Chapter 8

CONSERVING VISION

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INTRODUCTION

Ocular trauma is the sixth leading cause of blindness in the world following trachoma, xerophthalmia, onchocerciasis, cataract formation, and glaucoma.[1] Approximately 2.4 million individuals in the United States sustain ocular injuries annually; more than one-half of these injuries occur to individuals under 25 years of age.[2] Approximately 40,000 of them will suffer some degree of visual impairment and an estimated 1,500 will lose their sight permanently. Current estimates show that more than 900,000 individuals in the United States have permanent visual impairment caused by injury; 75% have monocular blindness.[3]

Ocular injuries are not without significant financial costs. Nationwide, ocular injuries account for an estimated direct cost of approximately $300 million in medical bills, compensation, and lost production time. For example, in 1980 the state of Ohio reported 6,457 work-related accidents that involved eye injuries, with direct medical and worker-compensation costs of nearly $20 million—approximately $3,067 per injury. These figures do not include either the associated costs of pain and anguish that eye injuries and blindness cause or the indirect costs (legal fees and judgments, time lost from work, costs associated with training replacement workers, or costs of repairing damaged equipment). Experts estimate that the indirect costs can be 5- to 10-fold higher than the direct costs.[4]

Statistics on industrial ocular injuries and principles used in industry to protect the eyes and vision have direct application to active-duty soldiers—in garrison or on the battlefield. While stationed in garrison, it is not unreasonable to assume that soldiers will suffer types and incidence of ocular injuries similar to their civilian counterparts. However, the battlefield, like the industrial workplace, may be both hazardous and lethal. In various worldwide military conflicts, eye injuries account for an estimated 4% to 9% of wartime injuries.[5–7] Soldiers with battlefield eye injuries must be evacuated to a fourth-echelon medical treatment facility (MTF) for definitive ophthalmic treatment and might not return to duty; even superficial foreign bodies in the eye will incapacitate a soldier at least 24 to 48 hours. To military commanders, losing 4% to 9% of their soldiers to eye injuries, even temporarily, may mean the difference between winning or losing a battle. As a result, efforts are currently underway to improve eye protection and reduce debilitating ocular injuries both in garrison and on the battlefield.

As compensation costs continue to rise, protecting and conserving vision has taken on increased importance. Initial efforts in occupational vision (sometimes referred to as industrial vision or eye safety) were directed toward reducing eye injuries by providing civilian employees working in eye-hazardous areas with industrial safety glasses. In 1992, occupational vision efforts within the army evolved to become the Vision Conservation Program, a more encompassing program composed of three program elements (occupational vision, eye safety, and environmental vision) and directed toward both soldiers and civilian workers.

LEGISLATION AND GOVERNMENTAL AGENCIES

The concept of occupational safety and health is relatively new, having evolved over the last 100 years. During the 19th century, on-the-job safety (including eye safety) was considered to be the responsibility of each individual employee, with employers assuming little or no liability in the event of an accident or death. The federal government did not become involved until the mid-1880s, and its focus was on job safety (the prevention of work-related accidents, injuries, and deaths) rather than occupational health (the prevention and control of work-related environmental disorders). Between 1890 and 1920, state governments became more active in job safety– and occupational health–legislation, while the federal government approached health problems through research and study programs. State laws, however, generally lacked uniformity (from state to state) and tended to be poorly enforced due to insufficient resources to hire inspection staffs.[8]

Occupational Safety and Health Act

Over the next 50 years, various federal initiatives to improve occupational safety and health were enacted, culminating with Public Law 91-596, the Occupational Safety and Health Act (OSHAct), which President Richard M. Nixon signed on December 29, 1970, and which went into effect in April 1971. The general-duty clause of the OSHAct emphasizes that each *employer* shall furnish to each of his employees not only employment but also

> a place of employment free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.[9(p4)]

In addition, employees are required to comply with the standards, rules, and regulations of the OSHAct and are responsible for their own actions and conduct. These provisions apply to safety in general as well as to eye safety.

Most of the OSHAct regulations that pertain to vision conservation are found in Title 29, Code of Federal Regulations, Section 133.[10] These regulations assert that protective eye and face equipment shall be required when there is a reasonable probability of the type of injury that this equipment can prevent. Eye protectors must provide adequate protection against certain hazards, be reasonably comfortable, fit snugly without interfering with the wearer's movements, be durable, tolerate disinfection, be easily cleaned, and be kept in good repair. Workers who require corrective lenses shall have the option of wearing prescription industrial safety eyeglasses, goggles over their ordinary dress safety glasses, or goggles that incorporate corrective lenses mounted behind the protective lenses. Eye protectors must be distinctly marked to facilitate their identification as approved industrial safety devices. The design, construction, testing, and use of ocular and facial protectors shall be in accordance with American National Standard Institute (ANSI) Standard Z87.1.[11]

Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA) has primary responsibility for

- developing mandatory job safety and health standards,
- enforcing the OSHAct through inspections of the workplace,
- maintaining a recordkeeping system to monitor job-related injuries and illnesses,
- implementing programs to reduce workplace hazards, and
- researching occupational safety and health issues.

OSHA requires that employers provide protective eyewear that meets ANSI standards at no cost to the employee.[10] Employees, management, and even visitors must wear approved eye protection when they enter or work in an eye-hazardous area. In some states, employers are required to provide any related technical services such as frame selection, lens design, ordering, verification, and fitting that are needed whenever corrective lenses are worn.[12] OSHA rules also require that employers provide safety training, including eye-safety training.

However, OSHA does not require employers to pay for their employees' vision examinations. Some federal agencies, including the Department of Defense (DoD), have taken the initiative to provide vision examinations for their employees who work in eye-hazardous areas. Most agencies have found that by providing eye examinations, they ensure that employees can see well enough to perform their jobs; worker productivity improves and the risk of costly eye injuries is reduced.

National Institute for Occupational Safety and Health

In conjunction with the passage of OSHAct, the National Institute for Occupational Safety and Health (NIOSH) was formed as a division of the Department of Health, Education, and Welfare (now the Department of Health and Human Services, DHHS) to assist in developing safety and health standards. Consequently, NIOSH is responsible for identifying occupational-safety and occupational-health hazards by gathering information through workplace surveys and laboratory research. Workplace surveys are accomplished through industrywide studies, which are specifically authorized by OSHAct. In addition to surveillance and data gathering, NIOSH conducts extensive research at its own laboratories and under contract at universities and private research institutes. Results of this research serve as the basis for recommending new health and safety regulations. These recommendations, known as *criteria documents*, are forwarded to OSHA, which has the ultimate responsibility for promulgating standards.

While NIOSH's first responsibility is to advise OSHA on standards, it also has other functions; for example, it publishes bulletins to inform health professionals about new health hazards and offers training programs on occupational safety and health. Numerous vision-related research projects, including studying the biological effects of ionizing and nonionizing radiation, have been performed at the institute's facility in Cincinnati, Ohio, and have resulted in several publications and articles concerning ultraviolet (UV) and infrared (IR) radiation.[13]

Food and Drug Administration

Before 1971, the eyeglass industry was largely unregulated. OSHAct was intended to protect industrial workers; there was no legislation like it to protect the vision of the general public. The lenses of dress safety glasses (street eyewear) were often ground extremely thin in order to improve their cosmetic appearance. Because these lenses shattered on minimal impact, many wearers' eyes were cut and irreparably damaged by broken glass.

To protect the vision of the general public, ANSI promulgated a voluntary set of standards for dress safety glasses in 1968. This standard, the *American National Standard Recommendations for Prescription Ophthalmic Lenses*, Z80.1-1968, recommended that all prescription lenses dispensed in the United States be impact resistant (the lenses should be able to withstand a specific impact: that from a ⅝-in steel ball dropped from a height of 50 in).[14] In December 1971, the Food and Drug Administration (FDA) issued a general policy statement on the use of impact-resistant lenses in eyeglasses and sunglasses. The general policy statement adopted an impact-resistance test similar to that stated in ANSI Z80.1-1968.

The Medical Devices Amendment of 1976 authorized the federal government to oversee the safety and effectiveness of all medical devices, including ophthalmic products such as eyeglass lenses, contact lenses, contact lens solutions, and ophthalmic medications.[15] Congress subsequently passed 21 CFR Part 801.410, *Use of impact-resistant lenses in eyeglasses and sunglasses*, which is also similar to ANSI Z80.1-1968.[16] Compliance with 21 CFR Part 801.410 by ophthalmic laboratories does not mean that the lenses are unbreakable or shatterproof; rather, it means that the lenses are impact resistant (as previously specified). Furthermore, the impact resistance of dress safety glasses should not be confused with that required for industrial safety glasses, which provide the industrial worker with greater eye protection.

American National Standards Institute

ANSI is a nongovernmental agency that has created more than 10,000 standards (with which compliance is voluntary). State and federal agencies often adopt ANSI standards as their own regulations, but ANSI's standards themselves have no statutory authority. Their purposes are to eliminate the duplication of standards and to develop a single, nationally accepted standard. The ANSI standards that apply to vision, and that have been (or will be) adopted by the FDA or by OSHA, include

- ANSI Z80.1-1987: American National Standard Recommendations for Prescription Ophthalmic Lenses;
- ANSI Z80.3-1986: American National Standard Requirements for Nonprescription Sunglasses and Fashion Eyewear;
- ANSI Z87.1-1989: American National Standard Practice for Occupational and Educational Eye and Face Protection;
- ANSI Z136.1-1986: American National Standard for the Safe Use of Lasers; and
- ANSI Z358.1-1990: American National Standard for Emergency Eyewash and Shower Equipment.

U.S. Army Environmental Hygiene Agency

In 1946, the Army Industrial Hygiene Laboratory, now the U.S. Army Environmental Hygiene Agency (USAEHA), initiated the Occupational Vision Program at some depots and arsenals within the army industrial base. This program was directed toward federal civilian employees rather than soldiers. By 1953, 19 army installations with 90,000 civilian employees had Occupational Vision Programs.[17] During the 1960s, the Occupational Vision Programs were expanded and directed toward civilian workers at all army installations. Presently, all army installations must have the Vision Conservation Program, which is directed toward both civilians and soldiers.

Currently, there are three optometrists (two military optometrists and one civilian industrial optometrist) who staff Program 63, *The Vision Conservation Program* within the Occupational and Environmental Medicine Division at USAEHA, located at Aberdeen Proving Ground (Edgewood Area), Maryland. Their mission is to write vision-conservation policies and doctrine for publication, to survey or assist the Vision Conservation Programs at various installations around the country, and to educate occupational health personnel on all aspects of vision conservation.

U.S. Army Regulations and Publications

U.S. Army Regulation (AR) 40-5, *Preventive Medicine*, Department of the Army Pamphlet (DA PAM) 40-506, *Vision Conservation Program*, and Technical Bulletin, Medical (TB MED) 506, *Vision Conservation*, constitute the basis for vision conservation in the army. Because army regulations are ever changing, readers should contact the USAEHA for the latest publications that pertain to vision conservation.[18]

THE VISION CONSERVATION PROGRAM

An effective vision conservation program requires a team of dedicated industrial and healthcare professionals: (*a*) an optometrist, an ophthalmologist, or both; (*b*) an occupational health physician, an occupational health nurse, or both; (*c*) an industrial safety specialist; and (*d*) an industrial hygienist. The installation medical authority (IMA) is responsible for appointing an optometrist as the installation vision conservation officer (VCO). In the absence of an optometrist, an occupational health nurse may be appointed as the acting VCO. The installation VCO is responsible for managing the installation's Vision Conservation Program, including assisting the industrial hygienist in identifying eye-hazardous areas and operations, advising the safety specialist on appropriate eye protection and vision-related safety issues, ensuring that employees working in eye-hazardous areas receive periodic vision screenings and vision examinations, and prescribing the appropriate corrective lenses for industrial safety glasses. The occupational health physician or nurse is responsible for monitoring the visual health of all employees, especially those who work in eye-hazardous areas, and for referring workers to an optometrist or ophthalmologist if they either fail the required vision screening or sustain an eye injury while on the job. The industrial safety specialist is responsible for approving all orders for *plano* (noncorrective) and prescription industrial safety glasses and for enforcing the wearing of safety eyewear throughout the workplace. The industrial hygienist is responsible for evaluating the workplace for eye-hazardous operations and taking action to reduce the risk of eye injuries.

An effective vision conservation program consists of the following essential elements, all of which will enhance vision, increase productivity, and reduce the risk of industrial eye injuries: (*a*) command and management commitment, (*b*) vision testing, (*c*) eye-hazard analysis, (*d*) accident prevention, (*e*) total participation, (*f*) education, (*g*) enforced use, (*h*) fitting and maintenance, and (*i*) emergency first-aid procedures.

Command and management commitment is absolutely essential for a dynamic vision conservation program. Commanders and supervisors bear the moral and legal responsibility for preventing eye injuries. Written policies and local standing operating procedures should be published to add emphasis and encourage compliance with the program.

Vision testing is utilized as part of preplacement and periodic physicals to find uncorrected vision problems that may decrease worker productivity, or, worse, lead to accidents. Workers who fail the vision screening should be referred for a complete vision evaluation to correct the visual deficiency.

Eye-hazard analysis requires the industrial hygienist or the installation safety specialist, or both, to evaluate every operation within the workplace, and to identify—and then mark with warning signs—all eye-hazardous operations. Once these hazards have been identified, the installation safety office should establish a job-title list that identifies those employees (by name) who work in eye-hazardous areas, the type of work that is done in each area, and the type of protection that is required for the job. At installations with access to the Occupational Health Medical Information System (OHMIS), the industrial hygienist should enter all data about eye-hazardous areas into the Health Hazard Information Management (HHIM) system, which is discussed in detail in Chapter 4, Industrial Hygiene.

Accident prevention can be a significant step in reducing or eliminating eye injuries. Safety training and motivation programs should also be utilized as a means for increasing safety awareness.

Total participation requires that eye protection be worn by all individuals (commanders, managers, soldiers, civilian employees, visitors, and contractors) when entering or working in eye-hazardous operations or areas. Plano safety glasses for visitors should be stocked at the installation safety office and at the entrances to buildings with eye-hazardous operations.

Education greatly enhances the effectiveness of a vision conservation program. All employees should be instructed in the proper use of eye-protective devices and should be reminded of the benefits of the program. A multidisciplinary team including plant supervisors, the occupational health nurse, the occupational health physician, the industrial hygienist, safety personnel, and the optometrist should develop the education program.

Enforced use is perhaps the most important, yet the most overlooked, element in an effective vision conservation program. Military and civilian supervisors should not hesitate to insist that soldiers and civilian employees wear their industrial safety glasses. Encouragement and rewards, rather than disciplinary procedures, should be used to encourage compliance, and whenever practicable, individuals who do wear appropriate eye protection should be praised or publicly rewarded. However, commanders and management should publish the disciplinary procedures that will be implemented when civilian employees or soldiers fail to comply with the safety rules and regulations for wearing industrial safety glasses. Typically, these consist of

- a verbal or written warning for the first infraction;
- a 1-day suspension, invoked if the individual's noncompliant behavior persists (soldiers may be subject to disciplinary action under the Uniform Code of Military Justice); and
- initiation of steps to remove habitually noncompliant individuals from the job.

Fitting and maintenance of eye-protection devices helps to ensure wearing compliance. Shops should be discouraged from ordering inexpensive, nonadjustable plano safety glasses; likewise, workers should not wear eye protection that is ill fitting or does not work properly. An optician or qualified technician should be available to adjust safety eyewear, both prescription and plano. Lens-cleaning stations, stocked with lens-cleaning solutions, tissues, and antifogging products, should also be available throughout the plant.

Emergency first aid should be taught to all soldiers and civilians who work in eye-hazardous areas, especially where a chemical splash is possible. Those who work in areas where airborne foreign bodies (such as dust) make superficial injuries likely should be taught how to irrigate eyes with water. Those who work in areas where *ballistic* wounds (penetrating injuries caused by projectiles) are possible should be taught simple eye-patch and eye-immobilization techniques. Those who work in areas where chemical hazards are likely should be instructed in the proper use of eyewash fountains and in methods for retracting coworkers' eyelids.

OCCUPATIONAL VISION

The *occupational vision* element of the Vision Conservation Program consists of vision screenings and examinations. It is directed toward ensuring that soldiers' and civilian workers' vision is at least adequate—and preferably the best possible—to enable them to work productively, efficiently, safely, and comfortably. At a minimum, workers must be able to see well enough to perform their jobs safely, without risking injury to themselves or their fellow workers, or face job reclassification. If resources are available, workers should be provided a full range of vision services as a means for increasing productivity. Initiating and maintaining this element of the program presupposes that economic gains will follow: better retention rates; increased training efficiency; improved job performance; greater job safety; and, for civilian workers, better industrial relations.

Screenings

Vision screenings are designed to evaluate an employee's visual system, the results of which may be used to help select personnel for employment or to identify those employees whose vision might need further evaluation. Vision screenings, however, should not be confused with vision examinations; vision screenings superficially test a number of visual functions, while vision examinations are more thorough and are directed toward remediating a visual problem. Civilian workers generally receive their vision screenings at the occupational health clinic, while soldiers receive their vision screenings at the physical examination section (as part of a routine physical) or at the installation optometry clinic.

Binocular vision screening instruments (Figure 8-1) are more accurate than a simple Snellen eye chart. While a Snellen chart can only evaluate visual acuity, modern binocular testing devices check multiple visual functions, including:

- central visual acuity at both a distance of 20 ft or greater and at the nearpoint (13–16 in);
- muscle balance and eye coordination (the ability to keep the eyes pointed or directed toward an object);
- depth perception (the ability to judge the spatial relationships of objects); and
- color discrimination (the ability to differentiate colors correctly).

In addition, auxiliary lenses can be used to adapt these instruments for evaluating visual acuity at intermediate distances. Some testing instruments are even capable of determining rudimentary visual fields (the area of space visible to an eye).

Standards

During World War II, Joseph Tiffin and a team of researchers at Purdue University studied more than 4

Fig. 8-1. The Armed Forces Vision Tester (AFVT), left, has been used for screening soldiers for decades and is still in use at most military entrance processing stations. The AFVT is mechanically operated, highly reliable, and is made of heavy-gauge steel. The AFVT is gradually being replaced by a new generation of lightweight, portable, and electronically operated vision screeners, such as the Titmus II Vision Screener, right. Other similar new vision screeners include the Optec 2000, manu-factured by Stereo Optical, Inc., and the Sight Screener II, manufactured by American Optical Company.

million workers at thousands of different job sites. The purpose of this research was to improve industrial production during the war, a time when the healthiest males were unavailable, by maximizing worker efficiency and reducing industrial accidents. At the conclusion of their research, they developed minimum vision standards for six different categories of jobs.[19] Applying these standards to job applicants ensured that their visual acuity was adequate for the job and determined if and when they needed to be referred for vision correction. As a result of this research initiative, industry, including the DA, has universally adopted the six job vision standards. They were created before the advent of video display terminals (VDTs) and personal computers (PCs), however. To correct for this, The Surgeon General added a seventh vision standard for VDT operators serving in or working for the U.S. Army (Table 8-1).

Further research and industrial experience have shown that individuals who meet these standards should be able to perform their jobs safely and efficiently. However, these vision standards are often misinterpreted and should *not* be used as criteria for vision referrals. For example, while it may have been perfectly acceptable to allow a plumber with 20/30 vision to continue working at his job (vision standard no. 5) during World War II, today's standard of care mandates that this worker be referred for a complete vision examination to correct his visual acuity to 20/20. If, after a thorough vision examination, the plumber has a best (corrected) visual acuity (BVA) finding of 20/30, interpretation of vision standard no. 5 suggests that the worker can still perform his job safely and relatively efficiently. If the plumber's vision deteriorates (eg, as a result of cataract formation) to a BVA of 20/50, then his duties should be reduced or he should be reclassified into a different job until his cataract is removed and his vision improves.

There may be times when stricter vision standards should be adopted. In jobs with higher-than-usual risks to eyesight and personal safety, the usual job vision standards may be inadequate. For example, depth perception is critical for machinists, who may require stricter depth perception than 50 seconds of arc, as listed in vision standard no. 4. Color perception may not be a requirement for every job, but it might be

TABLE 8-1

RECOMMENDED JOB VISION STANDARDS

Vision Standard	Job Category	Acuity Distance	Acuity Near	Muscle Balance Distance	Muscle Balance Near	Color Vision	Depth Perception
1	Administrative and clerical	20/30 20/25 OU	20/25 20/22 OU	4 eso 5 exo 0.5 vert	4 eso 5 exo 0.5 vert	Normal	NA
2	Inspector and assembler	20/35 20/30 OU	20/25 20/22 OU	4 eso 5 exo 0.5 vert	4 eso 5 exo 0.5 vert	Normal	50"
3	Vehicle driver, crane and forklift operator	20/25 20/22 OU	20/35 20/30 OU 0.5	4 eso 5 exo vert 0.5	4 eso 5 exo vert	Normal	40"
4	Machine operator	20/30 20/25 OU	20/30 20/25 OU	4 eso 5 exo 0.5 vert	4 eso 5 exo 0.5 vert	Normal	50"
5	Skilled trades: Plumber, millwright, and electrician	20/30 20/25 OU	20/25 20/22 OU 0.5	4 eso 5 exo vert 0.5	4 eso 5 exo vert	Normal	50"
6	Unskilled trades: Porter, warehouseman, and laborer	20/30 20/25 OU	20/35 20/30 OU	NA	NA	NA	NA
7	Video display terminal operator*	20/30 20/30†	20/25	NA 0.5	ortho 8 exo vert	NA	NA

*Unlike the other, earlier standards, this one has an additional, intermediate distance visual acuity requirement
†Intermediate testing standard
NA: not applicable
OU: both eyes
eso: esophoria, the amount of inward turning of the two eyes, relative to each other
exo: exophoria, the amount of outward turning of the two eyes, relative to each other
ortho: orthophoria, the eyes directed toward infinity, the absence of eso- and exophoria
vert: vertical phoria, the amount of upward or downward turning of the two eyes, relative to each other

a necessity for certain workers such as electricians or painters. Because 8% of all males and 0.5% of all females are color blind, only those with superior color perception should be placed in jobs that involve colored wiring codes or colored dyes or paints. Because color discrimination declines with age (due to mild sclerosis or yellowing of the crystalline lens), these employees, when they reach 40 years of age, should have their color vision checked during their annual vision screening or physical.

Examinations

Civilian workers and soldiers should be referred for a complete vision examination when they (*a*) have significant vision complaints, (*b*) fail the vision screening (according to predetermined vision criteria), or (*c*) fail to meet the minimum vision standards for their jobs. Determining why an individual failed a vision screening is best left to the professional judgment of an optometrist or ophthalmologist. Military personnel are required to obtain their examinations at the nearest MTF. Civilians who work in eye-hazardous areas will either be provided vision examinations at government expense at the nearest MTF or be reimbursed for an examination at a private facility. Other federal civilian employees (those not working in eye-hazardous areas) who fail the vision screening must arrange and pay for their own vision examinations and eyeglasses.

EYE SAFETY

Eye safety is the element of the Vision Conservation Program that attempts to eliminate the incidence of eye injuries. Whether the setting is an industrial plant, a military training exercise, or a battlefield, civilian workers and soldiers can be exposed to a variety of eye hazards. Military commanders, industrial managers, and supervisors must understand that eye-hazardous areas and operations exist and must ensure that these hazards are periodically surveyed by the industrial hygienist. Initial efforts to reduce the risk to workers and their vision should be directed toward instituting engineering controls, administrative controls, or both. Additionally, installations must provide workers with personal eye protection that is commensurate with the potential risks to vision, meets or exceeds the legal standards, is comfortable to wear, and is cosmetically appealing.

Incidence of Eye Injuries

Two recent studies have evaluated the nature and degree of eye injuries. According to data from the National Health Interview Survey (the value for N is not available), most ocular injuries that cause severe visual impairment occur within the home (30%), while the workplace is the second most common location (27%).[20] Using data that were recorded in the Eye Injury Registry of Alabama (EIRA) from a study of 736 serious eye injuries that occurred August 1982 through May 1986, the most common sites of eye injuries were the workplace (28%) and the home (27%), followed closely by recreation sites (25%) (Figure 8-2). Other eye injuries occurred during criminal assaults (11%), while traveling (5%), and at school (1%). Plotting the data by age revealed that individuals 20 to 29 years of age had the highest rate for eye injuries (32%), followed by individuals 30 to 39 years of age (25%) (Figure 8-3).[21]

The EIRA study also found that blunt instruments were responsible for the most eye injuries (32%), followed by sharp instruments (23%), hammer-on-metal (chips that fragment off while metal is hammered) (11%), gunshots (8%), BB guns or pellet guns (7%), and fireworks (4%) (Figure 8-4). Blunt trauma was caused by objects such as fists, tree limbs, thrown projectiles (including balls), and objects propelled by lawn mowers. Penetrating trauma was caused by broken glass, fish hooks, tree branches, nails, screws, scissors, and thorns. Both extraocular and intraocular metallic foreign bodies were caused by hammer-on-metal injuries. Bottle rockets were the predominant source of fireworks injury. Alkali burns were the most common chemical injury. These burns can occur when lye or commercial drain cleaners come into contact with the eyes (eg, during domestic assaults or accidents).[21]

Industrial Eye Injuries

Almost 70% of all industrial eye injuries result from flying or falling objects that strike the eye. Nearly 60% of the objects that cause these eye injuries are smaller than the head of a pin and travel at high velocities. An additional 20% of industrial eye injuries are caused by chemicals, while the remaining 10% result from objects that swing from a fixed position (such as tree limbs, ropes, chains, or tools) and are unexpectedly pulled toward the worker.[22]

A Census Bureau study done in 1980 showed that 63% of all work-related eye injuries occurred within the construction industry. Of the eye injuries that occurred there, the most prevalent were to metal workers and welders (20%), followed by plumbers (8%), carpenters (7%), electricians (4%), and painters (4%). The other major group of eye injuries was sustained in the automotive-repair industry and accounted for 18% of work-related eye injuries.[23]

The relatively high number of eye injuries that occur in industry each year is surprising, considering that the surface area of the eyes is only approximately 0.54% of the entire frontal body surface area. Experts believe that at least 90% of workplace eye injuries could have been prevented had the worker simply used industrial protective eyewear.[22] According to the Bureau of Labor Statistics, almost 60% of workers in selected occupations who suffered impact eye injuries were not wearing eye protection at the time of the accident. Most of the workers who wore eye-protective devices and still sustained an injury were wearing the wrong kind of protective device for the particular hazard.[24]

Militarily Unique Eye Injuries

The number and incidence of ocular injuries has increased with each military conflict (Table 8-2). More accurate recordkeeping probably accounts in part for this trend, but a second and probably more important reason is that the weapons used in modern warfare increasingly depend on fragmentation as their mechanism of injury. Modern ballistic weapons are designed to break up into thousands of small-mass, high-velocity metallic fragments. These tiny fragments not only

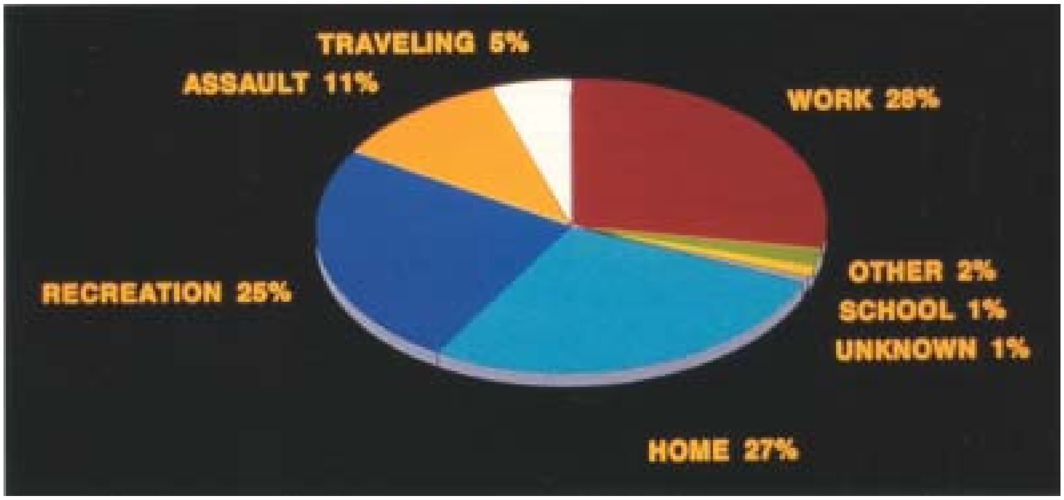

Fig. 8-2. The EIRA Study. Percentage of eye injuries by location of occurrence.

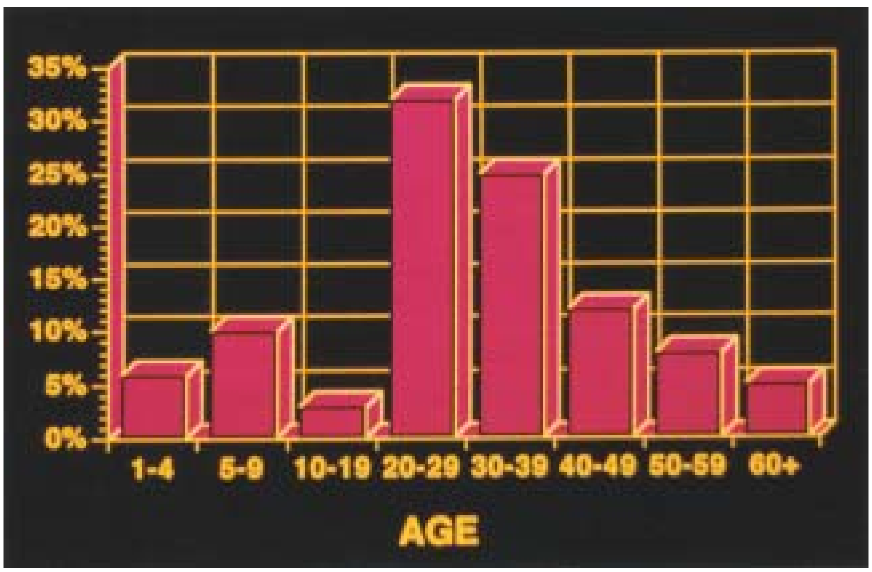

Fig. 8-3. The EIRA Study. Percentage of eye injuries by age.

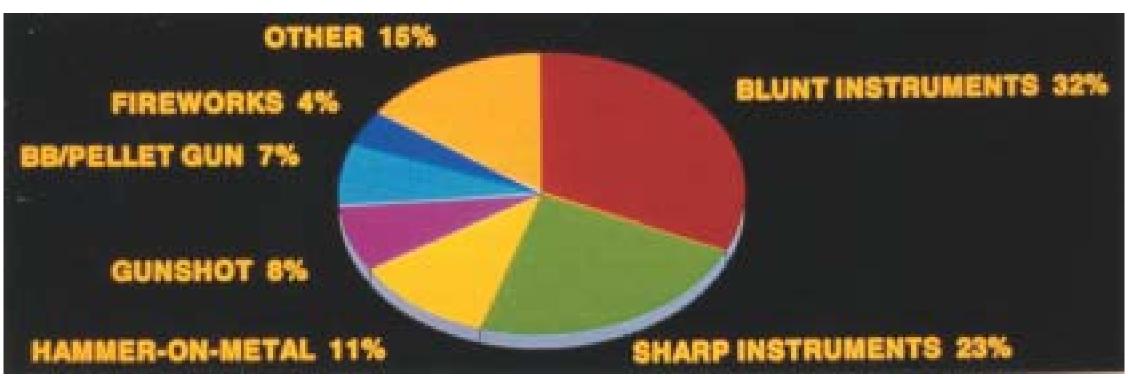

Fig. 8-4. The EIRA Study. Percentage of eye injuries by cause.

TABLE 8-2

INCIDENCE OF OCULAR INJURIES IN MILITARY ACTIONS

Military Conflict	Date	All Casualties (%)
American Civil War	1861–1865	0.57
Franco-Prussian War	1870–1871	0.81
Sino-Japanese War	1894	1.2
World War I	1914–1918	2.1
World War II	1939–1945	2.2
Korean War	1950–1953	4.1
Vietnam War	1965–1972	6.0–9.5
Arab-Israeli Six-Day War	1967	5.6
Arab-Israeli Yom Kippur War	1973	6.7
Arab-Israeli Lebanon War	1982	6.8

Sources: (1) Belkin M. Original, unpublished research. *Ophthalmological Lessons of the 1973 War: Prevention of Ocular War Injuries*. Jerusalem, Israel: Hadassan University Hospital, Dept of Ophthalmology. (2) Hornblass A. Eye injuries in the military. *Int Ophthal Clinics*. 1919;21:121–138.

cause vision-threatening injuries, but worse, they can also cause the loss of one or both eyes. (If these fragments were randomly to strike any other part of the body surface, the casualty might not even require evacuation from the battle zone.)

Each recent conflict has provided valuable information on the nature and extent of eye injuries that can occur when inadequate eye protection is worn. In the Six-Day War (1967), 25% of all eye injuries were perforations of the globe. In one battle for Jerusalem, there were only 100 casualties; 40 of them had perforating eye injuries. Ninety percent of these injuries were due to small-mass, high-velocity fragments, and nearly 25% of the injuries were bilateral perforations.[5,6] During the Vietnam War, an American soldier who was struck in the eye had a greater than 50% chance of losing it.[25] As a response to this rate, a primitive form of polycarbonate eye protection was tested on First Cavalry Division soldiers. This has led the U.S. Army Medical Department (AMEDD) and the U.S. Army Natick Research, Development, and Engineering Center to develop prototypes of eye protection: the Ballistic/Laser Protection Spectacle (BLPS) and the Special Protective Eyewear Cylindrical System (SPECS).

A change in the prevalent mechanism of injury in ocular casualties has occurred with technological advances in tactics and weaponry. Prior to the 1973 Yom Kippur War, the vast majority of eye injuries were due to the fragmentation of artillery projectiles. With the changes in tactics, only 14% of the eye injuries that were sustained during the 1973 Yom Kippur War were due to artillery projectiles. Instead, antitank weapons caused the highest number (72%). Sixty-five percent of the soldiers who sustained eye injuries were in tanks or armored personnel carriers, with tank commanders, tank crews, and armored infantry being the most vulnerable. Only a minority of eye injuries were inflicted on soldiers in open spaces.[5,6]

During peacetime, while troops are garrisoned, accurate eye-injury data have been difficult to obtain. To date, the army has neither an eye-injury data-collection form to collect such information nor a database from which to analyze it. However, it is not unreasonable to assume that statistics concerning civilian industrial workers might also apply to peacetime active-duty soldiers.[26,27] Data collected from army personnel during 1977 to 1981 revealed that 3,556 eye injuries, or approximately 710 eye injuries per year, had occurred. However, these figures are probably low because they include only soldiers who were hospitalized with eye injuries and exclude all soldiers who were examined in outpatient clinics. An analysis of the data reveals that the most prevalent causes of eye injuries were machinery or tool accidents (20%), land-transport vehicles (16%), athletics or sports (12%), falls or unspecified agents, (9%), and guns or explosives (7%).[28]

Ballistic and Mechanical Hazards

Ballistic and mechanical hazards are ubiquitous both in the industrial environment and on the battlefield. In industry, these hazards tend to be associated with metal shops (with equipment such as metal lathes, drill presses, and punch presses) and automotive shops (eg, rust particles can fall into the eyes of a mechanic who is working under a vehicle). During military training exercises and under battlefield conditions, many soldiers sustain ocular injuries when branches snap back into their faces, mortar or grenade fragments strike their faces, or rounds from their own weapons explode.

Foreign Bodies

Projectiles that impact and are retained on or around the eyes are called *foreign bodies*. They are generally classified as metallic or nonmetallic, toxic or nontoxic, and penetrating or nonpenetrating.

Civilian workers or military casualties with nonpenetrating foreign bodies of the cornea (Figures 8-5 and 8-6) require referral to an ophthalmologist or qualified optometrist for removal. Superficial foreign bodies (those that are located on or within the corneal epithelium) should be removed with irrigation, a needle, or a *spud* (a blunt, metal probe). Embedded foreign bodies or those with rust rings from iron-containing metals usually require removal with an Alger brush, dental burr, or large-gauge needle. Foreign bodies that penetrate into the corneal stroma will ultimately leave a scar. The resultant degree of visual impairment will depend on the scar's location: those that are closest to the center of the cornea will produce the greatest loss of visual acuity.

Penetrating foreign bodies (Figures 8-7, 8-8, 8-9, and 8-10) breach the cornea or sclera. These injuries usually occur during mechanical operations such as high-speed drilling, mechanical grinding, and pneumatic riveting. These perforating wounds of the cornea or sclera are often small and barely visible to the examiner and may have little or no associated pain (other than the initial insult to the eye). In many cases the entry wound is so small that diagnosis at the worksite is difficult; a hole in the iris or an irregular pupil may be the only evidence that the worker has sustained a penetrating injury. Fifteen percent of all intraocular foreign bodies are retained in the anterior chamber, 8% in the lens, 70% in the posterior chamber, and 7% in the orbit.[29] A worker who suspects that he or she has sustained a penetrating injury from a foreign body, and who was not wearing appropriate eye protection at the time, should be referred immediately to an ophthalmologist for evaluation, radiography, diagnosis, and possible surgery.

Blunt Trauma

A direct blow to the eye by a blunt missile (such as a clenched fist, a squash ball, or even a champagne cork) can produce one or more of the following signs: hyphema (a collection of blood in the anterior cham-

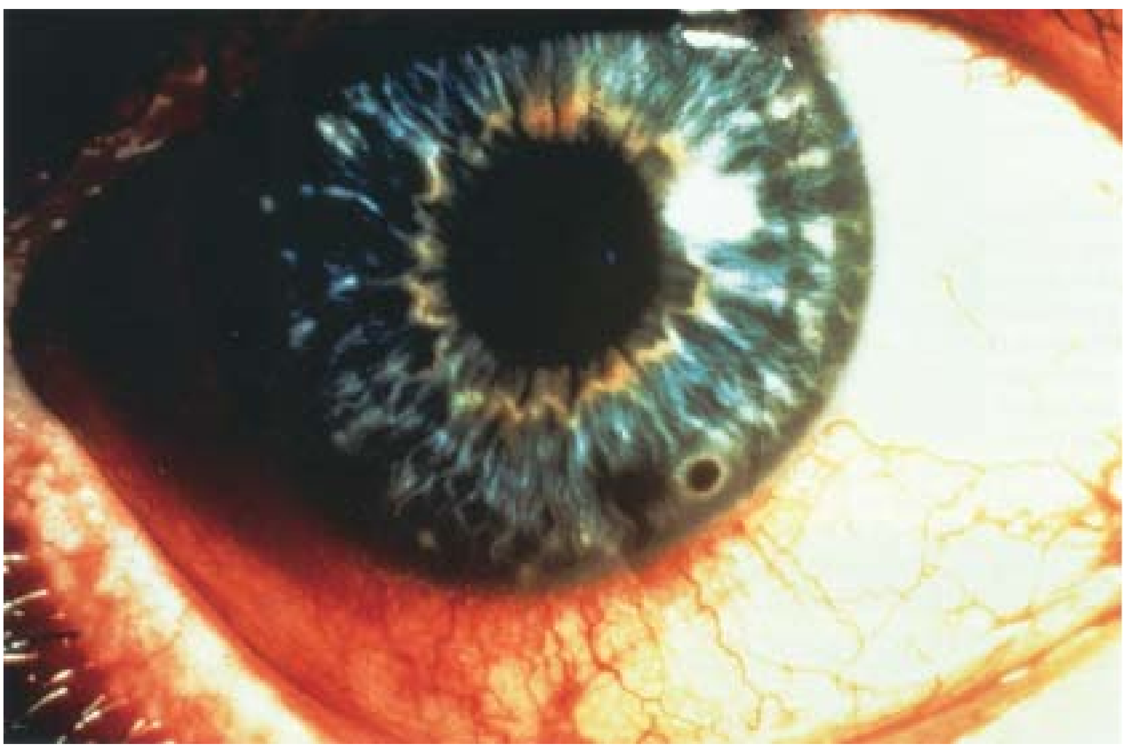

Fig. 8-5. Small, superficial, peripheral foreign bodies, such as that shown on the lower temporal portion of the cornea of the left eye, are often blown into the eye. These superficial foreign bodies can be easily removed (after the cornea has been anesthetized) with a needle or spud and leave little or no residual scarring. After the foreign body has been removed, treatment consists of topical antibiotics, analgesics, and a pressure patch (if the patient is uncomfortable); topical steroids should be avoided because they will slow healing. Photograph: Courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC.

Fig. 8-6. Iron-containing metallic foreign bodies are typically projected onto the eye and leave a rust ring, which must eventually be removed with a spud, needle, or Alger brush if proper healing is to occur. The rust ring pictured here (the metallic foreign body has already been removed) shows that the original metallic foreign body struck the cornea with minimal force, with damage limited to the corneal epithelium. However, foreign bodies that penetrate beyond the corneal epithelium into the corneal stroma will ultimately leave a corneal scar; scarring at or near the visual axis (the line of sight) can ultimately degrade visual acuity, depending on the size and density of the resulting scar tissue. Photograph: Courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC.

Fig. 8-7. A large, metal burr penetrated the lower temporal limbus of the left eye of a metal-lathe worker who was not wearing eye protection. The cornea and iris root were involved and ophthalmological surgery was required. Because the injury was peripheral to the visual axis, there was minimal effect on visual acuity; however, the worker missed several days of work. Photograph: Courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC.

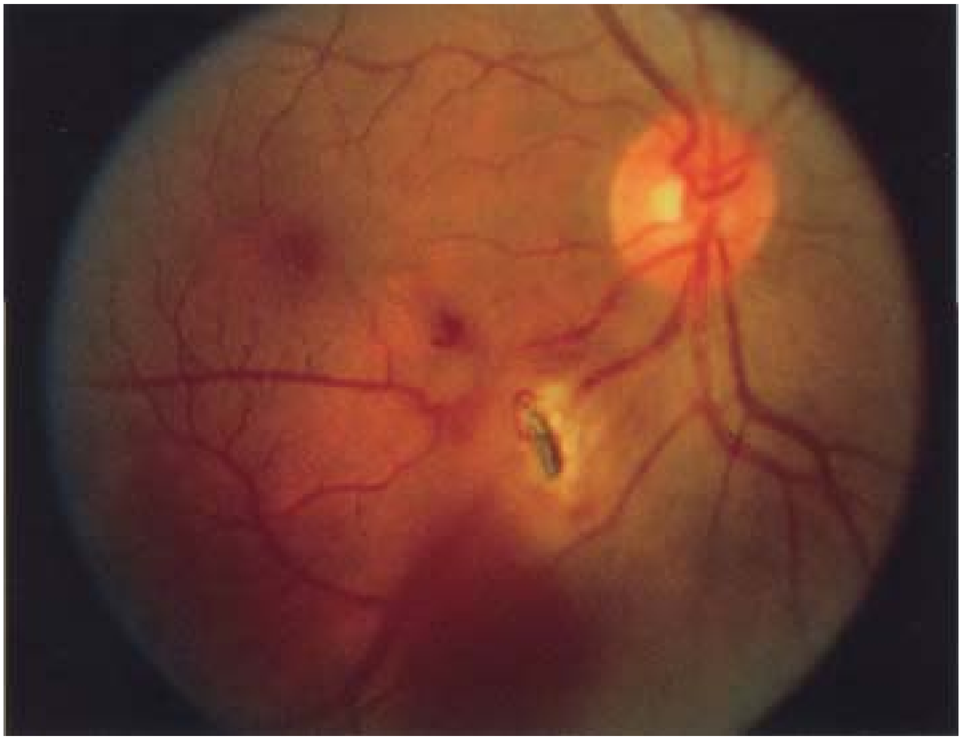

Fig. 8-8. Foreign bodies often have sufficient velocity to perforate the cornea or sclera—passing through internal structures such as the aqueous, iris, and vitreous—and can penetrate the lens or retina. Workers may not be fully aware that they have suffered an eye injury; the only visible signs may be some minor redness of the eye or an additional hole in the iris. These workers must be referred for evaluation and possible surgical treatment immediately. Industrial safety glasses might have precluded this injury.

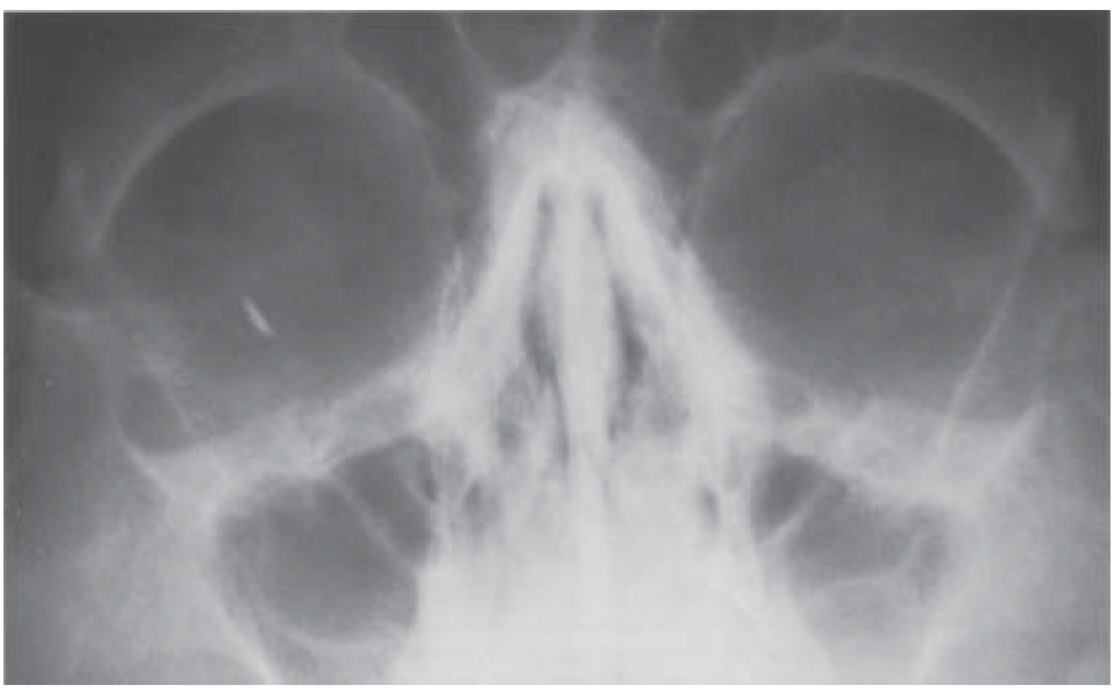

Fig. 8-9. Whenever a worker suspects that a penetrating eye injury has occurred, he or she should be referred for radiography and further evaluation. The penetrating metallic foreign body in the right eye is easily seen in this radiographic (Water's) view. Photograph: Courtesy of David Talley; formerly, Redstone Arsenal, Huntsville, Alabama.

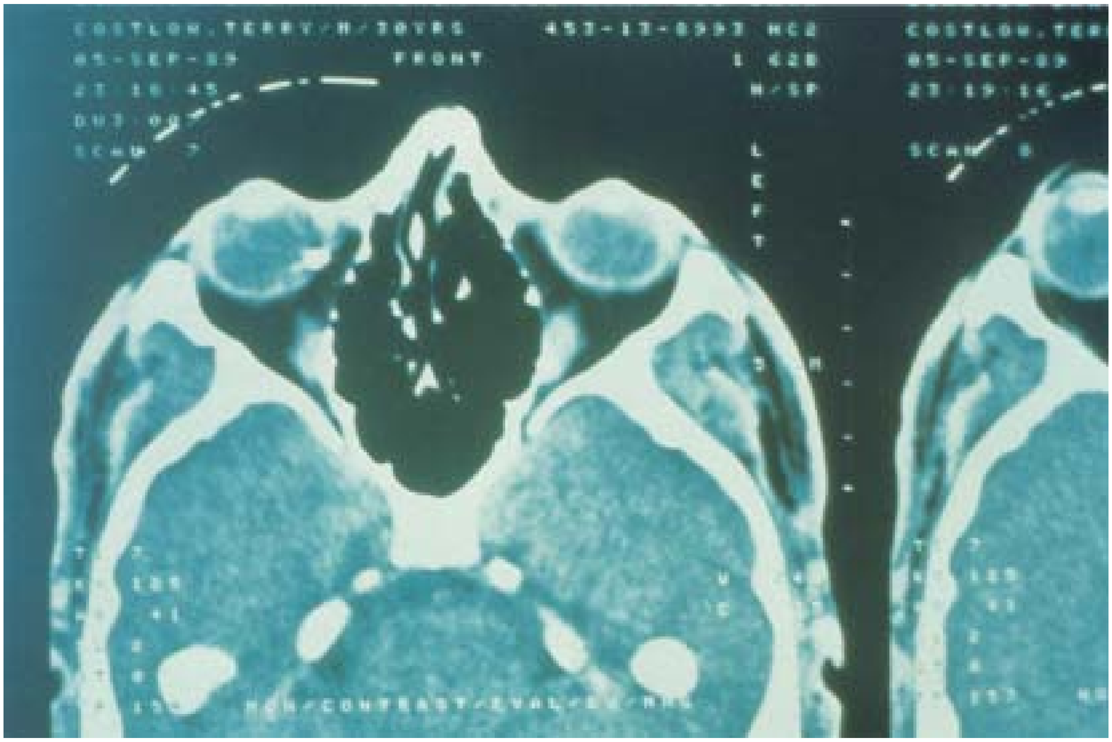

Fig. 8-10. A computed tomography (CT) scan is often useful in determining the exact location of a penetrating foreign body, especially if surgical removal is required. This large foreign body is lodged on the nasal retina of the right eye. Photograph: Courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC.

ber); subluxation (dislocation) of the crystalline lens; a blowout fracture of the orbital floor or nasal wall; iridodialysis (a rupture or tear of the iris from its base on the ciliary body); traumatic pupillary mydriasis (dilation caused by temporary or permanent paralysis of the sphincter muscle of the pupil); traumatic iritis; vitreous hemorrhage; and retinal hemorrhage, tears, or detachments. These signs all require that the patient be referred immediately to an ophthalmologist. Blunt trauma may also be characterized by ecchymosis (a black eye), subconjunctival hemorrhage, and occasionally, crepitus (air leaking under the skin) if a sinus has been injured.

Traumatic hyphemas (Figure 8-11) range from *mild*, wherein only a few erythrocytes are found floating in the anterior chamber during slitlamp examination; to *partial*, wherein blood pools in the lower portion of the anterior chamber; to *total*, wherein the anterior chamber virtually fills with blood. Partial hyphemas are usually resorbed through the trabecular meshwork of the anterior chamber within a few days. However, approximately 20% of hyphemas rebleed 3 to 5 days after the injury. Of the eyes that rebleed or have an initial total hyphema, 20% to 50% will be left with visual acuity of 20/40 or worse. Eight percent of the injured eyes that manifest hyphema will have a dislocated lens and approximately 7% will develop glaucoma in later years. Five to ten percent of traumatic hyphemas require surgical repair.[29] Complete bedrest is indicated, and an ophthalmologist should follow this condition to ensure that additional damage to the eye, which may not have been apparent initially, did not occur.

In a blowout fracture of the orbit, the energy of the impact forces the contents of the orbit (the eye, extraocular muscles, neurovasculature, and orbital fat) either downward, fracturing the orbital floor and forcing some of the orbital contents into the maxillary sinus, or nasalward, fracturing the wall of the ethmoid sinus. As a result, enophthalmus (the eye sinks into the orbit), diplopia (double vision), and entrapment of the extraocular muscles in the maxillary sinus or the ethmoid sinus can occur.

Chemical Hazards

While all eye injuries are considered to be potentially vision threatening and are emergency situations, chemical eye injuries must be treated immediately, even before the victim is transported to a medical facility for definitive care. *All chemical injuries, especially those that involve alkalis, pose a significant threat to*

Fig. 8-11. Hyphemas are usually caused by blunt trauma to an unprotected eye and vary from mild, in which there are a few erythrocytes in the anterior chamber, to total, where the entire anterior chamber fills with blood. This eye has a partial hyphema. It resorbed within a week with no loss of vision. All workers who suffer blunt trauma to the eye and adnexa should be referred for evaluation.

vision. The intact epithelium of the cornea resists damage from a rather wide pH range; however, a chemical with a pH less than 4 or greater than 10 increases cellular permeability of the corneal epithelium.[30] Immediate irrigation with water can help to prevent further loss of vision. Any delay in treatment can cause pain and irreversible loss of vision.

Any material that is labeled as an irritant or a corrosive can cause eye injury. Anterior segment burns from Mace or tear gas should be treated as chemical burns. Ocular injury from sparklers or flares that contain magnesium hydroxide should also be managed as chemical, rather than thermal, burns; if left untreated, the magnesium hydroxide will continue to cause damage to the eye long after the effects of the thermal damage have subsided.[29]

Acid Burns

Acid burns rapidly damage superficial tissues but are neutralized by protein barriers (which prevent deep penetration) within the first few minutes to hours (Figure 8-12). There are several exceptions, such as hydrofluoric acid or acids containing heavy metals, which can produce a penetrating injury because they resist the protein barrier. Automobile-battery explosions are probably the most common cause of acid burns to the eyes. These injuries tend to occur more frequently during the winter months when a lighted match or cigarette, or faulty jumper cables provoke an explosion.[28]

Alkali Burns

Alkali burns may initially appear innocuous, but they tend to progress rapidly and have a poorer prognosis than do acid burns (Figure 8-13). Alkalis such as lye, lime or plaster of Paris, or ammonia can penetrate to damage the deeper structures of the eye. Alkali burns tend to be more severe because alkalis combine rapidly with cell-membrane lipids; this disrupts the microstructure of the cell and the stromal mucopolysaccharides, causing the eye tissue to soften. Thus, alkali burns of the eye require immediate but careful decontamination and treatment.

Evaluation and Treatment

Chemical burns to the eye are classified as mild, moderate, or severe. Mild burns cause corneal opacification, blurring of iris detail, and minimal ischemic necrosis of the conjunctiva and sclera. Reepithelization will be sluggish and a mild corneal haze will form, usually resulting in minimal loss of visual acuity. Moderate burns cause stromal opacification, with increased corneal thickness and considerable iritis. Superficial neovascularization of the cornea and conjunctiva may leave persistent epi-

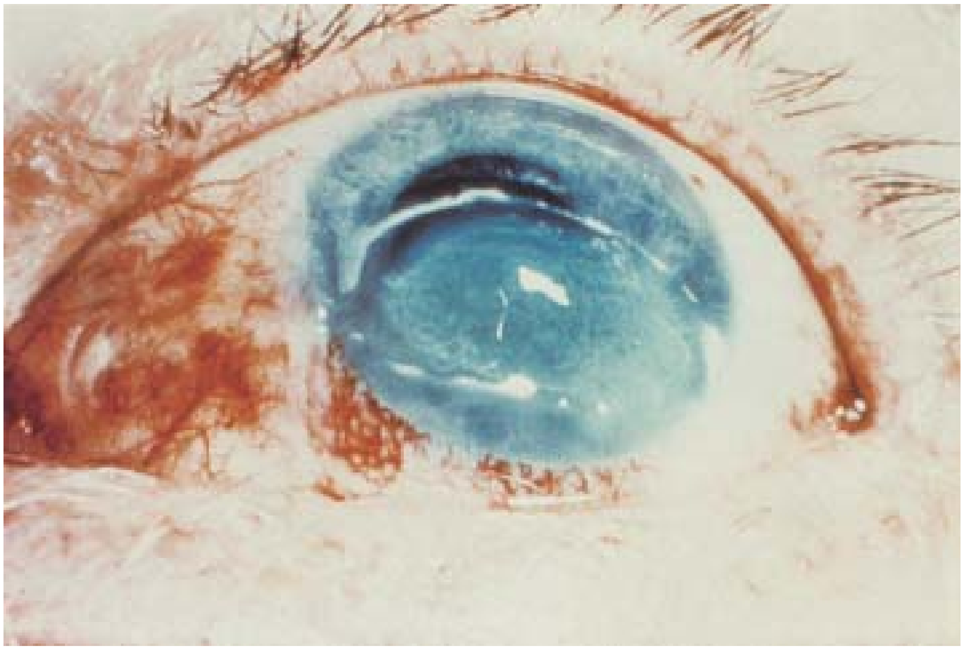

Fig. 8-12. Acid burns to the eyes are most commonly caused by battery explosions, as was this one. The fact that the casualty's upper lid prevented damage to the superior portion of the cornea is of little consolation. After the initial chemical trauma to the corneal epithelium, protein barriers limit deep penetration by the acid. Workers in jobs with higher-than-normal risk, such as chemists and battery maintainers, should wear chemical goggles and a face shield.

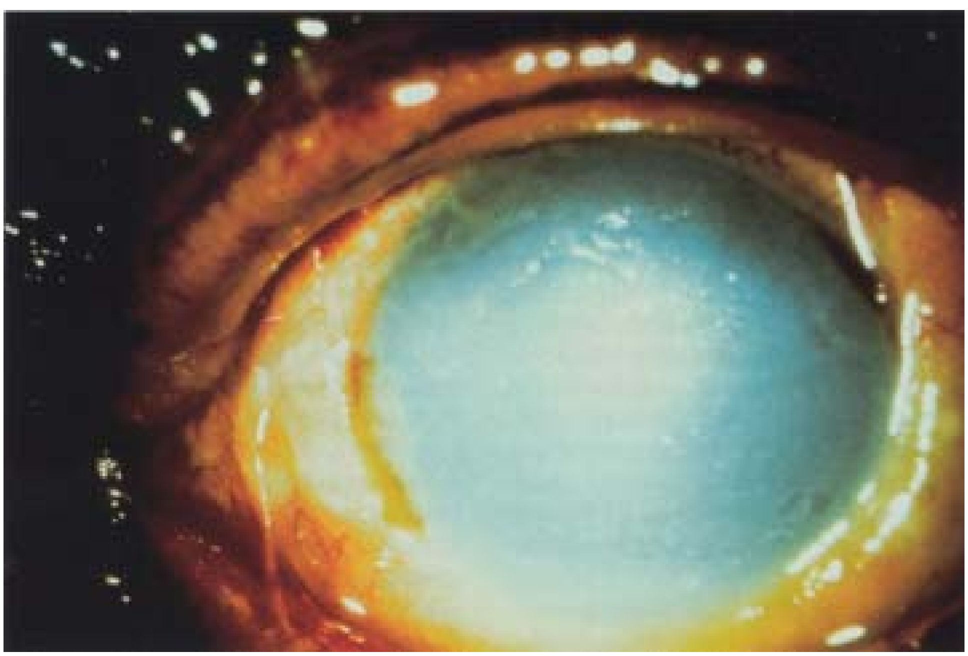

Fig. 8-13. Caustic alkali burns to the eye tend to be more serious and debilitating than acid burns. This cornea is extremely edematous, and blanching of the conjunctival and scleral vessels has occurred. To prevent further damage and deep-tissue penetration, alkali burns must be irrigated with water immediately; irrigation must continue while the casualty is transported to a medical treatment facility. Photograph: Courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC.

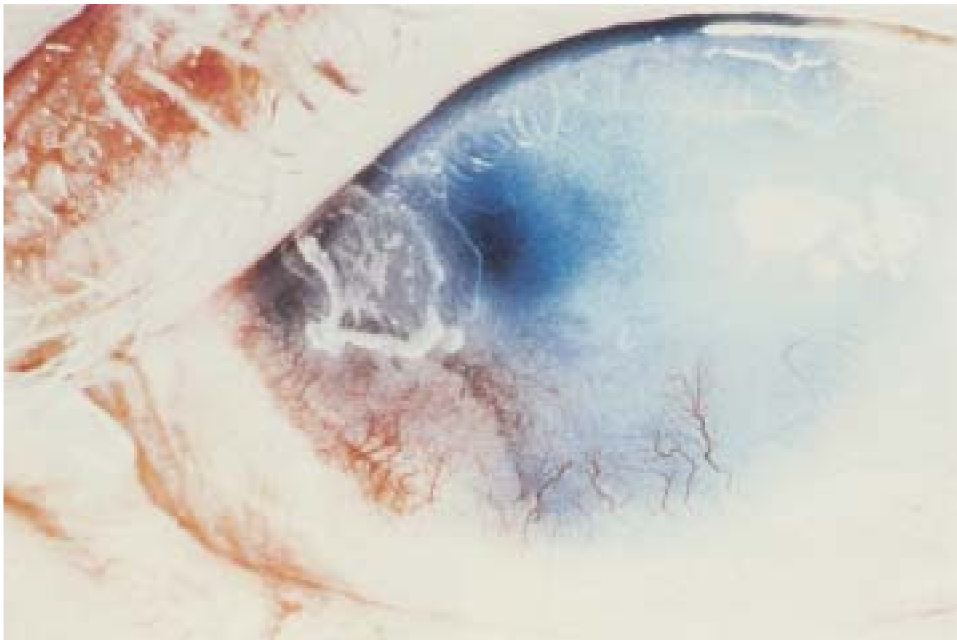

Fig. 8-14. Severe acid or alkali burns that have not been promptly and thoroughly irrigated with water often result in permanent corneal opacification and neovascularization. A full-thickness corneal transplant to restore vision in this eye will be difficult to perform because the vessels have encroached on the central cornea. If a corneal transplant is not possible, then this worker could wear a cosmetic soft contact lens with a painted iris. These lenses restore only the appearance, and not the function, of the damaged eye.

thelial defects that ultimately lead to stromal thinning and perforation. Permanent visual impairment invariably results (Figure 8-14). The most severe burns (usually alkali burns) cause marked corneal edema and haze, along with blanching of the conjunctiva and sclera. Due to the blanching effect of the damaged cornea, any underlying iritis may go undiagnosed. Ulceration eventually occurs and perforation, due to collagenase-like enzymes that are released to heal the inflamed tissues, may ensue.[29]

This cannot be overemphasized: *chemical burns—especially alkali—must be treated immediately.* Emergency treatment involves copious irrigation using the most readily available water. *Do not wait* for a sterile physiological or chemical neutralizing solution. The rescuers should hold the victim's eyelids apart even though spasm of the orbicularis oculi muscle can make this extremely difficult. During the initial 15-minute lavage (as a minimum), the rescuers should telephone the nearest emergency room or ophthalmologist's office to inform the staff of the victim's pending arrival. After the casualty arrives at the MTF, irrigation should continue for at least 1 hour or longer, or until pH (litmus) paper demonstrates that the conjunctival pH is normal (the pH has returned to 7.3–7.7). Eyelid retractors may be necessary to keep the victim's eye or eyes open, and topical anesthetics may be needed to relieve the pain.

Eyewash Fountains

ANSI Standard Z358.1-1981 gives directions for the proper installation and maintenance of eyewash fountains and showers. Because the first 15 seconds following a chemical splash are the most critical, the standard recommends that eyewash fountains and showers be located as close to chemically hazardous sites as possible, preferably within 50 ft. The standard also recommends that all eyewash fountains be installed at the same height and in the same position and operate in the same manner throughout the workplace. Hand- or foot-operated valves must allow the eyewash fountain or shower to remain on after they have been activated. Furthermore, the standard recommends that eyewash fountains be identified with a sign and that the surrounding area be painted a bright color, such as high-visibility yellow and black.[31] If feasible, an alarm should be installed on the fountain and should sound when the fountain has been activated, to notify fellow workers that a chemical accident has occurred.

Eyewash fountains should be checked and maintained routinely. Plumbed eyewash fountains must be

Fig. 8-15. Eyewash fountains and showers should be (*a*) located within 50 ft of a potential chemical hazard, (*b*) accessible, and (*c*) painted high-visibility colors. The hand- or foot-operated valves must allow the eyewash fountain or shower to remain turned on after being activated. Because chemical trauma to the eyes can cause severe spasm of the lid musculature, victims may be unable to open their eyes by themselves. Workers in chemically hazardous areas should be instructed on assisting injured coworkers at eyewash fountains.

able to deliver 3 gallons of potable water per minute for 15 minutes (Figure 8-15). In remote sites where a plumbed water source is not available, self-contained, portable eyewash stations must be able to deliver 0.4 gallons of water per minute for at least 15 minutes.[31] However, the use of portable eyewash stations (especially gravity-flow eyewash stations) is generally discouraged because the holding tanks must be cleaned regularly and the bacteriostatic water, which is expensive, must be changed monthly. Squeeze-bottle eyewash stations, which are often poorly maintained and have a propensity to harbor microorganisms, are prohibited by army regulations.[32]

Regardless of how well eyewash fountains and showers are installed and maintained, employees must be properly instructed in their use. Training should emphasize that victims may be unable to open their eyes after a chemical splash; the lid musculature can react so quickly and powerfully that it may be impossible for victims to open their eyes without help.

Concerns have surfaced recently regarding the safety of eyewash fountains. *Acanthamoeba polyphaga, A. hatchetti, and A. castellanii* are small, free-living protozoa found in soil, air, and water, and have been cultured from water standing in the pipes of eyewash fountains.[33] Eyecare specialists are concerned that acanthamoeba organisms could be introduced when the eyes are lavaged at a contaminated fountain after a chemical splash. Acanthamoeba keratitis, a rare but serious infection of the cornea, has most often been associated with contact-lens wearers who use homemade saline solutions made with contaminated tap water. To date, there have been no reported cases of acanthamoeba keratitis following the use of emergency eyewash fountains[34]; however, to reduce the risk of acanthamoeba contamination, army policy recommends that eyewash fountains be flushed weekly.[32] Army policy does not specify the length of time for flushing, but scientific literature recommends 3 minutes.[34]

Simple methods of eye irrigation tend to leave chemical residua that can continue to destroy the remaining cornea, in part because chemical burn victims fight to keep their eyes closed in spite of the absolute necessity for flushing the eyes with water. A new method of eye irrigation is being used at some emergency rooms and industrial facilities throughout the United States. The new irrigation method uses a Morgan lens: a large contact lens that can be slipped between eyelids that are open only 2 mm. A small polyethylene tube, which is connected to one side of the Morgan lens, pumps the irrigation solution into the eye. Once the lens is in place, the soothing bath of running fluid tends to calm most chemical-accident victims.[35]

Radiant Energy Hazards

Radiation hazards can be classified as industrial or environmental. Because many types of radiation are found in industrial settings, for purposes of this textbook they are classified within the realm of industrial eye safety. These hazards should be evaluated by the industrial hygienist and should be reduced or eliminated if they pose a threat to the workers' vision or ocular health.

Ultraviolet Radiation

UV radiation, the most common cause of light-induced ocular injury, is invisible to the human eye. It occupies the region of the electromagnetic (EM) radiation spectrum between the blue end of the visible-radiation region and the region of X radiation (Figure 8-16).

The categories of UV radiation are (*a*) UV-A (380–315 nanometers [nm] in wavelength), (*b*) UV-B (315–290 nm), and (*c*) UV-C (290–100 nm).[36–38] When individuals are exposed to sunlight, UV-A causes human skin to tan (the radiation stimulates the melanocytes to form pigment), and UV-B causes skin erythema or sunburn. (Large welding arcs can produce equally hazardous quantities of UV-B radiation.) UV-C is potentially the most dangerous to human health: it is used as a bactericidal and germicidal agent and is potent enough to kill humans. The ozone layer in the earth's upper atmosphere only partially absorbs UV-A and UV-B radiation; fortunately, however, it absorbs all solar radiation lower than 294 nm. Recent scientific literature reports that the protective ozone layer is thinning, and this could increase the amount of UV-C radiation to which we are exposed.[39] Currently, the only UV-C radiation sources that are detrimental to human health are manmade, such as germicidal lamps and some large welding arcs, and welders and employees who work in research laboratories are the most likely to be exposed to it.

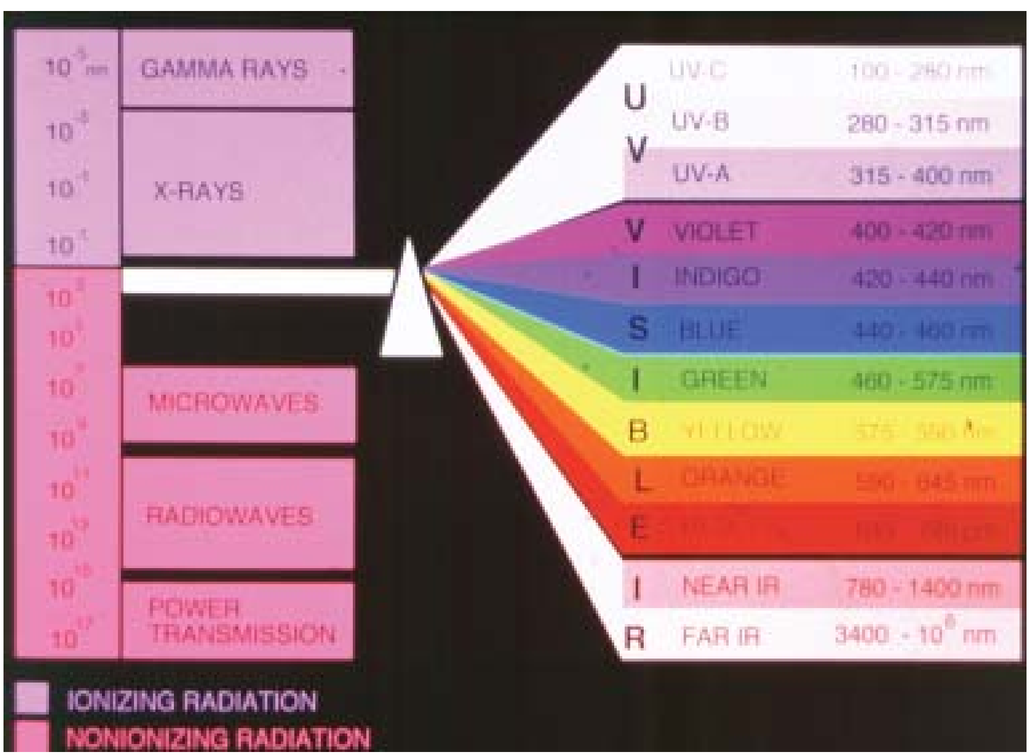

Fig. 8-16. Visible radiation, also known as light, occupies a very small region (400–780 nm) of the electromagnetic spectrum. Ultraviolet and infrared radiation, both invisible to humans, lie just above and below the visible spectrum.

Excessive exposure of the cornea to UV radiation causes photokeratitis, an acute ocular condition that is characterized by a massive sloughing of the central corneal epithelium. (Laymen call this condition "snow blindness" or "welder's flash.") The degree of corneal involvement depends on the victim's duration of exposure, the content of UV wavelengths that the source emits, and the energy level of the luminance. The latency for development of symptoms of UV photokeratitis varies from 30 minutes to 24 hours, depending on the radiation dose that was received. Symptoms can range from mild irritation and the sensation that an ocular foreign body is present to severe photophobia, pain, and spasm of the eyelids. Clinical signs include punctate lesions of the corneal epithelium that can be observed with a sodium fluorescein stain. Therapy for this condition includes short-acting cycloplegics, such as cyclopentolate (1%) or homatropine (2%), to relieve ciliary spasm. Topical antibiotics should be applied to prevent secondary infection. Pressure bandages, sedatives, and analgesics are not absolutely necessary but may make the patients more comfortable. Victims of UV overexposure are usually incapacitated 6 to 24 hours; complete reepithelization of the cornea usually occurs within 48 hours after the onset of symptoms.[29]

UV radiation was thought for many years to affect only the superficial structures of the eye (the cornea and conjunctiva). But recent studies suggest that the depth of tissue penetration is wavelength dependent. The cornea absorbs nearly all UV radiation of wavelengths shorter than 290 nm, but it allows longer UV wavelengths to be transmitted (to pass through it) to varying degrees: UV radiation with wavelengths of 250 nm to 200 nm (UV-C) primarily affects the corneal epithelium, while UV radiation with wavelengths of 315 nm to 295 nm (UV-B) tends to affect the corneal stroma and endothelium.[36]

While the cornea and the conjunctiva absorb most UV radiation, UV-A and UV-B (depending on their wavelength) can be transmitted to the lens and the retina. A recent study of 838 Chesapeake Bay watermen concluded that increased exposure to UV-B radiation increases the likelihood that *cortical cataracts* (opacification of the cortex or outer covering of the crystalline lens) will form.[40] However, the study failed to demonstrate any relationship between UV-A radiation and any type of cataract, or UV-B radiation and *nuclear cataracts* (opacification of the nuclear or innermost layers of the crystalline lens).

UV radiation can also cause retinal damage. In *phakic* eyes (eyes that have a crystalline lens), UV radiation with wavelengths greater than 320 nm is transmitted in varying degrees through the eye to the retina. In *aphakic* eyes (eyes that have neither a crystalline lens nor a plastic intraocular lens [IOL] implant), UV-A and UV-B radiation may cause retinitis. In cases of *pseudophakia* (eyes that have had the crystalline lens removed and replaced with a plastic IOL implant), ophthalmic surgeons are now using IOL implants that specifically block the transmission of UV radiation to the retina. Despite these medical advances, additional research on the retinal effects of UV radiation is needed.

Commercial and industrial sources that produce high-UV-radiant exposure levels (such as UV lasers, welding and carbon arcs, industrial sterilizers, spectrophotometers, and devices to photoharden dental resins) are more likely to produce harmful ocular and dermatological effects if UV protection is incomplete or inadequate. Engineering and administrative controls should be used to reduce the hazards from these sources before personal protective devices are required. Workers who are in close proximity to welding operations must be protected against accidental UV exposure with noncombustible or flame-resistant screens or shields. In addition, painted walls should have low reflectivity for UV radiation. Personal protective equipment (PPE) such as welding masks and goggles will be discussed later in this chapter.

Infrared Radiation and Heat

IR radiation occupies the portion of the EM spectrum just beyond visible red light and includes wavelengths 780 to 1,000,000 nm. IR radiation is used in industry to dry and bake paints and varnishes; heat metal parts for forging and thermal aging; and dehydrate textiles, paper, leather, meat, and pottery.

Although IR radiation can cause injuries to the cornea, iris, and retina, its damage to the lens is the most likely to degrade vision. Minor IR burns are usually of little consequence: they produce only temporary edema and erythema of the eyelids and little or no damage to the globe. However, continuous or excessive exposure, such as that from furnaces or similar hot bodies, has been known to produce heat cataracts. This type of lens opacity causes sloughing of the lens cortex and decreased visual acuity. Opacities of the posterior portion of the lens may also be observed.[41] These cataracts are becoming less common as large indus-trial blast furnaces become more automated.

Lasers

Lasers generate a beam of radiation that is *monochromatic* (of a single wavelength) and *coherent* (all of the EM waves are spatially in phase). The beam has a very small *angular divergence* (the light does not widen significantly over the length of the beam). Depending on the lasing medium, the output beam may be in the visible radiation region (400–780 nm) and would therefore be seen as light, or it may be in the invisible (UV or IR) regions. The output beam may be a continuous wave, a pulse, or a train of pulses, depending on the manner in which the energy is pumped into the lasing medium.

Laser energy can be transmitted to the eye in three ways. The most hazardous transmission method is *direct laser exposure*, in which the individual looks directly into the laser beam. The second and almost equally hazardous method is *specular reflection*, which occurs when laser energy is reflected toward the eye from a shiny, highly polished surface such as a mirror, a piece of flat glass, or even the inside of a tin can. The method that is least hazardous to the eye is *diffuse reflection*, in which the laser energy is reflected toward the eye from a dull (nonshiny) object such as a wall or a tree.

Depending on both the wavelength and the energy of the laser emission, individuals who inadvertently look at a laser beam may suffer ocular injury and possible loss of vision. Far-IR laser radiation (1,400–1,000,000 nm) and UV laser radiation cannot pass beyond the anterior structures of the eye. Consequently, low-energy UV- and far-IR-laser radiation are absorbed by the anterior segment of the eye and can cause photokeratitis similar to welder's flash. High-energy, far-IR radiation will produce thermal burns to all layers of the cornea, which may lead to permanent corneal scarring.

Visible light and near-IR laser radiation (780–1400 nm) can pass through the eye to reach the retina. The degree of retinal damage is directly related to the amount of ambient energy and the length of exposure. Long exposures (many seconds) cause photochemical damage to the retina, while short exposures result in thermal injury. The heat from the laser emission causes thermal coagulation of the photoreceptors and other structures of the retina. Pulsed lasers (lasers that emit radiant energy in very short [nanoseconds] exposures) create intense energy that cannot quickly be dissipated; consequently, retinal cells explode and create shock waves that mechanically destroy surrounding tissues and cause a loss of retinal function (Figure 8-17). The shock waves can also rupture blood vessels in the choroid or retina and cause detachment of the retina. Blood that hemorrhages into the vitreous humor can resorb slowly and mechanically obstruct vision (Figure 8-18). In this event, the prognosis for regaining normal vision is usually poor, especially if the damage occurs in the central macular area.

Classification of Lasers. As a result of the hazards that lasers pose, an empirical classification system has been established to warn users and observers of the associated risks:

- *Class 1 lasers* are safe under virtually all viewing conditions because the output beam is considered to be incapable of causing radiation damage, and is therefore exempt from any control measures or other forms of surveillance.
- *Class 2 lasers* are low-power devices that emit only visible radiation. The maximum power of this class is limited to 1 milliwatt (mW), which is measured by a 7-mm pupil diameter in a *viewing box* (a black-box model, which is used to simulate a human eye). Because the duration of the normal blink reflex is 0.25 seconds, and 1 mW is not injurious at this duration, Class 2 lasers are considered to be eye safe unless a person makes a deliberate attempt to look into the beam for a period longer than 0.25 seconds.
- *Class 3 lasers* are medium-power lasers and are subdivided into two subclasses. Class 3A lasers produce visible radiation that, when viewed directly, is not hazardous to vision; however, the beam may be hazardous when collected and directed into the eye, as with binoculars. Class 3B lasers produce sufficient power to produce injuries when viewed directly or by specular reflection. Class 3 lasers usually do not present a combustion hazard.
- *Class 4 lasers* are high-power lasers. They are hazardous to the eyes and skin when there is direct or specular-reflection exposure, and some very high power Class 4 lasers can be hazardous even with diffuse reflecting exposures.[42–45] Class 4 lasers can present a combustion hazard if used improperly.

Soldiers use lasers for training and weapons-fire control (Table 8-3). The Multiple Integrated Laser Engagement System (MILES) is a Class 3B training laser that is used to simulate the firing of conventional weapons. It is considered to be eye hazardous to a distance of 7 m; beyond 7 m, the energy diminishes sufficiently to make it eye safe (unless it is viewed through an unfiltered telescopic sight to a distance of 300 m). On the battlefield, two types of fire-control lasers are currently being used with modern weapons systems: *laser rangefinders*, which measure the distance to the target, and *laser target designators*, which irradiate a target with an optical signature that can be used as a homing beacon for laser-guided munitions.[44]

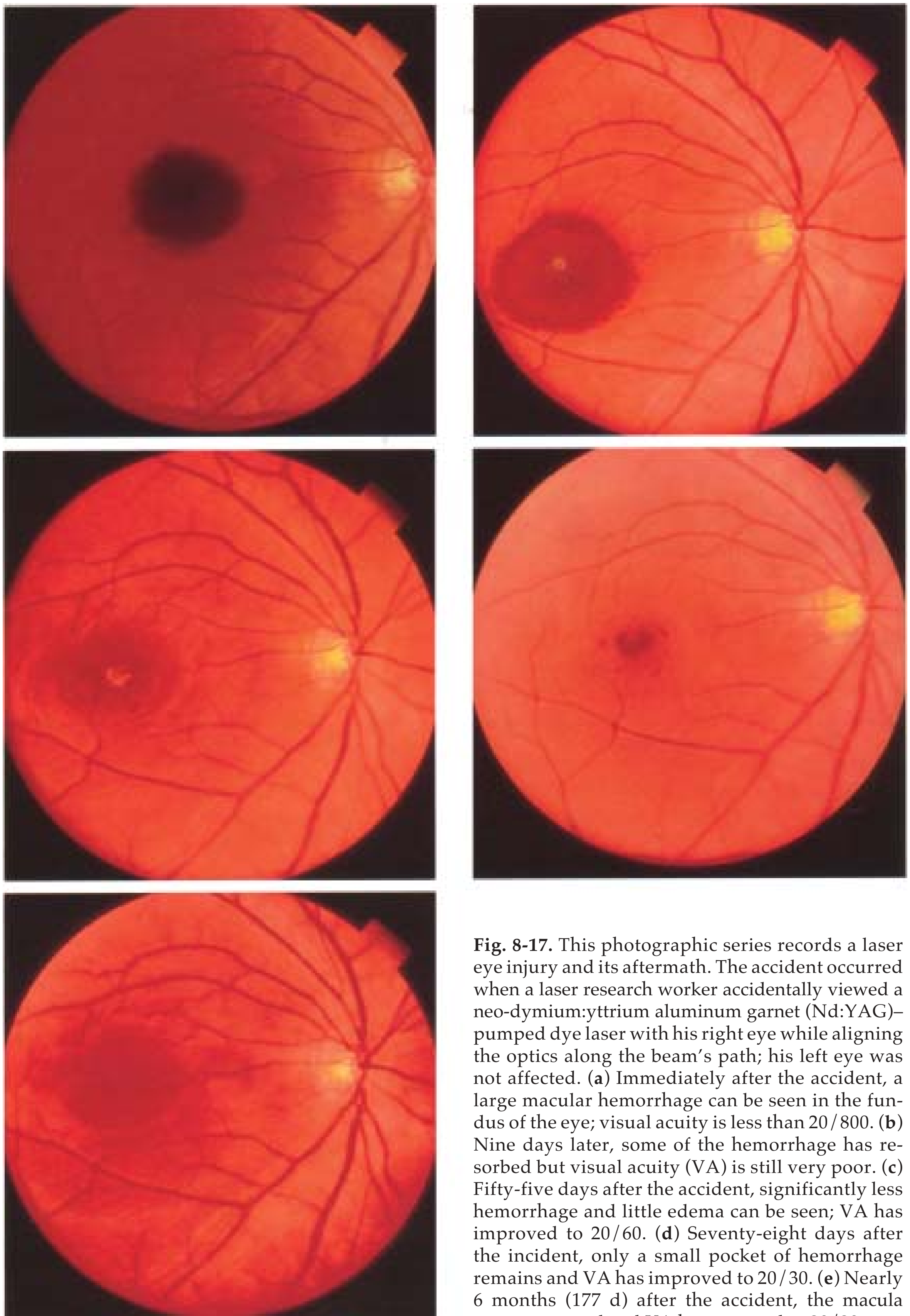

Fig. 8-17. This photographic series records a laser eye injury and its aftermath. The accident occurred when a laser research worker accidentally viewed a neo-dymium:yttrium aluminum garnet (Nd:YAG)–pumped dye laser with his right eye while aligning the optics along the beam's path; his left eye was not affected. (**a**) Immediately after the accident, a large macular hemorrhage can be seen in the fundus of the eye; visual acuity is less than 20/800. (**b**) Nine days later, some of the hemorrhage has resorbed but visual acuity (VA) is still very poor. (**c**) Fifty-five days after the accident, significantly less hemorrhage and little edema can be seen; VA has improved to 20/60. (**d**) Seventy-eight days after the incident, only a small pocket of hemorrhage remains and VA has improved to 20/30. (**e**) Nearly 6 months (177 d) after the accident, the macula appears normal and VA has returned to 20/20.

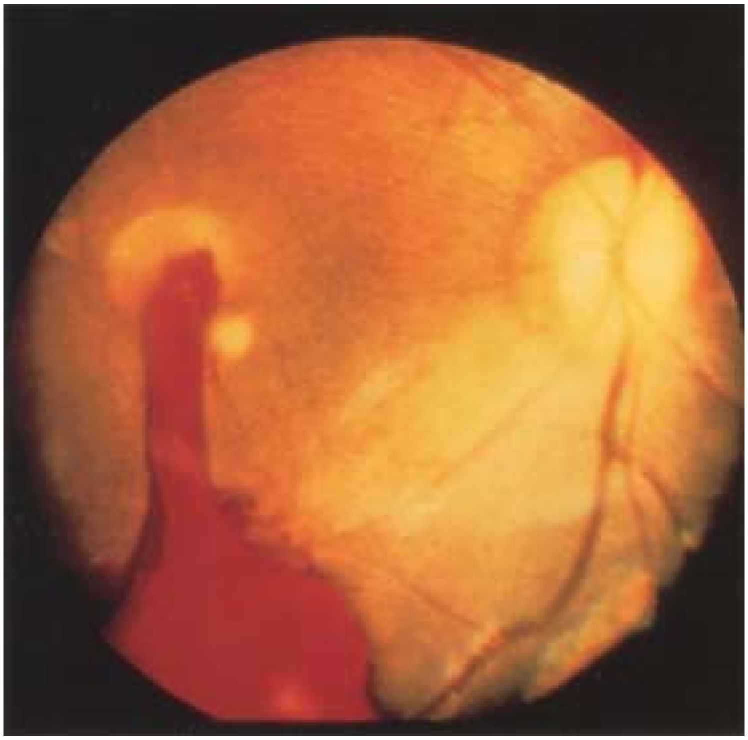

Fig. 8-18. Lasers, which destroy retinal tissue through to the vascular choroid, can cause hemorrhaging into the vitreous. Although the hemorrhage shown here will eventually be resorbed (albeit slowly), laser injuries involving the central macula usually do not have a good prognosis.

TABLE 8-3

TYPES AND CLASSES OF LASERS

Laser Type	Wavelength (nm)	Class*	Application
Gallium-Arsenide	905.0 (near IR)	1–3	Optical fiber communication, direct-fire simulators, and training devices Example: MILES
Helium-Neon	632.8 (red)	2	Distance measurements, bar code readers, patient alignment in radiology Example: M55 gunnery trainer
Ruby	694.3 (red)	4	Tank rangefinders Example: AN/VVG2, M40A3 Tank
Argon	510.0 (blue/green)	4	Entertainment, holography, printing plate manufacture, photocoagulation for diabetics
Nd:YAG†	1,064.0 (invisible, near IR)	4	Distance measurement and target marking Example: AN/TVQ2 ground laser designators and tank rangefinding
CO_2	10,600.0 (far IR)	4	Cutting welding, engraving, high-speed product labeling, and fire control Example: no CO_2 laser system is fielded currently

*Class designation depends on power output for any particular application
†Neodymium:yttrium, aluminum, garnet
Reprinted from Sliney DH, Kotulak JC. Hazards of fielded lasers. *Medical Bulletin of the US Army*. 1988;82:14–16.

Classification and Surveillance of Laser Workers. Appendix E of ANSI Standard 136.1-1986 provides guidance for the medical surveillance of the classifications of laser workers.[45] An *incidental worker* is a person whose work makes it possible, but unlikely, that he or she will be exposed to laser energy that is sufficient to damage the eye. Incidental workers include operators of fielded laser equipment, individuals who oversee laser use on approved laser ranges, and soldiers who participate in force-on-force laser-training exercises. A *laser worker* is a person who routinely works in a laser environment and therefore has a higher risk of accidental overexposure. Laser workers include those who regularly perform laser research, development, testing, and evaluation, and workers who perform routine laser maintenance.

The type of medical surveillance that is done on employees depends on the classification of laser work. According to the ANSI standard, incidental workers require only preplacement vision examinations using a screening protocol (distance and nearpoint visual acuity measurements). On the other hand, laser workers require a more extensive preplacement examination, which includes a medical history, visual acuity measurement, and selected examination protocols, depending on the type of laser that they will use. Periodic and termination examinations are advised but are not required.

Current U.S. Army policies concerning the medical surveillance of laser workers are similar to the ANSI standard. Incidental workers require preplacement and termination examinations utilizing a screening protocol (distance and nearpoint visual acuity measurements). Laser workers must also have preplacement and termination examinations, utilizing a different screening protocol (a medical history; distance and nearpoint visual acuity measurements; and an Amsler grid test, which tests macular function).

Laser Overexposure Incidents. Any DA employee—civilian or military—who is known or suspected to have been overexposed to laser radiation must be examined by an optometrist or ophthalmologist within 24 hours of being injured. In addition, the USAEHA must be notified by telephone as soon as possible after the incident, to initiate the investigatory process.[46] In most instances, patients suspected of having sustained a laser injury are evacuated to the Presidio of San Francisco, California, where they are evaluated at the Division of Ocular Hazards at Letterman Army Institute of Research (LAIR). Civilian employees who do not wish to be flown to LAIR can be followed by the nearest military ophthalmologist or their own civilian ophthalmologist at government expense. (With the Presidio scheduled to be closed, the Division of Ocular Hazards will be transferred to Armstrong Laboratory, Brooks Air Force Base, San Antonio, Texas, in 1993.) The laser equipment that was used during incident should be secured so the Laser Branch at USAEHA can do a full technical evaluation to determine if the injury was caused by equipment malfunction or operator error.

Clinicians who examine workers who may have been overexposed to a laser beam should avoid making a hasty diagnosis of laser injury until the alleged incident has been investigated and verified. Even if the ocular signs and symptoms are consistent with overexposure to a laser, the clinician should consider two additional factors before making a diagnosis: the circumstances of the exposure and any preexisting ocular lesions. The treatment for patients with confirmed laser injuries is usually limited to observation.

Thermal Radiation

Because the eyes are protected by the autonomic blink reflex, thermal injuries to the eyes tend to be limited to the eyelids, depending on the duration of the exposure. Most thermal burns are caused by boiling liquids, molten metal, flame, gasoline, explosions, steam, and hot tar. Glass and iron cause the most severe thermal injuries to the eyes and adnexa because their melting points are high: 1,200°C. Lead, tin, and zinc melt below 1,000°C and cause slightly less damage (Figure 8-19).[29]

Because lid edema and pain may make an objective examination difficult, applying topical anesthetic drops such as proparacaine or benoxinate may be necessary. Ocular burns should be treated with topical antibiotic ointment and sterile dressings; topical steroids may be necessary to decrease subsequent scarring between the eyelids and the globe.

Radio-Frequency Radiation

Radio-frequency (RF, 30 cm–1,000 m) and microwave (1 mm–30 cm) radiation have been implicated in the development of lens opacities. Cataractogenesis has been observed in rabbits when acute exposures of RF radiation exceeded 100 mW/cm^2 for more than 1 hour. Human exposure to 100 mW/cm^2 would immediately cause a *threshold response* (the individual would experience either segmental- or whole-body heating; he or she would immediately move away from the RF radiation beam and would know that a significant exposure had occurred). Currently, there is no evidence that chronic exposure to microwave fields of 10 mW/cm^2 or less can induce cataracts.[47] In 1977, a survey of 800 workers in the microwave industry at three army installations found no evidence of work-

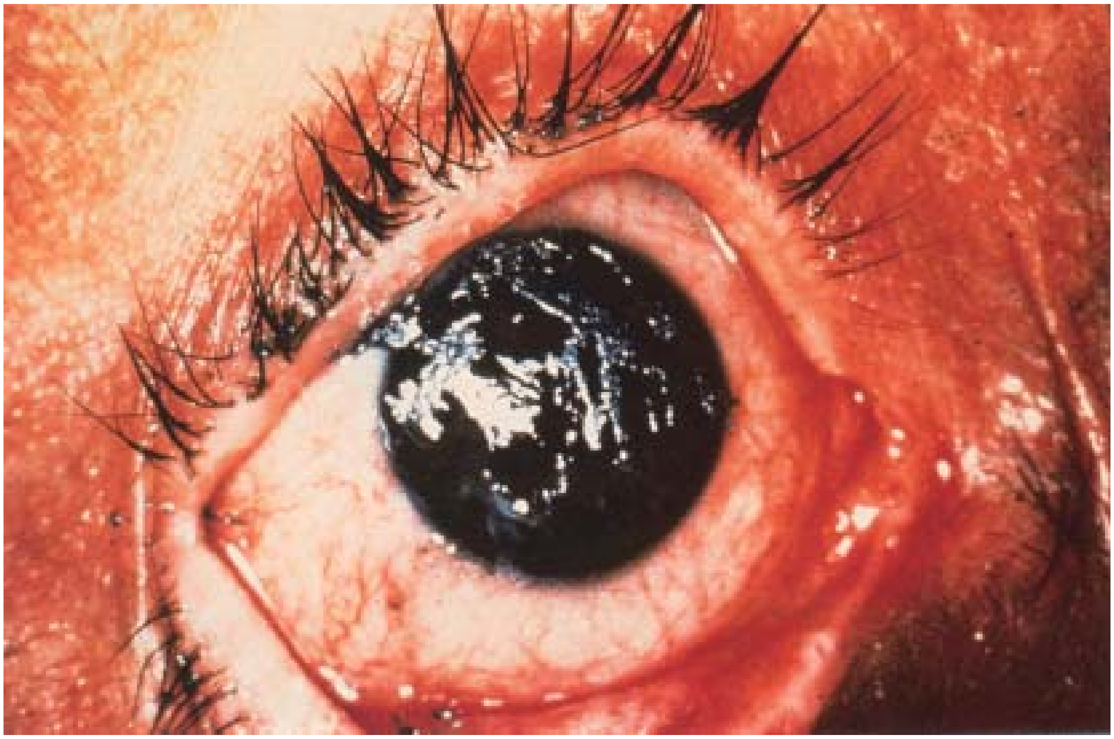

Fig. 8-19. Thermal injury to an eye exposed to molten lead. This burn could have been prevented had the worker been wearing industrial safety glasses.

related lens opacities.[48]

From 1986 to 1991, army policy required that either a screening or diagnostic protocol be done on all workers who might be exposed to RF radiation. The army has since eliminated its ocular-surveillance program because (*a*) RF exposure is a threshold effect, (*b*) there is no method for measuring cumulative dose over time, (*c*) the program has not been cost effective, and (*d*) it will not prevent RF exposures from occurring.

Individuals who experience an acute overexposure to microwave radiation (including whole-, segmental-, or localized-body warming) should be examined by a qualified physician within 24 hours of the injury. The examination should include a slitlamp examination of the eyes by an optometrist or ophthalmologist. For all DA civilians or military personnel, the physician must report the incident to the USAEHA.[46]

Electrical Current

The electrical field associated with power transmission is considered to be part of the EM spectrum and has a wavelength of 1,000 m. Accidents involving electrical current have been known to produce cataracts of the lens cortex and anterior capsule. As with other radiation-induced anomalies, the latency for cataract development can vary from months to years. Following an electrical-shock injury, periodic slitlamp examinations through dilated pupils should be performed to identify early cataract formation.

Ionizing Radiation

The cornea, lens, uvea, retina, and optic nerve may suffer injury from excessive exposure to ionizing radiation from cyclotron exposure or during beta irradiation of the periorbital area to treat malignancy. Radiation keratitis ranges from a superficial punctate epithelial staining to sloughing of large areas of epithelium, stromal edema with interstitial keratitis, and aseptic necrosis. X radiation and other ionizing energy sources are well-established causes of posterior subcapsular lens opacities; at high radiation doses these opacities can occur in a matter of months, while years may elapse before doses that are closer to the threshold level for injury cause cataractogenesis. Four hundred to 2,000 cGy of exposure are required for cataract-ogenesis.[41] Younger patients are more vulnerable to cataract formation than are older patients who receive the same relative dose or exposure. Intraretinal hemorrhages, papilledema, and central retinal-vein thrombosis are also possible but rarely occur.

SELECTING EYE PROTECTION

Wearing PPE, including eye protection such as industrial safety glasses, goggles, face shields, and welding helmets, cannot completely eliminate the possibility of ocular injury under all circumstances. Employers are required first to evaluate all eye-hazardous operations and then to attempt to reduce or eliminate each hazard through engineering or administrative controls, or both. If the elimination of eye-hazardous operations is not feasible by these plant changes, then the employer is required by law to provide PPE for all workers in proximity to the hazard. Protective eyewear is also mandatory for supervisors and others who must enter the hazardous environment, even if they are not physically involved in the operation.[10]

In some instances, other types of PPE in addition to eye devices must be worn, and this may influence the selection of eye and face protectors. For example, if respiratory protective equipment, a hardhat, or both are worn, safety glasses must be compatible with them. When management or safety specialists select PPE, they often make the mistake of providing only one type of eye protector. This simplistic approach fails to meet the variety of eye hazards present throughout the workplace. For example, industrial safety spectacles would offer inadequate protection to a worker in a battery shop: in the event of a chemical splash, the impact-resistant safety glasses would provide insufficient protection against battery acid. Furthermore, workers should not be allowed to wear their dress safety glasses as a substitute for approved industrial safety glasses; dress safety glasses are inferior to industrial safety glasses in many respects (Table 8-4).

Industrial eye protection must conform to OSHA regulations, which originally adopted the provisions of ANSI Standard Z87.1-1968. The 1968 standard was a design-oriented standard that dictated how industrial-eyewear manufacturers must design safety glasses.

TABLE 8-4

COMPARISON OF ANSI Z80.1 AND Z87.1 STANDARDS

Criteria	Z80.1-1979 ("Dress" Safety)	Z87.1-1989 ("Industrial" Safety)
Removable lenses:		
Minimum thickness:		
Nonprescription lenses	2.00 mm*	3.00 mm†
Prescription lenses	2.00 mm center thickness*	3.00 mm center thickness
Plus lenses > 3.00 D	1.00 mm edge thickness*	2.50 mm edge thickness
Drop ball impact test:	0.63 in. (15.9 mm) diameter steel ball, NLT‡ 15 g, dropped from 50 in.	1.00 in. diameter steel ball, dropped from 50 in.
Penetration test (plastic only)	N/A	44.20 g projectile, dropped from 50 in.
Frames:		
High-mass impact test	N/A	500.00 g pointed projectile, dropped from 130 cm (51.2 in.)
High-velocity impact test	N/A	0.25 in. diameter steel ball, traveling 150 fps
Nonremovable lenses:		
Minimum thickness	N/A	3.00 mm§
High-mass impact test	N/A	500.00 g pointed projectile, dropped from 130 cm (51.2 in.)
High-velocity impact test	N/A	0.25 in. diameter steel ball, traveling 150 fps
Penetration test (plastic only)	N/A	44.20 g projectile, dropped from 50 in.
Markings	N/A	Frames: Manufacturer's trademark and Z87 logo Lenses: Manufacturer's trademark

*Applies to air-tempered glass lenses only; all other lens materials must meet impact testing
†May be thinner (but not < 2.0 mm) if high-velocity impact test (0.25 in. diameter steel ball, traveling 150 fps) is met
‡NLT: not less than
§Plastic lenses may be thinner (but not < 2.0 mm) if all impact testing requirements are met

With the advent of newer materials like polycarbonate plastic for ophthalmic lenses, the new ANSI Standard Z87.1-1989 has adopted a more performance-oriented standard that encourages innovation as long as the eyewear meets rigid industrial safety performance tests.

Wearing compliance is usually the most difficult aspect of any vision conservation program. Compliance is often poor among workers who do not wear prescription eyeglasses. Employers who purchase more-stylish, better-fitting frames will have better rates of compliance among their employees. They will find that better compliance will decrease the incidence of eye injuries, which, in turn, will lower injury-compensation claims. Adequate supervision is also essential to ensure that eye protection is not only worn, but also is worn correctly.

Ballistic, Mechanical, and Impact Protection

ANSI Standard Z87.1 describes two basic types of impact industrial eye protection: goggles and spectacles (eyeglasses) (Figures 8-20, 8-21, and 8-22). Both are considered to be *primary* eye protectors (they can be worn without additional protection). Goggles are subdivided into two types according to their use: impact (for mechanical and ballistic hazards) and splash (for chemical hazards). They are also subdivided into two types according to their wearers: the cup type is for workers who do not require prescription lenses, whereas the cover type is designed to fit over dress or industrial prescription eyewear. When goggles are selected, ventilation to prevent fogging of the lenses should be evaluated. Impact goggles have multiple holes across the top for direct ventilation of warm, moist air. Dust and splash goggles should have baffles (indirect venting), which permit air to circulate but exclude dust and liquids.

Industrial safety eyeglasses are available with plano or prescription lenses. Frames for both types must be marked with the Z87 logo, which identifies them as an approved industrial safety frame. In addition, industrial safety lenses must be identified with the manufacturer's monogram or logo.[11]

Cost

In many instances, wearing compliance is directly related to the cost of industrial eyewear. Workers are more apt to wear high-quality eyewear than inexpensive, ill-fitting eyewear. Emmetropic workers (those who do not wear prescription eyeglasses) often feel uncomfortable wearing plano industrial safety glasses or goggles for long periods of time. Supplying these workers with inexpensive, ill-fitting safety glasses or goggles will severely degrade their wearing compliance. Likewise, ametropic workers (those who must wear prescription eyeglasses) will function more efficiently with prescription industrial safety glasses than if they are required to wear goggles over their dress safety eyewear. The USAEHA actively discourages the wearing of goggles or plano spectacles over dress safety eyewear because visual acuity and job performance can be degraded by multiple optical surfaces; this in turn decreases wearing compliance. A supervisor should balance the financial costs of providing safety eyewear to employees against the benefits of improved vision conservation and worker performance.

Frames. Frame selection is another major consideration when choosing eye protection. To encourage maximum wearing compliance, employers should stock (or allow their employees to order) safety frames in a variety of styles, sizes, colors, and materials, including metal and plastic frames. Because many eye injuries are caused by particles that hit the eye from the side, the new ANSI Standard Z87.1-1989 strongly recommends that side shields be ordered with all safety frames unless there is a specific reason to preclude them (such as restricting peripheral vision).

Lenses. In the current legal climate, all industrial safety spectacles should be ordered with polycarbonate lenses. This recommendation stems from a lawsuit in which an autoworker (wearing ANSI Z87.1-approved industrial safety glasses) was struck by a foreign object that shattered the glass industrial safety lenses. The court initially ruled that, because polycarbonate lenses were available and would have provided a greater degree of eye protection, both the employer and the supplier of the industrial safety glasses would be liable for the worker's injuries. The case was subsequently overturned due to a legal technicality; however, the issue of providing state-of-the-art materials still applies.

Polycarbonate lenses are approximately 15-fold stronger than thermally-tempered glass lenses and 5- to 6-fold stronger than regular CR-39 (the 39th Columbia resin formula, an ophthalmic-grade allyl resin) plastic lenses (Table 8-5). Polycarbonate lenses have two disadvantages when compared with either glass or CR-39 lenses: they are more difficult to manufacture and are slightly more expensive. Despite the safety advantages that are associated with polycarbonate lenses, however, many workers still prefer glass lenses because they are more resistant to scratches. In addition, polycarbonate lenses should not be prescribed for a

b

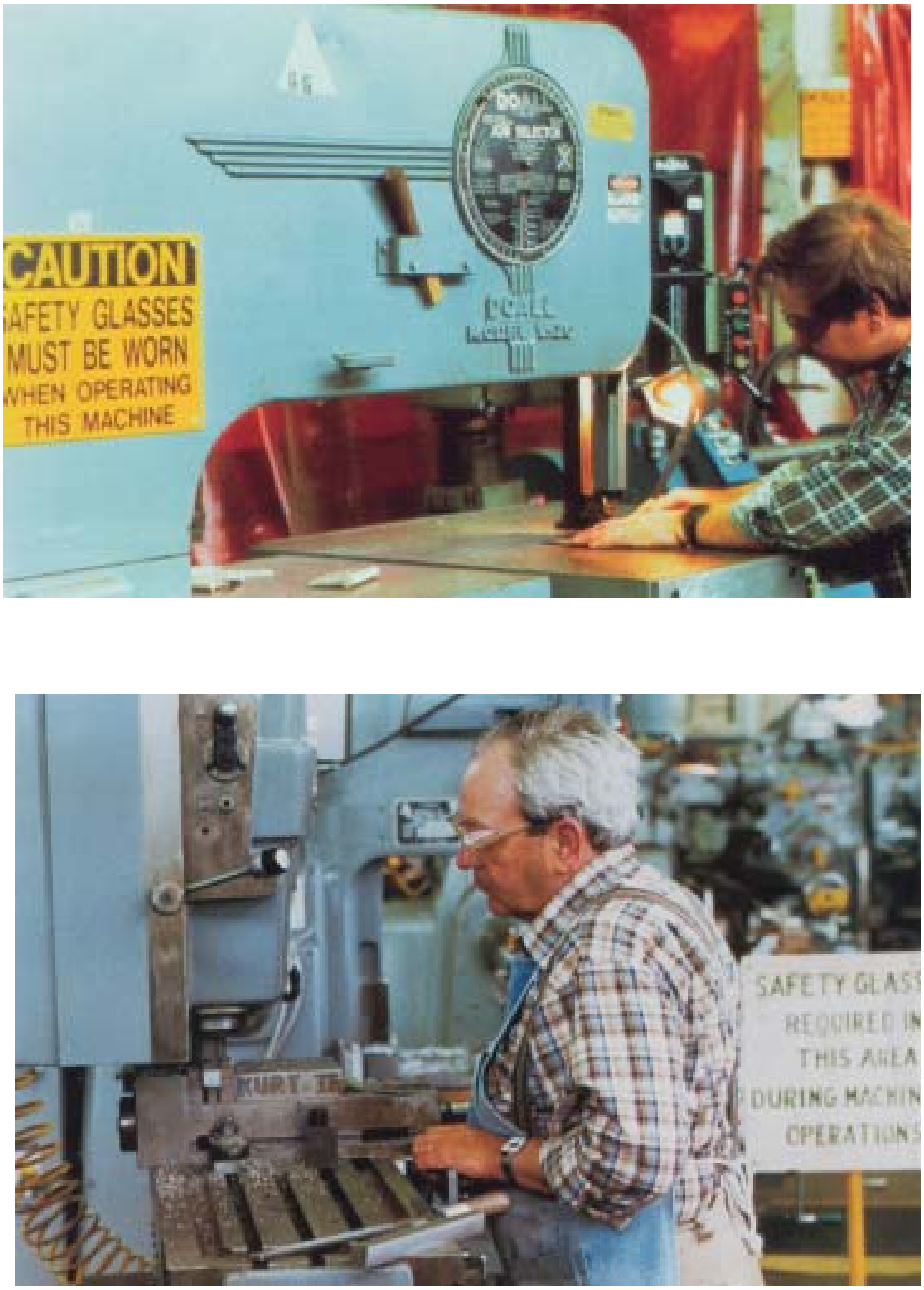

Fig. 8-20. Employees working in eye-hazardous areas must wear American National Standards Institute (ANSI) Z87.1-approved industrial safety glasses. (**a**) The young worker wears plano industrial safety glasses (with fixed side shields) while using a large industrial band saw; note the prominent yellow caution sign, reminding all employees to wear eye protection. (**b**) The older worker wears prescription industrial safety glasses, with removable side shields, in a fashionable metal frame. A choice of frame sizes and styles will usually improve wearing compliance.

Fig. 8-21. Automotive repair has the second-highest rate of eye injuries among workers. Rust often falls into the eyes of mechanics who work under vehicles; therefore, it is imperative that they wear industrial eye protection.

Fig. 8-22. The soldier on the left is wearing industrial safety goggles over the standard military-issue eyeglasses. Currently, the military optical fabrication laboratories do not manufacture American National Standards Institute (ANSI) Z87.1-approved industrial safety eyewear; however, soldiers can (and should) obtain civilian-style industrial safety glasses in the same manner as their civilian counterparts. The soldier on the right is wearing a pair of Visi-Specs (visitor's spectacles); these should be issued to temporary workers or visitors who must enter eye-hazardous areas. Caution should be exercised when issuing Visi-Specs because some are not ANSI Z87.1-approved.

TABLE 8-5

IMPACT DATA FOR OPHTHALMIC LENS MATERIALS

	Projectile Size					
	0.125 in		0.250 in		1.000 in	
Lens Material (3-mm thickness)	ft-lb	mph	ft-lb	mph	ft-lb	mph
Glass, heat treated	0.040	65	0.127	40	1.450	17
Plastic (CR-39)	0.370	196	0.950	109	1.09	15
Polycarbonate	4.24*	655*	12.6*	399*	> 9	> 42

*Impact data are for 1.9-mm polycarbonate

Source: Compiled by Davis JK, Gentex Optics, Inc., Dudley, Massachusetts, from research data from (1) Wigglesworth EC. A comparative assessment of eye protective devices and a proposed system of acceptance and grading. *Am J Optom Arch Am Acad Optom.* 1972;49:287–304; and (2) LeMarre DA. *Development of Criteria and Test Methods for Eye and Face Protective Devices.* Cincinnati, Oh: National Institute of Occupational Safety and Health, August 1977. NIOSH Research Project 210-75-0058. Reprinted with permission from Gentex Optics.

individuals who require corrections exceeding ±4.00 diopters; excessive chromatic aberration (colors that outline objects) may decrease visual acuity and patient acceptance.

The prescribing optometrist or ophthalmologist must decide whether the worker needs single-vision (monofocal), bifocal, trifocal, or some other type of occupation-specific lenses. Single-vision lenses are usually recommended for nonpresbyopic individuals or presbyopic individuals who work at a single working distance. Bifocal or trifocal lenses should be prescribed for presbyopic individuals whose job is performed at two or more distances. Some occupations, such as carpentry, require special double-segment lenses for working both overhead and at the normal reading position.

Photochromic and tinted lenses provoke controversy; some suggest that, in certain occupations, they may actually contribute to on-the-job injuries. One problem is that photochromic lenses are made of glass, which is less impact-resistant than plastic. Another problem is that tinted or photochromic lenses cannot adapt quickly enough to rapid changes in illumination. For example, if a forklift operator wearing photochromic lenses drives into a warehouse from the outside (from a bright to a dark environment), the lenses can increase the risk of serious injury: the time that is required for the photochromic lenses to change from dark to light may put the operator at risk of injuring himself or others if he cannot see properly as he enters the dark warehouse. However, while tints and photochromic lenses are controversial, there is little doubt that they improve wearing compliance: workers perceive sunglasses and photochromic lenses as a job benefit or perquisite.

Face Shields

Workers who require face and neck protection in addition to eye protection should use face shields (Figure 8-23). They are often worn by workers in metal manufacturing operations (such as grinding or machining of parts) where facial lacerations can be painful and disfiguring. They may also be worn in painting operations or areas where chemical splashes are likely. However, according to ANSI Standard Z87.1, face shields are considered *secondary* eye protection (they must be worn over a primary eye-protective device like industrial safety glasses or goggles). ANSI Standard Z87.1 requires that the manufacturer's trademark and the Z87 logo be visible, just as they must be on safety glasses.[11]

Chemical Protection

Chemical goggles (also known as splash goggles), face shields, or both should be worn wherever there is a risk of a chemical splash. Splash goggles are primary eye protectors, offering the same degree of impact protection as do impact goggles; however, splash goggles differ from impact goggles in that they have baffled or indirect ventilation that keeps liquids and chemicals out (Figure 8-24). Impact goggles, with their direct venting system, should *never* be used in chemically hazardous areas. The following guidelines have been established to protect the eyes from chemical splash:

Fig. 8-23. Face shields (secondary protectors) are designed to protect the entire face. They must be worn over industrial safety glasses, as pictured here, or chemical goggles (American National Standards Institute [ANSI] Z87.1–approved primary eye protectors).

Fig. 8-24. These soldiers are both wearing American National Standards Institute (ANSI) Z87.1–approved goggles. The soldier on the left is wearing chemical goggles with indirect venting (which prevents the direct transmission of fluids); the soldier on the right is wearing impact goggles. Impact goggles should never be worn if there is a risk of chemical splash, but chemical goggles do offer ballistic protection and they may be worn in ballistically and mechanically hazardous areas.

Fig. 8-25. For maximum eye, face, and neck protection against chemical splash and hazards, workers should wear face shields over their chemical goggles.

- If the risk of chemical splash is minimal to moderate, and if there is some risk of ballistic or mechanical injury, then chemical goggles may be worn alone.
- If the risk of chemical splash is moderate to high, and if there is increased risk of ballistic or mechanical injury, then the worker must wear both a face shield and chemical goggles for maximum protection (Figure 8-25).

Radiant Energy Protection

NIOSH and other agencies have studied the effects of UV and IR radiation and have issued guidelines on the maximum permissible exposure levels (PELs) and the use of filtering devices (Table 8-6). Filtering lenses are designed to reduce the intensity of specific wavelengths of optical radiation; the degree of reduction depends on the density of the filter. Filtering lenses, however, should not be confused with tinted lenses. Tinted lenses (such as those in sunglasses) reduce the overall intensity of the visible light and are usually not wavelength specific.

Ultraviolet Radiation

Welders tend to have a high degree of wearing compliance. One reason for this may be the image of specialized training that the welding helmet, like the hardhat, conveys. A second reason is that many (if not most) welders have had at least one overexposure to UV radiation and have experienced the painful effects of a photokeratitis. Despite this, however, some experienced welders continue to get overexposures because they often strike the welding arc before they bring the welding helmet into position.

In addition to protecting themselves against UV radiation exposure, welders must also wear ballistic eye protection to preclude any secondary injuries from stray foreign bodies (Figure 8-26). A 1985 study of the Workers' Compensation Board of Alberta, Canada, found that 21% of all reported eye injuries involved welders.

TABLE 8-6

GUIDE FOR WELDING SHADE NUMBER

Operation	Electrode Size (mm)	Arc Current (A)	Minimum Shade No.	Suggested Shade No.
Shielded metal arc welding	< 2.5	< 60	7	—
	2.5–4.0	60–160	8	10
	4.0–6.4	160–250	10	12
	> 6.4	250–550	11	14
Gas metal arc welding and flux cored arc welding		< 60	7	—
		60–160	10	11
		160–250	10	12
		250–500	10	14
Gas tungsten arc welding		< 50	8	10
		50–150	8	12
		150–500	10	14
Air carbon arc welding				
(Light)		< 500	10	12
(Heavy)		500–1,000	11	14
Plasma arc welding		< 20	6	6–8
		20–100	8	10
		100–400	10	12
		400–800	11	14
Plasma arc cutting				
(Light)		< 300	8	9
(Medium)		300–400	9	12
(Heavy		400–800	10	14
Torch brazing		—	—	3 or 4
Torch soldering		—	—	2
Carbon arc welding		—	—	14
	Plate thickness			
	(in)	**(mm)**		
Gas welding				
Light	< ⅛	< 3.2		4 or 6
Medium	⅛–½	3.2–12.7		5 or 6
Heavy	> ½	> 12.7		6 or 8
Oxygen cutting				
Light	< 1	< 25		3 or 4
Medium	1–6	25–150		4 or 5
Heavy	> 6	> 150		5 or 6

Reprinted with permission of the American Welding Society. Miami, Fla, 1992.

Fig. 8-26. Statistically, welders suffer the greatest number of radiant-energy eye injuries. In addition to wearing leather gloves, a leather apron, and hearing protection, welders must also wear American National Standards Institute (ANSI) Z87.1–approved industrial safety glasses (to preclude ballistic or mechanical eye injuries) in addition to the standard welder's helmet. The density of the filtering lens in the welding helmet depends on the type of welding torch used.

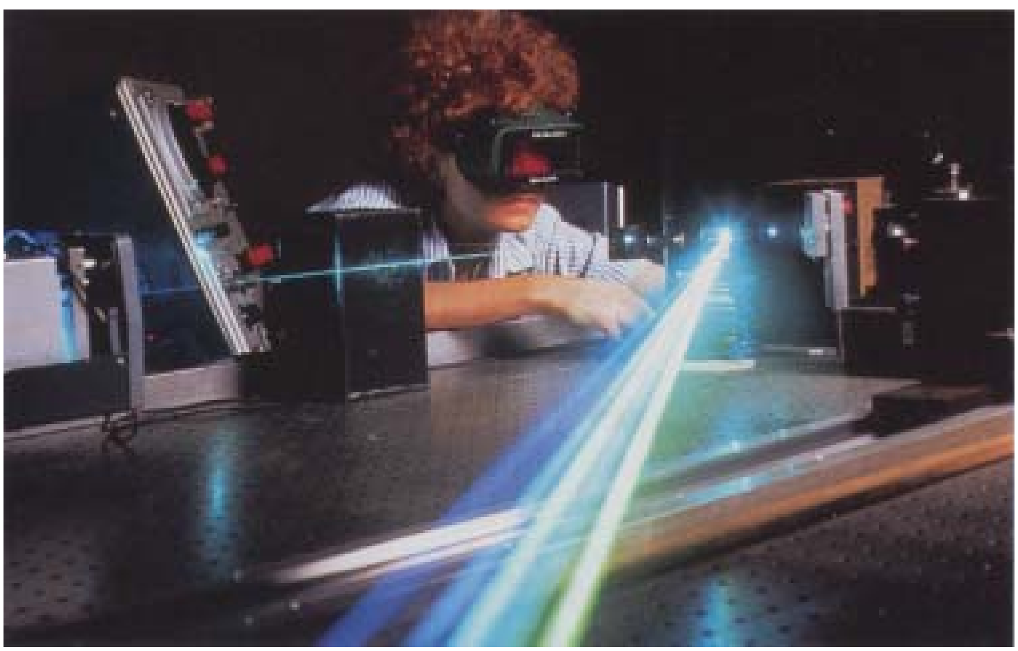

Fig. 8-27. Laser workers, such as laser maintenance personnel and laser researchers, must wear appropriate eye protection, consisting of wavelength-specific filtering lenses, whenever they work with or are near a laser. Laser goggles are preferred over laser spectacles: they prevent injuries to the retina from the side. Reprinted from the cover of *Occupational Health & Safety*. July 1990. © Photograph by Joe Griffin.

Nearly 75% of these injuries were caused by cold metal foreign particles, and occurred during nonwelding tasks such as chipping, grinding, or buffing.[49]

Infrared Radiation

IR-absorbing lenses vary according to the degree of absorption required. Unfortunately, good IR-absorptive lenses also diminish the transmission of visible light. Cobalt-blue filters are issued to workers who determine the temperature of the melt in steel manufacturing. Didymium lenses eliminate much yellow sodium flare, which is a common hazard in the electronics and glass industries.

Lasers

No single type of light-filtering device offers protection against all laser wavelengths. Currently, there are two types of filtering technology used to protect soldiers and workers against lasers: *dye absorbers* and *reflectors*. Dye absorber devices must be of sufficient filtering density for a particular wavelength of laser emission to provide appropriate vision protection (Figure 8-27). For example, to reduce a Class 4 laser from a 10-W output to a safe level of 1 mW, the filtering goggles (or spectacles) must be optical density 4 (able to reduce the radiant-energy level by a factor of 10^4) for that particular wavelength.

Reflective technology includes *dielectric stacks* and *holograms*. While these two processes are both considered to be reflective technology, the application of the technology differs slightly. For example, dielectric stacks reflect a given wavelength by layering 6 to 12 layers of two different dielectric (insulator) materials that are only as thick as one-half the wavelength to be reflected. Examples of dielectric materials are silicone dioxide and magnesium fluoride. If one laser wavelength (eg, helium-neon [He-Ne] at 632.8 nm) were to be reflected, then 12 layers of alternating dielectric materials, each layer being 316.4 nm thick, would be applied to a lens. If a second laser wavelength (eg,

a

b

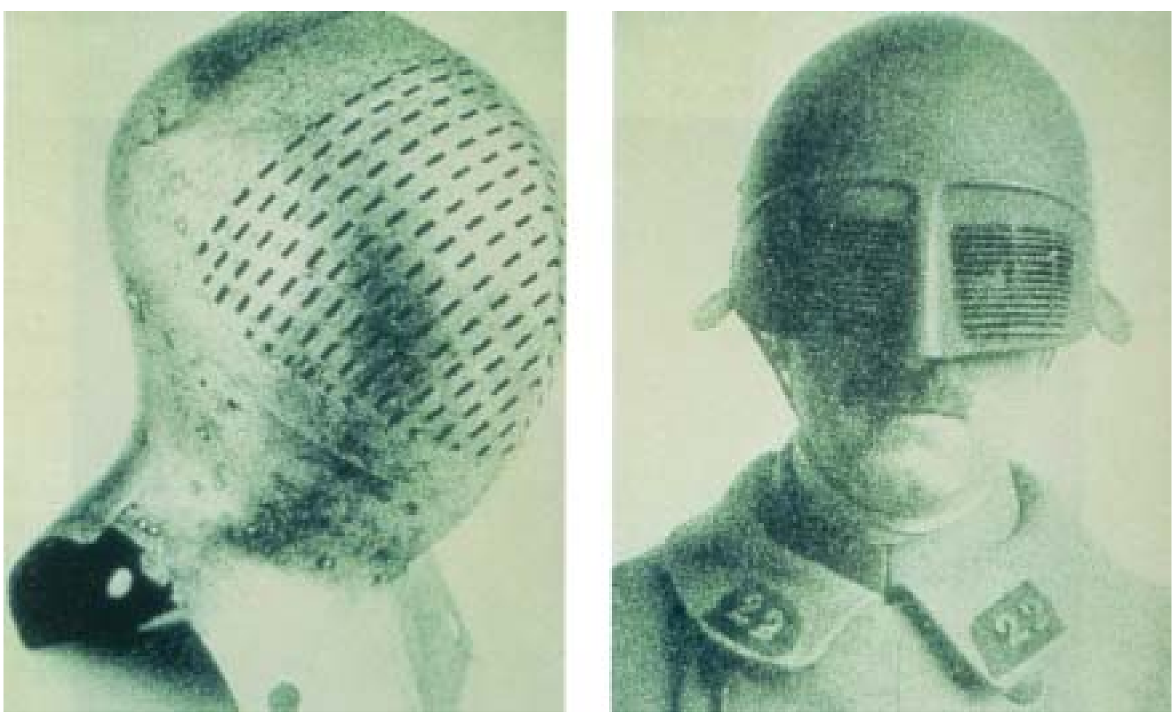

Fig. 8-28. (**a**) The Helm of 1514, never widely accepted, could be used only when the helmet rested on or was attached to the shoulders of the armored soldier (p100). (**b**) An experimental 1918 French helmet fitted with a Polack visor. The visor is shown dropped into place, but was designed to be worn up over the front of the helmet when not needed. The thin laminae and their vertical supports were mounted edgewise to interfere as little as possible with the soldiers' vision. However, as a defense against a missile or ball traveling at 600 fps, "the Polack visor is held to be worse than useless; it is penetrated, shattered, and an even more serious wound would be caused by the ragged ball and the inbent and broken ends of the visor's laminae" (p96).

c d

e f

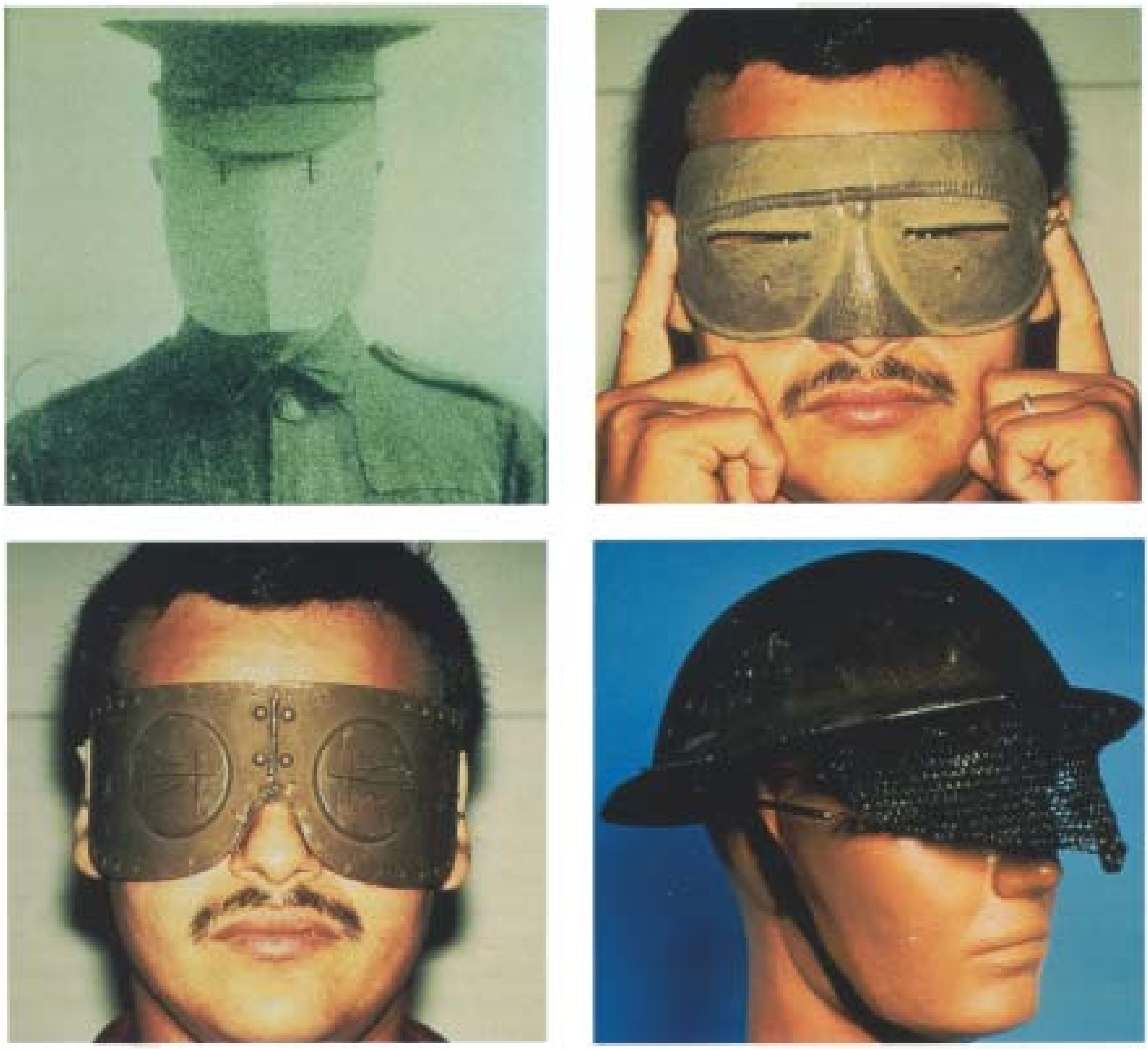

Fig. 8-28. (**c**) This British face shield (designed 1915–1916) consisted of a steel plate pierced with vertical and horizontal slits in front of each eye. It was designed to be worn fitted under the soldier's cap, but never progressed beyond the experimental stage (pp131–132). (**d**) U.S. Army Colonel W. Holland Wilmer suggested this 1918 visor design. It was based on the single-slot eye shield used by Native Americans in the northwest to protect against snow blindness. Made of soft steel, the visor fit snugly against the brow and cheeks by means of a sponge-rubber cushion, was attached to the soldier's helmet by a spring, and was designed to fit both British and American helmets. The visor permitted a wide range of vision. Note the apertures beneath the slits; they were positioned to allow the wearer a stereoscopic field of the ground immediately in front. These visors were disapproved because they were not readily kept in position (p236); (This photograph courtesy of Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC). (**e**) These 1917 British "splinter goggles," made of steel and weighing about 5.5 ounces, were said to allow surprisingly clear and extended vision through their narrow (0.2–0.6-in) slots. However, although these privately manufactured goggles were sold to allied soldiers, they never gained general acceptance (p233); (Photograph courtesy of Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC). (**f**) The chain-mail veil was the only eye defense produced by the British in large numbers (1916–1917). The visor, made of closely woven links, attached to a metal rod that passed under the brim of the helmet. Visors of this type were sent to the front during World War I, but the soldiers "found them to be annoying and soon cast them off….In actual use they produce dizziness, for the links of the visor change position in front of the wearer's eyes, following every movement of the helmet"(p133). The designers of this eye armor anticipated that it would prevent 50% of battlefield eye injuries. (This photograph courtesy of Colonel Francis G. La Piana, Walter Reed Army Medical Center, Washington, DC). Source: (figure legends a–f; photographs a–c, e): Dean, B. *Helmets and Body Armor in Modern Warfare*. Tuckahoe, NY: Carl J. Pugliese; 1977.

neodymium:yttrium aluminum garnet [Nd:YAG] at 1,064.0 nm) were to be reflected, then an additional 12 layers of alternating dielectric materials, each layer being 532.0 nm thick, would be applied over the first 12 layers of dielectric materials. Dielectric stacks have this advantage over filtering technology: they do not diminish broad bands of usable light as dye absorbers do. The disadvantages of dielectric stacks are twofold: the manufacturing process is still very expensive, and the degree of eye protection diminishes rapidly if the laser beam were to hit the dielectric stack *off-axis* (not perpendicular to the dielectric stack).

The underlying principle for hologram reflectors is similar to that for dielectric stacks. The difference is that the hologram utilizes a photographic film 20 μm thick, which contains hundreds of layers of high- and low-reflective regions. The advantages and disadvantages of hologram reflectors are the same as those for dielectric stacks. Perhaps the most significant disadvantage of reflective technology is that the reflections create a large battlefield signature, easily seen by enemy snipers and gunners. Future laser protection may combine both filtering and reflective technologies to protect against multiple laser wavelengths.

Eye protection for carbon dioxide lasers, which radiate intense energy and can cause thermal burns to human tissue including the eyes and skin, consists of regular industrial safety glasses (or a face shield) made with CR-39 plastic or polycarbonate plastic. Consequently, no tint or filtering device is needed. Glass lenses are not recommended for use in eye protectors because the energy intensity from the carbon dioxide laser beam could cause them to shatter.

Militarily Unique Eye Protection

Armies have always sought eye armor that would protect the vision of their fighting forces. However, soldiers have always resisted wearing such PPE because it restricted their peripheral vision, or was too heavy or cumbersome (Figure 8-28). The U.S. Army entered World War II with no eye protection for its soldiers. The sun, wind, and dust (SWD) goggle, however, was developed in 1942 for use in the African desert.

Efforts to develop eye armor continued after World War II. In approximately 1953, John Fair, an ophthalmologist who served in the Korean War, advocated (to no avail) that both ametropes and emmetropes wear a spectacle made of case-hardened glass refractive material, with cable temples and side shields. Later, an ophthalmology consultant to The Surgeon General anticipated the threat from battlefield lasers and advocated that AMEDD and the Army Materiel Command (AMC) work together to develop laser eye protection.[50] Developing eye protection remains a challenge today, because for the emmetrope it is considered to be body armor (a nonmedical item), whereas for the ametrope it is a refractive device (a medical item).

Despite development efforts during the 1950s and early 1960s, soldiers went to Vietnam with essentially no eye protection. Soldiers who were issued the SWD goggle usually wore them on top of their helmets (otherwise known as the Rommel position). In 1962, a researcher at the U.S. Army Natick Research, Development, and Engineering Center developed the technique to injection-mold polycarbonate plastic, which in turn led to the 2-mm-thick polycarbonate face shield that was used in the army aviator helmet; many pilots' eyes were saved during the Vietnam War because they wore this helmet while flying. Attaching the polycarbonate face shield to the infantryman's helmet was another idea that was proposed. Because the army could barely enforce the requirement that infantrymen wear a helmet, however, enforcing a requirement to wear eye protection was thought to be next to impossible.[50]

Because standard military spectacles do not provide adequate protection against ballistic or laser hazards, AMEDD developed the BLPS to provide more effective eye protection for soldiers during training and combat. The BLPS is a wrap-around polycarbonate spectacle with *spherical* lenses (designed to curve in two meridians), and provides protection against both ballistic projectiles and laser energy. It can be worn in garrison, while playing sports, while working around the house, or even while mowing the lawn. The kit includes a clear pair for everyday use; a tinted pair for sunny environments; and a green-tinted frontsert, which clips to the front of the BLPS, to protect the wearer against low-energy lasers. Ametropic soldiers are provided with a prescription backsert, which mounts behind the polycarbonate eyewear (Figure 8-29).

The SPECS system is similar to the BLPS in that it is made of polycarbonate plastic. However, it differs from BLPS in that the lenses are *cylindrical* (designed to curve in one meridian) to facilitate the application of dye absorbers, holograms, or dielectric stacks for protecting the soldier against laser hazards. Currently, there is no means for providing prescription lenses for ametropic soldiers.

Contact Lenses in Industry

Wearing contact lenses in eye-hazardous occupations has always been very controversial. Approximately 12 to 15 million Americans wear contact lenses; an additional 2 million new wearers are fitted each year.[51] Some people are absolutely required to wear

Fig. 8-29. From the left, the three soldiers are wearing clear Ballistic / Laser Protective Spectacles (BLPS), clear with the two-wavelength laser-protective frontsert, and amber (for sunny days). In addition to providing ballistic and laser protection to emmetropic soldiers, BLPS can be fitted with a lens carrier behind the protective eyewrap for ametropic soldiers. The fourth soldier, right, is wearing the Special Protective Eyewear Cylindrical System (SPECS) without reflective laser technology. Currently, SPECS is being developed for emmetropic soldiers only.

contact lenses to correct visual problems such as aphakia, high degrees of myopia, keratoconus, or irregular corneal astigmatism from corneal scarring. These workers may actually function more efficiently and be less prone to on-the-job accidents when they wear contact lenses than if they wear eyeglasses.[52] However, most contact lens wearers wear them for cosmetic reasons.

There are significant safety concerns regarding the use of contact lenses in industrial settings. One concern is that contact lens wearers, like emmetropic individuals, may not wear the safety glasses that the employer provides. Another concern is that dusty, oily, or chemically toxic environments may not be appropriate for wearing contact lenses: dust or foreign bodies can become trapped under rigid contact lenses, causing corneal abrasions, and toxic chemicals can be absorbed into the matrix of soft lenses, leading to a possible toxic exposure to the cornea. In addition, coworkers might be unable to remove the contact lenses if a chemical were to splash into the eyes, thus prolonging the contact time.[53]

Given the fact that some workers will not always wear their eye protection, unprotected workers who are wearing contact lenses will actually fare better against ballistic and chemical hazards than others whose corneas are unprotected. Both rigid and soft contact lenses reduce, and can sometimes deflect, the destructive forces associated with projectiles, foreign bodies, and chemical splashes. However, workers must be counseled regularly that contact lenses, by themselves, do not provide sufficient eye protection in an industrial environment against either ballistic or chemical hazards. Goggles or plano safety glasses must be worn over contact lenses, even though they defeat the cosmetic effect.

Wearing contact lenses in chemically hazardous environments provokes still more controversy. In 1978, NIOSH recommended that contact lenses not be worn when employees were working with any of several hundred listed chemicals. The rationale was that rigid contact lenses might trap chemical vapors beneath them, while soft contact lenses might absorb the vapors, which would prolong the contact time of the chemical. As a result, industrial safety specialists restricted the wearing of contact lenses in environments prone to chemical fumes and vapors, chemical splashes, dust, intense heat, or molten metals.[51] However, recent studies of rigid and soft contact lenses suggest that contact lenses act as a barrier, keeping chemical vapors away from the cornea and therefore minimizing injury.[54,55] However, persistent exposure to chemical vapors may have just the opposite effect: the vapors could be trapped or absorbed, leading to a toxic exposure of the cornea and conjunctiva.

Some workers will insist on wearing their contact lenses in eye-hazardous areas. Therefore, safety managers and supervisors should

- require the use of industrial safety glasses or goggles in conjunction with contact lenses,
- ensure that all workers always have a spare pair of eyeglasses or safety glasses readily available,
- provide workers with a clean area for removing their lenses, and
- instruct fellow workers in emergency contact-lens removal techniques.

Using contact lenses with commercial respiratory protective equipment and military protective masks has also been controversial. In May 1971, NIOSH and OSHA issued a regulation that prohibited the use of contact lenses with protective respiratory equipment in a contaminated atmosphere.[56] Similarly, the army prohibited the use of contact lenses with protective masks. However, a 1985 study of 13 firefighters reported that those who wore respiratory protective equipment were at greater risk of personal injury due to lost, bent, scratched, or fogged glasses than they were when they wore their contact lenses. In 1985, The Lawrence Livermore National Laboratory conducted a survey of 9,100 firefighters in the United States and Canada; of the 1,405 questionnaires that were returned, 403 firefighters reported that they wore contact lenses with respiratory protective equipment despite the regulation prohibiting it. Only six firefighters reported contact lens–related problems so severe that they needed to remove their masks.[57] In March 1987, OSHA announced that it would amend the contact lens prohibition and allow voluntary use of contact lenses.[58]

While the civilian sector is moving toward limited use of contact lenses with respiratory protective equipment, the army is still concerned that sweat will run into soldiers' eyes, causing excessive burning and stinging of the cornea. This could cause the soldier to unthinkingly unmask in a chemically contaminated environment. Currently, the army prohibits wearing contact lenses during gas-chamber exercises, field-training exercises, and combat.[59] It is anticipated, however, that army helicopter pilots will be allowed to request a waiver to this regulation because some aviation systems (such as the "Heads Up" display devices and the M43 protective mask) prohibit the use of spectacles.

ENVIRONMENTAL VISION

Environmental vision pertains to nonindustrial conditions such as illumination, VDTs, and UV radiation from sunlight that may have a detrimental effect on visual efficiency, ocular health, or both. Illumination and VDT problems often require that the surrounding environment be modified to improve workers' visual efficiency and productivity. Inadequate or insufficient illumination can significantly reduce productivity and simultaneously increase the number of work-related injuries.

Illumination

Illumination is an important element of vision conservation that is often overlooked. Industrial lighting should provide a safe working environment and improve visual efficiency, safety, and comfort. Fifty years ago, when wages were relatively low and incandescent lamps were inefficient, it was cheaper to hire additional workers to compensate for the inefficient work practices associated with poor lighting. However, with the passage of time, higher wages, and an ever-increasing variety of lamps being developed, it has become more cost effective to improve worker productivity by improving both the quantity and the quality of illumination in the workplace.

Illumination surveys are usually performed by the installation industrial hygienist. When an illumination survey is performed, three important factors should be evaluated: the quantity of illumination, the quality of illumination, and visual comfort. All three factors are interrelated and should complement one another.

Quantity of Light

The amount of light emitted by a light source that falls on a surface or work station (the quantity of illumination) should match the visual demands of the task. Detailed work (such as reading machinist's calipers) requires more illumination than gross tasks (such as driving a forklift). The Illuminating Engineering Society (IES) and many lighting-equipment companies publish tables of minimum recommended illumination by job categories (Table 8-7). However, minimum recommended levels of illumination should not be confused with the illumination levels that allow for maximum worker productivity. For example, the amount of light that is needed for maximum visual efficiency varies with the employee's age; an employee who is near retirement age often requires several times more illumination than a younger worker needs to see the same work.

The *illuminance*, or luminous intensity seen as visible light striking a surface of an object, is measured as the *candela* (candle), a unit based on luminous flux, the *lumen*, per unit area of surface. A source of light of 1 candela produces 4 steradians (π) lumens of luminous flux in all directions (Figure 8-30).

The intensity of illumination is expressed as the ratio of the illumination source and the radiated surface area, and is measured in units of *lux* (lumens/m^2), and the quantity of light, a parameter that includes the duration of light measured in seconds or hours. In practice, the luminous intensity from a source of light is measured in three different standard units:

- 1 lumen/cm^2
- 1 lumen/m^2 (1 lux, the modern metric term)
- 1 lumen/ft^2 (1 foot-candle [ft-c, the nearly obsolete term that is still used in the United States, especially in the lighting industry)]

TABLE 8-7

MINIMUM RECOMMENDED LEVELS OF ILLUMINATION

Task	Illumination (ft-c)	Examples
Casual	30	Warehouses
Rough	50	Reading large markings
Medium	100	Sewing, woodworking
Fine	500	Electronics

Adapted with permission from General Electric. Basic lighting considerations. In: *Industrial Lighting*. Cleveland, Oh: GE; 1969: 4.

The early photometric standard of light was actually a candle (made of sperm wax), hence the term *standard candle.* Later, the National Bureau of Standards retired the candle for carbon filament lamps and in 1948, a *new candle* standard was adopted. The new candle is based on the radiation of light emitting from a blackbody of platinum when the temperature is raised to the melting point of the noble metal, 2,047°K. At that temperature, 600,000 new candles/m^2 of luminous intensity is emitted (equivalent to 60 candles/cm^2).

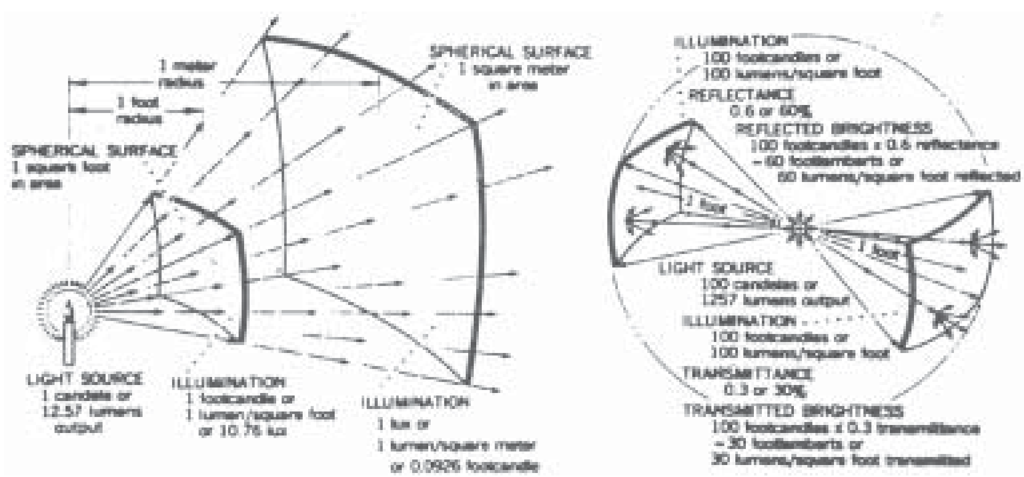

Fig. 8-30. The concept of illumination and its units of measurement, left. The amount of illumination falling on a 1 m^2 spherical surface, located 1 m from a light source that is emitting 1 candela (12.57 lumens) of output, is defined as 1 *lux* (1 lumen/m^2). The concept of luminance, right, which is defined as the amount of light transmitted through or reflected by a surface. Luminance is subjectively called "brightness." A surface that is illuminated with 100 lux and has a reflectance of 60% will measure 60 lamberts of luminance. Measurements of luminance portray true lighting conditions more accurately than do measurements of illumination. Reprinted with permission from General Electric. *Light Measurement and Control*. Cleveland, Oh: GE; 1971. Publication TP-118.

The historical confusion between the "brightness" of light as measured as intensity per unit area and "brightness" as judged subjectively through the human eye led to the use of the term *luminance,* expressed as candles per m^2. The standard unit of *relative spectral sensitivity* of the eye (equal to light of an intensity of 1.0 new candle, which equals 1.0 π of light source) is equivalent to 685 lumens / W of luminous efficiency at the wavelength 555 nm. In the visible part of the EM spectrum, the spectral sensitivity of the human eye can be plotted as a bell-shaped curve. At 555 nm, spectral intensity is 1.0. Spectral sensitivity decreases from 1.0 in spectral intensity as wavelength decreases to approximately 390 nm (at 400 nm, spectral intensity equals 0.0004), and spectral sensitivity also decreases from 1.0 in intensity as wavelength increases from 555 nm, to approximately 760 nm (at 760 nm, spectral intensity equals 0.00006). The wavelength of light to which the human eye is most spectrally sensitive is 555 nm, in the green part of the visible spectrum.

Illumination is categorized as either *general illumination* (the ambient light, which illuminates a broad area) or *supplemental task lighting* (lighting that is added to increase the visibility of certain tasks). Many industries use fluorescent, mercury, metal halide, or high-pressure sodium lamps to achieve 30 to 50 ft-c of general illumination. While 30 to 50 ft-c of illumination may be sufficient as general illumination, this amount may not be sufficient to produce maximum worker productivity; supplemental task lighting may need to be added above specific work stations. For example, many machine shops have a general illumination level of 50 ft-c; to increase productivity and reduce the risk of on-the-job accidents, supplemental lighting will need to be added over each machine to provide at least 100 ft-c of illumination at each work station. Increasing the general illumination level to 100 ft-c is not recommended because it is usually more expensive than supplemental task lighting, and the resulting increase in *glare* (excessively bright light that causes visual discomfort) might negatively affect overall productivity.

Unfortunately, most lighting surveys stop at measuring the number of footcandles emitted by the lighting source, which may lead to erroneous conclusions as to the adequacy of illumination. In terms of visual comfort and job performance, measurements of luminance (the amount of light emitted or reflected from a work surface toward an observer or worker) are perhaps more accurate (and more important) than measurements of illumination. In the simplest terms, luminance (which is measured in footlamberts or lamberts) is the product of illumination (in footcandles) and the luminous reflectance of the surface. Tasks involving dark-colored (such as gray) objects may require as much as 10-fold more illumination than tasks involving lighter-colored (such as yellow) objects to achieve the same degree of luminance or brightness. Unfortunately, a standard light meter does not measure luminance. However, by holding the meter 2 to 4 in from the surface to be measured, it can be used to approximate the measurement of luminance.

Quality of Illumination

Proper lighting (ie, the proper distribution and control of lighting) allows the worker to focus on the task at hand, rather than causing his or her eyes to stray (which, in turn, increases ocular fatigue and reduces work efficiency). Unlike the quantity of illumination (which is measured without regard to the human observer), the quality of illumination deals with the degree of brightness (ie, a person's impression of the relative intensity of light). To improve task perfor-

TABLE 8-8

RECOMMENDED MAXIMUM BRIGHTNESS RATIOS

	Environmental Classification		
	A	B	C
1. Between tasks and *adjacent darker* surroundings	3–1	3–1	5–1
2. Between tasks and *adjacent lighter* surroundings	1–3	1–3	1–5
3. Between tasks and more *remote darker* surfaces	10–1	20–1	*
4. Between tasks and more *remote lighter* surfaces	1–10	1–20	*
5. Between luminaires (or windows, skylights, etc.) and *surfaces adjacent* to them	20–1	*	*
6. Anywhere within normal field of view	40–1	*	*

*Brightness ratio control not possible

A: Interior areas where reflectances of entire space can be controlled in line with recommendations for optimum seeing conditions

B: Areas where reflectances of immediate work area can be controlled, but control of remote surroundings is limited

C: Areas (indoor and outdoor) where it is completely impractical to control reflectances and difficult to alter environmental conditions

Reprinted with permission from General Electric. Basic lighting considerations. In: *Industrial Lighting.* Cleveland, Oh: GE; 1969: 6. Publication TP-108.

mance and productivity, recommended minimum brightness ratios, also called luminance ratios, have been established for use in industry (Table 8-8). Brightness ratios can be controlled by the proper selection and location of lamps; painting or cleaning reflective surfaces (walls, ceilings, equipment, or floors); and supplemental task lighting.

Direct and indirect lighting techniques are used throughout industry to improve the quality of illumination. *Direct lighting* (light that falls directly on the task) is the most efficient type of illumination; however, it tends to produce shadows and glare. *Indirect lighting* (lighting that is reflected off adjacent ceilings or walls) is more comfortable to work under than direct lighting because it produces significantly less glare. Unfortunately, indirect lighting is less efficient (and therefore more expensive) than direct: because indirect lighting is reflected off adjacent ceilings and walls, more initial illumination is required to achieve the same illumination as direct lighting.

Color contributes to the quality of illumination as well. *Object color* is defined as the color of light reflected or transmitted by an object when it is illuminated by a *standard light source* (standard source A [a tungsten filament lamp operated at a color temperature of 2,856°K], or standard source B [an approximation of sunlight at noon, having a correlated color temperature of approximately 4,874°K], or standard source C [an approximation of daylight provided by a combination of direct sunlight and clear sky, having a correlated color temperature of approximately 6,774°K]). *Color rendering* is a term applied to lighting sources; an object will *render* different colors depending on the spectrum composition of the lighting source (Figure 8-31). Poor color rendering by an illumination source can distort color perception, increase ocular

a

b

c

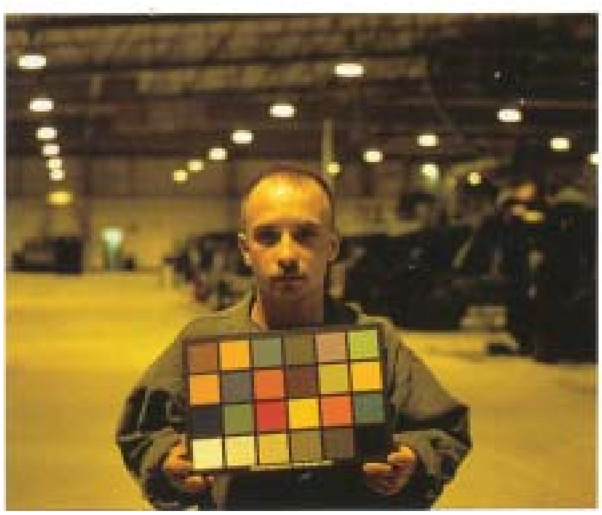

Fig. 8-31. Identical color boards photographed in three sources of illumination: (**a**) daylight, (**b**) mercury vapor lamps, and (**c**) high-pressure sodium (HPS) lamps. Mercury vapor lamps mimic the color-rendering properties of daylight, but the nearly monochromatic (589 nm) HPS lamps greatly distort color perception.

fatigue, and reduce worker productivity. Fluorescent lights, the lamps used most commonly in workplaces (due to their cost efficiency), emit a broad spectrum of light, giving them color-rendering properties second only to sunlight. Incandescent lamps also have excellent color-rendering properties but are less efficient and produce more heat than fluorescent lamps. Mercury vapor and metal halide lamps, often used in gymnasiums and large industrial bays, are even more efficient, but cause a mild distortion of color perception. High-pressure sodium-vapor (HPS) lamps are used in warehouses and many industrial manufacturing bays. They produce a golden white, broad-spectrum light with its maximum intensity centered around 589 nm. Low-pressure sodium-vapor lamps, which are the most efficient lamps made, are used to illuminate highways and parking lots. The golden orange light produced is almost monochromatic (consisting of a double wavelength at 589 and 589.6 nm) and significantly distorts color perception. As a general rule, lamps with good light efficiency tend to have poor color-rendering properties, and vice versa (Table 8-9).

TABLE 8-9

LAMP EFFICIENCIES

Luminaire Type	Lumens per Watt
Incandescent bulbs	17–23
Fluorescent tubes	70–80
Mercury vapor lamps	44–55
Multivapor lamps	80–90
High-pressure sodium lamps	115
Low-pressure sodium lamps	170

Sources: (1) General Electric. *Industrial Lighting*. Cleveland, Oh; GE; 1969, Pub TP-109. (2) General Electric. *Light Measurement and Control*. Cleveland, Oh: GE; 1971, Pub TP-118. (3) Kaufman JE, Christensen JF. *IES Lighting Handbook*. New York: Illuminating Engineering Society; 1972.

Visual Comfort

A worker's visual efficiency and comfort are maximized when glare from illumination sources or work surfaces or both are minimized. *Direct glare* comes from uncontrolled light sources (light sources without reflectors or diffusors). In order to reduce the uncomfortable and sometimes disabling effects that are associated with direct glare, lighting sources (such as lamps or windows) should be restricted by the use of appropriate reflectors, diffusors, blinds, or louvers. For example, light emitted from a bare light bulb is more harsh and uncomfortable than light emitted from a lamp equipped with a shade. *Reflected glare* comes from highly polished surfaces (such as desk tops, VDT screens, or glossy paper) and can cause significant visual discomfort. Reflected glare is controlled by moving the location of the light source or by changing the angle of the work plane so that the light does not reflect into the worker's eyes.

Illumination Dilemmas

In response to the world oil crisis, Congress passed the Energy Conservation Act in 1973 to reduce the federal government's use of energy and energy-related products such as natural gas and oil. The provisions of this act (Title 41, Code of Federal Regulation, Section 101-20.107, *Energy Conservation*) mandate that maximum illumination levels of work-station surfaces be no greater than 50 ft-c; of general work areas, no greater than 30 ft-c; and of nonwork areas such as halls, no greater than 10 ft-c. The purposes of reducing levels of illumination were twofold: to reduce electrical costs (which reduced the use of gas and oil) and to reduce air-conditioning costs (to offset the additional heat associated with increased lighting).

To maximize illumination and minimize electrical costs, many installations spent millions of dollars converting inefficient incandescent and fluorescent lamps to higher-efficiency HPS lamps. Most of these conversions were in poorly lit areas such as warehouses. Because warehouse lighting was successfully improved, similar conversions were made in industrial areas such as machine shops, and even in administrative offices. During routine USAEHA site visits, the staff received complaints from workers as a result of these conversions. Workers complained not only about the unnatural golden-orange color but also about their inability to discriminate colors properly in this light. For example, rust on metal parts, which is easy to see under fluorescent lighting or sunlight, cannot be seen under HPS lamps. Daytime shift workers had no complaints about the lighting (because the HPS lighting was supplemented with sunlight through the windows), but the evening and night shifts complained incessantly about the lighting.

Other problems associated with HPS lamps are excessive glare and headaches. Because HPS lamps are so efficient and cost effective, some installations have removed the supplemental task lighting from machine shops and have installed more HPS lamps than are usually necessary. This has resulted in machine shops having 75 ft-c to 100 ft-c of general illumination. While this meets the minimum IES-recommended levels of illumination for certain operations, the glare from so many HPS lamps can be tremendous; many workers wear hats indoors to reduce the glare and its consequent headaches.

To reduce worker complaints associated with HPS lighting and to improve productivity, the USAEHA has made several recommendations:

- No further conversions to HPS lamps should be made until the impact on workers has been assessed at the installation.
- HPS lamps should not be utilized in administrative offices, especially in buildings where sunlight cannot supplement the ambient lighting.
- General illumination levels should be reduced to 50 ft-c (or slightly less), but supplemental task lighting, which may have been removed, should be restored.
- Installations should mix mercury-vapor or multivapor lamps with HPS lamps to achieve a more natural spectrum of illumination.

Personal Computers and Video Display Terminals

In the workplace, typewriters have been supplanted by PCs and VDTs, not only in this country but also throughout much of the world. In 1975, there were fewer than 200,000 VDTs in use in the United States; 10 years later, after PCs were introduced, this number had grown to approximately 13 million units—with 100 million projected by the year 2000.[60] Concurrent with this phenomenal growth in VDT use came an increase in the clinical signs and medical symptoms of work-related health problems.

Problems with Vision

Approximately 50% to 75% of computer workers experience some form of visual discomfort, including fatigue, headaches, eyestrain, burning eyes, blurring of the monitor screen, intermittent double vision, distance blurring after using a PC, neckache, and backache.[60,61] This discomfort is most often attributed to visual problems of the worker, the surrounding environment, or a combination of both. Visual problems can stem from (*a*) uncorrected refractive errors, (*b*) accommodative problems or presbyopia, (*c*) binocular coordination problems, (*d*) glare, (*e*) contour sharpness, and (*f*) the flicker effect (which may cause fatigue, migraine headaches, and other nonvisual physical problems in certain flicker-sensitive people).[60,62] In addition, a dirty screen makes the information that is displayed more difficult to read, so screens should be cleaned daily.

The most common refractive condition associated with computer-related visual symptoms is latent or low *hyperopia* (farsightedness). Hyperopic individuals are usually able to compensate for the small degree of hyperopia by accommodating (or focusing) during short-term tasks; they usually do not require corrective spectacles until later in life. With the use of PCs, however, hyperopic individuals accommodate more extensively and eventually develop visual symptoms. Most of these individuals can be helped with *low-plus* (up to +1.25 diopters) lenses or bifocals.

Myopia (nearsightedness) does not usually produce visual symptoms in PC users. However, transient myopia (which is actually accommodative spasm) in otherwise emmetropic individuals can occur with prolonged use of PCs. Rather than wearing *low-minus* (up to –0.50 diopters) lenses, these individuals may benefit from visual training that is directed at relieving the accommodative spasm; in addition, they should wear either low-plus lenses or bifocals to relieve accommodative stress while working at their computers.

Astigmatism (a focusing anomaly that occurs at both distance and nearpoint viewing) can adversely affect PC workers. Individuals with moderate to large degrees of astigmatism usually wear glasses full time to correct the astigmatic error. Some individuals with small errors, however, function adequately without glasses until they are confronted by a visually intense task, such as looking at a computer screen for several hours. These individuals need to be referred for a visual examination.

Other vision-related problems include accommodative problems and presbyopia. PCs typically require an individual to accommodate for both the nearpoint (14–18 in) and intermediate (18–24 in) working distances. Some young individuals have dysfunctional accommodation systems and develop significant problems when working at a computer for prolonged periods. Everyone becomes presbyopic with age (an individual's amplitude of accommodation gradually diminishes). At approximately 40 years of age, prescription reading glasses or bifocals are usually required for any extensive reading or nearpoint task. Individuals with accommodative problems or presbyopia require a complete eye examination to assess their accommodative functions. Typically, these individuals will require either low-plus lenses or bifocals (to compensate for the lack of accommodation); in some cases, visual training (to improve the amplitude of accommodation) can be helpful.

Because working with PCs involves both nearpoint and intermediate distances, distance-specific spectacles should be prescribed: reading glasses, with sufficient depth of focus to encompass both distances; or bifocals, the upper section of which is used for the intermediate distance and the lower section for the standard reading distance. Conventional trifocals should be avoided; they tend to induce neck- and backaches due to improper positioning of the head (Figure 8-32). Special trifocals with an intermediate vertical-segment height of 10 to 14 mm (rather than the usual 7 mm) are available and may be prescribed in certain cases.

Some computer workers will have problems with their binocular vision. In many instances, visual symptoms stem from *esophoria* (overconvergence of the eyes) or *exophoria* (underconvergence or divergence of the eyes) at the intermediate or nearpoint working distances. Many individuals with esophoria or exophoria do not complain of visual discomfort until they are required to perform nearpoint tasks, such as using a PC, for extended periods. Like individuals with accommodative problems and presbyopia, these individuals also require a thorough eye examination.

In most esophoric patients, low-plus lenses should be sufficient to relieve the symptoms. In others, as well as in patients with exophoria, visual training is usually required to improve the eyes' abilities to converge and diverge. However, optometrists and ophthalmologists should avoid prescribing glasses with prism (to compensate for exophoria or esophoria); patients will accept prism initially, but will invariably require larger corrections of prism over time.

Glare causes considerable problems for PC users. Reflected glare (from overhead lights or nearby windows) makes the images on the screen difficult to see and causes eyestrain (Figure 8-33). Curtains or blinds can help control the glare from windows. Antireflection screens can significantly reduce the annoying effects of glare by reducing reflections.

Background or contrast glare is an even more significant problem at most PC work stations. If the general lighting is overly bright or if the screen is located in front of either a window or a white wall, the

Fig. 8-32. Workers who wear conventional bifocals or trifocals usually have few visual problems when doing routine desk work, but they often have problems when using a video display terminal. This office worker is trying to use a bifocal segment that is too weak for reading the monitor; at the end of an 8-hour day, she will undoubtedly have neck and back strain. To remedy this situation, this worker should have *occupation-specific* bifocals—with the intermediate prescription (for an 18–24-in. viewing distance) in the upper portion of the lens and the stronger reading prescription (for 14–18-in. reading distance) in the lower segment.

Fig. 8-33. Computer work stations should be positioned for maximum productivity. This worker might be distracted by glare from the window. Windows should be equipped with curtains, miniblinds, or both, to reduce direct glare. If this cannot be accomplished, the workstation should be moved so the source of glare is behind the worker.

iris will decrease the size of the pupil. This limits the amount of light that can reach the retina. The image on the screen will appear less bright, which can lead to eyestrain and headaches in operators who must view the screen for several hours. The solution is to decrease the ambient lighting to improve the brightness ratio between the background and the screen; however, if operators must work from hard copy, they should illuminate it with a spot lamp.

Contour sharpness is yet another problem for computer users. The sharpness of the images displayed on the monitor depends on the matrix (the number of horizontal and vertical dots per inch of screen). Older color graphics array (CGA) monitors (also known as red, green, blue [RGB] monitors) are being replaced with new-generation enhanced graphics array (EGA), video graphics array (VGA), and even higher-resolution monitors, which, because they have higher resolution, cause less eyestrain than the older models.

The McCollough Effect (an afterimage that causes white letters and objects to appear pink) is a startling visual phenomenon. It occurs in computer workers who spend long periods before a monochrome screen that displays green characters against a dark background. The theoretical explanation for this unusual phenomenon is that the green-stimulated retinal receptors become fatigued due to the constant stimulation; consequently, when the computer operator looks away from the screen, white objects are devoid of green, making them appear pink. Discovered in 1965, the McCollough Effect is seemingly harmless and relatively short lasting.

Radiation-Related Health Effects

A number of studies have associated cataract formation with PC use. In 1983, 10 anecdotal cases of cataracts were reported in VDT users; six of the patients had minor opacities that did not impair their vision, while four others had a history of exposure to other cataractogens. Many experts, however, discount the risk of cataracts. Testimony before a United States House of Representatives subcommittee suggests that 25% of the population of the United States has opacities of the lens without impaired vision, while approximately 4% of the population 35 to 45 years of age has age-related cataracts. In addition, radiation-induced cataractogenesis is thought to require exposures 10,000-fold greater than that expected from a PC.[60]

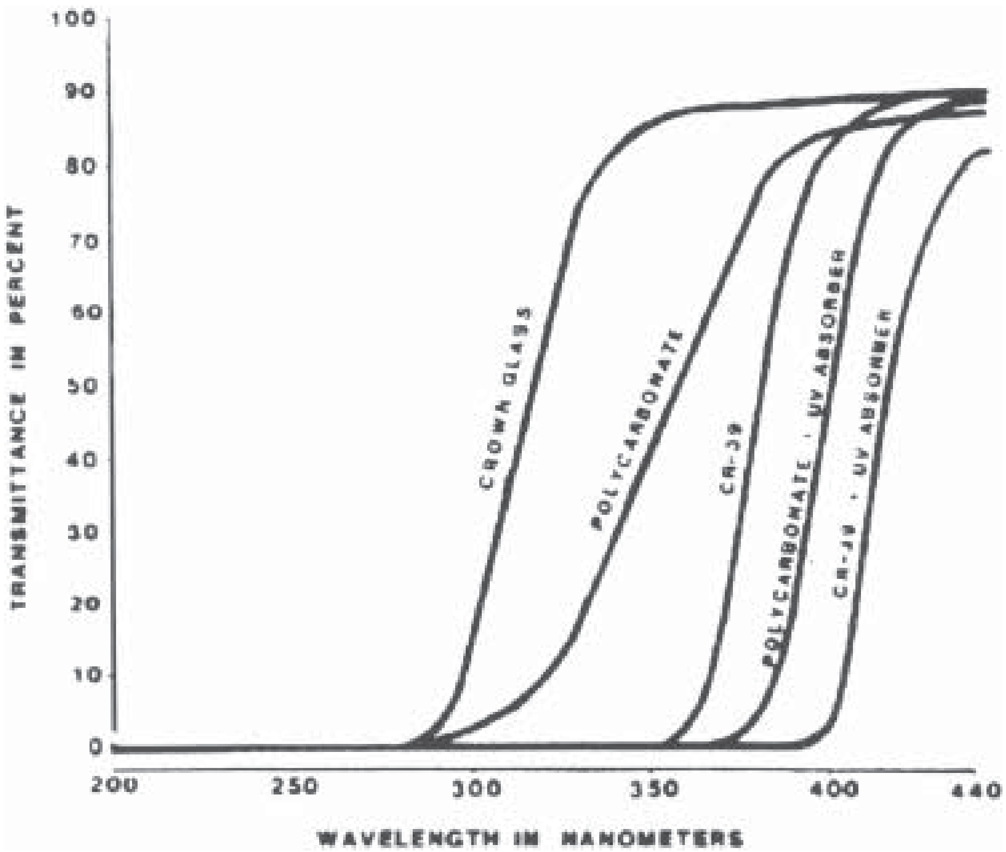

Fig. 8-34. Transmittances of different optical materials used to manufacture spectacle lenses. Source: Pitts DG. Ultraviolet protection, when and why? *Prob in Optom.* 1990;2(1):95–115.

Solar Ultraviolet Radiation

Although exposure to solar UV radiation is not considered to be an industrial hazard, it can be an occupational hazard. Many outdoor workers, including soldiers, can sustain excessive exposure and may be at risk for sunburn or premature cataract formation. Photokeratitis due to sunlight does not normally occur unless exposure levels are unusually excessive. Levels of solar UV radiation overexposure are difficult to estimate due to a number of variables including (*a*) the time of day, (*b*) the angle of the sun, (*c*) the latitude and altitude at which the person is working, (*d*) the degree of cloud cover, and (*e*) changes in the surrounding reflecting surfaces. For example, more than 60% of UV radiation exposure occurs between 1000 and 1400 hours, when the sun is highest in the sky. Furthermore, UV exposure increases by 15% for each kilometer of altitude (approximately 5% for each 1,000 feet). Clouds do not attenuate UV radiation; that is why sunburns occur even on overcast days. Green grass reflects only 3% to 5% of ambient UV radiation, while fresh and salt water reflect 3% to 8%, dry sand reflects 15% to 18%, and fresh snow reflects 85% to 95%. When all these factors are considered, snow skiing (due to the altitude and the reflectivity of snow) is the most UV-intensive environment, followed by sunbathing at the beach.[39]

Glasses with a filtering tint provide the best protection against low levels of solar UV radiation. However, it is dangerous to assume that all tinted glasses or sunglasses provide adequate or equal filtering protection. Data on lens materials reveal that regular glass lenses attenuate approximately 95% of UV radiation (the amount varies with the wavelength), followed by polycarbonate and then CR-39 (Figure 8-34). Manufacturers of CR-39 and polycarbonate lenses add UV inhibitors to prevent the virgin CR-39 polymer from yellowing as the lens absorbs UV radiation over time. While a clear CR-39 ophthalmic lens protects a wearer against low-level UV-C and UV-B radiation, it does not provide acceptable protection against UV-A radiation. Maximum protection against solar UV radiation occurs when CR-39 lenses are coated with an additional UV-absorbing dye called UV-400.[39]

SUMMARY

Soldiers require good, if not excellent, vision to be able to spot their enemies quickly and to fight to the best of their abilities. To this end, armies have sought eye protection: a soldier who has been blinded is both useless to the battlefield commander and at risk of being killed. The U.S. Army's interest in meeting the ever-increasing threats to vision and ocular health has expanded through the post–World War II inception of the Occupational Vision Program to the current Vision Conservation Program.

The Vision Conservation Program is an installation-based, dynamic program comprising three elements: occupational vision, eye safety, and environmental vision. The goal of the occupational vision element is to provide military personnel and DoD civilian workers with the best vision possible for them to work and recreate safely, productively, efficiently, and comfortably. Eye safety is directed toward eliminating injuries through training, administrative and engineering controls, and by providing individuals with appropriate PPE. The environmental vision element evaluates and provides solutions for environmental problems such as illumination and radiation (ionizing and nonionizing), which may negatively influence the worker's visual efficiency and health.

Perhaps the greatest challenge to the army and its Vision Conservation Program, after trying to field acceptable, standard-issue, eye-appropriate PPE, is wearing compliance—both on the job and off duty. Individuals who do not wear prescription eyeglasses are often uncomfortable wearing a device that does not obviously affect their performance. However, the use of eye protection can be expected to increase over time with safety leadership by supervisors and managers and continuous worker education and training.

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