans, and that static electric and magnetic fields and ELF electric fields are not classifiable as to their carcinogenicity to humans.

More than 100 million Americans use wireless communication devices, and this number continues to grow at a rate of about 50,000 new users daily.[26] If the use of wireless communication devices is ever associated with even the slightest increase in risk of adverse health effects, it could become a significant public health problem. Exposures to EMF above 300 MHz have shown a variety of biological responses including varied cell proliferation; reproduction, development, and growth effects; calcium efflux; increases in ornithine decarboxylase (ODC) activity; thermoregulation; cell membrane effects; neural effects; nueroendocrine effects; cardiovascular effects; hematopoiesis and hematologic effects; immune response; biochemical effects; cutaneous effects; cataracts and other ocular effects; increased blood–brain barrier permeability; and changes in behavior.[27] Any measurable change in biological systems may or may not be associated with adverse health effects.

A report of the potential health risks of RF fields from wireless telecommunication devices states: "Scientific studies performed to date suggest the exposure to low intensity non-thermal RF fields do not impair the health of humans or animals. However, the existing scientific evidence is incomplete, and inadequate to rule out the possibility that these non-thermal biological effects could lead to adverse health effects."[28] Although the quality of these studies has improved over time, they continue to suffer from poor exposure assessment information, the lack of a clear biological metric to measure, and confounding factors, such as multiple sources.

The scientific community continues to debate the level of protection necessary to prevent long-term health effects from RF exposures. Many European countries and the World Health Organization promote a precautionary approach by discouraging the widespread use of mobile phones by children for nonessential calls because they may be more vulnerable due to their developing nervous system and longer lifetime of exposures.[29] The Russian National Committee on Non-Ionizing Radiation Protection endorses the WHO precautionary approach and extends the recommendations for children to pregnant women, those suffering from a list of diseases or disorders, and recommends that the duration of cellular phone calls be limited to a maximum of 3 minutes followed by a 15-minute break between calls. The United States does not necessarily endorse the precautionary approach because, without clear, convincing epidemiologic evidence that a health hazard exists from RF exposures, this approach could adversely affect economic development.

Infrared and Ultraviolet Radiation

Infrared radiation (IR) lies at frequencies higher than those of radar waves and microwaves. Nearly 50 percent of the Sun's radiant energy is emitted as IR. It is strongly absorbed by water and the atmosphere, invisible to the eye, and can be detected as warmth by the skin. All objects with temperatures above absolute zero emit IR. In industry, significant levels of IR are produced directly by lamp sources and indirectly by sources of heat, such as heating and drying devices. The primary biological effect is thermal due to absorption in tissue water. For this reason, IR cannot penetrate the skin, leaving a sensation of heat that often serves as an adequate warning sign to take protective action or risk skin burns. The lens of the eye is particularly vulnerable to IR because the lens has no heat sensors and a poor heat-dissipating mechanism. Cataracts may be produced by chronic IR exposure at levels far below those that cause skin burns. Occupations typically at risk of IR exposure include glass blowers, furnace workers, foundry workers, blacksmiths, solderers, oven operators, workers near baking and drying heat lamps, and movie projectionists. Like RF radiation, IR exposure limits are frequency-based, except they represent conditions under which it is believed that

nearly all healthy workers may be repeatedly exposed without acute adverse effects. The limits for IR most recognized in the scientific community are published by ACGIH.[30] Control of IR hazards requires (a) shielding of the IR source and eye protection with appropriate IR filters, (b) maximizing the distance between workers and the IR source, and (c) reducing the time spent in areas with high levels of IR exposure.

Ultraviolet radiation (UVR) is produced by the Sun and artificially by incandescent, fluorescent, and discharge types of light sources. It is characterized by three distinct energy bands known as UV-A (400 to 320 nm), UV-B (320 to 280 nm), and UV-C (280 to 200 nm). The first two bands are principal UV components in sunlight, with nearly all of the UV-A reaching the surface of Earth, whereas most of UV-B is absorbed by the stratospheric ozone layer. UV-C is completely absorbed by the ozone layer and oxygen but is artificially produced on Earth. Industrial sources of UVR include arc welding, plasma torches, electric arc furnaces, germicidal and black-light lamps, and certain type of lasers. Because UVR wavelengths are so small, it presents a surface heating hazard.

The most common health effect from overexposure to UVR is the common sunburn (erythema). Chronic, low-level UVR exposure from the Sun is also associated with various skin effects including cancer (basal cell carcinoma, squamous cell carcinoma, and malignant melanoma), premature aging of the skin, solar elastosis (wrinkling), and solar ketatoses (premalignant lesions). Basal cell carcinoma and malignant melanoma are more strongly associated with a history of multiple sunburns, whereas squamous cell carcinoma is associated with total and occupational skin exposure. UVR exposures have also been associated with suppressing the immune system and developing cortical cataracts (UV-B exposure). Photosensitizing agents like coal tar, plants containing furmocoumarins and psoralens, such as figs, lemon and lime rinds, celery, and parsnips, and pharmaceuticals, such as chlorpromazine, chlorpropamide, and tolbutamide, can increase susceptibility to UVR. All these effects vary with individual susceptibilities and location with greater solar UVR exposures. Acute, high-level UVR exposures, especially from UV-B, result in eye injuries that are often realized several hours after the exposure. Photokeratitis (inflammation of the cornea) and photoconjunctivitis (inflammation of the thin transparent mucous membrane lining the inner surface of the eyelids) are usually reversible within several days. Intense UVR exposure also has an indirect impact on health through its ability to cause photochemical reactions. Small amounts of oxygen and nitrogen can be converted into ozone and oxides of nitrogen, which are respiratory irritants. Halogenated hydrocarbon solvent vapors can decompose into toxic gases such as perchloroethylene into hydrogen chloride and trichloroethylene into phosgene.

Controlling UVR from chronic low-level exposures requires the use of protective clothing and eyewear, sunscreen lotions, and reduced time of exposure. Controlling UVR from acute, high-level photochemical exposures may require proper local exhaust ventilation and isolation of UVR sources from the solvent process. Only qualified personnel

TABLE 7.10

Laser Classification

Class of Laser[a]	Hazard Potential
1	Pose no potential for injury. No safety measures required to either the eye or skin.
2; 2a	Visible beam posing no significant potential for injury. Blinking response limits exposure.
3; 3a; 3b	Modest potential for injury. Normal aversion response is not sufficient to limit eye exposure to a safe level. Skin hazards normally do not exist. May require safety precautions and personal protective equipment. Class 3b lasers require more safety precautions than Class 3a.
4	Serious potential for injury of the eye and skin. Requires safety precautions and personal protective equipment. Diffuse reflection viewing hazard. Potential fire hazard. Most laser systems for cutting, heat treating, and welding are Class 4.

[a] When Class 3 and 4 lasers are fully enclosed to prevent potentially hazardous laser radiation exposures, the system may be classified as a Class 1 system.

should determine the effectiveness of any particular form of personal protection.

Laser Radiation

Laser is an acronym for light amplification by the stimulated emission of radiation. Uses in industry include heat treatment, glazing, alloying, cladding, cleaning, brazing, soldering, conduction welding, penetration welding, cutting, hole drilling, marking, trimming, and photolithography.[31] Health and safety decisions are based on the class of laser and the wavelength of the laser source. The hazard classification system places lasers into four categories depending on their potential to cause harm from direct beam exposures (Table 14D-7). These exposures may result in at least four types of injury to the eyes and skin, each requiring a special consideration for selecting the appropriate personal protective equipment (Table 14D-8).

Nonbeam hazards, however, constitute the greatest source of noncompliance with United States federal safety codes. Some sources of nonbeam hazards include (a) improper electrical design, (b) lack of knowledge for production of laser-generated air contaminants (LGAC), (c) unwanted plasma radiation, (d) excessive noise levels, (e) inadequate ventilation controls, (f) fire hazards, (g) explosion issues from high-pressure tubes, and (h) exposure to toxic chemicals and laser dyes. Most of these hazards are associated with Class 3b and Class 4 lasers. In practice, it is always desirable to totally enclose the laser and beam path to prevent direct beam and nonbeam exposures.

Unlike most other workplace hazards, there is generally no need to perform workplace measurements because of the highly confined beam dimensions, the minimum likelihood of changing beam paths, and the difficulty and expense of laser radiometers. However, measurements must be performed by manufacturers to ensure proper laser classification. Laser safety standards are published by government agencies and independent and industrial standards organizations. In the United States, the American National Standards Institute publishes general safety requirements for users ([ANSI] Z136.1 *Standard for the Safe Use of Lasers*). It is not law but forms the basis for state and OSHA requirements. Other laser safety standards and state-specific regulations exist, but these primarily apply to Class 3b and Class 4 installations and maintenance activities.

The ISO and the International Electrotechnical Commission (IEC) have published standards

TABLE 14D-8

Laser Injuries

Type of Hazard	Laser Wavelength (nm)	Target Tissue	Comment
UV photochemical injury	180 to 400 180 to 400 295 to 380	Skin Cornea Lens	Eye protection is required whenever a bluish-white light is seen at the laser focal point.
Blue-light photochemical injury	400 to 550	Retina	Retinal burn has been referred to as "eclipse blindness."
Thermal injury	400 to 1,400 1,400 nm to 1 mm	Retina Skin Cornea Conjuctiva	Nd:YAG lasers pose the greatest risk because the beam image can be intensified of the order 100,000. Most common injury from laser radiation exposure. Biggest concern with CO_2 lasers.
Near-IR thermal injury	800 to 3,000	Lens	Results from molten metal or large, heated surface during treatment. This hazard is only of concern for repeated, chronic exposures.

similar to those in the United States. Two requirements in the ISO documents that affect manufacturers are (a) all systems must be Class 1 during operation; and (b) the manufacturer must specify which materials the equipment is designed to process. Achieving a Class I laser rating can be done by installing appropriate engineering controls.

Controlling all aspects of potential laser exposures is complex and requires a qualified individual to assess the direct and nonbeam hazards. Control measures include process isolation, local exhaust and building ventilation, training and education, restricted access, proper housekeeping, preventive maintenance, and use of appropriate personal protective equipment.

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The findings and conclusions in this chapter are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

FIFTH EDITION

OCCUPATIONAL AND ENVIRONMENTAL HEALTH

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