CHAPTER 15

Environmental Health Hazard Analysis and Assessment

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15.1 INTRODUCTION[1]

Health hazards associated with both military and civilian systems and equipment involve various aspects of the human–environment interface. The relationship between the environment and human health has been recognized for centuries and has become even more evident as society and technology advance. Often these relationships are considered in very compartmentalized ways such as in the workplace, home, or ambient (outside) environment. In the civilian sector, on the federal level, concerns about workplace health hazards are the responsibility of the Occupational Safety and Health Administration (OSHA). Responsibilities for environmental health hazards outside the workplace are assigned to a variety of other federal agencies such as the Environmental Protection Agency (EPA), agencies within Department of Health and Human Services, Food and Drug Administration (FDA), and others. These responsibilities are similarly divided at state and more local governmental levels. In the military services, programs that address these types of concerns have a variety of descriptors [e.g., environment, safety, and occupational health (ESOH); environmental and occupational health (EOH); and environment, health, and safety (EHS)]. There are specialized professionals and special detection and monitoring equipment and techniques to address issues associated with compartmentalized spaces. For example, an industrial hygienist may only deal with workplaces and use OSHA or National Institute of Occupational Safety and Health (NIOSH) sampling and analytical methods and guidelines to detect and characterize occupational health concerns. An Environmental Health Scientist may only deal with the ambient environment and use EPA sampling and analytical methods and guidelines to detect and characterize health concerns.

For simplicity, we will consider the health concerns that are addressed in this chapter to be within the discipline of *environmental health*. *Environment* is defined as all factors that

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are external to the human body. Thus, environmental health represents the relationship of the human–environment interface. When all environmental factors are considered collectively, they are considered to be the *macroenvironment*. Other, more specific human–environment interfaces, such as workplace exposures, indoor air quality issues, confined spaces, and others, can be considered to be *microenvironments*. When one assesses environmental health impacts, all exposure sources should be considered. Therefore, the risk assessment process (i.e., hazard determination, dose–response assessment, exposure assessment, risk characterization) should include the exposures from all microenvironments.

Many products that we use in our society can have potential dangers that may be inherent in their composition or may result from the way that they are used, stored, or disposed. For example, vehicles that use combustion engines and fossil fuels can generate a variety of potentially dangerous exhaust products such as carbon monoxide. Some vehicles (e.g., large trucks, aircraft, etc.) also can emit high noise levels that may damage hearing. Even the clothes that we wear may be treated with chemicals that can be harmful under certain conditions (e.g., pesticide-impregnated military garments) or they may be a factor associated with the development of temperature-related diseases. The potential dangers can be minimal or negligible if the hazardous component is very small, if people's contact with it is very limited, or if it is shielded to prevent human exposure. In the civilian community federal laws and federal and industry guidelines and practices provide standards and criteria for the safe design of many commodities.

When military equipment and systems are developed or acquired, concerns about many environmental health issues may converge. All of the military services—army, air force, navy, and marines—have formal programs to develop and acquire equipment and systems. And all services focus on health concerns for the people who must use, maintain, or otherwise handle military equipment. These people may be exposed to a variety of environmental health hazards that are chemical, biological, or physical in nature. As part of the human systems integration (HSI) program, the military services are required to have a formal process to evaluate new and modified military systems and equipment for potential health hazards and to acquire recommendations for eliminating or minimizing such hazards during design [U.S. Department of Defense (DoD), 2001].

The following discussion describes the health hazard analysis process applied by the U.S. Army as one example of how a DoD service identifies and mitigates environmental health hazards associated with military equipment and systems during the materiel acquisition process.

15.1.1 U.S. Army Health Hazard Assessment Program

The U.S. Army has consolidated the health aspects of HSI under a single centralized program, the Health Hazard Assessment (HHA) program. The HHA program is part of the army's Preventive Medicine Program; therefore, it applies a public health perspective to prevent soldiers from being exposed to harmful levels of chemical, physical, and biological agents.

The HHA program has a specific responsibility and support structure that promotes interaction between the combat development, materiel development, and medical communities. The U.S. Air Force, U.S. Navy, and U.S. Marine Corps also provide medical consultation, review, and support to their materiel developers but in a more decentralized

manner. This discussion focuses upon the centralized army HHA program as a convenient method of organizing and presenting information about the various health categories. Even though the focus is on the army HHA process, it is the intent of this chapter to reflect state-of-the-art assessment practices for the various health categories. Therefore, from this approach one can extrapolate the technologies to health assessments being performed by other military services for similar or the same health hazards. It should be noted that occasionally there are joint developments where the army, air force, navy, and marines combine resources and efforts to develop materiel to be used by all services. During joint developments the Army may take the lead for the health issues and use the HHA program to identify and assess health concerns.

Combat scenarios and conditions are expected to be extreme, stressful, and harmful to the health and well-being of military personnel. In fact, we have come to expect that in combat, and, to a lesser extent, during military training, some soldiers will be killed or injured from causes other than enemy aggression. These effects are classified as Disease and Nonbattle Injuries (DNBIs) and are reported to account for a significant numbers of casualties (Lynch et al., 1999). Also, as exemplified in the next paragraph and as presented in more detail by Gaydos (1988, 1993), past history shows that military forces have been exposed to stresses from their own weapons and equipment causing adverse health effects and casualties. The adverse health consequences associated with the use of military weapons and equipment contributes to DNBI casualty statistics. Even if disease or death does not occur, such stresses can adversely affect soldiers' ability to perform their mission. The purpose of the HHA program is to eliminate (where possible) or (if not) to minimize such adverse conditions. In doing so, HHA may provide benefits ranging from enhancing soldier capability and mission effectiveness to preventing disease and loss of life.

Since the beginning of the U.S. Army its medical officers, and subsequently the Army Medical Department (AMEDD), have been providing commanders with informal health hazard information about military weapons and equipment. This informal process continued through the Civil War, World War I, and World War II until the late 1970s with issues involving exposure to toxic gases and vapors arising from guns and combustion engines, especially when used in confined spaces such as armored tanks (Gaydos, 1988, 1993). In 1976, blast overpressure hazards were identified during the development of the M198 towed howitzer, and the army surgeon general was asked for help to overcome this hazard (Gross and Broadwater, 1993; Gaydos, 1988). Also during the late 1970s the AMEDD became involved with the assessment of carbon monoxide health hazards from exposure in the Bradley fighting vehicle (Gross and Broadwater, 1993; Gaydos, 1988). In both of these situations the medical community was not involved with the development process until its later stages. The M198 howitzer and Bradley health issues should have been identified and addressed early in the conceptual stages of the acquisition process "to preclude costly and even unacceptable changes" (Gaydos, 1988). These events eventually led to the development of the formal HHA program during the early 1980s. In 1983 U.S. Army Regulation 40-10, *The Army Health Hazard Assessment Program in Support of the Materiel Acquisition Decision Process*, was published and marked the formal beginning of the army's HHA program. Since that time the HHA program has made great strides in providing formal health hazard support to the army's materiel acquisition decision process. For more detail about the history, background, or specific procedures associated with the HHA program, the reader should consult Gross and Broadwater (1993) and Gaydos (1988, 1993).

15.1.2 Military and Equipment Health Hazards

There are nine health hazard categories typically addressed by the HHA program: acoustic energy, biological substances, chemical substances, oxygen deficiency, radiation energy, shock, temperature extremes and humidity, trauma, and vibration. These hazards are listed in Figure 15.1 along with a brief description. A more detailed description of each category and subcategories and examples of the types of equipment and systems that may produce them are provided later in this chapter.

Acoustic Energy
The potential energy that transmits through the air and interacts with the body to cause hearing loss or damage to internal organs,

Biological Substances
The exposure to microorganisms, their toxins, and enzymes.

Chemical Substances
The hazards from excessive airborne concentrations of toxic materials. Exposure occurs through inhalation, ingestion, and skin or eye contact.

Oxygen Deficiency
The displacement of atmospheric oxygen from enclosed spaces or at high altitudes.

Radiation Energy
Ionizing: The radiation causing ionization when interfacing with living or inanimate matter
Nonionizing: The emissions from the electromagnetic spectrum with insufficient energy to produce ionization of molecules.

Shock
The mechanical impulse or impact on an individual from the acceleration or deceleration of a medium.

Temperature Extremes & Humidity
The human health effects associated with high or low temperatures, sometimes exacerbated by the use of a materiel system.

Trauma
Physical: The impact to the eyes or a body surface by a sharp or blunt object
Musculoskeletal: The effects to the system while lifting heavy objects.

Vibration
The contact of a mechanically oscillating surface with the body.

Figure 15.1 Health hazards assessed through the army health hazard assessment program.

This chapter presents the health aspects of HSI by discussing the U.S. Army's perspective as reflected in its HHA program. Each of the nine heath hazard categories and pertinent subcategories are defined and further discussed in terms of the technology to detect, measure, analyze, and assess them. Examples of equipment and systems that produce each hazard are presented in addition to the many professionals who may be involved with the assessment process. There also are discussions about some of the common tools that support the overall HHA program and that are associated with all hazard categories. These include risk assessment and risk assessment codes, the exposure control hierarchy, the medical cost avoidance model, and the hazard tracking database.

15.2 HEALTH HAZARD CATEGORIES

There are nine health hazard categories routinely assessed by the AMEDD in support of the HHA program. This section defines and describes each hazard category, and when necessary subcategories, and provides examples of the types of equipment or systems that may have such hazards.

15.2.1 Acoustic Energy

The health hazard category of acoustic energy refers to the effects that result when people are exposed to *steady-state noise*, *impulse noise*, and *blast overpressure*. This discussion is limited to the health effects that can occur from exposure to such phenomena in air and not in any other media (e.g., water, other fluids, soil, and other solid material).

Acoustic energy is that energy caused by pressure waves that propagate through the air to interact with the body. The risk of injury from the various forms of acoustic energy is directly proportional to the amount of energy that forms the pressure wave. More specific detail concerning the physics of sound (e.g., pressure, intensity, power, frequency, and propagation) may be found in Bruce et al. (1998).

The terms *sound* and *noise* sometimes are used synonymously to refer to acoustic energy. Noise typically is defined as an unwanted or unnecessary sound [American Industrial Hygiene Association (AIHA); 1975]. There also may be psychological and social components to the reaction to noise (e.g., residents in neighborhoods close to airports, military installation, race car tracks, etc.); however, these are not discussed in this chapter.

Sound may interact physically with the body in a manner that can cause an adverse effect. There are two categories of noise that are of interest to the heath hazard assessor: steady-state noise and impulse noise. Blast overpressure is a form of impulse noise that also is addressed here.

Steady-State Noise Steady-state noise is a variation in air pressure around the ambient atmospheric pressure. The duration of the variation exceeds 1 second (U.S. Army, 1996). Steady-state noise can be continuous, intermittent, or fluctuating. The primary health effect that is caused by steady-state noise is hearing loss. Noise-induced hearing loss is progressive, and its onset is generally imperceptible. Initially, individuals may be unaware of any hearing loss and may not have problems in quiet listening situations. Noise-induced hearing loss is characterized by reduced hearing sensitivity at frequencies above 2000 hertz (Hz). Other symptoms may include ringing in the ears

(tinnitus), a temporary muffling of sound after noise exposure, and a sensation of fullness in the ears. Continued, unprotected exposure to hazardous noise levels causes progressive hearing loss into the lower frequencies and a marked loss in communication ability. Individuals with a high-frequency noise-induced hearing loss may complain that they can hear people talking, but they cannot understand their words. Repeated long-term exposure to high-intensity steady-state noise causes permanent hearing loss. Other health effects from exposure to steady-state noise (e.g., tissue heating) is physically possible but has not been encountered at the noise levels generated by equipment evaluated for military use.

There are numerous sources of steady-state noise. Examples found in both military and civilian settings include wheeled and tracked vehicles, self-propelled artillery, aircraft (rotary and fixed wing), communication headsets and speakers, alerting or warning signals, power generators, training simulators, maintenance tools and equipment, gas torches, and compressed air or gas (U.S. Army, 1994a; Gross and Broadwater, 1993; Leibrecht, 1990). People may be exposed to steady-state noise by operating this equipment or simply by being in close proximity of the hazardous noise sources.

Impulse Noise Impulse noise is a variation in air pressure above the average atmospheric pressure lasting less than 1 second (U.S. Army, 1996). This phenomenon is referred to as impulse noise when it causes auditory effects. When there are non auditory effects, it is referred to as blast overpressure (discussed in the next section).

The primary health effect that is caused by impulse noise is hearing loss. At low noise levels, impulse noise does not cause adverse health effects. However, as the noise level increases, it produces a recoverable loss in hearing sensitivity referred to as a temporary threshold shift (TTS). If the TTS is small and recovers rapidly, long-term consequences are minimal. However, the short-term consequences could have adverse effects on performance when the detection of faint sounds is important. A large TTS could indicate an inner ear injury requiring more than 24 hours to recover. An injury of this type could be cumulative and could lead to a permanent hearing loss in addition to an adverse effect on performance that is dependent upon hearing ability. Impulse noise at higher levels can cause larger losses of hearing sensitivity that never completely recover to produce a permanent threshold shift (PTS). The PTS is indicative of a permanent organ injury. A PTS adversely affects hearing-dependent performance. At very high levels, impulse noise can cause tympanic membrane (eardrum) rupture and damage the ossicular chain and inner ear.

A few examples of items that produce impulse noise include pistols, machine guns, grenades, mortars, cannons, tank guns, howitzers, recoilless rifles, rockets, missiles, nuclear explosives, training simulators, and impact tools and equipment (U.S. Army, 1994a; Gross and Broadwater, 1993; Leibrecht, 1990). Some of these items are found in both the civilian and military environments.

Blast Overpressure Blast overpressure is a special case of impulse noise produced generally by the rapid burning of material. A blast wave is characterized as variations in ambient pressure over time (pressure–time history). This increase in ambient pressure is called blast overpressure. The level of blast overpressure in a specific location depends on the energy of the explosion, the distance from the point of detonation, the elapsed time since explosion, and the measurement technique. Fuel air mixtures produce large overpressures with long durations while weapons produce modest peaks with shorter durations.

Blast overpressure can produce nonauditory injuries to gas-containing organs in the body. These include the middle ear, upper respiratory tract, lung, and gastrointestinal tract.

The health effects that occur from blast overpressure exposure can range from those that are transient and insignificant to death. They include trivial surface petechiae, rupture of the visceral pleura, pneumothoraces and hemothoraces, gross hemorrhage, and pulmonary edema.

Examples of typical sources that produce blast overpressure are mortars, cannons, tank guns, howitzers, recoilless rifles, rockets, missiles, explosives, and nuclear warheads (U.S. Army, 1994a; Gross and Broadwater, 1993; Leibrecht, 1990).

15.2.2 Biological Substances

Biological substance health hazards are those that are associated with living organisms or emanate from them. The organisms include poisonous plants and animals and a wide variety of human pathogenic microorganisms and/or their associated toxins. A biological hazard may produce disease, death, or a debilitating condition when the agent is introduced to a susceptible host in sufficient quantity to cause an adverse effect. It may be introduced by ingestion (e.g., contaminated food or water), inhalation (e.g., viruses, mold/fungi spores), skin contact (e.g., poison ivy or oak), or injection (e.g., a snake bite or bee sting).

Biological hazards may come from a broad spectrum of sources that may include microorganisms (e.g., bacteria, viruses, rickettsia, molds, etc), parasites, venomous insects, and other animals (e.g., reptiles, amphibians, marine animals, etc.), insect vectors, and poisonous and toxic plants. More detailed information concerning these types of hazards may be found in Russell (1996), Norton (1996), Kotsonis et al. (1996), U.S. Army (1994b), and Beneson (1990). Some specific examples of biological hazards are

- diseases transmitted to humans by various animal species, primarily insect and rodent vectors, such as malaria, encephalitides, hemorrhagic fevers, Lyme disease, leishmaniasis, plague, and rabies;
- various communicable diseases and allergic-type reactions to animal dander, which cause adverse respiratory or gastrointestinal symptoms resulting in noncombat lost time during training exercises and wartime activities;
- exposure to toxic plants such as poison ivy, poison oak, and numerous other common species;
- exposure to stinging and biting insects and arthropods such as bees, wasps, ticks, flies, mosquitoes, fire ants, spiders, scorpions, and centipedes;
- exposure to species of poisonous lizards and snakes such as Gila monster, coral snake, and pit vipers, including rattlesnakes, water moccasins, and copperheads;
- exposure to bloodborne pathogens such as hepatitis B and human immunodeficiency virus (HIV) as a result of work injury or improper medical waste disposal;
- diseases and debilitating ailments resulting from substandard levels of personal hygiene and sanitation such as dermatitis and other skin diseases, body, head, and crab lice, and scabies; and
- poor sanitation and personal hygiene practice (which includes potential hazards associated with operation of food service facilities and management of field rations), microbiological quality of water supply, solid and liquid waste disposal, management

of sewage disposal, infectious and medical wastes, pest management, graves registration, and field sanitation and personal hygiene practices.

The following are examples of military equipment-related situations encountered during HHAs that require analysis of biological hazards:

- new rations and field-feeding systems (e.g., methods of cooking, packaging, and delivering foods; equipment evaluation of food safety criteria; field cleaning and sanitizing processes; solid and liquid waste disposal; and pest management considerations);
- field water treatment and packaging systems (e.g., microbiological analysis, water treatment methodology, distribution system including plumbing, storage and packaging, and backflow and cross-connection control);
- field waste collection and disposal systems (e.g., field expedient disposal methods, wastewater disposal, recycling requirements, hazardous waste, effluent discharge and runoff, pest management considerations, and pollution prevention);
- field housing units and support facilities (e.g., tents and shelters, laundry and bathing facilities, personal hygiene standards, and pest management considerations); and
- new field uniforms (e.g., construction materials and design, field laundry operation, insecticide impregnation, snake and insect bite protection, and handling if exposed to bloodborne pathogens).

15.2.3 Chemical Substances

Chemicals are prevalent and ubiquitous in the environment. They can occur naturally in the environment; however, many are man made (synthetic) and introduced into the environment through anthropogenic ways. Typically, the HHA program assesses chemicals that are synthetic and/or processed (e.g., mined, refined, etc.) or their by-products. As defined for the HHA program, the chemical substances health hazard category focuses on toxic liquids and solids and excessive airborne concentrations of mists, gases, vapors, fumes, or particulate matter (Gross and Broadwater, 1993).

People or the environment may be exposed to potentially harmful chemicals during the development, use, storage, and ultimate disposal of military equipment. People can be exposed through several routes to include inhalation, ingestion, dermal (skin) absorption, or direct injection (parenteral).

The sources of chemical concerns typically addressed in the HHA process include both military-unique and nonmilitary-unique operations and equipment. Examples of such sources include wheeled and tracked vehicles, vessels, aircraft, weapon systems (e.g., guns, rifles, rockets, missiles, etc.), smokes and obscurants, chemical agents, and maintenance and logistics operations. Table 15.1 presents some examples of military systems that have been evaluated and their associated chemical hazards.

Military-Unique Chemical Standards Some chemical substances are found more frequently in a military environment and/or the nature of the exposure pattern (e.g., frequency, duration, or concentration) is significantly different from that which occurs in non military settings. Therefore, the AMEDD, through its research efforts and in coordination with other military organizations (e.g., the materiel and combat development communities), developed military-unique exposure levels for such substances.

TABLE 15.1 Examples of Military Systems and Associated Chemical Hazards

Military System	Chemical Hazard(s)
Avenger	Hydrogen chloride
Landing Craft Utility	Degreaser, welding and soldering fumes, sanding/grinding particulates
M43A1 Protective Mask	Bromobutyl natural rubber
Theater High Altitude Area Defense System (THAAD)	Diesel engine exhaust, rocket motor propellant and oxidizer, fire-extinguishing agents, nuclear–biological–chemical agents, off gassing
M-109A6 Paladin 155-mm Self-Propelled Howitzer Munitions	Lead
JAVELIN Advance Antitank Weapon System	Lead

Carbon monoxide (CO) is one example of a chemical substance that has unique military concerns. It is a chemical substance most frequently identified as a potential hazard by the HHA program (U.S. Army, 1996). Its military-unique exposure standard is based upon the level of carboxyhemoglobin (COHb) that develops in the blood. Blood levels are determined by taking test data collected from weapon systems (i.e., measured CO concentrations) and applying it to an equation, which also has a computerized format, that was developed to estimate COHb levels (MIL-HDBK-759B, 1992; MIL-STD-1472D, 1989). The equation is also used to determine maximum allowable consecutive executions (MACEs) for firing from weapons systems (e.g., tanks and howitzers) and the number of minutes required between firings to allow predicted COHb levels to drop below allowable guidelines. Additional information concerning the military-unique CO standard can be found in several military references (MIL-HDBK-759C, 1995; MIL-STD-1472F, 1999; U.S. Army, 1996).

There are specific military guidelines for fog oil (U.S. Army, 1990b), some nerve agents (U.S. Army, 1990c), and mustard exposure (U.S. Army, 1991b). More detailed discussions concerning military-unique aspects of carbon monoxide, lead, various types of smokes and obscurants, diesel engine exhaust, and chemical warfare agents can be found in the *U.S. Army Health Hazard Assessors Guide* (U.S. Army, 1996).

The National Research Council's Committee on Toxicology (NRC-COT) develops military-unique exposure limits for a number of airborne contaminants for the DoD and National Aeronautical and Space Administration (NASA). The NRC-COT recommends exposure limits that allow army personnel to function in emergency situations with the unlikelihood of suffering from irreversible health effects. These limits are known as emergency and continuous exposure guidance levels (EEGLs) and short-term public emergency exposure limits (SPEGLs) (NRC, 1984a–c, 1985a,b, 1986, 1987, 1988). The specific chemicals are listed in Table 15.2.

15.2.4 Oxygen Deficiency (Ventilation)

The oxygen deficiency category addresses a variety of situations and conditions that affect the availability of oxygen in breathable air. This section discusses low oxygen concentrations as they relate to confined spaces, enclosed spaces, and ventilation needs.

TABLE 15.2 Specific Chemicals Addressed in Emergency and Continuous Exposure Limits for Selected Airborne Contaminants (EEGLs) and Short-Term Public Emergency Exposure Limits (SPEGLs)

Volume	Chemicals
1	Acetone, acrolein, arsine, carbon disulfide, chloroform, fluorine, mercury vapor, methane, ozone, sulfuric acid
2	Chlorine; chlorine trifluoride; ethanolamine; fluorocarbon 11, 12, 21, 113, 114; isopropyl alcohol; phosgene; sodium hydroxide; sulfur dioxide; vinylidene chloride; xylene
3	Bromotrifluoromethane (Halon 1301)
4	Aluminum oxide, carbon monoxide, ethylene glycol, hydrogen sulfide, methanol, nitrogen dioxide, nitrogen tetroxide, nitrous oxide
5	Hydrazine, monomethylhydrazine, 1,1-dimethylhydrazine
6	Benzene, ethylene oxide
7	Ammonia, hydrogen chloride, lithium bromide, toluene
8	Lithium chromate, trichloroethylene

An *oxygen-deficient atmosphere* is an atmosphere that contains less than 19.5 percent oxygen by volume (29 CFR 1910.146). *Ventilation* is one of the principal methods to control health hazards and may be defined as causing fresh air to circulate to replace contaminated air (Olishifski, 1985).

A *confined space* is an enclosed area that is large enough to accommodate a person's body, has limited means for entry and exit, and is not designed or intended for continuous human occupancy (Schroll and Harris, 1998). A confined space may create conditions that can affect the nature of its atmosphere. Oxygen deficiency may occur when gases or vapors exceed their upper explosion limit and when oxygen is consumed by chemical reactions (e.g., rusting) or biological reactions (e.g., biological breakdown of organic materials). Also, oxygen can be displaced by an inert gas (e.g., nitrogen) or by the operation of an internal combustion engine (Schroll and Harris, 1998; Todd, 1998). In addition to causing oxygen-deficient atmospheres, confined spaces also may concentrate air contaminants to hazardous levels, cause dangerous oxygen-enriched environments, and have an internal configuration that can cause its contents to trap, crush, and/or asphyxiate someone (NIOSH, 1979). Additional information concerning the characteristics of confined spaces may be found by referring to Dinardi (1998), NIOSH (1979), and OSHA standards (29 CFR 1910.146).

Similar to confined spaces, the military considers the health aspects of *enclosed spaces*. Enclosed spaces differ from confined ones in that they are designed for detail work or occupancy for extended periods of time and are designed to receive adequate ventilation (MIL-HDBK 759B, 1992).

Examples of confined spaces include but are not limited to storage/holding tanks, vessels, silos, pits, sewers, pipelines, tank cars, boilers, septic tanks, and utility vaults. Examples of enclosed spaces that are frequently encountered in the military include mobile vans, shelters, crew compartments, and vehicle cabs (MIL-HDBK 759C, 1995).

15.2.5 Ambient Pressure Changes

The human body can experience oxygen deficiency effects that result from decreased barometric pressure. Reduced atmospheric pressure decreases the rate at which oxygen diffuses into the blood. Thus, people who are exposed to low-pressure environments suffer

the effects of a variety of hypobaric health hazards, which may include hypoxia, Benign Acute Mountain Sickness (Benign AMS), AMS, and Chronic Mountain Sickness (Monge's Disease) (Popendorf, 1998).

Hypobaric hypoxia can affect mental performance, judgment, sleep, and physical work capacity (Fulco and Cymerman, 1988; Houston, 1984). Specific information concerning, AMS can be found in a variety of references (Fulco and Cymerman, 1988; Hackett and Roach, 1987; Houston, 1984; Young and Young, 1988; Hackett et al., 1976, 1989; Hackett and Rennie, 1977; Montgomery et al., 1989; Reeves and Schoene, 1991; Tso, 1992). Based upon these references, the following paragraphs briefly describe AMS-associated effects and conditions. For more detail, the reader should consult the aforementioned references.

Benign AMS can occur when people move to higher elevations in a short period of time. Headache, anorexia, nausea, insomnia, labored breathing, and general weakness characterize its effects. These may occur as one ascends, but typically the effects occur 6 to 48 hours later, and they usually disappear in 3 to 5 days. Acute mountain sickness is rare below 2400 m (8000 ft) elevation but is very common above 3600 m (12,000 ft).

Acute mountain sickness (other than benign) is characterized by high-altitude pulmonary edema (HAPE) and/or high-altitude cerebral edema (HACE). The progressive symptoms of HAPE include fatigue, labored breathing on exertion, nonproductive cough, labored breathing at rest, a cough progressing from producing frothy white to slightly bloody sputum, and coma followed by death within 6 to 12 hours. High-altitude cerebral edema can occur in mountaineers who ascend rapidly to altitudes higher than 2400 m. Often occurring in conjunction with HAPE, HACE is a complication that results from rapid exposure to very high altitudes. It is characterized by mental dysfunction (hallucinations, bizarre behavior) and neurological abnormalities (ataxia, paralysis, cerebellar signs) and may progress to coma and death.

Monge's disease is similar symptomatically to benign AMS and may exhibit characteristics of HACE. However, it is rare and occurs after chronic (years of) exposure (Popendorf, 1998).

Decompression sickness (DCS) also can occur at high altitudes and is similar to that associated with diving (Popendorf, 1998). Even though it is not a cause of oxygen deficiency, DCS is considered when assessing barometric risks.

Environments that have decreased barometric pressure are found at high terrestrial elevations or are simulated in a hypobaric chamber. Typical occupations that encounter the elevation hazard include high-altitude construction, mining, and aviation (Popendorf, 1998). The military deploys its forces to terrestrial altitudes that are greater than 2500 m (8200 ft) where their health and performance can be affected adversely. Many strategic areas of the world, including the Middle East, Asia, and South America, contain land areas with elevations greater than 3000 m (10,000 ft) (U.S. Army, 1975). Military personnel deployed to these elevations are exposed to the hazards of hypobaric hypoxia and the AMSs presented in this section.

A hypobaric chamber facility can simulate high-terrestrial-altitude conditions by reducing the chamber pressure using vacuum pumps. These chambers are used to observe and determine the effects of hypobaric conditions on people in laboratory studies.

15.2.6 Radiation Energy

Radiation is electromagnetic energy that can be divided into two broad categories—that which causes matter to ionize (i.e., *ionizing radiation*) and that which does not cause

matter to ionize (i.e., *nonionizing radiation*). Both nonionizing and ionizing radiation can be further subclassified by wavelength, frequency, and energy (Fig. 15.2). The types of nonionizing radiation and fields include ultraviolet, visible light, infrared, microwaves, radar, television, radio waves, extremely low frequency, electric fields, and magnetic fields. Ionizing radiation types are X-rays, gamma rays, and cosmic rays. This section presents and discusses health hazard issues associated with both nonionizing and ionizing radiation.

Nonionizing Radiation The following discussion is organized by first presenting information that generally applies to all forms of nonionizing radiation. Subsequent subparts of this nonionizing section provide information specific to laser/optical radiation and radio-frequency radiation (RFR), respectively. Even though the nonionizing radiation spectrum includes several types of radiations, the focus of the HHA radiation energy health hazard category, and subsequently this subsection, is on laser optical radiation. In addition to information about RFR and laser, discussions about other forms of nonionizing radiation and other forms of optical radiation can be found in Hitchcock et al. (1998) and Moeller (1997). The American Conference of Governmental Industrial Hygienists (ACGIH) (2002) presents Threshold Limit Values (TLVs)® for RFR and laser sources, in addition to TLVs for magnetic fields, microwave radiation, light and near-infrared radiation, and ultraviolet radiation.

Injury from exposure to nonionizing radiation occurs when energy is absorbed by biological tissue. The mechanism and type of tissue injury varies and depends upon the part of the electromagnetic spectrum that is involved. Photochemical effects dominate when energy is absorbed from ultraviolet and short-wavelength visible radiation exposure. Thermal effects dominate when there is exposure to visible and infrared optical radiation. For most of the nonionizing radiation spectrum, the effect is limited to superficial organs such as the skin and eyes.

Nonionizing radiation does not create ions when interacting with matter. Because ions are charged particles, they are chemically more active than their electrically neutral forms. Chemical changes that occur in biological systems are cumulative and can be detrimental or even fatal. By contrast, the biological effects of nonionizing radiation are caused primarily by thermal stress (i.e., the accumulation of heat). When heat is dissipated, the effects do not persist (they are not cumulative). When the thermal stress is extreme, however, persisting injuries such as erythema, cataracts, and burns can occur.

Laser Optical Radiation Lasers emit light in a very narrow bandwidth (i.e., a single wavelength or color (monochromatic)) that propagates in a highly directional manner characterized by low divergence (beam spread) (Hitchcock et al., 1998).

Optical (laser) radiation occupies that portion of the electromagnetic spectrum that is the optical radiation region (Fig. 15.2). The eye is the most susceptible organ system to laser radiation in the visible and nonvisible infrared region of the spectrum, because the incident energy is focused to a small spot on the sensory retina.

Optical radiation is emitted by a large variety of army systems. These include communications systems, combat surveillance systems, fire control systems, and target acquisition systems. In addition to laser radiation, some systems also are high-intensity light sources. Optical radiation in this spectral region also may be emitted secondarily from rocket exhausts, the detonation of explosives, and warm bodies.

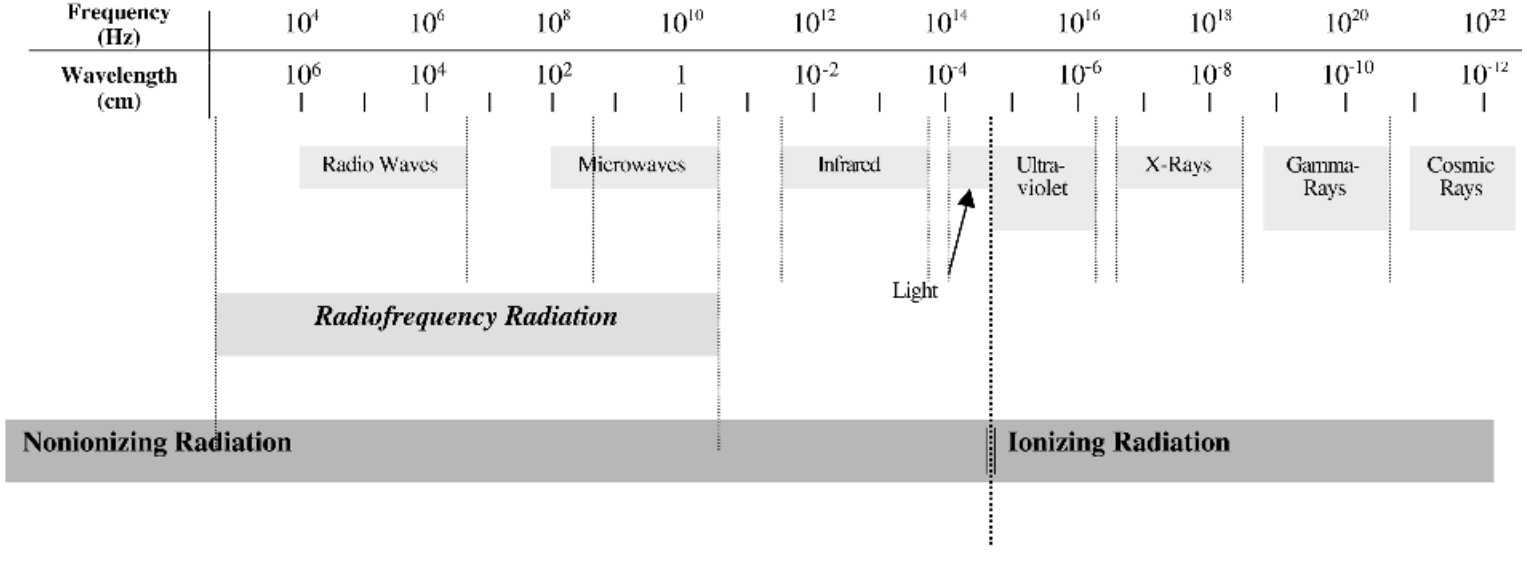

Figure 15.2 Electromagnetic spectrum showing approximate frequencies in cycles per second (H_2) and wavelengths in centimeters (cm) of selected types of radiation.

Radio-Frequency Radiation The approximate location of RFR on the electromagnetic spectrum can be seen in Figure 15.2. It can heat tissue to cause a radio-frequency (RF) burn, which can be internal and life threatening. Another cause of biological effects is the induction of RF current in the body. This RF current can stimulate nervous tissue resulting in shock effects.

When RFR is absorbed by biological tissue and converted to heat, if the amount of energy absorbed exceeds the body's ability to dissipate heat, thermal stress or injury can occur. The site of energy absorption varies depending upon the orientation of the individual and the frequency of the energy. In the upper frequency bands (used by radars and satellite/communication sets), the effect is limited to external organs such as the eyes and skin. Internal organs may be affected at lower frequencies as the result of deep-body heating or induced currents. Other factors that influence individual sensitivity to RFR are the individual's unique physiology (especially height, weight, and gender) and the external environment (such as temperature and humidity). Furthermore, energy deposition is not uniform throughout the body but is a function of the dielectric characteristics of various body tissues.

During the operation of most RFR sources, users are exposed to low levels of RFR; the amount of RF energy absorbed does not stress the thermoregulatory system. Consequently, no effects are observed and individuals cannot perceive the RF energy being absorbed. There are no known long-term health effects from chronic exposure to low-level RFR. The perception of RFR does not imply that an injury has occurred, especially when most of the energy is deposited near the surface of the skin where temperature sensors abound. It is expected that many systems' operators will at some time in their career perceive a mild warming sensation near an RFR source. A few systems are capable of producing painful RFR intensities if the exposure is long enough. Although there may be no damage, the exposed individual will likely avoid repeating the encounter. In extreme cases, the incident could affect the operator's performance. For increasing intensities and exposure times, the threat of tissue damage increases. Acute effects such as cataracts and burns are possible. Ultimately, the injury may become life threatening or cause a permanent disability.

For RFR less than 100 megahertz (MHz), RF shock and burn may result from induced current. Two interactions may result relative to one or both of these effects: either a spark discharge, when one is close to an RF energized conductor, or a current or flow to ground while one is making contact with an RF energized conductor. The spark discharge phenomenon is comparable to what happens after walking on a carpet and touching a grounded object—a spark is drawn. A burn results if enough current enters the body through a small cross section. Spark discharges are expected near an antenna; however, these discharges are unacceptable coming from the transmitter chassis. The threshold for RF current perception is a function of frequency, surface area of the contact point, and individual sensitivity. The current is perceived as heat if it is above 100 kilohertz (kHz). It is perceived as a tingling sensation if the current is below 100 kHz. Although the limits are intended to prevent perception, there is no threat associated with it. The next effect is annoyance resulting from mild shocks. The individual will act to avoid repetitive shock. Individuals startled by an RF shock could injure themselves or someone else while jerking away from the source of the shock. Several serious effects may occur below 100 kHz and at sufficient current densities. Life-threatening situations can result when individuals are unable to release the conductor; they may be unable to breathe or their heart may fibrillate. Fortunately, there are very few tactical systems operating in this frequency range.

Interference with electronic life support systems (e.g., pacemakers) is an indirect effect of RFR exposure. The FDA tests all such devices to ensure that they are not susceptible at the RFR levels frequently encountered. Due to advances in pacemaker technology, the potential for pacemaker interference is virtually nonexistent.

Radio-Frequency electromagnetic waves are emitted by a large variety of army systems for communications, combat surveillance, fire control, and target acquisition. These waves are produced by converting electricity into RFR using various types of generators. It has nothing to do with radioactivity, and natural sources of RFR are inconsequential. Furthermore, unless the generator is operating, RFR will not be present. In fact, many systems are designed to minimize the amount of radiation emitted to prevent detection. These sources of RFR include the following types of systems: radars, radios, satellites communications set, industrial sealers, and electronic countermeasures sets [see U.S. Army (1996) for additional information concerning these systems].

Ionizing Radiation Ionizing radiation is electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter. Examples of ionizing radiation are alpha and beta particles, X-rays, gamma rays, neutrons, and heavily charged ions. The reader should consult the HHA *Assessor's Guide* (U.S. Army, 1996), McCarthy (1998), and Moeller (1997) for additional information concerning ionizing radiation measurement units and typical natural and iatrogenic exposures. The ACGIH (2002) presents TLVs for ionizing radiation.

The absorption of ionizing radiation in biological material may lead to excitation or ionization. In humans this may be demonstrated by genetic and somatic effects. The induction of cancer is the primary somatic effect. Other somatic effects include effects on growth and development, cataract of the eye lens, life shortening, fertility, and sterility. Exposure *in utero* may induce cancer during childhood. The genetic effects through mutagenesis are expressed, not in the irradiated individuals, but in their immediate or remote offspring.

There are electronic devices that are capable of emitting ionizing radiation (U.S. Army, 1996). Examples of these are X-ray machines, linear accelerators, electron microscopes, cyclotrons, RF generators that use klystrons or magnetrons, and other electron tubes that produce X-rays. There also are materials or combinations of materials that emit ionizing radiation. Such materials may be special nuclear material such as plutonium or enriched uranium; source material such as uranium or thorium; by-product material such as any radioactive material yielded in or made radioactive by exposure to radiation incident to the process of producing special nuclear material; naturally occurring or accelerator-produced radioactive material (NARM), such as radium, classified as source material; and materials containing induced or deposited radioactivity.

Ionizing radiation is used directly in army materiel systems as calibration and check sources for radiation, detection, indication, and computation (RADIAC) or other survey-type instruments, as a source of radio luminescence in meters and gauges, as an ionization source in various devices, and as radiographic sources. Indirectly, ionizing radiation may be emitted from an army materiel system as natural radioactivity or radioactivity incorporated into material or a component of the system.

15.2.7 Shock (Acceleration, Deceleration)

Shock is a health hazard category that has been evaluated infrequently in the HHA program. Consequently, its concepts, hazard evaluation, risk concerns, and implications

toward soldiers have not been fully developed. In 1995, the health hazard community developed an assessor's guide to describe various health hazards associated with military systems and to document how the risks from being exposed to such hazards were estimated (U.S. Army, 1996). Shock was not included in this guide and was to be included at a later date. However, some concepts concerning this area of health hazard concern were assembled. These concepts are presented here but are not intended to be the definitive approach to evaluating shock in the HHA process. Rather, they are presented only to give the reader some idea about some of the factors that need to be considered when shock is assessed as a health hazard. The following information is compiled from a number of references to include the Society of Automotive Engineers standards (SAE, 1986, 1995).

Shock, impact, and *impulse* are terms used to describe the rapid and violent application of mechanical forces to the human body. These forces are characterized by short durations and high magnitudes. Impact injury may be described by the deformation of body tissues in excess of their failure limits, resulting in the destruction of their anatomical structures and, more importantly, the disablement of their physiological functions. The parameters of impact and the physical response of the human body are the focus of biomechanics research that attempts to understand the mechanisms of injury and to determine limits of human tolerance to impact.

Impact is considered to be *blunt* when the forces are distributed over some area of the body and do not cause penetrating injury. Examples of extremely short blunt impacts, 5 to 10 milliseconds (msec) in duration, are those produced by the rear surface of a body armor as it defeats a bullet or by the striking of the exposed head against rigid surfaces. When the direct blunt impact is cushioned by soft tissues of the body, such as blows to the abdomen, or when the striking surface deforms under impact, as in the case of energy-absorbing steering columns in modern automobiles, forces of 10 to 50 msec in durations are generated in the interaction.

Indirect impacts where the forces are generated as a result of sudden whole-body *accelerations* or *decelerations* are generally the longest type of impact, with durations ranging from 50 to 250 msec. For example, the crewmember in a ground vehicle is subjected to whole-body deceleration when the vehicle is brought to a sudden stop. Another example of whole-body deceleration is exposure of the seated pilot during a vertical helicopter crash. Examples of whole-body impact acceleration include a mine blast under a truck, the ballistic impact of a missile with a tank, and the seat ejection of a fixed-wing aircraft.

Penetrating injuries, which are produced by high-speed missiles or sharp objects, involve the concentration of forces over a small area of the body. Because the magnitudes and durations of such forces are difficult to measure, the severity of the impact is generally characterized by the energy of the striking object.

Impact to the human body may occur as a result of aircraft crashes, ground vehicle accidents, mine explosions, parachute opening shocks, landing falls, weapon recoil, and other interactions between the soldier and his or her environment during training or battle missions.

15.2.8 Heat Stress

Exposure to excessive heat levels can cause heat stress, which can lead to heat strain. This section briefly describes and characterizes these conditions and the factors associated with

them. The information presented here is based on selected references (U.S. Army, 1980a, 1996; ACGIH, 2002; Burr, 1991; Gagge and Gonzales, 1996; Levine et al., 1995; Sawka et al., 1993, 1996; Stephenson and Kolka, 1993; Bishop, 1998; Ramsey and Beshir, 1998; NIOSH, 1986). The reader should consult these references for additional detail.

Heat stress is the product of an interaction of work activity (e.g., a military mission) and environmental factors with physiological factors (U.S. Army, 1996). Work activity can be characterized by factors such as clothing, load carried, terrain, and work rate. Environmental factors include temperature, humidity, solar load, and wind speed. Examples of physiological factors include fitness, hydration, acclimatization, rest, nutrition, medication, and health.

Heat stress can lead to heat strain. Heat strain is characterized by one or more of the following: hyperthermia, increased sweating rate (this decreases heat stroke), dehydration, compromised cardiovascular control, and an increased heart rate (U.S. Army, 1996). Heat strain can result in heat-related injuries such as heat cramps, heat exhaustion, and heat stroke. Mental and physical performance decrements can occur at dehydration levels that are higher than and/or hyperthermic levels lower than those that cause injury. Heat cramps and heat rash also can develop from excessive exposure to heat (Bishop, 1998).

Heat strain is caused by the interaction of work activity (e.g., a military mission) and environment with individual physiological factors (U.S. Army, 1996). The type, intensity, and duration of physical work required by an activity directly affects metabolic heat production. Clothing, especially chemical-protective (CP) clothing and equipment (e.g., heavy backpacks, heavy and/or awkward equipment, etc.), can have a profound affect on bodily heat production and storage. Chemical warfare (CW) treatment drugs such as atropine also increase heat storage by inhibiting sweating.

Environmental factors, such as ambient temperature, humidity, radiant-heat load, and wind speed, affect heat balance. If the ambient temperature (measured as dry-bulb temperature) is sufficiently hot (i.e., greater than or equal to body temperature), it will prevent direct heat transfer away from the body by convection/conduction and radiation. Evaporation will be the only route available for heat loss. Wind speed can aid evaporative heat loss, but clothing, vehicles, and shelters will impede evaporation. If the ambient humidity [measured as dewpoint temperature, wet-bulb temperature, vapor pressure or relative humidity (RH)] is high (i.e., greater than 50% RH), evaporative heat loss is compromised, and heat production by or heat transfer to the body cannot be dissipated.

Individual physiological factors that affect thermoregulation and heat balance include the following: acclimation status, aerobic fitness, hydration and nutrition, general health, use of pharmaceuticals, skin disorders, febrile illness, sleep status, age, gender, and anthropometric factors (i.e., body fat, size, surface area) (U.S. Army, 1996). For more detailed discussion on heat stress, thermoregulation, metabolic heat, and environmental factors associated with heat stress, the reader should consult Bishop (1998), Ramsey and Beshir (1998), and the HHA *Assessor's Guide* (U.S. Army, 1996).

Shelters, vehicles, and clothing are examples of military materiel systems that may cause heat stress. Shelters may cause heat stress if adequate air ventilation and air conditioning are not maintained. Consideration must be given to the added heat load of heat-generating equipment, such as computers, when assessing the heat stress or workspaces. Vehicles also may cause heat stress if air ventilation and/or air conditioning is inadequate. Again, consideration must be given to any additional heat-generating sources such as engines, which should be adequately insulated from the crew compartment.

Garment systems, especially CP garments, can interfere with thermoregulation by impeding evaporation of sweat, the most important physiological mechanism for dissipating heat in hot environments.

15.2.9 Cold Stress

Exposure to low temperatures can cause cold stress and injuries. The following paragraphs briefly describe and characterize these conditions and factors associated with them and are based upon selected references (Burr, 1993; U.S. Army, 1976; DoD, 1988; Freund et al., 1994; Young, 1988; Young et al., 1992a,b, Bishop, 1998; Ramsey and Beshir, 1998; ACGIH, 2002). The reader should consult these references for additional detail.

Cold stress is the product of an interaction between work activity and environmental factors (U.S. Army, 1996). Work activity can be characterized by factors such as type of physical work and its associated metabolic rate, work duration and intensity, clothing worn, equipment used, and exposure to wetness. Environmental factors include ambient air temperature, humidity, water temperature (if immersion occurs), humidity, radiant or solar load, terrain (including snow consistency and depth), exposure to wetness, and wind speed. Cold temperatures interact with wind to enhance cooling power, which commonly is referred to as *windchill*. Physiological factors (e.g., rest—sleep status), nutrition, dehydration, general health, medication, anthropometry, age, gender, and training also interact to affect the susceptibility to cold injury. Using CW treatment drugs also affects susceptibility to cold stress.

Cold temperatures can cause a general decrease in body temperature and/or affect specific body areas (U.S. Army, 1996). Generalized cold injury is called *hypothermia*, which is the reduction of body-core temperature. Hypothermia can affect the cardiovascular system and victims may lose consciousness (ACGIH, 2002). Other effects include loss of manual dexterity and fine motor skills, decreased visual acuity, and some psychological responses (Ramsey and Beshir, 1998).

Cold temperatures also can cause freezing injuries (frostnip and frostbite) and nonfreezing injuries (chilblains, trench foot, and immersion foot) to exposed skin and peripheral extremities (e.g., hands, fingers, feet, toes, nose, etc.). Cold stress causes shivering. It also affects peripheral and superficial (skin) blood vessels by causing them to constrict, especially in the extremities, nose, and ears. Other responses to cold stress include skin cooling and reduced blood flow to the hands and feet that can lead to blunted sensations of touch and pain and loss of dexterity and agility during cold exposures longer than an hour. Dehydration can impair performance and increase the risk of injury. It is a response to cold-induced diuresis and/or inadequate fluid intake or nutrition.

Shelters, vehicles, and clothing are examples of military materiel systems that may cause cold stress (U.S. Army, 1996). Shelters may cause cold stress if adequate heating is not maintained. Vehicles also may cause cold stress if heating is inadequate. Clothing systems can cause cold stress and injury if they are not properly insulated, layered, and ventilated. Nonfreezing injuries may occur if clothing restricts blood circulation and the hands or feet get wet.

15.2.10 Trauma (Physical and Musculoskeletal)

Trauma is a health hazard category that has been evaluated infrequently in the HHA program. Consequently, its concepts, hazard evaluation, risk concerns, and implications

toward soldiers have not been fully developed. In 1995, the health hazard community developed an assessor's guide to describe various health hazards associated with military systems and to document how the risks from being exposed to such hazards were estimated (U.S. Army, 1996). Trauma was not included in this guide and was to be included at a later date. However, some concepts concerning this area of health hazard concern were assembled. These concepts are presented here but are not intended to be the definitive approach to evaluating trauma in the HHA process. Rather, they are presented only to give the reader some idea of some of the factors that need to be considered when trauma is assessed as a health hazard. The primary focus of this section is limited to health consequences addressed by the U.S. Army's ergonomics program. Consequently, much of this presentation is taken directly from the army's pamphlet that addresses the ergonomics program (U.S. Army, 2000). DiNardi (1998) provides specific details about work-related musculoskeletal disorders (WMSDs), work method evaluations, and epidemiological evidence. Other references that the reader may consult for additional information include those by Snook and Ciriello (1991, 1974), Snook and Irvine (1968), Ciriello and Snook (1978, 1983), Snook et al. (1970, Snook (1985), Garg and Ayoub (1980), Ayoub et al. (1980a,b), Asfour et al. (1986), and Ayoub (1991).

The ACGIH identifies ergonomics as "the term applied to the field that studies and designs of the human-machine interface to prevent injury and illness and to improve work performance" ACGIH (2000, p. 109). DiNardi (1998, p. 727) describes ergonomics as "the science of fitting workplace conditions and job demands to the capabilities of the work population." The American Industrial Hygiene Association recognizes that ergonomics is "a multidisciplinary science that applies principles based on the physical and psychological capabilities of people to the design or modification of job, equipment, products, and workplaces" DiNardi (1998, p. 727). Other terms for WMSDs include cumulative trauma disorders (CTDs), repetitive-motion illnesses (RMIs), and repetitive strain injuries (RSIs) (ACGIH, 2002).

The WMSDs are caused or aggravated by repeated biomechanical stress and microtrauma (U.S. Army, 2000). Over time, repeated microtrauma can evolve into a painful, debilitating state involving muscles, tendons, tendon sheaths, and nerves. Some examples of WMSDs include tendonitis, tenosynovitis, bursitis, chronic muscle strain, and nerve entrapment syndromes (e.g., carpal tunnel syndrome).

There are specific workplace conditions that can contribute to the development of WMSDs (U.S. Army, 2000). These are considered to be occupational risk factors and include the following: repetitive motions (especially during prolonged activities), sustained or awkward postures, excessive bending or twisting of the wrist, continued elbow or shoulder elevation (e.g., overhead work), forceful exertions (especially in an awkward posture), excessive use of small muscle groups (e.g., pinch grip), acceleration and velocity of dynamic motions, vibration, mechanical compression, restrictive workstations (e.g., inadequate clearances), improper seating or support, inappropriate hand tools, machine-pacing and production-based incentives, extreme temperatures, and extended exposure to hazardous or annoying noise. The combined effect of several risk factors in one job or workstation may lead to a higher probability of causing a WMSD.

There are many jobs that can cause WMSDs. In addition to the workplace conditions identified in the army ergonomics pamphlet (previous paragraph), DiNardi (1998) also lists some of the typical job activities associated with common CTDs of the upper extremities. These activities are diverse and include functions such as turning screws, grinding, buffing, polishing, hammering, surgery, typing, keying, wiring, etc. Given such diversity,

it is not difficult to conclude that most military systems and equipment, either by their use or maintenance, are potential candidates for causing or aggravating WMSDs.

15.2.11 Vibration

When a vibration phenomenon involves the entire body, it is known as *whole-body vibration (WBV)*. When only specific parts of the body are involved, it is described as *segmental vibration*. Segmental vibration usually occurs to the hands, wrist, and arms and also may be described as *hand-transmitted vibration*. The primary focus on vibration hazards in the HHA program has been with WBV associated with vehicles. Consequently, the majority of this presentation is on WBV.

Vibration is an oscillatory motion characterized by alternate increase and decreases in displacement (U.S. Army, 1996). Oscillatory motions or vibrations in the human usually occur through physical contact with a vibrating source. Whole-body vibration occurs when oscillatory motions are transmitted to the entire body through contact with a vibrating source at the feet of a standing individual, at the buttocks of a seated individual, and along the entire side of the body of a supine individual.

Segmental vibration occurs when a specific body segment is in contact with a vibrating source, but the vibrations are not typically transmitted to other parts of the body. The major area of concern for segmental vibration is the hand–arm system; therefore, this also is referred to as *hand-transmitted vibration*. Griffin (1990) identifies disorders related to hand-transmitted vibration to include those associated with the vasculature, bones and joints, peripheral nerves, musculature, central nervous system, and the whole body. Additional information concerning hand-transmitted vibration can be found in Bruce et al. (1998) and ACGIH (2002).

Resonance is a factor that affects the hazard potential of vibration exposure. Resonance describes the interaction between the human body and a vibration source such that the body causes the vibration to amplify. This resonant vibration can cause large displacements in the body, which can result in damage (Bruce et al., 1998).

Signatures obtained from military ground vehicles operating over secondary and cross-country routes suggest that the traditional methods of defining oscillatory motion and evaluating the effects of vibration during operation of these vehicles may not be adequate (U.S. Army, 1996). These signatures are categorized as *repetitive impact* or *repeated impact* and are defined as broadband vibrations with embedded shocks. Vibration with high crest factors (ratio of peak acceleration to the root-mean-square acceleration) is considered to be repetitive impact. Military research suggests that evaluation criteria separate from that of International Organization for Standardization (ISO) 2631 (ISO, 1985) is required to assess repetitive impact for military equipment and scenarios (U.S. Army, 1996; Village et al., 1995a–c; Cameron et al., 1995).

The effects associated with exposure to vibration include physiological changes, discomfort, performance decrements, pain, and degenerative processes (U.S. Army, 1996). Examples of physiological effects include increases in heart rate, respiration rate, cardiac output, mean arterial blood pressure, pulmonary ventilation and oxygen uptake, and hyperventilation (U.S. Army, 1996). Discomfort and pain have been observed to affect the lower back, gastrointestinal and stomach areas, and thoracic area (U.S. Army, 1996; Henzel et al., 1966; Temple et al., 1965). Low-back discomfort can ultimately lead to clinical diagnosis of degenerative diseases, including herniated discs, osteochondrosis, spondylosis, and other disorders of the spinal column (U.S. Army, 1996; Bruce et al.,

1998). Among the field studies, back disorders were by far the most widely reported illness or injury associated with WBV (U.S. Army, 1996).

Back pain has been associated with the prolonged and repeated operation of both air and ground military vehicles, and vibration exposure is considered to be a factor in the generation of these symptoms (U.S. Army, 1996). Military helicopter pilots have reported symptoms of low-back pain and general discomfort after about 4 hours of flight (VanIngen-Dunn and Richards, 1992). Some air force and army helicopter pilots have reported that back pain disappears immediately upon removal of the vibratory stress associated with helicopter flight. Others have reported that it takes four to five days for the pain to disappear.

There are few studies on vibration conducted with women subjects. Those that exist have found that women are more sensitive to higher frequencies, but there appear to be no reported significant differences in comfort (U.S. Army, 1996). However, there are reports of increased gynecological and menstrual disorders in female drivers exposed to WBV (Böhm, 1964; Brovko, 1975).

The primary source of WBV is from transportation vehicles, including ground, air, and water vehicles. Vehicle vibrations can be generated by exposure to specific environmental conditions (e.g., ground terrain, wave conditions) and/or vibrations occurring by design (e.g., engines, rotor blades, etc.). These vibrations are transmitted to the operator or the passenger. Other sources of WBV include heavy machinery and buildings and vibrations that are transmitted directly through air or water. For example, military ground crews can be exposed to WBV resulting from exposure to aircraft propeller washes.

The primary source of segmental vibration occurs with the operation of hand tools. Tools that produce the most severe vibrations include chain saws, jackhammers, and tools used in a factory environment.

Whole-body vibration exposure and its consequences are unique in the military environment as compared to the civilian community (U.S. Army, 1996). The exposures are typically much longer due to the need for extended operations, and the vibrations are more severe due to the adverse conditions encountered in some military environments. This is a consequence of the greater maneuverability and speed required of these vehicles for combat readiness, effectiveness, and survivability. The wide range of operational capabilities required of military vehicles is the primary reason that military-unique standards will be developed and recommended for assessing WBV health hazards.

15.3 TOOLS AND TECHNIQUES

Regardless of the hazard category that is evaluated, health hazard assessors rely upon various tools and techniques to help estimate and characterize potential risks. Generally, these tools and techniques can be characterized as those that are used to detect and quantify potential hazards, methods to assess potential health impacts, and control measures to eliminate or reduce hazards to acceptable levels. This section presents information about the various tools and techniques that are applied to the various HHA categories.

15.3.1 Acoustic Energy

The tools and techniques that are applied to assess acoustic energy health hazards are associated with measuring noise sources and acquiring data and the interpretation of the

measurements. Based upon the measured levels and the potential risk, various controls can be recommended to eliminate or reduce hazardous noise levels.

There are several types of devices that can be used to measure noise. These include sound-level meters, noise dosimeters, sound intensity meters, narrow-band analyzers, tape recorders, and graphic-level recorders. Some sound-level meters are able to record a "peak" response and measure impulse noise. Refer to discussions by Bruce et al. (1998) for detailed information concerning instruments typically used to measure and assess noise levels.

When noise levels are recorded, the unit of measurement typically is in decibels (dB), a logarithmic scale. Sound can be measured on several response scales depending upon its nature (i.e., steady state, impulse, etc.). The frequency scale may be a flat response or it may be weighted. For example, when steady-state noise is measured with a sound-level meter, it is set on a scale that approximates how the human ear responds to sound. This is an A-weighing network; therefore, the measurement units are expressed as dBA. Noise data also may and should include an octave-band analysis to assess the contribution of various frequencies.

The measurement requirements for military equipment are detailed in a military standard (MIL-STD-1474D, 1991). Typically, measurements are taken at each operator and crew position and at representative positions where individuals are likely to be located during typical system operation. The measurements are made with the system and all auxiliary equipment operating in a normal mode. The data acquired from measuring noise levels are applied to algorithms that allow the health hazard assessor to recommend exposure durations and levels (e.g., the number of rounds that can be fired from a weapon in a given period of time) that will prevent soldiers from being harmed. Details about the nature and application of such algorithms and possible recommendations can be found in the *U.S. Army Health Hazard Assessor's Guide* (U.S. Army, 1996).

Measuring and assessing blast overpressure involves recording noise data and estimating risk by applying the data to a computer model (INJURY) developed by the U.S. Army. This model predicts the probability of injury to the tympanic membrane, upper respiratory tract, and lung due to insults from blast waves (see U.S. Army, 1996).

Control strategies for eliminating or minimizing the potential hazards from noise are the same as those for other occupational hazards. The ideal control is to design and build systems so that they do not produce hazardous noise levels. When this is not feasible, other control measures may be used. Typical measures for noise control include use of personal protection equipment and limiting the exposure duration. Earmuffs and earplugs are the types of personal protection often used to reduce steady-state and impulse noise exposure. Blast overpressure usually is controlled administratively (e.g., limiting the number of blast events) or by controlling the distance between people and the blast site. Several other additional references should be consulted for details concerning personal protection equipment and other measures for controlling and minimizing noise hazards (Donahue and Ohlin, 1993; U.S. Army, 1996; Bruce et al., 1998).

Example 15.1 Acoustical Hazard Assessment of a Mortar System The M-120 series 120-mm *Battalion Mortar System (BMS-120)* is an example of a system that was assessed for acoustical hazard (U.S. Army, 1995b). The BMS-120 is a smoothbore, muzzle-loading, indirect fire mortar system. The system consists of the M-120 Towed Mortar, transported by a one-quarter-ton truck, and the M121 carrier configuration mounted in a modified M113 Armored Personnel Carrier. Its 7000-plus-meter (m) maximum range, high rate of fire, and

excellent stability give the weapon a high trajectory and allow it to be fired from behind high cover. Even though a Blast-Attenuating Device (BAD) was developed to reduce exposure at crew locations, an assessment of the BMS-120 revealed blast overpressure as a potential health hazard. Impulse noise levels in excess of 140 decibels peak (dBP) is hazardous and will cause permanent hearing loss. The BMS-120 can produce noise levels in excess of the recommended limits. The HHA report required that 120-mm mortar crews wear earplugs (preferably E-A-R™ brand) during firing. When the mortar is fired, all personnel within 200 m wear approved hearing protection, medically trained personnel check crew members to assure proper fit of the E-A-R™ earplugs, and soldiers are informed about the significant risk of hearing loss from the BMS-120 and the proper use of hearing protection.

15.3.2 Biological Hazards

The process of measuring and evaluating biological health risks involves several steps (U.S. Army, 1996). These include evaluating the design and operation criteria from the mission needs statement, the operational requirements document, and the detailed test plan; comparing design and operation criteria against existing military and other reference standards; determining any untested criteria by comparing the detailed test plan to army standards and other reference standards; and developing test protocols to fill any information gaps.

Evaluating biological hazards is complex, requiring knowledge and skills in many scientific disciplines. This process consists of collecting (sampling), identifying, and measuring (quantifying) the potential hazardous organism or substance. Many sampling and analytical techniques to identify and measure biological hazards are available to scientists. Some examples of these are presented in Table 15.3.

Once sampling and analysis are completed, the risk to the target population is characterized. The health implications and outcome of biological substances may not always be clear. In some circumstances, a level of subjectivity and professional judgment is necessary. The assessment of such hazards may simply be to determine compliance with consensus standards or guidelines [e.g., drinking water standards (Safe Drinking Water Act), food sanitation standards (Model Food Code)]. If there is no such standard, then applying a risk assessment and management process may be necessary to estimate the impact to human health.

Protecting the soldier from exposure to biological substance(s), which can result in illness or loss of system effectiveness, requires installing and using multiple and overlapping controls. These may range from design and engineering solutions that prevent exposures to the use of personal protective equipment to block biological agents and prevent them from entering the body. Examples include immunizations, prophylactic drugs, personal hygiene, design and maintenance of soldiers' uniforms, screening and bed netting, ventilation, insecticidal sprays and repellents, and the application of sanitation standards in the areas of food and water.

Example 15.2 Biological Hazards Evaluation of an Environmental Control System The *Electrical Generator/Environmental Control System (EG/ECS)* was evaluated for biological hazards (U.S. Army, 1995b). The EG/ECS provides electrical power and heating and air conditioning for components of the Deployable Medical System (DEPMEDS). Each DEPMEDS is comprised of tentage arranged with Rigid Wall Tactical International Standards Organization Shelters. The EG/ECS consists of a 100-kilowatt generator system, a power distribution center, and an Environmental Control Unit (ECU). The ECU is set up outside the

TABLE 15.3 Examples of Sampling, Analytical, and Assessment Methods for Biological Hazards

Biological Hazard	Examples of Methods
Animal or plant allergen	Sampling—collecting specimens Analysis—sensitivity reaction assay (reference, Hayes), patch test Assessment—risk assessment
Insect vector poisonous arthropod, poisonous snake	Sampling—trapping Analysis—taxonomic identification by morphological characteristics Assessment—risk assessment
Microorganism	Sampling—surface swipes, air-filtering techniques Analysis—taxonomic identification by morphological and biochemical (metabolic) characteristics, immunoassay techniques, DNA assay Assessment—compliance with consensus standards, risk assessment
Poisonous plant	Sampling—collecting specimens Analysis—taxonomic identification by morphological characteristics, chemical analysis Assessment—risk assessment
Sanitation	Sampling—methods associated with microorganisms, animals, and insects Analysis—methods associated with microorganisms, animals, and insects Assessment—compliance with consensus standards: time-temperature controls (e.g., food handling), physical construction and type of material (e.g., food preparation and storage equipment, drinking water treatment and storage devices)
Toxin	Sampling—grab and bulk sampling of neat substances or contaminated media (e.g., water, food, soil, etc), surface swipes, air-filtering techniques Analysis—chemical analysis (direct-reading equipment, chromatography, spectometry, infrared and UV detection, etc.; reference, current chemical analytical text, NIOSH/OSHA), a variety of acute and chronic toxicity assays (reference, Hayes) Assessment—compliance with consensus standards, risk assessment

shelter and delivers conditioned air through a 9-ft supply duct to a nylon plenum running the length of the ceiling. Return air is recirculated to the unit through a second duct located at floor level. The ECU dehumidifies the return air by passing it across the evaporator coil where heat is extracted by the refrigerant. As the air is cooled, water vapor condenses and collects in the drip pan underneath the coil. Ideally, the condensate should drain from the pan and empty outside the ECU through the drain holes located on the right and left sides. An HHA of the system revealed, however, that without drain lines into the drip pan the condensate collects in the pan and causes the water to stagnate. Stagnant water in air-cooling or heating systems is an ideal growth medium for thermophylic *Actinomyce*s, the causative agent of hypersensitivity

pneumonitis and for *Legionella pneumophila*, the causative agent of legionellosis. Exposures to air contaminated with these microorganisms may induce severe health problems. The HHA report, therefore, recommended that suitable fittings and drain hoses be installed from the condensate drip pans of the ECU and routine inspections of the drip pan and drain hoses be performed to assure condensate is emptying from the ECU.

15.3.3 Chemical Hazards

When evaluating chemicals, there are several steps: identifying, sampling, analyzing, quantifying, assessing hazard and risk, and recommending controls. There are tools and techniques for each of these events. The interrelated tasks of chemical identification, sampling, and analysis are done using similar or related tools and techniques but also may require some that are unique to the task. For example, chemical identification may be done in the field using direct-reading instruments. However, some chemicals or field conditions may require that a sample of the chemical or environmental media (e.g., air, water, soil, etc.) be collected and taken to a laboratory for analysis.

Examples of direct-reading instruments are prominent in the assessment of air contaminants. Technologies include colorimetric indicators (e.g., detector tubes), airborne particulate analyzers (e.g., optical, electrical, piezoelectrical, and beta attenuation analyzers), and gas and vapor analyzers (e.g., electrical, radioactive, thermal, electromagnetic, chemi-electromagnetic, and chromatographic analyzers) (Lioy and Lioy, 1983; Todd, 1998).

Laboratory analytical techniques for chemical substances are as varied as, and sometimes similar to, the direct-reading technologies. Examples of chemical analytical methods applicable to the HHA process are reviewed by Draper et al. (1999) in their discussion of industrial hygiene chemistry. Some of the technologies that they discuss include spectrometry (e.g., infrared spectrometry, atomic absorption spectrometry, inductively coupled plasma spectrometry, ultraviolet/visible spectrophotometry, and mass spectrometry), and chromatography (e.g., gas chromatography, liquid chromatography, high-performance liquid chromatography, and ion chromatography). The review also lists several other analytical methods, including microscopy, X-ray spectroscopy, electroanalysis, immunoassay, and surface analysis. Other references that should be consulted concerning sampling and analytical techniques for chemicals in a variety of environmental media are published by the EPA [1983, 1988a,b, 1990–1995 (there are others; these are a few examples)], the Occupational Safety and Health Administration (OSHA, 1996), the NIOSH (NIOSH, 1994), and others [e.g., American Water Works Association (AWWA), 1995].

Once chemicals are identified and their presence in the environment is quantified, their hazards must be determined and the risk to people and the environment estimated. This involves the process of risk assessment where hazard determination, dose–response assessment, and exposure assessment are integrated to provide a risk characterization (NRC, 1983).

Chemical hazards often can be determined by searching references and scientific literature. There are a variety of commercial references (e.g., Clayton and Clayton, 1991; Klaassen, 1996; Hayes, 1994; Lewis, 1999), government reports and references (e.g., NIOSH criteria documents, NIOSH/OSHA guidelines for chemical hazards, EPA criteria and health effects assessment documents, the Agency for Toxic Substances and Disease Registry Toxicological Profiles, and others), and professional organization sources [e.g., The ACGIH, and the American Industrial Hygiene Association (ACGIH, 2000; AIHA,

2001)] that present summary or detailed information about the hazards of specific chemicals and the basis for recommended exposure levels. Also, there are a number of databases that can be accessed through the Internet. Examples of such databases can be found at the National Institutes of Medicine, National Library of Medicine Internet site and include the Hazardous Substances Data Bank (HSDB), Integrated Risk Information System (IRIS), Chemical Carcinogenesis Research Information System (CCRIS), GENE-TOX, Environmental Mutagen Information Center (EMIC), and Developmental and Reproductive Toxicology and Environmental Teratology Information Center (DART/ETIC).

When chemical hazard information is not available or is determined to be insufficient, toxicological and/or epidemiological studies may be required to produce the information. In the military medical research and support organizations [e.g., the U.S. Army Medical Research and Materiel Command, the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), the Naval Medical Research Institute, the Naval Health Research Center Toxicology Detachment, and the U.S. Air Force Institute for ESOH Risk Analysis] often are the organizations that would conduct such studies.

Epidemiology studies may be either *descriptive* or *analytical*. Descriptive studies assess the amount and distribution of health outcomes within a population or community by focusing on person, place, and time. Analytical studies may be either *experimental* or *observational*. In experimental studies an investigator controls exposure to an agent of interest. For example, a group of people with similar characteristics would be identified; then some would be exposed to a chemical and subsequently compared to others that were not exposed. Obviously, for ethical reasons, this is done rarely. Therefore, most epidemiology studies are analytical, which may be either *retrospective* or *prospective* studies. Retrospective studies assess effects from past exposures. Prospective studies determine how people are exposed currently and then monitor them through time to determine if future exposure effects occur. Biostatistical measures are applied to the study data to summarize them and to determine their significance. More detailed discussion about standard epidemiology research and study methods may be found in references by Tyler and Last (1998) and Mausner and Kramer (1985). Biostatistical methods are presented in references by Daniel (1983), Klienbaum and Kupper (1978), and Ott (1988).

When human epidemiology studies are not available or to further support existing studies, laboratory toxicological studies may be performed. Frequently these experimental studies are conducted on laboratory animals (e.g., rats, mice, dogs, monkeys, rabbits, and pigs), and the results are extrapolated to humans. Toxicology studies may be designed to evaluate effects that occur from an acute exposure by a single dose or multiple doses in a 24-hour period. Short-term studies (e.g., subacute and subchronic exposures) may range in durations from 14 days to 2 years. Long-term studies (e.g., chronic and lifetime exposures) may extend through the life of the test animals (Moeller, 1997). A variety of other types of studies that do not use laboratory animals also may provide supporting information to confirm toxicological end points or mechanisms. Some examples include the use of microorganisms (e.g., *Salmonella* sp.) and insects (*Drosophila*) to elucidate mutagenic potential, cell cultures (e.g., for neurotoxicity), and enzymes (e.g., for hepatic and renal toxicity). Hayes (1994) presents detailed discussions of various toxicological assay methods.

As with many of the other health hazards, the risk associated with chemical exposures may be based upon existing standards and criteria. If there are no existing standards or

criteria, then risk assessment and management procedures are applied to establish recommendations for soldier protection.

Control measures to protect against the harmful effects from chemical exposure include the range of options presented toward the end of this chapter.

Example 15.3 Chemical Hazard Assessment of the Paladin Self-Propelled Howitzer The *M109A6 Paladin* is a self-propelled armored and full-tracked howitzer suitable for worldwide deployment with heavy division forces. It is an example of a chemical hazard assessment (U.S. Army, 1995b). Previous HHAs of the howitzer noted exposure to lead during the firing of munitions. The Howitzer Improvement Program (HIP) Program Manager, therefore, requested an additional assessment to address the health hazards associated with the substitution of inorganic tin foil for the lead foil decoppering agent in the propelling charge of the M109A6 munition. Trials of munitions using lead in the propelling charge and trials using tin as a replacement for lead in the propelling charge were conducted and compared. The trials with lead showed concentrations at various crew positions as high as 10 times the permissible exposure level (PEL) for lead. In contrast, in trials using tin as a replacement for lead, the exposure levels never reached one-tenth of the tin PEL. Because the testing data indicated that overexposure to tin when firing munitions is remote, the HHA report recommended substituting inorganic tin foil for the lead foil decoppering agent in the propelling charge of the M109A6 Paladin howitzer.

15.3.4 Oxygen Deficiency—Ventilation

Confined spaces should be tested for oxygen levels and other contaminants prior to entry and monitored continuously during occupancy (Schroll and Harris, 1998). Because of the need for instantaneous information, especially when confined spaces are occupied, direct-reading instruments are used to measure and monitor atmospheric oxygen levels. The instruments that are used typically are colorimetric indicators or electrochemical sensors (i.e., potentiometric and coulometric analyzers) and heat-of-combustion detectors. More detailed information about these technologies and specific products can be found in Todd (1998), Nader et al. (1983), and Saltzman (1983).

Ventilation is one of the principal methods to prevent or eliminate oxygen-deficient atmospheres in confined and enclosed spaces. It can be accomplished by supplying forced air to either dilute or displace air contaminants (Schroll and Harris, 1998). Exhaust ventilation, coupled with fresh makeup air, also can be used to remove oxygen-reducing point-source contaminants. Ventilation rates and air exchanges are determined by fan capacity, duct size, and type of contaminants to be removed. Instruments that can be used to determine air exchange rates, airflow, and air capacity include a variety of products that measure pressure, volumetric flow rate, and air velocity. Examples of such instruments include the U-tube manometer, pitot tube, vane anemometer, thermal anemometer, inclined anemometer, aneroid gauges, smoke tube, and tracer gas. Additional details about industrial ventilation system design, measurement techniques, and instrumentation are presented and detailed in the ACGIH *Industrial Ventilation* manual (ACGIH, 2001).

Enclosed spaces are not routinely tested and monitored for oxygen levels because ventilation normally is part of the design for the space. For example, there are specific ventilation requirements for personnel enclosures (e.g., shelters, armored vehicles, etc.) and vehicle cabs (MIL-STD 1472F). However, when the ventilation system is not functioning properly, oxygen deficiency should be considered as a possible outcome and assessed prior to returning the system to normal operation.

Sometimes it is necessary to remove oxygen from a confined space to prevent a fire or explosion. This can be done by *inerting*, which requires introducing a nonreactive (inert) gas (e.g., nitrogen, argon, or carbon dioxide) to displace the oxygen (Schroll and Harris, 1998). Individuals who enter this type of space must wear a supplied air respirator. A supplied air respirator also can be worn if ventilation cannot be used or if it will not correct an oxygen-deficient atmosphere.

Example 15.4 Health Hazard Assessment of Ventilation on a Landing Craft An HHA that involved ventilation concerns was performed on the *Landing Craft Mechanized (LCM-8)* (U.S. Army, 1995b). The LCM-8 is a U.S. Navy–designed, welded-steel, twin diesel-powered watercraft approximately 73 ft long and capable of carrying 60 tons. The vessel is designed to transport personnel and cargo in resupply or waterborne tactical operations. The army has a fleet of approximately 96 vessels, each with a crew of six enlisted soldiers. The Service Life Extension Program (SLEP) is a product improvement program intended to upgrade the engine and transmission performance of the existing fleet of LCM-8 Mod-1 vessels and extend their service life 20 years. A review of the design and description of the LCM-8 Mod-1 SLEP noted several health hazards, including confined spaces and the use of fire-extinguishing agents. Fatalities occur in confined spaces as a result of encountering one or more potential hazards. Liquid fuel fires on the LCM-8 are frequently extinguished by discharging carbon dioxide (CO_2) from portable fire extinguishers directly on the burning material. When CO_2 is discharged in a confined space or room, an oxygen-deficient atmosphere may result due to air displacement. The HHA report recommended that when a CO_2 discharge starts, personnel should consider the space oxygen deficient and employ appropriate confined-space entry procedures; enclosed spaces, crew spaces, and spaces containing diesel fuel tanks comply with current U.S. Coast Guard regulations for ventilation; and all personnel be trained in the hazards associated with confined-space entry and work procedures. (The reader should note that CO_2 has toxic properties that should be considered in addition to its ability to displace oxygen.)

15.3.5 Ambient Pressure Changes

The physical principles associated with the gas laws—Boyle's law, Dalton's law, and Henry's law—are key to the understanding of the nature of hypobaric conditions and the relationship with oxygen. These laws relate factors such as pressure, volume, temperature, mass, molecular weight, and others to gas properties and their effects. Gas principles and laws can be reviewed in Popendorf (1998) or any college-level general chemistry textbook.

Boyle's law can be applied to the expansion and contraction of gases in bodily organs (e.g., lung, ear, sinuses, and gastrointestinal tract) due to external pressure changes. These effects can cause pain and physical trauma in affected organs. Dalton's law (the law of partial pressures) addresses the significance of partial pressures exhibited by individual gases in a mixture and the summed effect of all the gases. Henry's law can be used to predict the body's absorption of gases from lung alveoli, their transport rate in blood, and the amount that may concentrate and be stored in various tissues in the body.

Ambient total pressure changes can be predicted by using an equation that is based upon various gas law principles. Popendorf (1998) discusses how this equation is derived and shows how the predicted pressures can be compared to values in various physiological tables to estimate health outcomes.

Techniques discussed by Popendorf (1998) to control, prevent, or minimize occupational health hazards in hypobaric environments reflect the range of options available in

other typical workplaces. These include engineering controls (e.g., increasing air pressure in aircraft cockpits and cabins), using personal protective equipment (e.g., equipment similar to supplied air respirators that increase the availability of oxygen by increasing its molar fraction in the breathing air), and acclimatization. An acclimatization timetable is required to allow individuals to adapt to hypobaric conditions at high elevations. If acclimatization does not occur, work activities, especially complicated tasks, may be jeopardized by serious health problems. Military guidelines for high-altitude operations suggest a deployment timetable that permits some degree of acclimatization prior to mission execution (U.S. Army, 1975).

15.3.6 Nonionizing Radiation

There are dose–response relationships for a wide range of exposure conditions to include wavelength, pulse duration, pulse repetition frequency, source size, exposure, and dose. Response criteria include clinically visible response cutaneous erythema, minimally visible retinal lesion, microscopic cellular change, or permanent or temporary changes in visual function. From such dose–response relationships, comprehensive PELs were established. However, many exposure conditions inherent to new military developmental systems lack sufficient biological basis to assess the hazards. Generally, these situations are addressed by extrapolating from existing PELs.

There are several regulatory standards and criteria for the use, control, and exposure to radiation. These are enumerated in the army's HHA *Assessor's Guide*, which includes federal laws and regulations, national and international guidelines, DoD requirements, and army regulations and guidelines (U.S. Army, 1996).

Laser Radiation Laser radiation control measures are based upon limiting access to the beam. This is achieved by a number of methods. The primary protective method is to block the beam by materials opaque to the laser wavelength(s). The greatest difficulty has been in providing laser-protective materials, which provide transparency for vision. Currently, there are no universally acceptable, general-purpose, eye-protective filter materials that do not block the visible wavelengths required for vision. Range restriction is another method to limit access to the beam when PELs are exceeded. Control of laser operation by engineering controls, such as enclosures and safety interlocks, can eliminate or control the hazard (see MIL-STD 1425A, 1991).

Radio-Frequency Radiation The sequence of events and considerations for assessing and controlling potential RFR hazards from military systems are detailed in the HHA *Assessor's Guide* (U.S. Army, 1996). These include performing a nonionizing radiation protection study, taking field measurements, comparing measurements to established exposure limits, recommending control strategies, and assigning a risk assessment code (RAC).

Hitchcock et al. (1998) describes several types of instruments that can be used to measure RF fields, body currents, and contact currents. These include instruments that make densitometric measures, current monitors, personal monitors, and frequency counters.

There are engineering administrative control strategies to minimize exposures and health hazards associated with RFR (U.S. Army, 1996). Examples of engineering controls include using system sector blanking to prohibit radiation in certain areas, incorporating

dummy loads, shielding high-voltage power supplies, and incorporating warning devices when the sources are activated. Administrative controls are publishing warning messages in technical manuals; providing safety training and briefings; periodically inspecting waveguides, interlocks, etc.; and installing barricades, fences, signs, and warning devices to prohibit access to unauthorized areas.

As dictated by army regulations (U.S. Army, 1980b, 1990d), RFR source safety evaluations typically are performed by USACHPPM scientists during various stages in the concept, development, and fielding of army materiel systems. Most of these systems are evaluated in the concept, research, and early development testing phases and usually are completed before the initiation of a HHA.

Exposure limits documented in U.S. Army Regulation 40-5 (U.S. Army, 1990d) and DoD standards are routinely applied for evaluating potential health hazards from new materiel. In the absence of exposure criteria, the USACHPPM consults with the U.S. Army Medical Research and Development Command's Walter Reed Army Institute of Research (WRAIR). The USACHPPM staff professionals will conduct an initial system evaluation and special and periodic installation RFR surveys. The information acquired from the special studies and routine surveys are entered into a database for evaluating potential health hazards from new material. The database consists of technical reports maintained by the USACHPPM. All reports and related publications, especially those that include recommendations for corrective action, are peer reviewed. The USACHPPM staff professionals make a number of recommendations for alleviating and reducing exposures to levels beyond PELs.

Risk assessment codes are assigned for non compliance with the recommendations of the study. The hazard severity is assigned based on the RFR exposure levels. The matrix that is used as a guideline for determining hazard severity is shown in the HHA *Assessor's Guide* (U.S. Army, 1996). The hazard probability is a subjective determination based on the experience and knowledge base of USACHPPM engineers. The assignment of an RAC is also subject to the review of an USACHPPM physician and is, therefore, a medical decision.

Example 15.5 Health Hazard Assessment of RFR Source on an Air Defense System The *HAWK Air Defense Guided Missile System (ADGMS)* exemplifies a RFR source for which an HHA was developed (U.S. Army, 1995b). The HAWK ADGMS defends against low- and medium-altitude attacking aircraft. The phase III product improvement program provided a highly mobile air defense system that can search for, detect, and designate hostile targets. The primary search, detection, and designation equipment consists of one continuous-wave acquisition radar and one high-power illuminator radar. The primary health concerns are exposure to RFR during tactical operations, field maintenance, and depot-level maintenance activities. The HHA identified several situations in which excessive exposures could occur and recommended the following actions to control those exposures: (1) publish warning messages in all appropriate technical and field manuals; (2) enroll maintenance personnel in a medical surveillance program; and (3) use warning lights, signs, barricades, and alarms to prevent soldiers from entering potential exposure areas in the field.

15.3.7 Ionizing Radiation

The HHA methodology for radiation hazards from military systems includes an identifying process and an evaluation process, which are detailed in the HHA *Assessor's Guide* (U.S. Army, 1996). The evaluation process consists of a hazard identification step and an

exposure assessment step. The exposure assessment step involves the use of selected exposure standards (U.S. Army, 1995b; 10 CFR 20) and computer dosimetry models (e.g., the army's radiological bioassay and dosimetry program, the REMEDY program[2], or the medical internal radiation dose (MIRD) to estimate internal dose.

Ion particle–counting instruments and dose-measuring instruments are types of instruments used for detecting and measuring ionizing radiation. The principles of ion particle–counting instruments are used both in portable radiation–detection instruments and in laboratory instrumentation for measuring radioactivity in environmental samples and bioassay specimens. Examples of ion particle–counting instruments are the gas-filled particle counter (e.g., the ionization chamber, proportional counter, and Geiger counter) and the scintillation detector. The response of a dose-measuring instrument is proportional to the energy it absorbs. Examples of dose-measuring instruments are the free-air ionization chamber (laboratory instrument), the air-wall ionization chamber (condenser-type pocket dosimeter), the ion current chamber (cutie pie), and the thermoluminescent dosimeter. Since neutrons are not directly ionizing, they must interact with another medium to produce a primary ionizing particle, and therefore, require refinements in detectors for measurements and dosimetry. The army HHA *Assessor's Guide* (U.S. Army, 1996) and McCarthy (1998) have additional details concerning instruments for measuring ionizing radiation.

There are several regulatory standards and criteria for the use, control, and exposure to ionizing radiation. These are enumerated in the army's HHA *Assessor's Guide* and include federal laws and regulations, national and international guidelines, DoD requirements, and army regulations and guidelines (U.S. Army, 1996).

15.3.8 Shock

Known human tolerances to impact are summarized in a Society of Automotive Engineers report (SAE, 1986). The report focuses on automotive crash injuries; however, the tolerances may generally be applied to aviation and other combat vehicle impact loading conditions. The following information is derived primarily from literature associated with automotive crash injury assessments.

Injury ratings of automotive crashes traditionally are measured on the abbreviated injury scale (AIS), which ranges from zero to five. This scale may not be entirely appropriate for soldiers in a combat environment, because many injuries rated as serious but survivable (i.e., an AIS of 3) can cause temporary incapacitation to the soldier and may lead to further life-threatening exposures. Therefore, it is necessary to adjust some injury threshold levels (ITLs) commonly applied in the automotive environment to reflect the secondary threat resulting from crew incapacitation in a combat environment.

Several types of test manikins have been used to evaluate and certify new automobiles and are intended primarily to simulate a seated driver or passenger in automobile crashes. These manikins are not able to test spinal load and lateral chest impacts, which are relevant concerns for some military systems. However, these are the state-of-the-art manikins and must be used in the absence of better test surrogates in axial (vertical) and lateral (transverse) impacts.

In order to assess risk, an injury assessment value (IAV) is measured and compared to the lower bound of an ITL. The numerical relationship between the known ITL and the measured IAV defines an *injury assessment criterion*. Injury criteria have been established for the prediction of head (closed-brain) injuries; chest trauma; cervical, spinal, and lumbar

spinal column fractures; and pelvis and lower extremity injuries. These criteria translate engineering measurements, such as forces, accelerations, and deflections, into probabilities of injury occurrence.

The engineering measurements needed for valid injury assessment must be obtained by following standard and accepted instrumentation and signal processing guidelines. Measurements are obtained from transducers that are mounted in the test surrogate (manikin) and attached to electronic data recorders. High-speed cinematography can be used to produce a visual record of the impact response of the test surrogate and to complement electronic data recordings.

Head injury predictions are based upon acceleration signals, measured at the head center of gravity, in the forward (A_x), leftward (A_y), and upward (A_z) directions. Neck injury predictions are based on measures of the neck axial (F_z), shear (F_x) forces, and the neck pitch (M_y) moment. Chest injury is predicted from chest acceleration signals that are measured in the forward (A_x), leftward (A_y), and upward (A_z) directions. Lower spine (lumbar) injury predictions are based on measures of forward (F_x) and leftward (F_y) shear, upward (F_z) axial forces, and fore/aft (M_y) and lateral (M_x) bending moments. Lower extremity injury prediction is based on strength data of femur and tibia bones, under compressive (F_z), shear, and bending loading. The reader should refer to the appropriate (1995) standard SAE for specific details concerning these and other measures.

Example 15.6 Health Hazard Assessment for Shock from a Parachute An example of a system that received an HHA for shock is The *tactical assault personnel parachute (TAPP)* (U.S. Army, 1995b). The TAPP was designed for use in low-altitude mass tactical assault airborne operations in order to lower the rate of descent and reduce the potential for landing injury. An initial HHA of the TAPP identified musculoskeletal trauma resulting from excessive opening forces and impact velocity as a potential adverse health effect to personnel during training and combat airborne operations. Although additional data were needed to fully assess the TAPP, the Initial HHA recommended including the current and improved paratrooper helmets in the TAPP test program to evaluate the effect of helmet mass on neck loads during opening shock and crushable foam on reducing deceleration in the head during parachute landing falls.

15.3.9 Heat Stress

There are several heat stress indices that are used to estimate the potential for people to develop heat illness. They combine measures of temperatures, humidity, and air velocity to produce a single numerical indicator of heat stress potential. Examples of these indices include the wet-bulb global temperature (WBGT), the wet-globe temperature (WGT), and the heat stress index. The formulas for these indices and details concerning their application are offered by Ramsey and Beshir (1998) and the ACGIH (2002).

There are a variety of instruments that measure temperature, radiant heat, humidity, and air velocity, and some electronic devices integrate the individual measures to produce a single heat index. Examples of each of these are presented by Ramsey and Beshir (1998). Examples of heat-measuring devices include liquid-in-glass thermometers, bimetallic thermometers, resistance thermometers, and thermocouples. Radiant heat can be measured with a radiometer or globe thermometer. Humidity can be measured with a psychrometer or hygrometer. Air velocity can be measured with a vane or thermal anemometer. Both a NIOSH publication (NIOSH, 1986) and the army's heat injury medical bulletin (U.S.

Army, 1980) show and describe how to assemble a device for determining the WBGT using a wet-bulb thermometer, a shielded thermometer, a dry-bulb thermometer, and a black-globe thermometer.

A psychrometric chart can be used to determine dry-bulb temperature, wet-bulb temperature, relative humidity, vapor pressure, or dew point (Ramsey and Beshir, 1998). Heat strain can be predicted by use of a computerized model (Gonzalez and Stroschein, 1991; Pandolf et al., 1986, 1971).

Engineering and administrative controls and personal protective equipment can be employed to prevent or minimize the occurrence of heat stress. Engineering controls may include air conditioning, ventilation, and isolation of heat sources. A microclimatic cooling vest is an example of personal protective equipment. Application of a work–rest schedule based upon a heat indicator level and planned consumption of adequate quantities of drinking water are examples of administrative controls. Detailed information concerning heat stress control and injury prevention strategies can be found in references by Bishop (1998), the ACGIH (2002), and the U.S. Army (1980a). Design considerations for military systems (e.g., vehicles and shelters) are found in MIL-HDBK-759A (1981) and MIL-STD-1472F (1999).

Example 15.7 Heat Stress Assessment of the Pedestal-Mounted Stinger A heat stress HHA example is the *pedestal mounted stinger (AVENGER)* weapon system (U.S. Army, 1995b). The AVENGER consists of a Stinger missile and.50-caliber machine gun pedestal that is turret mounted on a high-mobility multipurpose wheeled vehicle (HMMWV). Used against enemy fixed- and rotary-wing aircraft, the AVENGER is operated by a two-person crew (a driver and a gunner). The AVENGER is used for training and combat missions in a variety of environmental conditions, including hot weather. An HHA of the system identified heat stress as a potential adverse health effect to AVENGER personnel. When AVENGER fire missions of only 60 minutes or less were conducted with outside temperatures ranging from 82 to 85°F, test personnel reported that the gunner's station in the turret and the driver's station in the vehicle cab became uncomfortably hot. AVENGER crew members dressed in chemical protection suits (mission-oriented protective posture gear) during a chemical scenario to endure an even more significant heat load. Elevations in the driver's and gunner's core body temperatures may cause performance decrements or heat illness, such as cramps, exhaustion, and heat stroke. Since actual fire missions may last as long as 12 hours, the HHA report recommended installing a microclimatic cooling system in the AVENGER for use at all normally occupied crew positions. Administrative guidelines, such as work/rest/maximum work periods and water requirements information, were provided for interim use until the cooling system could be installed.

15.3.10 Cold Stress

Windchill is expressed as an *equivalent chill temperature*, which reflects the cooling power of wind on exposed skin (Ramsey and Beshir, 1998; ACGIH, 2002). Ramsey and Beshir (1996) show how the equivalent chill temperature (windchill index, WCI) can be calculated from the relative air velocity and the air temperature. The ACGIH (2002) presents a table that shows the resultant windchill index at given wind speeds and temperatures. The table also indicates whether there is "little danger," "increasing danger," or "great danger" of a given WCI causing exposed skin to freeze. The windchill chart also may be found in the army's cold injury medical bulletin (U.S. Army, 1976) and references by Jones et al. (1993) and Young et al. (1992a,b). Instruments for measuring air

temperature and velocity were presented earlier in the heat stress section and can be found in the reference by Ramsey and Beshir (1998).

Clothing systems designed for cold temperatures must be layered, provide adequate insulation, and fit properly (U.S. Army, 1996). Loose clothing layers with air spaces between them, under a wind- and water-resistant outer garment, and insulated boots play key roles in preventing cold injury. Ramsey and Beshir (1998) discuss and present an equation to calculate an *index of required clothing insulation (IREQ)*. The IREQ is an international standard (ISO, 1993) that allows one to calculate the amount of insulation required for the body to maintain thermal equilibrium.

Engineering and administrative controls and personal protective equipment can be employed to prevent or minimize the occurrence of cold stress. Engineering controls may include provision of adequate heating sources in vehicles and shelters. Design considerations for military systems (e.g., vehicles and shelters) are found in MIL-HDBK-759C (1995) and MIL-STD-1472 F (1999). The ACGIH (2002) provides guidelines for a work–warming regimen for people who work in extremely cold environments ($-26^{\circ}C/-15^{\circ}F$ and below).

Detailed information concerning cold stress control and injury prevention strategies can be found in references by Bishop (1998), the ACGIH (2002), and the U.S. Army (1976).

15.3.11 Trauma

The tools and techniques of ergonomics are associated with hazard analysis, prevention, and control. These techniques and examples are listed in the army's ergonomics manual (U.S. Army, 2000) as follows:

> Complete a detailed analysis to further evaluate those jobs or worksites having WMSD risk factors as determined by systematic passive and active surveillance. The analysis should systematically consider the concept of multiple-causation and the degree of WMSD risk. Trends, including age, gender, work task, and time of injury should be considered. Work tasks or portions of the process that contain risk factors should be identified. Both problems and solutions should be identified.(p.4)

As a part of the analysis, data should be reviewed and analyzed. There are established data, analytical tools, and methods that may be helpful during a detailed analysis. Examples of these include incidence and severity rates (e.g., a log of federal occupational injuries and illnesses or equivalent); accident and injury reports and lost work time or absenteeism reports by job, unit, department, or facility; checklists, questionnaires, and interviews (see U.S. Army, 2002); and direct observation, videotape analysis, and job analyses (see U.S. Army, 2002). Assessment methodologies may include static and dynamic strength testing, timed activity analysis, biomechanical analysis, and cardiovascular measurements. The NIOSH provides guidance for assessing lifting (NIOSH, 1998).

There is a hierarchy of hazard prevention and control strategies that include process elimination, engineering controls, substitution, work practices, administrative controls, and personal protective equipment. Details and examples of these strategies can be found in the army ergonomics manual (U.S. Army, 2000). Both DiNardi (1998) and the ACGIH (2002) present discussions concerning control strategies and methods to prevent or reduce the risk of developing WMSDs. The ACGIH (2002) also presents a TLV for the hand, wrist, and forearm that is based on hand activity level and peak hand force.

Example 15.8 Trauma Assessment for an Air Defense System The HHA developed for the *Vulcan Air Defense System (VADS)* is an example of a trauma assessment (U.S. Army, 1995b). The VADS provides air defense against low-altitude threats and ground coverage against stationary or moving targets, such as personnel, trucks, and lightly armored vehicles. The system includes an M168 20-mm cannon, capable of delivering selected rates of fire of 1000 or 3000 rounds per minute. An HHA identified the potential for musculoskeletal trauma when crew members are required to lift ammunition boxes containing 100 rounds and weighing 97 pounds per box from an auxiliary ammunition carrier to the ammunition feed chute of the weapon. The height of the lift varies depending on the height of the system's carrier but does not exceed 3 ft. Since human engineering design criteria specifies 87 pounds as the maximum allowable weight for a one-time, one-person, two-handed lift to 3 ft, the HHA recommended (1) keeping the distance of the lift between the ammunition carrier and the ammunition feed chute to less than 3 ft or requiring a two-person lift and (2) coordinating with the U.S. Army Human Engineering Laboratory to investigate the need for alternate work practices or engineering design modifications to mitigate the lifting hazard.

15.3.12 Vibration

The current accepted method for assessing the effects of WBV is that as described in ISO (ISO, 1985). The U.S. version of ISO 2631 is American National Standards Institute (ANSI) S3.18 (ANSI, 1979). Transducers (e.g., accelerometers) and recorders are used to acquire vibration data. Bruce et al. (1998) describe the equipment and its placement for measuring vibration. The primary method for quantifying vibration is to define the motion in three translational axes (ISO, 1985). The translational motions include the fore-and-aft direction (x), lateral direction (y), and longitudinal or vertical direction (z).

There are several steps followed in order to apply the data derived from the ISO 2631 process to the HHA process (e.g., establishing hazard probability and severity and risk assessment codes):

- establishing an operational test matrix,
- collecting operational WBV data,
- developing the test condition probability classification for each mission, and
- defining the test condition severity classification for the vehicle based upon the WBV exposure criteria presented in ISO 2631.

The specific details for each of these steps are described in the army HHA *Assessor's Guide* (U.S. Army, 1996).

The methods for reducing WBV exposure can be through design or by administrative controls. Design methods may involve the vehicle suspension system and/or the seating system (U.S. Army, 1996). The vehicle suspension characteristics should allow for a wide range of vehicle loads but avoid a natural frequency in the region of human resonances. Seat cushioning and suspension mechanisms can attenuate the transmission of vibration to vehicle occupants. Administrative controls can include rest periods or intermittent participation in specific mission profiles.

The ACGIH has recommended TLVs for both WBV and hand-transmitted vibration (ACGIH, 2002). Bruce et al. (1998) provide additional details concerning exposure criteria, measuring techniques, and control measures for both WBV and hand-transmitted vibration.

Example 15.9 Vibration Assessment for the Fast Attack Vehicle An HHA addressing vibration was developed for the *fast attack vehicle (FAV)* (U.S. Army, 1995b). The FAV is a lightweight, all-terrain vehicle capable of high-speed, cross-country travel with high maneuverability and agility. The vehicle serves as a weapons or communications carrier/platform for antiarmor, reconnaissance, deep attack, and other missions that require speed, agility, or the negotiation of rough terrain. A review of the system's performance specifications and development testing identified excessive levels of whole-body vibration. Portable ride meters affixed to the driver's seat demonstrated that the FAV could not be driven for more than 1 minute over a rough surface course at speeds greater than 40 mph. More importantly, the predominant acceleration for the FAV occurred in the 3–5-Hz range—frequencies at which the body's internal organs may resonate. In addition, during development testing, 50 percent of the personnel reported kidney and back-related injuries. These injuries were attributed to the shock and vibration sustained by soldiers due to inadequate cushioning of the seats. The HHA report, therefore, recommended entering soldiers who operate the FAV into a medical surveillance program for whole-body vibration, giving special attention to the genitourinary and musculoskeletal systems and improving the shock absorbency of the FAV's seats and suspension system.

15.4 HEALTH HAZARD ASSESSMENT EXPERTISE

There are numerous scientists, engineers, and technicians who specialize in the health and engineering sciences that support the HHA program. Generally, these individuals are members of the AMEDD. The major army medical organizations that are involved with the HHA program include the USACHPPM (Aberdeen Proving Grounds, Maryland) and the U.S. Army Medical Research and Materiel Command (Fort Detrick, Maryland). These organizations and others involved with the program are listed in an HHA procedures guide (U.S. Army, 1994a). Table 15.4 lists various scientists, engineers, and physicians who may do HHAs or provide information to support them. The following paragraphs provide additional detail about the specific roles of some of these professionals.

Acoustical Energy (Noise and Overpressure) A variety of professionals may be involved with acquiring and interpreting noise data and making recommendations to control hazard sources. These may include industrial hygiene and environmental health professionals, audiologists, and acoustic engineers. In the recent past, army physicians were involved in the assessment of blast overpressure to apply and validate a model to predict the potential for developing adverse health effects.

Biological Substances Many scientific disciplines are involved in evaluating biological hazards. Several types of scientists and health professionals are versed in the nature and characteristics of microorganisms. Some examples include microbiologists, virologists, and mycologists. These specialists and others (e.g., physicians and veterinarians) also may be versed in aspects of communicable, infectious, and zoonotic diseases.

Chemical Substances Multiple specialists may be involved with assessing chemical hazards. There are several factors that may influence who may be involved with the assessment. These include identifying, sampling, and analyzing the chemical(s); quantifying the potential exposure; determining hazard and risk; and recommending appropriate control measures. The skills and expertise of analytical chemists, industrial hygienists,

TABLE 15.4 Examples of Technical Experts Who May Support or Provide Health Hazard Assessments

Hazard Category	Technical Experts
Acoustic energy	Industrial Hygienist, Environmental Health Scientist, Audiologists, Acoustic Engineers, Physicians (Blast Overpressure)
Biological substances	
Animal or plant allergen	Physician, Immunologist
Insect vector	Entomologist, Zoologist, Biologist
Microorganism	Microbiologist, Virologist, Mycologist, Physician, Veterinarian, Biologist
Poisonous arthropod	Entomologist, Zoologist, Biologist
Poisonous snake	Zoologist, Herpetologist, Biologist
Sanitation	Sanitarian, Environmental Health Scientist, Environmental Engineer, Biologist
Toxin	Toxicologist, Physician, Biologist
Chemical substances	
Chemical identification	Analytical Chemist
Chemical sampling	Analytical Chemist, Industrial Hygienist, Environmental Health Scientist
Chemical analysis and quantification	Analytical Chemist
	Analytical Chemist, Industrial Hygienist, Environmental Health Scientist
Hazard and risk assessment	Industrial Hygienist, Environmental Health Scientist
	Toxicologist, Risk Assessor, Industrial Hygienist, Environmental Health Scientist
Control(s) recommendation	Industrial Hygienist, Environmental Health Scientist
Shock	Physicist, Engineers (Automotive Safety Engineer, Biomechanical Engineer), Physicians
Temperature extremes and humidity	Physiologist, Physician, Environmental Health Scientist, Industrial Hygienist
Trauma	Ergonomist, Biomechanical Engineer, Human Factors Engineer, Industrial Hygienist, Physician, Environmental Health Scientist
Vibration	Biomechanical Engineer, Human Factors Engineer, Industrial Hygienist, Physician, Environmental Health Scientist

toxicologists, other environmental health professionals, toxicologists, and risk assessors may be employed to assess chemical hazards.

Oxygen Deficiency (Ventilation) Professionals who may measure and assess oxygen-deficient environments typically include industrial hygienists, gas-free engineers, and environmental health professionals. These are individuals who are trained to operate

direct-reading instruments that measure atmospheric oxygen concentrations and are knowledgeable about the risks associated with oxygen-deficient atmospheres.

Oxygen Deficiency (High Altitude) Physicians, especially aviation medicine and diving medicine specialists, and certain physiologists are knowledgeable about the dynamics and effects of oxygen deficiency due to reduced pressure atmospheres. Some industrial hygienists also are specialized in this area.

Radiation Energy Health physicists are the primary professionals who measure and assess radiation hazards. Also, some industrial hygienists and other environmental health professionals may be specially trained in radiation assessment.

Shock People who would be proficient to assess shock include professionals who are skilled in physics and engineering. This would include physicists and engineers, especially automotive safety engineers and biomechanical engineers. Physicians also may be involved with helping to define and establish when detrimental health effects occur to body organ systems.

Temperature Extremes and Humidity (Heat Stress) There are several professionals who may evaluate and assess the potential for people to develop heat stress. Physiologists and physicians may be involved in predicting the types of health effects that may occur at various levels of heat exposure and subsequent to the development of heat-related medical conditions. Environmental health professionals and industrial hygienists typically monitor ambient and work environments and recommend control measures to prevent heat-related illness.

Temperature Extremes and Humidity (Cold Stress) There are several professionals who may evaluate and assess the potential for people to develop cold stress and injury. Physiologists and physicians may be involved in predicting the types of health effects that may occur at various levels of cold exposure and subsequent to the development of cold-related medical conditions. Environmental health professionals and industrial hygienists typically monitor ambient and work environments and recommend control measures to prevent cold-related illness.

Trauma People who would be proficient to assess ergonomic concerns would include ergonomists, biomechanical engineers, human factors engineers, industrial hygienist, some physicians, and some environmental health professionals. The Department of the Army considers "trained ergonomics personnel" to be "health care, industrial hygiene, environmental (health) science, safety, or engineering personnel with approved training in ergonomics" (U.S. Army, 2000, p.17).

Vibration People who would be proficient to assess vibration hazard potential would include biomechanical engineers, human factors engineers, some industrial hygienists, some physicians, and some environmental health professionals.

15.5 HEALTH HAZARD ANALYSIS PROCESS

In this section, the overall HHA process is described in terms of HHA requirements and general guidelines.

15.5.1 Why and When to Do an HHA

The objective of HSI is to develop military equipment and systems that will "fit the soldier, sailor, airman" by improving the interface between the person and the system. This improvement includes protecting the health of the soldier/sailor/airman by eliminating or minimizing stresses that could occur from health hazards. Thus, the primary objective of the HHA program is to identify, assess, and eliminate or control health hazards associated with the life-cycle system management of weapon systems, munitions, equipment, clothing, training devices, materiel systems, and information systems (U.S. Army, 1995b). Other specific supporting objectives are to protect the serviceman, enhance mission effectiveness, and contain costs. These are to preserve and protect health, reduce performance decrement, enhance system effectiveness, reduce system design retrofits needed to control or eliminate health hazards, enhance readiness, and reduce personnel injury and illness compensation (U.S. Army, 1995b).

The HHA process should begin early in the life cycle of a system. This could occur as early as during the identification of requirements and needs, usually a combat developer's responsibility, and subsequent generation of documentation. Alternatively, the process could begin when the materiel developer is identified and formulates a development plan. However, the HHA process never should be delayed beyond concept exploration. When initiated beyond concept exploration, the process suffers because of competition for resources and a compressed development timeline. The HHA report (HHAR) (to include the initial and updated HHARs) should be provided to the materiel developer early in the acquisition process so that it can be considered during various decision stages (milestones). The HHAR also should serve as a source document to influence other aspects of the acquisition and development process (e.g., test plans, market investigations, safety releases, and system technical and training publications).

The HHA process also supports the acquisition of commercial off-the shelf (COTS) items and nondevelopmental items (NDIs). Even if a commercial product has been evaluated for health concerns, the HHA process can determine if the commercial or any other health assessment is relevant to the intended U.S. military use.

15.5.2 HHA Program Directives and Guidelines

The HHA program was developed by the U.S. Army in response to many years of addressing health hazards associated with the use of military weapons, equipment, and other systems. It became obvious that it was better to anticipate and address such issues when systems were being conceptualized and developed rather than after they were fielded and in use. Thus, in 1981 the army surgeon general formalized the HHA program by developing and coordinating the publication of Army Regulation (AR) 40-10, *Health Hazard Assessment in Support of the Army Materiel Acquisition Decision Process* (the current version is U.S. Army, 1991a). Since then the program has been integrated with DoD provisions that require a variety of human factor concerns to be addressed during system acquisition. Also, the requirement to integrate the HHA program into the materiel

acquisition and development process has been incorporated into a number of army medical, personnel, safety, and other regulations. Examples of these are given in Table 15.5.

15.5.3 Military-Unique Hazards

One of the roles of the HHA program is to address situations that are unique to the military and do not have a direct civilian correlate (Gross and Broadwater, 1993). When military design, specifications, or requirements render compliance with civilian health standards infeasible or when no regulatory standard exists for such military application, DoD components can develop and publish special military standards, rules, or regulations prescribing occupational safety and health measures (DoD instruction 6055.1). Conse-

TABLE 15.5 Selected Department of Defense Publications and Army Regulations that Address Integration of Health Hazard Assessment Program into Materiel Acquisition Decision Process

Publication Number	Publication Title
	Department of Defense Publications
Regulation 5000.2-R	*Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs*
Instruction 6055.1	*DoD Occupational Safety and Health Program*
Instruction 5000.36	*System Safety Engineering and Management*
MIL-HDBK 759A	*Human Factors Engineering Design for Army Materiel*
	U.S. Army Publications
Regulation 40-10	*The Army Health Hazard Assessment Program in Support of the Materiel Acquisition Decision Process*
Regulation 40-5	*Preventive Medicine*
Regulation 602-2	*Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process*
Regulation 602-1	*Human Factors Engineering Program*
Regulation 15-14	*System Acquisition Review Council Procedures*
Regulation 70-1	*Systems Acquisition Policy and Procedures*
Regulation 70-10	*Test and Evaluation During Development and Acquisition of Materiel*
Regulation 70-15	*Product Improvement of Materiel*
Regulation 70-142	*Materiel Release, Fielding, and Transfer*
Regulation 200-1	*Environmental Protection and Enhancement*
Regulation 385-16	*Systems Safety Engineering and Management*
Regulation 70-75	*Survivability of Army Personnel and Material*
PAM 700-142	*Instructions for Materiel Release, Fielding, and Transfer*
Available from USACHPPM	*U.S. Army Health Hazard Assessment Program Strategy*
Available from USACHPPM	*Health Hazard Assessment Manual—Procedures Guide*
Available from USACHPPM	*Health Hazard Assessor's Guide*
Available from USACHPPM	*Materiel Developers Pocket Guide to Systems Health Hazards*

quently, some of the health standards presented earlier in this chapter were developed to be applied uniquely to military situations.

15.5.4 U.S. Army Health Hazard Assessors Guide

The *U.S. Army Health Hazard Assessor's Guide* (U.S. Army, 1996) was a major reference for the contents of this chapter. This guide was developed and authored by scientists from the Army Medical Department, especially the U.S. Army Center for Health Promotion and Preventive Medicine and the U.S. Army Medical Research and Materiel Command (USAMRMC), and some from other organizations (see acknowledgment note at end of chapter). It was created to be a cumulative technical reference document and to serve as a guide to the medical criteria and standards used to assess health hazards associated with army systems. The guide's developers intend that it be updated routinely in order to incorporate new trends and technology and remove outdated information. The guide presents key information used by health hazard assessors in the various hazard categories to include definition of the hazard, hierarchy of criteria and standards, methods of developing army-specific criteria and standards, and methods for measuring hazards and interpreting health risks.

15.6 TOOLS THAT SUPPORT THE OVERALL HEALTH HAZARD ASSESSMENT PROCESS

There are several tools that are applied in the HHA process to all of the various hazard categories. They either complement the hazard assessment directly or the HHA process in general.

15.6.1 Risk Assessment and Risk Assessment Codes

One purpose of the HHA program is to convey to the materiel developer the risks associated with the operation and maintenance of military systems. The NRC described a process that involves risk assessment and risk management that is applicable to the HHA process (NRC, 1983). In the HHA process the Army Medical Department, through the USACHPPM, is the health *risk assessor*. The materiel developers (acquisition community, e.g., program and project managers) are the *risk managers*. Risk assessment generally is a four-stage process that evaluates the potential for people to develop disease or die from exposure to biological, chemical, or physical agents. The risk management process is separate from but includes the risk assessment. Managing risk includes consideration and integration of a variety of other factors (e.g., technology, economics and funding, politics, social concerns, military needs and requirements, and others) that influence the outcome of design and production decisions. Risk assessment and management paradigms are discussed in a variety of references [Roberts and Abernathy, 1995; Abernathy and Roberts, 1994; NRC, 1983; Presidential/Congressional Commission on Risk Assessment and Risk Managemet (PCCRARM), 1997a,b].

The health hazard assessor (or independent medical assessor as identified in AR 40-10 U.S. Army, 1991a) estimates the health risk potential and provides this information, qualitatively and quantitatively, to the developer. The four basic steps in the risk assessment process are hazard identification, dose–response assessment, exposure assess-

ment, and risk characterization. Hazard identification is the process of determining the type of adverse health effects that a biological, chemical, or physical agent may cause. Dose–response assessment relates the severity of an adverse health effect in response to exposure to specific amounts or quantities of agents. Exposure assessment determines who will be exposed and how they will be exposed; the medium (e.g., air, water, soil, food, etc.), the routes (e.g., inhalation, ingestion, skin contact), the duration, the amount, etc. The risk characterization is the quantitative and/or qualitative expression of risk that combines the hazard identification, dose–response assessment, and exposure assessment.

The risk characterization is the tool that allows the independent medical assessor to convey the health risk and recommend to the materiel developer exposure levels to agents that should not cause adverse health effects to soldiers who use or maintain military systems. The assessment of such hazards may simply be to determine compliance with consensus standards or guidelines. If there is no such standard, then applying a risk assessment and management process may be necessary to estimate the impact to human health and develop a criteria or guideline to protect the health of soldiers.

The materiel developer then incorporates the health risk information (HHA) into the materiel acquisition development process. The developer is expected to make design and/or process changes that will incorporate the HHA recommendations to produce a system that will not cause any adverse health problems. However, it is not always possible or feasible to totally eliminate all conditions that can cause adverse health problems. Realistically, the developer must make design and production decisions based upon a variety of factors. Thus, the developer should integrate the health and medical recommendations into the overall decision process. When adverse health conditions cannot be totally eliminated, they should be reduced to some acceptable protective level. This level may be difficult to define and its pursuit should promote coordination and interaction between the developer and the HHA community.

In the military the estimated degree of risk that is associated with each health hazard is assigned a RAC. The RAC is an alphanumeric index that is based upon a hazard's probability (A, frequent; B, probable; C, occasional; D, remote; E, improbable) and its severity (I, catastrophic; II, critical; III, marginal; IV, negligible). Detailed discussion of RACs and their implications can be found in Gross and Broadwater (1993) and U.S. Army (1990a, 1991a) regulations. This alphanumeric designation is an example of how risk characterization is communicated to materiel developers.

15.6.2 Exposure Control Hierarchy

A key element of the HHA program is to identify and recommend strategies that will eliminate or decrease exposures to hazardous agents. Generally, there are several ways that any one potential hazard can be controlled. Throughout this chapter there are various controls discussed for each of the hazard categories. Various controls are presented here to show the reader that there is a hierarchy of possible control strategies. Such strategies may range from completely eliminating the hazard from the system or process to removing the person from the system or process. Generally removing the hazard and engineering controls is the best strategy because they do not rely upon an individual to comply with an activity or practice. Thus, there is a hierarchy of control strategies that can be recommended to control health hazards. The hierarchy of control strategies, in order of preference from a health perspective, includes engineering controls, work practices, personal protection, and administrative controls. These strategies and some examples

TABLE 15.6 Hierarchy of Control Strategies and Examples to Eliminate or Control Chemical, Physical, and Biological Hazards

A. Engineering controls	C. Personal protection
• Elimination • Substitution • Isolation • Enclosure. • Ventilation • Process change • Product change	• Respiratory protection • Gloves • Apron • Eye goggles • Ear muffs and plugs
B. Work practices	D. Administrative controls
• Housekeeping. • Dust suppression • Maintenance. • Sanitation • Work practices • Education • Labeling and warning systems • Waste disposal practices	• Work–rest cycles • Exposure time limits • Environmental monitoring • Medical control • Management program

are provided in Table 15.6. The reader should consult Corn (1984) and the HHA procedures guide (U.S. Army, 1994a) for additional detail and examples of control strategies.

15.6.3 Medical Cost Avoidance Model

Historically, it has been difficult for public health practitioners to quantify the economic impact of preventive programs. Generally, it is difficult to predict how much disease, illness, or death public health programs will prevent and then relate it to economy. However, given that such programs require funding to operate, they must compete for economic resources. Funding resources often are allocated based upon priority of need, and economic impact (e.g., cost savings) is one factor that is considered in decisions to allocate funds. Therefore, public health and preventive medicine practitioners need ways to quantify their economic impact. Bratt et al. (1997) developed a *medical cost avoidance model (MCAM)* that estimates medical costs for health hazards based on risk assessment codes. This model estimates total medical costs for unabated health hazards based on the costs for clinic visits, hospitalization, lost time, disability, rehabilitation, and death. It quantifies health hazard costs, improves the understanding of a stated health risk, and assists materiel developers with making risk management and trade-off decisions concerning corrective actions.

15.6.4 Hazard Tracking Database

As the HHA program has matured, an electronic database maintained at the USACHPPM was developed and evolved to record and monitor the health hazards associated with

military equipment and systems. The current database tracks results of HHAs and provides reporting designed to assist the HHA program manager in daily activities. Also, it is a resource for medical planners and advisors to use that can identify and estimate potential hazards that soldiers may encounter as they train and conduct missions. When new materiel systems are being considered for development, the database can be queried to provide information about health hazards associated with similar systems. Also, when existing systems are being considered for product improvement or modifications, the database can be queried to provide information about their existing health hazards. Additional information about the database, its history, and capabilities can be found in a discussion by Murnyak et al. (2002).

15.7 SUMMARY

By presenting the U.S. Army's HHA program, this chapter defines the typical hazards associated with military equipment and systems and demonstrates how the military services address the health component of the DoD HSI requirements. The reader should recognize that the sciences applied to and the process of conducting health assessments for military equipment are detailed and complex. Generally, these systems and equipment are evaluated by several health scientists in a multidisciplinary manner. Materiel developers should plan for and integrate this process into their acquisition and development plans and allow sufficient time for early and later HHAs to include the time for acquiring necessary data. Therefore, it should be evident that there is a need to integrate health concerns into the development and acquisition process during the early stages (e.g., during concept exploration). Early integration can help avoid costly retrofits to correct or eliminate hazardous conditions. The military services continue to apply state-of-the-art science, technology, and medical knowledge to assess and control military health hazards in order to protect and preserve the health of U.S. military forces and to enhance the military mission.

NOTES

1. Much of this chapter was either based upon or inspired by the contents of the *U.S. Army Health Hazard Assessor's Guide* (U.S. Army, 1996), which was developed and authored by scientists from the Army Medical Department, especially the U.S. Army Center for Health Promotion and Preventive Medicine and the U.S. Army Medical Research and Materiel Command. While it is recognized that this guide is a military publication and a public domain document, the contributions of these scientists and engineers should be recognized for their contributions and dedication to the health hazard assessment program and military public health and preventive medicine. Therefore, I wish to acknowledge the following individuals for their contributions to the guide (the organizations shown are the ones where they worked during the development of the guide): Major John Albano, U.S. Army Aeromedical Research Laboratory; Major (retired) David Alberth, U.S. Army Center for Health Promotion and Preventive Medicine; Dr. Nabih Alem, U.S. Army Aeromedical Research Laboratory; Lieutenant Colonel Gregory Argyros, Walter Reed Army Medical Center; Lieutenant Colonel (retired) Gary Bratt, Office of the Surgeon General; Major Barkley Butler. U.S. Army Aeromedical Research Laboratory; Lieutenant Colonel James Carroll, U.S. Army Medical Research and Materiel Command; Mr. John DeFrank, U.S. Army Center for Health Promotion and Preventive Medicine; Mr. Jim Devine, U.S. Army Research Institute of

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