CHAPTER 20

VISUAL ENVIRONMENT

This chapter addresses the visual environment, which includes lighting, color, and signage. Many aspects of the visual environment contribute to accidents, whereas other characteristics help prevent them. Engineers need to understand the visual environment and how it relates to accidents and their consequences.

20-1 ILLUMINATION

Lighting or lack of lighting can contribute to accidents. People need to see what they are doing and where they are going. Some aspects of lighting are distracting or interfere with tasks. One study suggests that approximately one fourth of all accidents involve poor lighting. Another study found that falls are much more frequent in the evening and at night, which suggests a relationship to lighting conditions.

In 1973, all three engines in a jumbo jet failed because O-ring seals were missing. The failure nearly caused the pilot to ditch the plane and its 172 passengers in the Atlantic Ocean. During the investigation of this incident, mechanics for the airline testified that it was too dark in the service area to see if the seals were in place.

A patron entered a restaurant from the bright sunlight for a noon lunch. The restaurant was dimly lit to create an aesthetic effect. The patron fell down a step that was only a few feet from the entrance, claiming he was unable to see it.

Illumination and Lighting

The human eye detects light in wavelengths within the range of 380 to 750 nm (see Figure 21-1). Ultraviolet light lies below and infrared light lies above the visual range.

Figure 20-1 illustrates a light source and what happens to light distributed from it. The intensity of a source is measured in Candela or candlepower. The output of a light source, such as a lamp, is expressed in units of lumens (lm), which originally was defined as the light from a standard candle falling on a 1 ft^2 area 1 ft from the candle.

Light leaving a source goes in many directions and may not scatter uniformly in all directions. As light travels farther from its source, its energy diminishes. Like other point source radiant energy sources, light intensity decreases in relation to the square of the distance from the source. The light at one unit of distance from a source will be reduced to one quarter the amount at two units from the source. Flux is the light travelling through some unit of area. Luminous flux has units of lumens (lm).

Eventually, light from a source arrives at a surface. Illumination is light falling on a surface. Illumination has units of footcandles (fc) or lux (lx). If 100 lm arrive at a 1-ft^2

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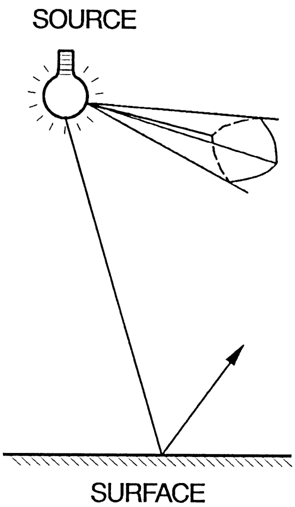

LOCATION	TERM	UNITS
Source	Luminous Intensity Luminous Flux	Candela Lumens
Distribution	Illumination	Footcandles
Arriving at Surface	Illuminance	Lumens/sq ft. Lux
Reflecting Surface	Reflectance	Percent
Light Reflected	Luminance	Footlambert Candela/sq m

Figure 20-1. Light distribution and illumination terminology.

surface, the illumination is 100 fc. If 100 lm arrive at a 1-m^2 surface, the illumination is 9.29 lx (1 fc = 10.764 lx).

The light arriving at a surface is absorbed, transmitted, or reflected. The reflectance of a surface is the portion of arriving light that is reflected. Reflectance, a property of the surface, is reported in percent. Luminance is the light emitted or reflected from a surface per unit area. Luminance has units of foot lamberts.

Light sources are daylight and artificial light, normally from electric lighting devices. Typically, a lighting fixture has a lamp and a luminaire. Luminaires help distribute the light in some desired pattern. There are several types of artificial light sources. Major types are incandescent, fluorescent, and high-intensity discharge (mercury and sodium vapor and halogen). Each type produces a different spectrum of wavelengths.

Lighting is classified as general or supplementary. General lighting provides lighting to a large area. It may be direct, which allows light to move from the source directly to surfaces, or indirect, which provides light by reflecting it from surfaces such as walls or ceilings. Task lighting is a common form of supplementary lighting. Located near a particular task, task lighting supplements general lighting to provide the amount and quality of light required.

Emergency lighting is another class of lighting important for safety. Emergency lighting typically is backup lighting that provides light when normal light sources fail. Emergency lighting has an alternate power supply, typically batteries. Interiors of buildings and exit routes have emergency lighting as required by fire codes and other standards.

Hazards

The major hazards associated with lighting involve illumination levels, changes in illumination levels, qualitative aspects of lighting, and flicker of some light sources.

Illumination Levels If there is too little light, one cannot see well. Insufficient light leads to errors and sometimes to accidents. An error may be placing a hand into a dangerous location or machine, not seeing a step and falling, or failing to detect a problem or a faulty part. An error may result from not seeing a situation that is dangerous and not being able to react quickly enough.

Extremely bright light sources can injure the receptor cells in the eyes. For example, even a brief look at the sun can damage the eye. Similarly, looking at the light from arc welding can cause eye injury very quickly.

Even when bright lights are not sufficient to cause injury, they can create afterimages that obscure portions of the visual field until the receptor cells have had a chance to recover. The afterimage from a flash of a camera or similar bright light is a common experience. The afterimage may lead to errors in vision and to accidents.

A bright light in the visual field may interfere with the ability to see or detect an object. The result may be visual errors and accidents.

Changes in Illumination Level Changes in illumination level interfere with the ability of the eyes to adjust quickly enough to permit seeing without error. Examples of changing light levels are the transition from bright outdoor light to dark interiors or from a bright area of a building to a dark one. Another example is looking at a brightly lit task, then turning the eye to focus on a location that is darker.

There are two ways the eyes adjust to changing light levels. In one form of adjustment, the iris increases and decreases in diameter to adjust the size of the pupil. This occurs quite quickly to changes in illumination. The pupil size also changes in response to startle and interest: pupils enlarge when a person is interested in someone or something or when someone is surprised.

The eyes also adjust photochemically to changes in light level. Photochemical changes provide sensitivity changes as great as 100,000 times or more. The concentration of rhodopsin in receptor cells of the retina is related to the sensitivity of the cells to light. Increases in light arriving at the retina reduce light sensitivity by reducing the concentration of rhodopsin. This is called light adaptation. One achieves full light adaptation in approximately 3 min. After being exposed to bright light and then the level of light droping to low levels for a period, the retina must adjust to the dark. This is called dark adaptation. Changes in rhodopsin concentration in dark adaptation may take 30 min to several hours.

Qualitative Aspects of Lighting Some qualitative aspects of lighting are glare and luminous contrast. Glare is the presence of a bright light in the visual field. *Direct glare* occurs when the light in the visual field is a light source. An example of direct glare is the headlights of an oncoming car at night. *Reflected glare* occurs when a bright light reflects from a surface. An example of reflected glare is the reflection of a light on a glossy page, which obscures the print. Glare can lead to errors in perception and detection that result in accidents and may produce afterimages or delay visibility resulting from adaptation.

Luminous contrast refers to the changing light levels of an environment. For example, one may look at work on a desk that has a certain illumination. Shifting the eyes to a wall presents a much darker or lighter level of illumination. When there is too much difference between the two surfaces, the eyes have difficulty adapting, which may lead to visual errors.

Flicker and Strobe Effects Some light sources are not constant and rapidly flicker on and off. The gas in a fluorescent tube actually turns on and off 120 times per second under 60-Hz electrical power. Most people do not notice this because the eyes tend to fuse images that flash at frequencies higher than 15 to 18 times per second. A flickering light source may be distracting or disturbing. Some people seem to be sensitive to fluorescent light flicker.

When an object oscillates or rotates and a bright light flashes on and off at the same frequency as the motion, the object appears to stand still. One can measure the speed of rotating machine parts with a strobe light that has an adjustable frequency for its flashes. A person who does not realize that the light source is flashing on and off may perceive that an object is not in motion. For example, placing a hand into the moving equipment that appears to be stationary may cause injury.

Other Lighting Effects There are other effects of light that can be distracting or can lead to errors in vision and visual perception. Some workplaces use sodium vapor lights to reduce energy costs. Sodium vapor lights produce light that is primarily in the yellow region. The light makes normal color appear different. Color coded information may not be perceived correctly.

Recent studies determined that a small portion of the population suffers from seasonal affective disorder. This condition affects people during the winter months in northern climates when there is limited daylight. Depression may result and can be severe and can severely affect performance. A daily dose of high-intensity, full-spectrum (nearly matching the spectrum of sunlight) fluorescent light for 2 to 4 hr eliminates the depression in 90% of the cases.

When there is a bright light source in the visual field, one tends to turn the head and eyes toward it. This phenomenon is called phototropism. The presence of such lights can be distracting.

Shadows may cause errors in perception of an object, but they also may be beneficial. Shadows from side lighting of difficult to see objects may make these easier to see.

Characteristics of People Individual variations among people add to potential problems associated with lighting. For example, in low light levels, the rod cells in the retina are the receptors. The rod cells are not sensitive to color and the cone cells, which sense color, are not effective in low light. Studies indicate that night vision, which refers to the function of rod cells in low light levels, diminishes with age. Compared with someone who is 20 years old, a 45-year-old person needs four times the light to achieve the same level of perception, and by age 60 years, the light levels required are double those required at age 45 years.

Many people aged 55 and older have some degree of cataracts. Cataracts are an opaqueness that develops in the lens and its encapsulating tissue. They also may occur on the cornea. Cataracts can occur in children or at young ages. Cataracts filter the light entering the eye and reduce the amount reaching the retina. They also cause light to scatter. If cataracts are severe enough, the scattering can produce multiple images, reduced acuity and color perception, and cause other vision problems. In extreme cases, cataracts cause blindness.

There are many visual disorders that require correction. Some result from aging. Without correction, visual errors increase.

Controls

Illumination Levels Illumination standards determine the amount of light suitable for various tasks. They are based primarily on the type of task. Current standards include adjustment factors for age, speed or accuracy, and reflectance of the task background. Table 20-1 is a summary of recommended illumination levels for interior lighting. Table 20-2

TABLE 20-1 Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors

Type of Activity	Illumination Category	Ranges of Illuminances (lx)	Ranges of Illuminances (fc)
General lighting throughout space			
Public spaces with dark surroundings	A	20–30–40	2–3–4
Simple orientation for short, temporary visits	B	50–75–100	5–7.5–10
Working spaces where visual tasks are only occasionally performed	C	100–150–200	10–15–20
Illuminance on task			
Performance of visual tasks of high contrast or large size	D	200–300–500	20–30–50
Performance of visual tasks of medium contrast or small size	E	500–750–1,000	50–75–100
Performance of visual tasks of low contrast or very small size	F	1,000–1,500–2,000	100–150–200
Illuminance on task, obtained by a combination of general and local (supplementary lighting)			
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2,000–3,000–5,000	200–300–500
Performance of very prolonged and exacting visual work	H	5,000–7,500–10,000	500–750–1,000
Performance of very special visual tasks of extremely low contrast and small size	I	10,000–15,000–20,000	1,000–1,500–2,000

TABLE 20-2 Weighting Factors To Be Considered in Selecting Specific Illuminance within Ranges of Values of Each Category

	Weighting Factor		
For illuminance categories A through C			
Room and occupant characteristics	–1	0	+1
Occupant ages (yrs)	Less than 40	40–55	Over 55
Room surface reflectances[a]	>70%	30–70%	<30%
For illuminance categories D through I			
Task and worker characteristics	–1	0	+1
Worker ages (yrs)	Less than 40	40–55	Over 55
Speed and/or accuracy[b]	Not important	Important	Critical
Reflectance of task background[c]	>70%	10–70%	<30%

[a] Average weighted surface reflectances, including wall, floor, and ceiling reflectances, if they encompass a large portion of the task area or visual surround.
[b] In determining whether speed and/or accuracy is not important, important, or critical, the following questions need to be answered: What are the time limitations? How important is it to perform the task rapidly? Will errors produce an unsafe condition or product? Will errors reduce productivity and be costly?
[c] The task background is that portion of the task on which the meaningful visual display is exhibited.

gives data for determining adjustment factors used in selecting levels within tasks, and Table 20-3 provides the data for deciding what value to select for a particular category. The *IESNA Lighting Handbook* is a long-standing, recognized authority on lighting standards and is the source for the recommendations above.

TABLE 20-3 Decision Data for Selecting Illumination Values within Categories

Categories	Sum of Weighting Factors	Value to Use
A to C	−2 or −1	Low
	0	Medium
	+1 or +2	High
D to I	−3 or −2	Low
	−1, 0, or +1	Medium
	+2 or +3	High

TABLE 20-4 Minimum Illuminance Levels for Safety[a]

Hazards requiring visual detection	Slight		High	
Normal[b] activity level	Low	High	Low	High
Illuminance levels				
Lux	5.4	11	22	54
Footcandles	0.5	1	2	5

[a] Minimum illuminance for safety of people. These are absolute minimums at any time and at any location on any plane where safety is related to seeing conditions. Refer to *IESNA Handbook* for recommendations on particular types of facilities and areas.
[b] Special conditions may require different illuminance levels. In some cases, higher levels may be required as, for example, where security is a factor. In some other cases, greatly reduced levels, including total darkness, may be necessary, specifically in situations involving manufacturing, handling, use or processing of light-sensitive materials (such as photographic products). In these situations, alternate methods of ensuring safe operations must be relied on.

Example 20-1 Assume that a visual task involves small objects and medium contrast. It is also known that some of the people who will perform the task are older than 55 years of age. Speed for the task is critical. The reflectance of the task background is 50 percent. What is the preferred illumination level?

From Table 20-1, the task falls within category E. There are three illumination levels possible. To decide which of the three is preferred, determine the adjustment factor. From Table 20-2, age has a +l factor, speed a +l factor, and reflectance a value of zero. The total is +2. According to Table 20-3 for category E, when a weighting factor is +2 or +3, the high value from Table 20-l is used. Therefore, the preferred illumination level is 1,000 lx.

The American National Standards Institute publishes standards of the Illuminating Engineering Society of North America (IESNA). NFPA 101 identifies minimum lighting requirements for various occupancies and exiting activities. In some cases, the minimum is 1 fc, which is a very low level and may not be sufficient for transition zones where one experiences a sudden change in illumination. This is particularly true if the transition involves dark adaptation. The life safety and exit codes also have standards for emergency lighting. IESNA has a list of illuminance levels regarded as *absolute minimums for safety alone*; see Table 20-4. Note that in all illumination designs, one must start with illumination levels higher than desired because the luminaires and lamps normally become dirty and reduce actual illumination levels with time. Cleaning will restore original lighting levels.

Quality of Lighting The quality of lighting may affect error rates and cause accidents. For many applications, control of illumination levels alone is not sufficient. Designs must control illumination quality as well.

One should analyze workstations to avoid direct or reflected glare. This is particularly true where tasks are critical or continue for extended periods. For example, a surface of a machine that has a dangerous action may become polished. A reflected light source may obscure the dangerous location, which could lead to placing hands erroneously in the danger zone at the wrong time. Screens on computer monitors illustrate the continuous problem. Reflections of light sources on the screen can cause eye strain, changes in head position that lead to fatigued neck and shoulder muscles, and related effects. This family of cumulative disorder is sometimes called VDT (visual display terminal) syndrome. Recent monitor designs significantly reduce such problems.

One also should analyze workstations for brightness ratio or luminance ratio. This refers to the difference in lighting level between the task and the surround. One may be brighter than the other. The goal is to minimize the difference in illumination levels between a task and its surround and keep the difference within certain ratios. This reduces the degree of adaptation required in a visual task as eyes focus on the task, then the surround, and back to the task. There are often practical limitations that may not permit achievement of this goal. Table 20-5 lists recommended luminance or brightness ratios for industrial settings.

Guarding can reduce dangers of oscillating and rotating equipment. This is particularly true when there is gas-vapor lighting that may produce strobe effects.

Example 20-2 An industrial task is to be illuminated to a level of 100 lx. What is the minimum illumination required for an adjacent surface? For a remote surface?

From Table 20-5, the recommended maximum luminance ratio between a task and an adjacent darker surround is 3 : 1. Therefore, the minimum illumination required for the adjacent area is $100 \times {}^{1}/_{3} = 33.3$ lx. From Table 20-5, the ratio between a task and remote darker surfaces is 10 : 1. The minimum illumination recommended for the remote surfaces is $100 \times {}^{1}/_{10} = 10$ lx.

The reflectance of surfaces should be controlled to prevent reflective glare from interfering with visual tasks. Table 20-6 lists recommended reflectance values for industrial, interior environments.

TABLE 20-5 Recommended Maximum Luminance Ratios[a]

	Ratio by Environmental Class[b]		
Surfaces	A	B	C
Between tasks and adjacent darker surroundings	3 : 1	3 : 1	5 : 1
Between tasks and adjacent lighter surroundings	1 : 3	1 : 3	1 : 5
Between tasks and more remote darker surfaces	10 : 1	20 : 1	—
Between tasks and more remote lighter surfaces	1 : 10	—	—

[a] From ANSI/IESNA RP7, *Practices for Industrial Lighting.*

[b] A = interior areas where reflectance of surfaces can be controlled. B = areas where reflectances in immediate work area can be controlled, but control of remote surround is limited. C = areas (indoor and outdoor) where it is impractical or difficult to control reflectances.

TABLE 20-6 Recommended Reflectance Values[a]

Surface	Reflectance (%)
Ceiling	80–90
Walls	40–60
Desk and bench tops, machines, and equipment	25–45
Floors	Not less than 20

[a] From ANSI/IESNA RP7, *Practices for Industrial Lighting*.

20-2 COLOR

Color and Safety

Color is useful in safety for marking hazards and coding information. For example, color can mark edges of steps and other changes in walking surfaces, and it can code classes of information, including safety information and signs.

One limitation for color coding is that a small portion of the population is color blind. Color blindness occurs primarily among males. Approximately 6% of adult males have a marked reduction in color sensitivity, and less than 1% of adult males are totally color blind. Color blindness can lead to errors. For example, color-blind electricians have attached the green ground wire in equipment to a hot lead and energized the equipment. A color-blind driver depended on the position coding of red and green to interpret traffic signals correctly. At one location, the red light was at the bottom and led to a motor vehicle accident.

Another limitation of color coding is that one must remember the meaning of the colors. However, if color coding is applied consistently over time, the general meaning of the colors becomes well known in a culture. We call such well-known conventions population stereotypes. For example in the United States, standard traffic signals have led to a general knowledge among the population. Most people understand that red means stop or danger, yellow means caution, and green means go. The nuclear power plant accident at Three Mile Island, Pennsylvania, taught us some lessons about the importance of applying color coding consistent with learned population stereotypes.[1] The color coding of signal lights on the Three Mile Island control room panels did not always follow the red-green convention. Chapter 33 discusses this accident further.

Color Standards

There are several standards that include color codes for safety information and information that could help one recognize hazards. American National Standards Institute (ANSI) standards in the Z535 series define color codes, signs, tags, and symbols for safety applications. Table 20-7 lists standard color markings for hazards. DOT has color standards for highway signage and markings. OSHA regulations include color coding for respiratory protective equipment, signage, and accident prevention tags. ANSI A13.1 defines standard markings (including colors) for identification of piping systems. The Army-Navy Aeronautical Specification AN-C-56 is a standard for three colors recognizable by most color-blind people. Other organizations have developed recommendations for the application of color in other safety communication applications.

TABLE 20-7 Standard Color Codes for Marking Hazards[a]

Color	Use
Red	Fire equipment, danger, emergency stops
Yellow	Marking hazards
Green	First aid, safety equipment
Black/white	Traffic marking, housekeeping
Orange	Dangerous parts of machines or equipment
Blue	Informational signs
Reddish purple	Radiation hazards

[a] Excerpt from ANSI Z535.1, *Safety Color Codes*.

The National Institute for Standards and Technology (NIST) studied 59 safety colors under seven different types of light sources.[2] The study resulted in recommended changes to certain colors in ANSI Z535 to make them easier to differentiate and recognize.

20-3 SIGNAGE

Signage and Safety

Signs take many forms. They may be large to provide safety information for a large area or they may be in the form of tags for lockout and tagout procedures. They mark hazards at particular locations on machines and equipment and in buildings and they provide warnings on products. They need to incorporate standard color codes where applicable. For many use environments, signs should be multilingual or include symbols that are not language dependent. Because not everyone understands or recalls the meaning of many symbols, symbols are more effective if coupled with text information.

Signage Standards

There are number of standards for marking hazards and communicating safety information through signage. ANSI publishes several standards on signage. Regulations of the Department of Transportation, OSHA,[3] Consumer Products Safety Commission (CPSC), and other federal agencies also contain signage standards important for safety. There is a United Nations system for labeling hazardous materials. The International Standards Organisation (ISO) publishes standards for signs and symbols. Many consensus standards contain specifications for signage. Examples are the National Electric Code and the National Fire Code. The Association for the Advancement of Medical Instrumentation (AAMI) has established standards for symbols and signs on medical equipment.[4]

Signs must meet many characteristics to be readable (see Chapter 33), particularly when used as warnings and instructions (see Chapter 7).

EXERCISES

1. What illumination level is recommended for public areas with dark surroundings, where all age groups will use it, accuracy of information is important, and reflectance of the task background is 35%?

2. What illumination level is recommended for an industrial task involving very small items for an entire workday, where items are of low contrast? Several workers are older than 55 years and speed is critical. The task background has a reflectance of 65%.
3. An assembly task is to have 40 fc of light. If more remote surfaces are darker than the task, what is the least amount of light you would recommend for the surrounding dark surfaces?
4. You are to design the entrance to a restaurant. The interior decor is to be dimly lit to create an intimate dining mood. The decor is to be in place even at lunch time, when full sunlight may be present outdoors. Part of the dining area is to be sunken relative to the entry level and other parts are to be elevated from it. Determine what lighting levels and lighting placement you would recommend for different areas of the restaurant. Justify your decisions, allowing for visual adaptation of patrons. Some patrons may be older than 65 years, have some form of cataracts, or have macular degeneration. What other design features would reduce hazards?

REVIEW QUESTIONS

1. What units of measure are used for the following forms of light?
   (**a**) light output from a source
   (**b**) luminous flux
   (**c**) light arriving at a surface
   (**d**) light emitted or reflected from a surface
   (**e**) reflectance of a surface
2. Characterize the following:
   (**a**) general lighting
   (**b**) supplemental lighting
   (**c**) direct lighting
   (**d**) indirect lighting
3. For each of the following, identify at least one hazard and control:
   (**a**) illumination level
   (**b**) change in illumination level
   (**c**) qualitative aspects of lighting
   (**d**) flicker of a lighting source
4. How long does full light adaptation take?
5. How long does full dark adaptation take?
6. Which receptor cells in the eyes are sensitive to color?
7. Which receptor cells in the eyes are most sensitive to low light?
8. How do cataracts affect vision?
9. How is color used for safety?
10. Name two limitations for using color coding.
11. Name one limitation of text signage.
12. Name one limitation of symbols.

NOTES

1 Sheridan, T. B., "Human Error in Nuclear Power Plants," *Technology Review*, February: 23–33 (1980).

2 NSBIR-86-3493, *Safety Color Appearance Under Selected Light Sources*, National Bureau of Standards, Washington, DC, 1987.

3 29CFR1910.144 Safety Color Code for Marking Physical Hazards; 29CFR1910.145 Specification for Accident Prevention Signs and Tags.

4 ANSI/AAMI/IEC TIR 60878, *Medical Equipment Symbols and Safety Signs*, Association for the Advancement of Medical Instrumentation, Arlington, VA.

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- IESNA RP-7 Practice for Industrial Lighting
- IESNA RP-8 Practice for Roadway Lighting
- IESNA RP-11 Design Criteria for Lighting Interior of Living Spaces
- IESNA RP-16 Nomenclature and Definitions for Illuminating Engineering
- IESNA RP-22 Recommended Practice for Tunnel Lighting
- IESNA RP-27.1 Recommended Practice for Photobiological Safety for Lamps and Lamp Systems—General Requirements
- IESNA RP-27.2 Recommended Practice for Photobiological Safety for Lamps and Lamp Systems—Measurement Techniques
- IESNA RP-27.3 Recommended Practice for Photobiological Safety for Lamps—Risk Group Classification and Labeling
- IESNA RP 28 Recommended Practice on Lighting and the Visual Environment for Senior Living
- IESNA RP-29 Recommended Practice on Lighting for Hospitals and Health Care Facilities
- IESNA RP-30 Recommended Practice on Museum and Art Gallery Lighting
- Z535.1 Safety Color Code
- Z535.2 Environmental and Facility Safety Signs
- Z535.3 Criteria for Safety Symbols
- Z535.4 Product Safety Signs and Labels
- Z535.5 Accident Prevention Tags

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