CHAPTER 10
SAFETY

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10.1 WHY SAFETY?

The ASME Code of Ethics says: "Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties." This consideration is not new. Tacitus [10.1], about the first century A.D., said: "The desire for safety lies over and against every great and noble enterprise." Even some 2000 years earlier, the first known written law code [10.2], while not specifically mentioning safety, clearly implied a necessity for a builder to consider safety.

The National Safety Council [10.3] says:

> Each year, accidental deaths and injuries cost our society in excess of $399 billion—in the United States alone. This figure includes lost wages, medical outlays, property damage and other expenses. The cost in human misery is incalculable. Accidents are the fifth leading cause of death. The Council believes that accidents are not just random occurrences, but instead result mostly from poor planning or adverse conditions of the environments in which people live, work, drive and play. In our view, "accidents" nearly always are preventable—as are many illnesses.

If for no other reason, one should emphasize safety as a matter of enlightened self-interest.

Those who design machines and who have an interest in productivity and cost control serve their "customers" well if risks are at a minimum, as interruptions called accidents will also be at a minimum.

10.2 WHAT IS SAFETY?

One dictionary [10.4] definition is: "The quality or condition of being safe; freedom from danger, injury or damage." Most other dictionary definitions are similar. Hammer [10.5] says: "Safety is frequently defined as 'freedom from hazards.' However, it is practically impossible to completely eliminate all hazards. Safety is therefore a matter of relative protection from exposure to hazards: the antonym of danger." Lowrance [10.6] says: "A thing is safe if its risks are judged to be acceptable." This definition contrasts sharply with the Webster definition (which indicates "zero" risk) and, like Hammer's, implies that nothing is absolutely free of risk. Safety is a relative attribute that changes from time to time and is often judged differently in different contexts. For example, a power saw, a lawnmower, or similar powered equipment that may be "safe" for an adult user may not be "safe" in the hands of a child.

Lowrance's definition [10.6] emphasizes the relativistic and judgmental nature of the concept of safety. It further implies that two very different activities are required in determining how safe a thing is: *measuring risk,* an objective but probabilistic effort, and *judging the acceptability* of that risk, a matter of personal and/or societal value judgment. In addition, the level of acceptable risk involves moral, technical, economic, political, and legal issues.

Technical people are capable of measuring risks, and are generally qualified to do so. The decision as to whether the general public, with all its individual variations of need, desire, taste, tolerance, and adventurousness, might be (or should be) willing to assume the estimated risks is a value judgment that technical people are no better qualified (and perhaps less qualified) to make than anyone else.

10.3 HAZARD, RISK, AND DANGER

There is substantial confusion about the meaning of words such as *hazard, risk,* and *danger.* Webster [10.4] defines *danger* as "liability to injury, pain, damage or loss; hazard; peril; risk." Webster [10.4] makes some distinction by further saying, "Hazard arises from something fortuitous or beyond our control. Risk is doubtful or uncertain danger, often incurred voluntarily."

One can also consider a hazard to be (1) any aspect of technology or activity that produces risk or (2) the potential for harm or damage to people, property, or the environment, including (3) the characteristics of things and the actions (or inactions) of individuals. One can also consider risk to be a measure of the probability and severity of adverse effects.

With all the products liability litigation in the United States, a clear distinction among these three words for legal purposes has developed. In this context, a *hazard* is a condition or changing set of circumstances which presents an injury potential, such as a railroad crossing at grade, a toxic chemical, a sharp knife, or the jaws of a power press. *Risk* is the probability of injury and is affected by proximity, exposure, noise, light, experience, attention arresters, intelligence of an involved individual, etc. Risk (probability of exposure) is obviously much higher with a consumer product than with an industrial product to be used by trained workers in a shop environment. *Danger* is the unreasonable or unacceptable combination of hazard and risk. The U.S. courts generally hold as unreasonable and unacceptable any risk which can be eliminated by reasonable accident prevention methods. A high risk of injury could be considered reasonable and acceptable *if* the injury is minimal and the risk is recognized by the individual concerned. (Lowrance's use of *risk* seems close to the legal definition of *danger.*)

As might be expected, there is extensive and ongoing debate over the meaning of "reasonable" or "unreasonable." The American Law Institute [10.7] says *unreasonably dangerous* means that

> The article sold must be dangerous to an extent beyond that which would be contemplated by the ordinary consumer who purchases it, with the ordinary knowledge common to the community as to its characteristics. Good whiskey is not unreasonably dangerous merely because it will make some people drunk, and is especially dangerous to alcoholics; but bad whiskey, containing a dangerous amount of fusel oil, is unreasonably dangerous.

The American Law Institute further says:

> There are some products which, in the present state of human knowledge, are quite incapable of being made safe for their intended and ordinary use. . . . Such a product, properly prepared, and accompanied by proper directions and warnings, is not defective, nor is it unreasonably dangerous.

The American Law Institute [10.7] says that a product is in a defective condition if "it leaves the seller's hands, in a condition not contemplated by the ultimate user, which will be unreasonably dangerous to him." Peters [10.8] indicates that a California Supreme Court decision, *Barker* v. *Lull* [10.9], established a good assessment of "defective condition." This provides three definitions (or criteria) for manufacturing defects and two for design defects.

Defective Conditions

Manufacturing defects

1. Nonconformance with specifications
2. Nonsatisfaction of user requirements
3. Deviation from the norm

Design defects

1. Less safe than expected by ordinary consumer
2. Excessive preventable danger

Manufacturing Defects. A failure to conform with stated specifications is an obvious manufacturing defect; this is not a new criterion. The aspect of user satisfaction may not be as well known, but in the legal context it has long been recognized that a manufacturing defect exists when there is such a departure from some quality characteristic that the product or service does not satisfy user requirements. Under the third criterion (deviation from the norm), added by Barker, a manufacturing defect occurs (1) when a product leaves the assembly line in a substandard condition, (2) when the product differs from the manufacturer's intended result, or (3) when the product differs from other ostensibly identical units of the same product.

Design Defects. A product may be considered to have a design defect if it fails to perform as safely as an ordinary consumer would expect. This failure to perform safely is interpreted in the context of intended use (or uses) in a reasonably foreseeable manner, where *foreseeable* has the same meaning as *predicted* in failure-modes-and-effects, fault-tree, or hazard analyses. It appears that many "ordinary" consumers would have no concept of how safe a product should, or could, be without the expectations created by statements in sales material, inferences from mass media, general assumptions regarding modern technology, and faith in corporate enterprise.

A design defect also exists if there is excessive preventable danger. The real question is whether the danger outweighs the benefits; this can be answered by a risk-benefit analysis which should include at least five factors: (1) gravity of the danger posed by the design (i.e., severity of the consequences in the event of injury or failure), (2) probability (including frequency of and exposure to the failure mode) that such a danger will occur, (3) technical feasibility of a safer alternative design, including possible remedies or corrective action, (4) economic feasibility of these possible alternatives, and (5) possible adverse consequences to the product and consumer which would result from alternative designs. Additional relevant factors may be included, but design adequacy is evaluated in terms of a balance between benefits from the product and the probability of danger. For example, an airplane propeller and a fan both move air. The fan is guarded or shielded, whereas the propeller is not. Quantification is not required but may be desirable.

10.4 DESIGNER'S OBLIGATION

The designer or manufacturer of any product—consumer product, industrial machinery, tool, system, etc.—has a major obligation to make this product safe, that is, to reduce the risks associated with the product to an acceptable level. In this context, *safe* means a product with an irreducible minimum of danger (as defined in the legal sense); that is, the product is safe with regard not only to its intended use (or uses) but also to all unintended but foreseeable uses. For example, consider the common flat-tang screwdriver. Its intended use is well known. Can anyone say that he or she has never used such a screwdriver for any other purpose? It must be designed and manufactured to be safe in all these uses. It can be done.

There are three aspects, or stages, in designing for safety.

1. Make the product safe; that is, design all hazards out of the product.
2. If it is impossible to design out all hazards, provide guards which eliminate the danger.
3. If it is impossible to provide proper and complete guarding, provide appropriate directions and warnings.

10.4.1 Make It Safe

In designing any product, the designer is concerned with many aspects, such as function, safety, reliability, producibility, maintainability, environmental impact, quality, unit cost, etc. With regard to safety, consideration of hazards and their elimination must start with the first concept of the design of the product. This consideration must be carried through the entire life cycle. As Hunter [10.10] says,

> This must include hazards which occur during the process of making the product, the hazards which occur during the expected use of the product, the hazards which occur during foreseeable misuse and abuse of the product, hazards occurring during the servicing of the product, and the hazards connected with the disposal of the product after it has worn out.

Since each design is different, the designer needs to give full consideration to safety aspects of the product, even if it is a modification of an existing product. There is no fixed, universal set of rules which tells the designer how to proceed. There are, however, some general considerations and guidelines.

Hazard Recognition. Hazard recognition needs to start at the earliest possible stage in a design. Hazard recognition requires much background and experience in accident causation. There is extremely little academic training available, although the National Safety Council (NSC) and many other organizations publish information on this topic. Any threat to personal safety should be regarded as a hazard and treated as such. These threats come from several sources.

Kinematic/Mechanical Hazards. Any location where moving components come together, with resulting possible pinching, cutting, or crushing, is in this class. Examples are belts and pulleys, sets of gears, mating rollers, shearing operations, and stamping operations with closing forming dies. The author can remember working in a machine shop where individual machines (lathes, grinders, shapers, planers, etc.) were driven by belts and pulleys supplied by power from a large prime mover. Such shops had (1) a great number of nip-point hazards where belts ran onto pulleys and (2) a possible flying object hazard if a belt came apart or slipped off the pulley. Development of low-cost, reliable electric motors which could be used to drive individual machines removed the belt-pulley hazards but introduced a new electrical hazard.

Electrical Hazards. Shock hazard, possibly causing an undesirable involuntary motion, and electrocution hazard, causing loss of consciousness or death, are the principal electrical hazards for people. Electrical faults ("short circuits") are the major hazard to property. Massive arcing, cascading sparks, and molten metal often start fires in any nearby combustible material. Any person in the vicinity of a large electrical fault could be severely injured, even though the danger of electric shock has been reduced by ground fault devices.

Energy Hazards. Any stored energy is a potential energy hazard if the energy is suddenly released in an unexpected manner. Compressed or stretched springs, compressed gas containers, counterbalancing weights, electrical capacitors, etc., are all possible sources of energy hazards. Energy hazards are of major importance during servicing of equipment. A designer must develop methods and procedures for placing the product in a "zero-energy state" while it is being serviced.

Flywheels, fan blades, loom shuttles, conveyor components, and, in general, any parts with substantial mass which move with significant velocity are kinematic energy hazards which can damage any objects (including humans) which interfere with their motion.

Human Factors/Ergonomic Hazards. All consumer products and most industrial and commercial equipment is intended to be used by humans. Ergonomics, defined as the art and science of designing work and products to fit the worker and product user, is a top-priority consideration in the design process.

The human is a wonderful creation, capable, in many ways, of exceeding the machine's capability. The human can adjust to unusual situations; the machine cannot. The human can decide to go over, under, or around an obstacle, and do it; the machine cannot. In an emergency situation, the human can exceed normal performance to a degree that would cause a machine to fail (blow a fuse, pop a gasket, etc.). Unfortunately, the human can also make mistakes which lead to accidents.

Human beings exhibit a multitude of variations: height, weight, physical strength, visual acuity, hearing, computational capability, intelligence, education, etc. Designers must consider all these variables, and their ranges, as they recognize that their product will ultimately be used by humans.

The designer certainly must consider the hazards in the design when it is used or operated in the intended manner. The designer must also recognize that the product may be used in other, unintended but foreseeable, ways. As noted above, a hazard is any aspect of technology or activity that produces risk. The designer must provide protection against the hazards in all uses which can be foreseen by the designer. Unfortunately, a most diligent and careful search for foreseeable uses may still leave a mode of use undiscovered. In litigation, a key question is often whether the specific use was foreseeable by a reasonably diligent designer.

When humans are involved, there will be errors and mistakes. Some errors are extremely difficult, if not impossible, to anticipate. In many situations, people will abuse equipment. This is commonly a result of poor operating practices or lack of maintenance. In other situations, the user may take deliberate action to fit two components together in a manner which is not intended, e.g., to make and install thread adapters on pressurized gas containers. There is no question that the designer cannot anticipate all these possibilities and provide protection. Nevertheless, the designer is not relieved of a substantial effort to anticipate such actions and to try to thwart them.

Environmental Hazards. Internal environmental hazards are things which can damage the product as a result of changes in the surrounding environment. For example, in a water-cooled engine, the water can freeze and rupture the cylinder block if the temperature goes below the freezing point. This freezing problem can be alleviated by using freeze plugs which are forced out of an engine block if the water freezes, adding antifreeze to the cooling water, or using an electrical heating coil in place of the oil drain plug (standard winter equipment in cities like Fairbanks, Alaska).

External environmental hazards are adverse effects the product may have on the surrounding environment. These include such items as noise; vibrations, such as those from forging and stamping operations; exhaust products from internal combustion engines; various chemicals such as chlorinated fluorocarbons (Freon); polychlorinated biphenyls (PCBs); electronic switching devices which radiate electromagnetic disturbances; hot surfaces which can burn a human or cause thermal pollution; etc.

Hazard Analysis. Hazards are more easily recognized by conducting a complete hazard analysis, which is the investigation and evaluation of

1. The interrelationships of primary, initiating, and contributory hazards which may be present
2. The circumstances, conditions, equipment, personnel, and other factors involved in the safety of a product or the safety of a system and its operation
3. The means of avoiding or eliminating any specific hazard by use of suitable design, procedures, processes, or material
4. The controls that may be required to avoid or eliminate possible hazards and the best methods for incorporating these controls into the product or system
5. The possible damaging effects resulting from lack, or loss, of control of any hazard that cannot be avoided or eliminated
6. The safeguards for preventing injury or damage if control of the hazard is lost

Various approaches to hazard analyses are found in many places. Hammer [10.11], [10.12], [10.13], Roland and Moriarty [10.14], and Stephenson [10.15] present typical approaches. Additional techniques are discussed below.

For those concerned with consumer products, the Consumer Product Safety Commission (CPSC) publishes much of the results of its accident data collections and analyses in the form of Hazard Analyses, Special Studies, and Data Summaries.

These identify hazards and report accident patterns by types of products. Information is available from the National Injury Information Clearinghouse, CPSC, 5401 Westbard Avenue, Washington, DC 20207.

Consumer products, as the term implies, are those products used by the ultimate consumer, usually a member of the general public. Service life, in most instances, is relatively short, although some items such as household refrigerators and clothes washers and dryers may operate for many years. In contrast to consumer products, industrial and commercial products are intended to provide revenue for their owners and normally have a relatively long service life. This long life is an advantage from the economic viewpoint. From the safety aspect, however, it tends to perpetuate safety design problems for years after safer designs have been developed and distributed in the marketplace. Because of this long life, extra care is required in designing for safety.

Failure Modes and Effects Analysis (FMEA). Failure modes and effects analyses are performed at the individual component level very early in the design phase to find all possible ways in which equipment can fail and to determine the effect of such failures on the system, that is, what the user will experience. FMEA is an inductive process which asks: What if? An FMEA is used to assure that (1) all component failure modes and their effects have been considered and either eliminated or controlled; (2) information for design reviews, maintainability analysis, and quantitative reliability analysis is generated; (3) data for maintenance and operational manuals are provided; and (4) inputs to hazard analyses are available.

Failure Modes and Criticality Analysis (FMECA). In any product, some components or assemblies are especially critical to the product's function and the safety of operators. These should be given special attention, with more detailed analysis than others. Which components are critical can be established through experience or as a result of analysis. Criticality is rated in more than one way and for more than one purpose. For example, the Society of Automotive Engineers (SAE) has an Aerospace Recommended Practice (ARP 926). The method described in ARP 926 establishes four categories of criticality (as a function of the seriousness of the consequences of failure) and is essentially an extension of FMEA which is designated failure modes, effects, and criticality analysis (FMECA).

Fault-Tree Analysis (FTA). Fault-tree analysis is substantially different from FMEA in that it is deductive rather than inductive. FTA starts with what the user experiences and traces back through the system to determine possible alternative causes. The focus is on the product, system, or subsystem as a complete entity. FTA can provide an objective basis for (1) analyzing system design, (2) performing tradeoff studies, (3) analyzing common-cause failures, (4) demonstrating compliance with safety requirements, and (5) justifying system changes and additions.

Fault Hazard Analysis (FHA). FMEA considers only malfunctions. FHA has been developed to assess the other categories of hazards. FHA was developed at about the same time as FTA, but it does not use the same logic principles as FTA or have the quantitative aspects of FMEA. It was first used by analysts with no knowledge of FTA and by those desiring a tabulated output, which FTA does not provide. FHA is qualitative. It is used mainly as a detailed extension of a preliminary hazard analysis.

Operating Hazards Analysis (OHA). FMEA, FMECA, FTA, and FHA are primarily concerned with problems with hardware. OHA, on the other hand, intensively studies the actions of operators involved in activities such as operating a product, testing, maintaining, repairing, transporting, handling, etc. Emphasis is primarily on personnel performing tasks, with equipment a secondary consideration. The end result is usually recommendations for design or operational changes to eliminate hazards or better control them. OHAs should be started early enough to allow time for consideration and incorporation of changes prior to release of a product for production.

Design Review. Design review is an effort, through group examination and discussion, to ensure that a product (and its components) will meet all requirements. In a design of any complexity, there is a necessity for a minimum of three reviews: conceptual, interim, and final. Conceptual design reviews have a major impact on the design, with interim and final reviews having relatively less effect as the design becomes more fixed and less time is available for major design changes. *It is much easier and much less expensive to design safety in at the beginning than to include it retroactively.*

A more sophisticated product may require several design reviews during the design process. These might be conceptual, definition, preliminary (review of initial design details), critical (or interim review, or perhaps several reviews in sequence—review details of progress, safety analyses, progress in hazard elimination, etc.), prototype (review of design before building a prototype), prototype function, and preproduction (final review—the last complete review before release of the design to production).

These periodic design reviews should (1) review the progress of the design, (2) monitor design and development, (3) assure that all requirements are met, and (4) provide feedback of information to all concerned.

A design review is conducted by an ad hoc design review board composed of mechanical designers, electrical designers, reliability engineers, safety engineers, packaging engineers, various other design engineers as appropriate, a management representative, a sales representative, an insurance consultant, an attorney specializing in products liability, outside "experts" (be sure they are truly expert!), etc. Members of the design review board should not be direct participants in day-to-day design and development of the product under review, but should have technical capability at least equal to that of the actual design team. Vendor participation is highly desirable, especially in conceptual and final design reviews. Design review checklists should be prepared well in advance of actual board meetings. These checklists should be thoroughly detailed, covering all aspects of the design and expected performance. They should include all phases of production and distribution as well as design. Checklists should be specific, detailed, and not used for any other product. New checklists should be developed for each new product. It is good practice for a designer or manufacturer to have some sort of permanent review process in addition to the ad hoc board for each individual product. This permanent group should evaluate all new products, reevaluate old products, and keep current with trends, standards, and safety devices.

If properly conducted, a design review can contribute substantially to avoiding serious problems by getting the job done right the first time. Formal design review processes are effective barriers to "quick and dirty" designs based on intuition (or "educated guesses") without adequate analyses.

Standards. Once a design problem is formulated and the intended function is clear, the designer should collect, review, and analyze all pertinent information relative to standards, codes, regulations, industry practice, etc. From this study, the designer can usually get assistance in hazards analysis and formulate the design constraints resulting from the known requirements. One must be clear on which requirements are voluntary and which are mandatory. Standards published by the American National Standards Institute (ANSI) are considered voluntary, consensus standards. A voluntary standard need not necessarily be followed in designing and manufacturing a product, although it is strongly recommended that such standards be followed, or exceeded, in the design. However, if a municipality, state, or federal agency includes a given standard in its requirements, then that standard becomes mandatory, with the force of law. For example, ANSI Standard A17.1, *Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks*, is a voluntary standard. If a city incorporates that standard in its building code, then the standard is mandatory and must be followed in constructing a building in that city.

Standards are published by many different organizations. Some of the better known are the American National Standards Institute (ANSI), 11 West 42nd St., New York, NY 10036; American Society for Testing and Materials (ASTM), 1919 Race St., Philadelphia, PA 19103; Underwriters Laboratories, Inc. (UL), 333 Pfingsten Road, Northbrook, IL 60062; and National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269. The federal government has many agencies which establish and publish a large number of standards and regulations. Proposed regulations are published in the *Federal Register*, with the public invited to comment. After the comment period is over and all hearings have been held, the final version is published in the *Federal Register* with a date when the regulation becomes effective. All approved and published federal regulations are collected in the *Code of Federal Regulations (CFR)*. There are 50 CFR titles covering all areas of the federal government. All published regulations are reviewed and revised annually. The *Index of Federal Specifications, Standards, and Commercial Item Descriptions*, issued annually in April by the General Services Administration, is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

More than 35,000 documents have been generated by nearly 350 standards-writing organizations in the United States. There is a two-volume *Index and Directory of U.S. Industry Standards*. Volume 1 contains the subject index and lists all applicable standards from all sources for any selected subject. Volume 2 contains a listing of all standards-publishing organizations in alphabetical order of their acronyms. The index is published by Information Handling Services of Englewood, Colorado. It is available from Global Engineering Documents, which has offices at 2805 McGaw Ave., Irvine, CA 92714 and 4351 Garden City Drive, Landover, MD 20785. Global can also supply copies of any desired document for a fee.

The Department of Defense (DoD) has a large number of military handbooks, military standards, and military specifications which can be applied to civilian and commercial products as well as to military needs. (These require that all the desirable features be designed into the product from the start of the design effort rather than being added at the end after testing and evaluations have shown deficiencies. This design approach is totally applicable to nonmilitary products.) These DoD documents are available from the Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19210.

Occupational Safety and Health Administration (OSHA). The federal Occupational Safety and Health Act establishing the Occupational Safety and Health Administration (OSHA) was passed in 1970. One of its goals was "to assure so far as possible every working man and woman in the nation safe and healthful working conditions." OSHA regulations have the force of law, which means that employers must provide a workplace with no recognized hazards. Thus employers cannot legally operate equipment which exposes workers to unprotected hazards. Consequently, designers must design hazards out of their products before these products reach the market. The regulations are published in title 29 of the CFR. Section 1910 applies to general industry. As the act went into effect, the administrators were allowed to draw on the large number of existing safety standards and adopt them as they saw fit over a period of two years. Many of these standards were adopted by reference when the act became effective in 1971. Today, many of these standards are obsolete but, unfortunately, are still being used as the basis for OSHA regulations. In addition, there are many products which did not exist in 1971, and new standards have been developed for such products. For example, OSHA standards for mechanical power presses are based on the 1971 edition of ANSI B11.1. Since that time, the B11 Committee of ANSI has published at least 18 standards relating to the larger field of machine tools. Designers should not rely on OSHA regulations alone, but should determine the availability and applicability of the latest published standards. OSHA regulations obviously must be used with caution. Even though many are obsolete, they still have the force of law. OSHA regulations can be obtained from the U.S. Government Printing Office.

Maintenance. Maintenance safety problems can be separated into those that occur during maintenance, from lack of maintenance, or from improper maintenance. Improper maintenance, for example, might be a situation in which electrical connections on a metal case were not installed correctly, thus producing a hazardous condition where none had existed previously. There seems to be little the designer can do to prevent a lack of maintenance. Much improper maintenance can be avoided by designing products in such a way that it is extremely difficult to reassemble them incorrectly.

There is no question that equipment of all kinds does require periodic adjustment or replacement of parts. There is much evidence that designers have too often failed to consider the hazards to which maintenance personnel will be exposed, even in routine maintenance. During maintenance, safety devices must often be disconnected and/or protective guards removed to permit the necessary access. In this context, maintenance personnel may need to put parts of their bodies in hazardous locations which were protected by the necessarily inoperative safety devices. It is the responsibility of the designer to provide protection in this situation.

Lockouts, Lockins, and Interlocks. Many injuries and fatalities have occurred when a worker unwittingly started equipment while a maintenance worker was in the equipment. It is necessary to make it impossible for machinery undergoing maintenance to be started by anyone other than the maintenance worker. CFR 1910.147(c)(2)(iii) [OSHA] requires the designer to provide lockout protection.

A lockout prevents an event from happening or prevents an individual, object, force, or other factor from entering a dangerous zone. A lockin maintains an event or prohibits an individual, object, force, or other factor from leaving a safe zone. Locking a switch on a live circuit to prevent the current being shut off is a lockin; a similar lock on a switch on an open circuit to prevent it being energized is a lockout. Both lockouts and lockins can be accomplished by giving each individual worker a personal padlock and key (any duplicate key would be in a central office in a locked cabinet). This procedure can mean placing multiple locks on a lockout panel.

Interlocks are provided to ensure that an event does not occur inadvertently or where a sequence of operations is important or necessary and a wrong sequence could cause a mishap. The most common interlock is an electrical switch which must be in the closed position for power to be supplied to the equipment. If a guard, cover, or similar device is opened or left open, the machine will not operate. Smith [10.16] comments on two accidents, one involving a screw auger for mixing core sand in a foundry, the other involving a large batch mixer. In both cases, maintenance workers suffered permanent disabling injuries when another worker switched on the equipment. In both cases, a lockout or an interlock which would function when the cover was lifted would have prevented the injuries. Although interlocks are usually very effective, they can be rather easily bypassed by using some means to keep the switch closed.

Zero Energy. Many products require storage of energy for operation. For example, energy is stored in any spring which is changed during assembly from its free, unstressed dimensions. This energy storage also exists in cables, cords, and chains which are loaded in tension. Other sources of stored energy are compressed gases, energized electronic power sources, lifted counterweights, etc. The zero-energy concept requires the designer to provide protection for any operator or maintainer of equipment against the consequences of the unanticipated release of stored energy; that is, there must be a means of neutralizing these energy sources in an emergency situation or during maintenance work.

Fail-Safe Designs. Product failures produce a significant fraction of accidents. Fail-safe design seeks to ensure that a failure (1) will not affect the product or (2) will change it to a state in which no injury or damage will occur.

1. Fail-passive designs reduce the system to its lowest energy level. The product will not operate until corrective action is taken, but the failure-initiating hazard will cause no further damage. Circuit breakers are a good example of fail-passive devices.
2. Fail-active designs maintain an energized condition that keeps the system in a safe mode of operation until corrective action can be taken or the system is replaced by an alternative system. Redundancy using standby equipment is an example of a fail-active system.
3. Fail-operational designs allow safe continuation of function until corrective action can be taken. Fail-operational is obviously preferred, if possible. The ASME requires fail-operational feedwater valves for boilers. Water must first flow under, rather than over, the valve disk. If the disk is detached from the valve stem, water will continue to flow and allow the boiler to function normally. Designs should be made fail-safe to the greatest degree possible.

General Principles. Hunter [10.10] gives the following statements as general principles or guidelines for designing safe products:

1. Recognize and identify actual or potential hazards, then design them out of the product.
2. Thoroughly test and evaluate prototypes of the product to reveal any hazard missed in the preliminary design stages.
3. Make certain that the product will actually perform its intended function in an acceptable manner so that the user will not be tempted to modify it or need to improvise possibly unsafe methods for using it.
4. If field experience reveals a safety problem, determine its real cause, develop a corrective action to eliminate the hazard, and follow up to make certain that the corrective action is successful.
5. Design equipment so that it is easier to use safely than unsafely.
6. Realize that most product safety problems arise from improper product use rather than product defects.

Safety Checklists. Hammer [10.12], [10.13] and the National Safety Council [10.17] give lists of basic safety requirements for use in developing safe designs. For example, at the top of his list, Hammer [10.12], [10.13] says: "Sharp corners, projections, edges, and rough surfaces which can cause cuts, scratches, or puncture wounds will be eliminated unless required for a specific function." There are 21 more items in the list.

Acceptable Conditions. Hammer [10.12], [10.13] notes that safety engineers (perhaps no one else?) generally consider the following conditions acceptable and indicative of good design:

1. Any design which requires at least (a) two *independent* malfunctions, or (b) two *independent* errors, or (c) a malfunction and an error which are *independent* to cause an accident
2. Any design which positively prevents an error in assembly, installation, connection, or operation that analysis shows would be safety-critical
3. Any design which positively prevents a malfunction of one component (or assembly) from causing other failures which could cause injury or damage (fail-safe)
4. Any design which limits and controls the operation, interaction, or sequencing of components (or subassemblies) when an error or malfunction could cause an accident—for example, when activating switch B before activating switch A could cause damage (interlock)
5. Any design which will safely withstand a release of greater energy than expected, or normally required
6. Any design that positively controls buildup of energy to a level which could potentially cause damage (for example, use of a shear pin to protect a shaft)

10.4.2 Guarding

As indicated above, if it is impossible to design out all hazards, it is necessary to provide guards. The basic legal requirements are set forth in CFR 1910.212, *General Requirements for All Machines* (OSHA), which says:

> (a) Machine guarding (1) Types of guarding. One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks. Examples of guarding methods are barrier guards, two-hand tripping devices, electronic safety devices, etc.
>
> (2) General requirements for machine guards. Guards shall be affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible. The guard shall be such that it does not offer an accident hazard in itself.

One should note the key word *all* in the heading. Further, the use of *shall* makes the requirement for guards mandatory.

Most of the dangerous hazards from moving parts of machines occur in three areas:

1. *Point of operation.* This is where the machine works on the workpiece to shape, cut, etc.
2. *Power train.* This is the set of moving parts which delivers power to the point of operation. These parts include shafts, gears, chains, pulleys, cams, etc.
3. *Auxiliary components.* These are such items as feeding mechanisms and other components which move when the machine is in operation.

All of these have obvious nip points. Less obvious nip points are between an augur screw conveyor and the trough, between a tool rest and a grinding wheel or part being turned on a lathe, between the spokes of a handwheel and the guide or support behind it, and between a translating component and a fixed component close to it, (that is, a shear of any kind) (see Smith [10.18]). In general, a nip point occurs when two components are in close proximity with relative motion which reduces the separation between them. There are other hazards, such as potential pressure vessel explosions and bursting flywheels, but one can take the position that these kinds of hazards should be eliminated in the original design.

The general requirement for a guard is that the point of hazard be substantially enclosed, screened, barricaded, or otherwise protected so that persons, whether workers or bystanders, cannot inadvertently come in contact with the hazard.

Mechanical Guards. Mechanical guards, the most common type, can be fixed, adjustable, or interlocked. Grimaldi and Simonds [10.19] give the basic requirements for a mechanical guard as:

1. It must be sturdy to prevent damage to the guard from external sources or interference with the operation of the machine. Either of these possibilities would probably result in the operator removing the guard and not arranging to have it repaired and replaced.
2. It must permit required maintenance operations without necessitating excessive labor for dismantling and reassembling the guard, or else there will be a tendency to omit its installation.
3. It must be properly mounted. The mounting must be rigid to prevent objectionable rattles or interference with working parts. The mountings should be strong enough so that they will not fail under use.
4. It should be designed so that there are no detachable parts, which if removed and not replaced would reduce its guarding effectiveness.
5. It should be easy to inspect, and a periodic checkup program, as a part of the maintenance procedure for shop equipment, should be established in order to continue its effectiveness.

Fixed guards should be used wherever possible, since they provide permanent protection against hazardous machinery components. Adjustable guards are used when the mode of operation of the machine is expected to change and adjustment will be necessary to accommodate a new set of dimensions. Once adjusted, the guard should function as a fixed guard. Interlocked guards prevent operation of the machine until the guards have moved into positions which keep the worker out of the hazardous zone. It is essential that the guard put the machine in a safe mode if the guard should fail for any reason (fail-safe).

Pullbacks are bands strapped around the operator's wrists with cords or cables running from the bands to a pulling mechanism synchronized with the down stroke of a power press. If the operator does not remove his or her hands from the hazard area, they are automatically pulled away. This pullback occurs even if the press recycles on its own. Pullbacks are not complete protection, however; the author knows of at least one situation in which injury to the worker resulted from a recycle. Pullbacks require adjustment to each operator, frequent inspection, and diligent maintenance. They are often objectionable to the worker, who feels tied to the machine.

Barrier gates are simple mechanical devices which are opened and shut by machine motion during the operating cycle. This allows the operator to approach the point of operation, e.g., to feed work stock, but protects against any part of the body being in the hazard zone when the machine is activated. In most cases, there is an interlock that shuts off the power when the gate is open and prevents opening the gate when the machine is in motion.

Electromechanical Devices. Presence-sensing devices commonly use (1) a light beam and a photoelectric cell ("electric eye") to stop the machine if the light beam is interrupted or (2) a radio-frequency electromagnetic field which is disturbed by the capacitance effect of the intruding body.

Distance/Separation Guarding. A very logical and effective way of guarding is by separation or distance. The question of location must be considered by the designer. For example, tables of distances and the corresponding openings permitted are given in CFR 1910.217(c)(2)(vi) (OSHA) and in ANSI Standard B11.1. As a sample, if the distance from the point of operation is 1.50 to 2.50 in, the maximum width of opening is 0.375 in; if the distance is 5.50 to 6.50 in, the maximum width of opening is 0.75 in. The dimensions in the tables have been chosen to prevent the fingers of the average-size operator from reaching the point of operation.

Input/Output Systems. Systems for feeding stock and ejecting workpieces can provide more safety if semiautomatic or fully automatic systems are used. Perhaps the most desirable is a robotic system for mechanical feeding of stock and retrieval of parts. Although more expensive, robots can work where there is a high noise level, can work at a higher temperature than is tolerable for most humans, and can perform repetitive monotonous tasks indefinitely. One hazard is that the robot may strike a bystander. This hazard, however, can be avoided by barriers or presence sensors.

Auxiliary Equipment. Auxiliary equipment is generally used in connection with other protective devices to give an additional measure of safety. For example, it is very difficult to provide complete point-of-operation guarding for a band saw, since the saw blade must be exposed in order to accomplish the desired function of cutting material. When small or narrow pieces are being cut, the operator's fingers can get too close unless a push stick or push block is used. The block allows control over the workpiece to get the desired result but keeps the operator's fingers away from the hazard zone. A great variety of pliers, tongs, tweezers, magnetic lifters, suction cup lifters, etc., are available for use as auxiliary equipment. Such auxiliary equipment may need to be adjusted for use in different applications.

Controls. Operating controls can be designed to ensure that the operator is out of the hazard zone, such as the point of operation. If only one pushbutton is provided, the operator's other hand could be in the hazard zone. To prevent this, two buttons are provided, far enough apart to require use of both hands and arranged in series so that both must be pushed to activate the machine. If the stroke time is long enough for the operator to push the buttons and still get a hand into the hazard zone, a requirement that both buttons be held down until the stroke is essentially completed can be incorporated. There is a temptation for workers to tie down one of the buttons, which obviously defeats the two-button safety feature. To circumvent this, both buttons must be pressed within a short time period. If the allowable delay is exceeded, the machine will not operate. While most machines should have a two-button control system, there are situations, such as control of an overhead crane, in which a single set of on-jog-off buttons is acceptable because the operator is physically distant from the hazard zone.

Another aspect of control buttons is that the start, or operate, button (or buttons) should be recessed to reduce the possibility of inadvertent operation. Start buttons are also usually green in color. A stop button should have a large, mushroom-shaped head which is not recessed. This stop button should be easily reachable from the normal operating position for use in case of an emergency. The usual color for stop buttons is red.

In cases where a machine runs continuously, while the operator is exposed to hazards in any manner, use of a control which can immediately trip the switch—that is, stop the machine—is necessary. The stop button, noted above, is one possibility. In other cases, a trip wire is placed where a worker can easily reach it from any location of the work station. Pulling on this wire will stop the operation. In one situation (Smith [10.18]), there was a trip wire, but it was not close enough to be effective when a worker had a hand caught in a shear nip point. In other situations, a force- or pressure-sensitive bar has been used. When the bar is pushed (for example, if the operator stumbles, loses balance, or is pulled into the machine), the machine will be deactivated. The location of the bar is critical. It must be located where it will be effective in an emergency but will not be inadvertently activated by the material being processed. Presence-sensing devices, "electric eyes," IR beams, etc., can also be used to deactivate equipment. Machines which continue to run after power is cut off require a brake for quick stopping.

Data Sources. As noted above, OSHA regulations and ANSI standards are available that can provide much information on guarding. Pertinent data can be found in many other publications, such as Hunter [10.10] and Grimaldi and Simonds [10.19]. Information is also available from the National Safety Council [10.17], [10.20], [10.21]. It might also be noted that the National Safety Council has videos available for employee training.

10.4.3 Warnings

As noted above, in those situations in which it is not possible to provide complete and effective guarding, or in those situations where such guarding would severely impair the intended function of the product, it is necessary to provide appropriate directions and warnings.

It is obvious that eliminating all the potential hazards in a design and/or providing effective guarding is not a simple task. In some cases, it is impossible. Developing a proper, effective warning is generally considered even more difficult. In large measure, this is because there is hardly consensus, let alone anything approaching unanimity, on what is a truly adequate and acceptable warning for a given situation. Nonetheless, a full-scale effort must be made.

Directions are instructions intended to ensure *effective* use of a product. *Warnings,* in contrast, are intended to ensure *safe* use, that is, to inform of hazards and of improper use, and to instruct how to guard against these, if possible. The distinction is clear in concept, but it is not always possible to tell whether a given statement is a direction or a warning. Lehto and Miller [10.22] say:

> Perhaps the best way to initially distinguish between warnings and other forms of safety-related information is to state that warnings are specific stimuli which alert a user to the presence of a hazard, thereby triggering the processing of additional information regarding the nature, probability, and magnitude of the hazard. This additional information may be within the user's memory or may be provided by other sources external to the user. Much of the current controversy regarding warnings is actually related to the need for this additional information.

There are three criteria which must be met for a warning to be fully effective:

1. The message must be received.
2. The message must be understood.
3. The endangered person must act in accordance with the message.

A warning is not effective unless it changes the potential behavior of the endangered individual.

Types of Warnings. Injury or damage can often be avoided by a focus on the existence of a hazard and the need for careful action. Every method for calling attention to a hazard requires communication; each of the human senses, singly or sometimes in concert, has been used for this purpose.

Visual Warnings. It is widely recognized that most information on hazards, perhaps as much as 80 percent, is visually transmitted to personnel. There are more variations of visual methods than of methods involving the other senses. A hazardous area is often more brightly illuminated than other areas in order to focus attention on it. A piece of equipment can be painted in alternating stripes or in a bright, distinctive color; for example, fire trucks are now being painted greenish-yellow rather than red for better visibility. Signal lights are often used—for example, on emergency vehicles and at railroad crossings at grade. Flags and streamers can be used. Signs are common, eg, highway signs.

Auditory Warnings. Auditory warnings may have a shorter range of effectiveness than visual warnings, but their effectiveness may be greater in that short range. Auditory warnings are often coupled with visual warnings, as on emergency vehicles. Typical devices are sirens, bells, or buzzers; an example is the intermittent sound of a horn on heavy equipment which is backing up.

Olfactory Warnings. Odorants can be used in some limited, although effective, ways, such as the addition of small amounts of a gaseous odorant to natural gas to warn of leaks.

Tactile Warnings. Vibration is the major tactile means of warning; an example is rumble strips on highways. Vibration in machinery may mean the beginning of serious wear or lubrication failure. Temperature sensing, or at least an indication of significant temperature change, can also be included in this category.

Tastable Warnings. These may have little use in machine applications, but they have been used in various ways to provide warnings concerning foods and medicines.

Written Warnings—Labels. Much confusion exists, especially within the legal system, concerning the meaning of *warning* when applied to products and their uses. The major reason may be that warnings are usually considered to be synonymous with the explicit "warning labels" which are sometimes placed on products. One consequence is that sources of information which do not explicitly (in words) describe the hazard, specify its intensity, provide instructive countermeasures, and strongly advocate adherence may not be considered adequate warnings. Another reason for the confusion is that society seems to expect warnings to perform multiple functions.

Warnings should supplement the safety-related design features of a product by indicating how to avoid injury or damage from the hazards which could not be (1) feasibly designed out of the product, (2) designed out without seriously compromising its utility, or (3) protected against by providing adequate guards. In theory, providing such information will reduce danger by altering people's behavior while using a product or by causing people to avoid using a product. From the litigation viewpoint, warnings often perform functions that have little to do with either safety or transfer of safety-related information. A manufacturer may view warnings as a defense against litigation. One consequence is extensive use of warning labels. Such use often means products with warning labels which yield no increase in safety. Even more unfortunately, some manufacturers may use warnings instead of careful design, which is absolutely unacceptable.

As indicated above, for a warning to be effective, the endangered person must receive the message, understand it, and act in accordance with it. The designer and manufacturer obviously have no control over the action, but they do have substantial control over sending the message and making it understandable. Failure on the part of the endangered person to do any one of the above results in failure of the communication process and the warning being ineffective. Consider, for example, a situation in which (1) 40 percent of the users read the warning, (2) 50 percent of those readers truly comprehend and understand the warning, (3) 40 percent of those act properly in accordance with the warning, and (4) the action is sufficient to avoid injury 90 percent of the time. On the basis of these numbers, the probability of the warning being completely effective is 7 percent. Whatever numbers one may use, the probability of a warning being effective is relatively low. This probability is certainly no higher than the percentage of users who read the warning. There is general agreement that many people who see a warning label do not read it. Many do not even see the label. This obviously can be discouraging to someone trying to develop a proper, effective, warning label. Nonetheless, a major effort must be made.

Every warning, including labels, has an *alerting function.* The warning label must be prominently located, that is, in a position such that the user has great difficulty avoiding seeing it. The warning label must be distinctive; that is, it must be sufficiently different from other labels that there is no question of its identity. Shape has an influence; shapes with rounded or curved boundaries are not as effective in attracting attention as shapes with sharp corners. Rectangles seem to be more effective than squares or triangles. Labels with five or more sides are rarely used on industrial or consumer products.

Three signal words (in relatively large letters) and color combinations are normally used to attract attention.

1. *DANGER.* The hazard can immediately cause (1) death or (2) severe injury upon contact with the source of hazard. Letters should be white on a red background.
2. *WARNING.* (1) The hazard can immediately cause moderate injury, or (2) death or severe injury may eventually result from contact with the source of hazard. Letters should be black on an orange background.
3. *CAUTION.* (1) The hazard can immediately cause minor injury, or (2) moderate injury may eventually result from contact with the source of hazard. Letters should be black on a yellow background.

Every warning, especially a label, has a *message.* This message must be clear, simple (unambiguous), succinct, and convincing. Short words are preferred, and there should be as few words as possible. Long sentences with technical terms should be avoided. There are indications in the literature that directions and warnings should be written at sixth-grade level. The use of indices such as the Flesch Reading Ease Formula, Gunning's Fog Index, or McElroy's Fog Count (Klare [10.24]) can be helpful in this respect. For products which will be used only within a country or region in which there is one common language, the choice of language is obvious. For products which will be used in regions with different languages, warning labels must be in those languages. Those who write labels in languages different from that of the manufacturer must be knowledgeable about the linguistic characteristics of those regions.

A partial solution to the problem of the need for multiple languages is the increasing use of pictographs. A pictograph communicates an idea or concept in one symbol which is universally recognized. For example, there is general recognition that a 45° red diagonal line (from upper left to lower right) through an annulus forbids whatever is displayed within the annulus (for example, a lighted cigarette within the annulus indicates that smoking is not permitted). General guidelines for pictographs are

1. Use a simple design for the symbol.
2. Use only one idea per pictograph.
3. Use only correct colors and shapes.
4. Locate the symbol as close as possible to any related words.

Words on the label must be legible by the average person, some of whom may have uncorrected visual impairments. ANSI Standard Z535.4 [10.25] gives requirements for wording and colors to be used. These differ from those in the standards issued by OSHA and the CPSC. ANSI Z535.4 also specifies letter size. Signal words must be at least 3 mm high (9-point type), and the text must be at least 1.5 mm high (5 points minimum). (*Point* is a measure of type size equal to 0.013837 inch; there are essentially 72 points per inch.) This is a consensus standard and represents the minimum acceptable to those involved in developing the document. There are many who believe that lettering should be larger. Bailey [10.26], for example, notes that "type size in books and magazines usually ranges from 7 to 14 points with the majority being about 10 to 11 points. Probably the optimum range is from 9 to 11 points—sizes smaller or larger can slow reading speed."

A warning label should be *permanent*. It should not fade or fall off before the end of the product's service life. Most labels are decalcomanias. Fortunately, they are available with a base of tough, wear-resistant material and good adhesive backing. Some products have warnings on stamped or embossed plates that are permanently secured to the product. Operator's manuals and/or maintenance manuals commonly accompany the product when it is shipped from the manufacturer but do not always find their way to the product in its operational situation. Providing a tough, dirt- and lubrication-resistant envelope which contains the manual and is "permanently" attached to the product (such as a power press or similar machinery) by a short chain can be useful for the worker.

CFR 1910.145 (OSHA) specifies requirements for accident prevention signs. By reference, two ANSI standards, Z35.1, *Specifications for Accident Prevention Signs*, and Z53.1, *Safety Color Code for Marking Physical Hazards*, were incorporated. Designers should consult these as soon as a decision is made to incorporate warnings. It should be noted, however, that in 1979, ANSI Z53 Committee on Safety Colors was combined with ANSI Z35 Committee on Safety Signs to form ANSI Z535 Committee on Safety Signs and Colors. Five subcommittees were formed to update the Z35 and Z53 standards and write two new standards. These are listed in References [10.25], [10.27], [10.28], [10.29], and [10.30]. One might note that the Society of Automotive Engineers (SAE) has a recommended practice, J115 [10.31], relating to safety signs. This is generally consistent with the ANSI 535 series, but there are some differences. (This situation is an example of old standards still having the force of law in OSHA standards, even though these old standards have been replaced by much more recent standards.)

Figure 10.1 shows a label (full size) which was used on a fiberglass ladder about 20 ft (6 m) long. It is suggested that this label be critiqued in light of the above comments before reading further. How good is it? How effective is it? Assuming that

FIBERGLASS
SINGLE & EXTENSION LADDER
FOR SAFETY, READ CAREFULLY

INSPECTION

1. Inspect upon receipt and before use.
2. Never climb a damaged ladder. Return for repair or discard.
3. Check all working parts, rivets, bolts, rope and cable for good working order.
4. Never use ladder with missing parts.
5. Discard if exposed to fire or chemicals.

SELECTION

1. Use 300 lb., and 200 lb. Duty-Rated Ladder for maintenance and heavy-duty work. Never use ladder jacks on 200 lb. or 225 lb. Duty-Rated Ladders.
2. Use ladder with correct duty rating to support combined weight of the user and material. Ladders are available with duty ratings of 200, 225, 250, 300 lb.

SET-UP AND USE

1. Set up ladder at 75½° by placing bottom ¼ of length being used out from vertical resting point.
2. Set ladder on firm level ground. Never lean sideways and never use on ice or snow.
3. Use proper size ladder. Never use temporary supports to increase length or to adjust for uneven surfaces.
4. Keep rungs free from wet paint, mud, snow, grease, or other slippery material.
5. Extend only from ground. Never extend from top or by bouncing.
6. Never walk or jog ladder while on it.
7. Securely engage ladder locks before climbing.
8. Erect ladder with fly (upper) section above and resting on base (lower) section.
9. Each section of a multi-section ladder shall overlap the adjacent section by 3 ft. up to and including 36 ft.; by 4 ft. over 36 ft., up to and including 48 ft.; by 5 ft. over 48 ft., up to and including 60 ft.
10. Always have the four ends of the ladder rails firmly supported.
11. Always tie top and base to building.
12. Project ladder minimum of 3 feet above roof edge.
13. Tie down ladder before stepping onto roof.
14. Never over-reach. Move ladder instead. Keep belt buckle inside ladder side rails.
15. Never use in high winds.
16. Never overload. Ladder designed to support one person when properly used.
17. Never use as a horizontal platform, plank or material hoist.
18. Never use on a scaffold.
19. Never fasten different ladders together to increase length.
20. Never apply a side load to ladder to push or pull anything while on ladder.
21. Never drop or apply impact load to ladder.
22. Never sit on end of ladder rails.
23. When reassembling, properly engage all guide brackets and lock prior to use.
24. Never use in front of unlocked doors.
25. Fly section must have safety shoes if used as a single ladder.
26. Hooks may be attached at or near top for added security.
27. To support the top of a ladder at a window opening, a stabilizer should be attached to span the window.
28. Never use ladder when you are in poor health.
29. Never use if taking drugs or alcoholic beverages.
30. Recommend never using if over 65 years of age.

CLIMBING INSTRUCTIONS

1. Never climb onto ladder from the side or from one ladder to another.
2. Face ladder when ascending or descending. Maintain a firm grip and stand on middle of rung.
3. Never stand above 3rd rung from top.
4. Never climb above support point.

STORAGE

1. Support ladder on racks when stored.
2. Never store material on ladder.
3. Properly support ladder in transit.

FOR ADDITIONAL INSTRUCTIONS, SEE ANSI A14.5

FIGURE 10.1 A black-and-white reproduction of a decalcomania label to be placed on the inside of a side rail of a fiberglass ladder. The heading was yellow lettering on a black background. The text lettering was black on a yellow background. The reproduction is 100% of original size. See page 10.18 for discussion.

users do indeed see the label, how many will read it, especially with that length and type size? Of those who do read it, how many will really comprehend what the manufacturer is trying to say? This label was not well thought out, either in content or in phrasing, which is ambiguous or without clear meaning in several statements. The label does not provide clear instruction on use or explicitly warn of the consequences of hazards. It appears to use direction and warning statements without distinguishing between them. This label is clearly inferior and essentially ineffective. The inference (Smith and Talbot [10.32]) is that the manufacturer was trying to cover all possibilities to provide "protection" against product liability suits.

A warning that helps prevent an injury may not make great advertising copy, but it should be considered a necessity. One might note that warnings are not new. When Samuel Jones began manufacturing "Lucifer" matches (smelling of "hellfire and brimstone") in 1829, he printed the following warning on the boxes: "If possible, avoid inhaling the gas that escapes from the combustion of the black composition. Persons whose lungs are delicate should by no means use Lucifers." In terms of the above discussion, this is a relatively good statement.

Sources. There has been much written with regard to warnings in both the technical and the legal literature. The best (technical) source currently available for understanding the nature of warnings and the difficulty in writing them is Lehto and Miller [10.22], [10.23].

10.5 HUMAN FACTORS/ERGONOMICS

Human beings interact with all products in designing, manufacturing, operating, and maintaining them. Human beings constitute the most complex subsystem in any system because of their abilities and limitations. In addition, the number and variety of actions that people, either as individuals or as a group, can take in any situation generates a high probability that any deficiency in the system will be linked to, and affected by, personal factors that can generate an accident. In other words, the most erratic, and the least controllable, parameter in any system is the human being.

In the design and development of a new product or system, the majority of the most critical decisions to be made are related to human performance. Informed decisions require the designer to have a good understanding of human engineering, human factors, and ergonomics. These three terms are often used interchangeably, but there are differences. Perhaps the broadest in scope is human engineering, which is a technical discipline primarily concerned with the interdependencies and interactions of humans and machines. Problems are highly likely when the two come in contact. Human engineering attempts to minimize these problems and obtain maximum effectiveness in any human-machine operation by integrating the best capabilities of both.

The designer must avoid any design which expects, or requires, individual operators to (1) exceed their available physical strength, (2) perform too many functions simultaneously, (3) perceive (or detect) and process more information than is possible, (4) perform meticulous tasks under difficult environmental conditions, (5) work at peak performance (or capability) for long periods, (6) work with tools in cramped spaces, etc. Insofar as possible, *the designer should adapt the machine to the human.*

The designer may think in terms of the "typical" or "average" human. This view is much too simple. People come in assorted sizes, shapes, capabilities, and varieties. Even when it may be appropriate to design for the "average," the designer must remember there is a range of differences from that average.

Some products are designed for limited groups, such as infants, children, teenagers, the elderly, or the infirm. In such cases, the characteristics of the specific group must be emphasized. When designing for the "public," the designer needs to provide for the characteristics of the entire range of people, from babes in arms to nonagenarians. For example, doors, ramps, escalators, entries, etc., must be appropriate for a baby in a perambulator, a healthy and active man or woman, and a handicapped or elderly person with a walker or in a wheelchair. The task is not easy.

How does one proceed? The designer must be well informed on anthropometrics (physical characteristics), how people tend to behave or perform, and how to combine such data to achieve a suitable, effective, and safe design. A wealth of literature is available.

Hunter [10.10] includes enough anthropometric data to give insight into the kind of data to expect. He also provides much information on sources of information. He comments on Department of Defense documents which provide substantial and significant information. The objectives of these various documents can be applied with equal validity to both civilian and military products.

The aspect of human behavior is largely a question of psychology, a topic about which most engineers know little. Little information which is directed toward engineers seems to be readily available. One possible source is Grandjean [10.33].

There are many publications which provide varying degrees of insight and help in applying human factors information to design. Two which are particularly useful are Woodson [10.34] and Salvendy [10.35].

One of the many objectives of the designer is to minimize the probability of "human error," where human error is any personnel action (1) that is inconsistent with established behavioral patterns considered to be normal or (2) that differs from prescribed procedures. Predictable errors are those which experience shows will occur and reoccur under similar circumstances. The designer must minimize the possibility of such errors.

It is recognized that people have a strong tendency to follow procedures which require a minimum of physical and mental effort, discomfort, and/or time. Any task which conflicts with this tendency is highly likely to be modified or ignored by the person who is expected to execute it.

One of many important considerations in design is to follow common stereotypical expectations as much as possible. Consider a few examples:

1. Clockwise rotation of a rotary control (knob) is expected to increase the output.
2. Movement of a lever forward, upward, or to the right is expected to increase the output.
3. On a vertically numbered scale, the higher-value numbers are expected to be at the top.
4. On vehicles, depressing the accelerator is expected to increase speed, and depressing the brake is expected to decrease speed. One expects the right foot to be used to apply force to the accelerator, then moved to the brake pedal.

Smith [10.36] tells of a forklift truck which violated this fourth item: The left foot depressed a pedal which increased speed but applied a brake when the foot was lifted.

Sources. Hunter [10.10] cites SAE Recommended Practice J833, *Human Physical Dimensions,* and other SAE documents. NASA has a three-volume *Anthropometrics Source Book* (Volume 1 has data for the designer, Volume 2 is a handbook of anthropometric data, and Volume 3 is an annotated bibliography) available from the NASA Scientific and Technical Information Office, Yellow Springs, OH 45387. The Department of Defense has a basic handbook, *Human Engineering Procedures Guide,* DOD-HDBK-763. One of the basic military specifications is *Human Engineering Design Criteria,* MIL-H-1472. DoD documents normally refer to additional references; MIL-H-1472, for example, refers to 54 other documents. All DoD and MIL documents can be obtained from the Standardization Documents Order Desk, 700 Robbins Ave., Philadelphia, PA 19111. A limited set of references is given following the references cited in this chapter.

10.6 SUMMARY

The designer or manufacturer has a moral, ethical, and legal obligation to provide safe products. If that is not enough motivation, there is a matter of enlightened self-interest. There are three aspects to this obligation: (1) The product must be made safe. (2) If it is not possible to design out all hazards, guarding must be provided. (3) If complete and proper guarding cannot be provided, appropriate directions and warnings must be provided. It is absolutely unacceptable to use a warning in a situation where safe design or proper guarding is possible. It is not an easy task to write a proper and effective warning, since no warning is effective unless it changes the potential behavior of the endangered individual.

The most difficult variable in product design is the human in the human-machine system. Perhaps the designer needs to keep Murphy's law in mind: If anything can go wrong, it will. If that is not enough, there is O'Toole's law: Murphy was an optimist. Developing a truly safe product is not an easy task, but it can be done.

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