32
Control of Physical Hazards

Marjory E. Anderson

32.1
Introduction

As with the design of chemical processes, engineers can encounter contract requirements that pose safety and regulatory challenges during the design of facilities, machinery, and equipment. The physical hazards associated with machines, facility layout, equipment arrangement, and other physical aspects of the design may pose a risk to people, property, and the environment and must be considered. Some of the most common hazards addressed by safety professionals, and therefore loss prevention engineers, include:

1) noise
2) temperature
3) height
4) pinch points and machine guarding
5) confined spaces
6) power sources
7) lighting.

This chapter discusses some considerations relating to the physical hazards listed above and then examines some possible methods of abating or controlling those hazards and assuring the safety of people, property, and the environment.

32.2
Considerations

Engineers are frequently enlisted to design buildings and equipment for business that utilize a variety of hazardous elements as a part of the intended process. As discussed in the previous chapter, Control of Chemical Hazards, the Occupational Safety and Health (OSH) Act contains permissible exposure limits (PELs) (OSHA, 2010) that relate to some of these hazards, such as noise. The Occupational Safety and Health Administration (OSHA) also discusses requirements for other hazards,

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

such as machine guarding and confined spaces, that spell out what employees must be protected from in addition to methods of protecting them. OSHA frequently refers to the hazards as areas where employees have a ''duty'' to provide protection, and the methods are often referred to as ''systems'' that have specific criteria to make them compliant. In addition, there are various American National Standards Institute (ANSI) standards defining best practices for the protection of employees from a wide array of physical hazards. Some examples include:

1) ANSI/ASSE A10.1-2011 Pre-Project and Pre-Task Safety and Health Planning (ANSI, 2011a)
2) ANSI/ASSE A10.26-2011 Emergency Procedures for Construction and Demolition Sites (ANSI, 2011b)
3) ANSI/ASSE Z590.3-2011 Prevention Through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes (ANSI, 2011c)
4) ANSI/ASSE A10.13-2011 Safety Requirements for Steel Erection.

It can also be helpful for the engineer to find guidance from standards published by the American Society of Mechanical Engineers (ASME), such as

1) ASME Y14.5-2009 Geometric Dimensioning and Tolerancing (ASME, 2009a)
2) ASME B30.27-2009 Material Placement Systems (ASME 2009b)
3) ASME B5.52-2003 Power Presses: General Purpose, Single-Point Gap Type (ASME, 2003).

OSHA Standards are enforceable by law in the United States and must be considered in every design if the engineer hopes to bring a safe, usable, and practical fruition to the design. ANSI and ASME standards, although not directly enforceable by law in the United States, in most cases, are kept current by their respective publishers and will therefore provide more up-to-date best practices for the engineer to consider and utilize, as l discussed below. This is done through a hypothetical facility design that is explored under Specific Considerations following the discussion of the Hierarchy of Controls.

32.2.1
Hierarchy of Controls

In controlling hazards, there is a preferred hierarchy to follow. This hierarchy provides for decreasing levels of control as deemed feasible for a specific task or operation. The hierarchy is as follows in Table 32.1 (ANSI, 2011)

The idea behind this hierarchy is that the best, most effective, and most feasible means of protection is to be used for control of any hazard. The designer should always start at the top of the hierarchy and work down as controls are proven infeasible for some documentable reason.

Elimination is the ideal in hazard control. This is the complete elimination of the hazard in question. For example, if a process involves a given hazard, such as a fall hazard due to personnel needing to climb a ladder to reach valves 10 ft above the

Table 32.1 ANSI hierarchy of controls.

Most preferred	Risk avoidance: prevent entry of hazards into a workplace by selecting and incorporating appropriate technology and work methods criteria during the design process
	Eliminate: eliminate workplace and work methods risks that have been discovered
	Substitution: reduce risks by substituting less hazardous methods or materials
	Engineering controls: incorporate engineering controls/safety devices
	Warning: provide warning systems
	Administrative controls: apply administrative controls (the organization of work, training, scheduling, supervision, etc.)
Least preferred	Personal protective equipment: provide personal protective equipment (PPE)

surrounding floor level, then the valves could be moved to the floor to eliminate the need to climb and therefore eliminate the chance of falling.

The second most effective means is substitution. In this control method, a lower hazard chemical or material is substituted for one that poses a higher hazard. For example, consider the use of solder to connect and seal panels for a copper roof. The solder used could contain lead, which will become airborne as a fume when it is heated during the welding process. Lead carries with it health risks from which employers need to protect their employees. Perhaps a solder that does not contain lead can be substituted to prevent any exposure to lead fume.

Engineering controls are varied and are usually accomplished by developing a means of keeping the hazard and the operator, or materials, separate. For example, if a punch press is used to create a product, dies used in this process will present the hazard of crushing injury should an operator's hand become caught in the point of operation. The design engineer may be able to engineer this hazard out by creating guards, integral to the press, which will prevent hands from being placed in the point of operation. Machine guarding is discussed further in Section 32.3.

Next are administrative controls; simply put, these controls amount to written procedures for conducting a task or using a material. One such control might be a lockout/tagout procedure. The procedure would outline, step-by-step, how a given machine is to be rendered safe by isolating energy sources. The downside to this control is that it allows for variation in work based upon personal preference or decision, thereby defeating the purpose of the procedure and increasing the hazard to personnel.

The final means of control, and the least effective, is personal protective equipment (PPE). PPE should only be used when none of the other controls can be feasibly accomplished or in combination with one or more of the other controls. PPE includes protective clothing, safety shoes, safety glasses, gloves, respirators, and the like. The problem that this control presents is that it is entirely reliant upon personal compliance with its use in order to provide any protection.

Design engineers must carefully consider all available options in controlling hazards and document why one or more of the control levels discussed above cannot be attained. They must also document which level can be attained and how it will be attained in order to provide the greatest control possible for the hazards introduced. Some specific controls, and how they may be effective, will be defined below. It is up to the design engineer to determine the usefulness of any of these controls during the design process.

32.2.2
Specific Controls

A company has been hired to design a new expansion for an industrial plant. This expansion will comprise a new loading dock that is to provide more room for material storage and handling, in addition to ample space for trucks to maneuver. The project team has decided on a plan as in Figure 32.1.

Considering this layout, what possible concerns, or hazards, can be identified? Your safety professional will likely consider each of the following as key items in designing safety into this project:

32.2.3
Walking and Working Surfaces and Varying Levels

In the experience of the author, one often overlooked concern is the surface on which employees and visitors will be walking and working, at least from the standpoint of the safety of that surface. These surfaces can include floors, platforms, scaffold planking, catwalks, crawl spaces, and so on. One concern is that if these surfaces are not made in a way that fits the work to be done, it can result in injuries from slips, trips, and falls (either from height or on the same level). These surfaces

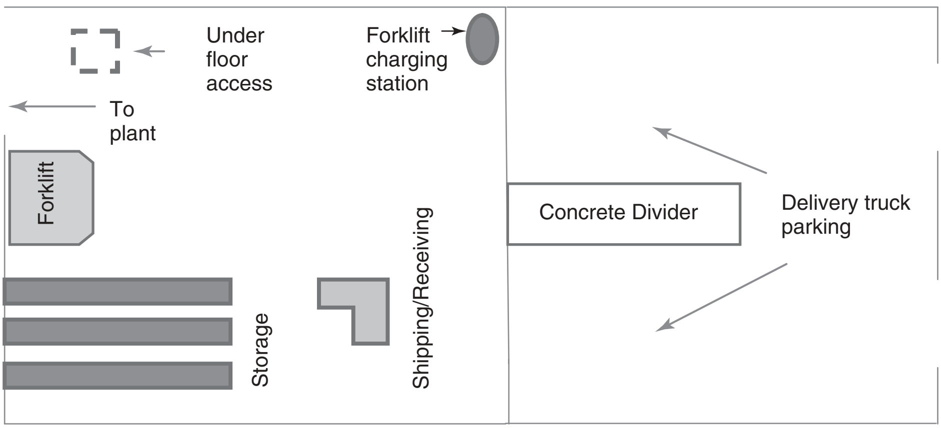

Figure 32.1 Loading dock layout plan.

can become wet or icy depending upon weather conditions and potential spills. This problem can be mitigated through the use of textured and anti-skid flooring.

Another problem to consider is that hard surfaces can also result in high pressure on the feet of persons standing and walking for long periods. This is due to the weight of a person imparting force against the surface and the surface imparting an equal force back against the person's feet. Since the area of the foot is small relative to the size of an adult, force is not spread over a significant area and therefore the pressure on the foot is more per square inch than it would be if the force was spread over a larger surface. Cushioning such as from anti-fatigue mats can mitigate this problem by distributing the force over a wider area and thereby reducing the pressure applied to a person's feet.

Loading docks are typically concrete or paved surfaces that incorporate some metallic floor surfaces. In the example above, trucks will be pulling into a paved garage up to a loading platform that will likely incorporate metallic dock levelers. So there will be hard surfaces that will not provide cushioning when stepped upon. They will also readily collect water and, in winter weather, turn icy. Each of these hazards needs to be addressed in some manner and can be addressed most effectively during the design process. Perhaps anti-fatigue flooring can be provided in the areas where people will frequently be standing and walking for long periods. Heating systems, such as the Electric In Slab Floor Heating System by Warmup, Inc. can be designed into flooring to prevent icing and the floors can be sloped towards drainage gutters so that water will not accumulate (Warmup, Inc., 2011).

A major feature of the new loading dock is that trucks will pull into a garage and back up to the loading platform. This means that there will be two different working levels, which will create the need for bi-level access via stairs or ramps. It will also create the hazard of falling to a lower level. These too are areas that need to be addressed during design. Stairs and ramps will be required to meet certain design criteria put forth in OSHA standards. According to OSHA 29 CFR 1910.24 (OHSA, 2011c), fixed stairways must meet several requirements, such as:

1) Minimum width of 22 in.
2) Specified angles as in Table D-2 of the standard (Table 32.2 here).
   29 CFR 1910.24(e) "Angle of stairway rise." Fixed stairs shall be installed at angles to the horizontal of between 30 and 50°. Any uniform combination of rise/tread dimensions may be used that will result in a stairway at an angle to the horizontal within the permissible range. Table D-2 of the standard (Table 32.2 here) gives rise/tread dimensions which will produce a stairway within the permissible range, stating the angle to the horizontal produced by each combination. However, the rise/tread combinations are not limited to those given in the table.
3) Slip-resistant tread.
4) Railings on open sides.
5) Vertical clearance above any tread of 7 ft minimum.

It may also be possible to incorporate slip-resistant flooring to prevent slipping on the dock itself. Guardrails will need to be placed on the upper level if it is 48 in or

Table 32.2 Rise/tread dimensions which will produce a stairway within the permissible range.

Angle to horizontal	Rise (inches)	Tread run (inches)
30°35′	$6^1/_2$	11
32°08′	$6^3/_4$	$10^3/_4$
33°41′	7	$10^1/_2$
35°16′	$7^1/_4$	$10^1/_4$
36°52′	$7^1/_2$	10
38°29′	$7^3/_4$	$9^3/_4$
40°08′	8	$9^1/_2$
41°44′	$8^1/_4$	$9^1/_4$
43°22′	$8^1/_2$	9
45°00′	$8^3/_4$	$8^3/_4$
46°38′	9	$8^1/_2$
48°16′	$9^1/_4$	$8^1/_4$
49°54′	$9^1/_2$	8

more above the lower level. There is no mandated material for these items provided that dictated requirements can be met. There is opportunity for creativity on the part of the engineer when designing safety protections. The only requirements will be dictated in OSHA regulations, the International Building Code (IBC), and other regulations depending upon where the work is being done.

32.2.4 **Confined Space**

In the example layout (Table 32.1), there is an area marked "under floor access." This access is needed to clean out drains, provide access to mechanical features of dock levelers, and other potential maintenance activities. This area is considered a confined space because, as defined in OSHA 1910.146 (b) (OSHA, 2011e):

1) it has limited access, and
2) it is not intended for continuous human occupancy, but
3) it can be entered by employees.

The key here is to design the space to mitigate hazards that may turn this into a hazardous space for employees.

First, identify the hazards. It is reasonable to assume that, since drains will be in place, water might accumulate in the space due to clogs or plugs causing overflow or a defect (crack, hole, etc.) in the gutter system. Another potential hazard is electrical wiring used to operate the dock leveler as water conducts electricity and line faults or exposed wiring could be contacted by moisture from the drains. Also, with vehicles operating outside this space, carbon monoxide could accumulate along the floor of this vault. Finally, consider the fact that maintenance activities will be conducted here – could the employees then be using chemicals, such as cleaners and lubricants, in this space that may possess irritant properties? – possibly. This means that chemical exposure is another potential hazard. So, what does this mean for the design team? The design team needs to know about the above hazards and consider whether or not design elements can be included to prevent exposure to hazards in this space.

Water accumulation may be possible if drains become clogged or if the material from which the drains are constructed cracks or rusts and develops holes. Therefore, slip-resistant flooring could be included in the design to prevent personnel from slipping and falling on wet floors. A sump could also be included in case accumulation is not noticed in a timely manner. Waterproofing is another potential option to prevent seepage from external spaces.

What about electricity? The necessity cannot be eliminated, but easily accessible shut-offs that can be locked out to prevent operation could be included in the design. Lockout as a control measure is discussed in Section 32.3. Another consideration is electricity to provide ample illumination for employees to conduct work. Wire is already being run to operate our dock levelers so it makes sense to run additional wiring to provide for lighting within the space. This too can help to eliminate hazards as personnel will not be relying on low light levels from flashlights, which could cause them to miss something that may cause problems, such as tools or other items left on the floor that an employee can trip over.

Now, what about chemical vapors, and carbon monoxide gas? Carbon monoxide accumulation can result in the displacement of oxygen, thereby creating an asphyxiation hazard. Chemicals such as cleaners and lubricants could contain ingredients, such as ammonia, which can cause skin, eye, and/or respiratory irritation. If it cannot be determined that there is no way either of these materials could enter the space, at any time and in any concentration that could lead to irritation or difficulty in breathing, then ventilation is probably the best means of mitigating these hazards. Design ventilation in at the beginning and it is much easier to incorporate into the building. Ventilation as a control method is discussed in Section 32.3.

These may not be the only options available to the design engineer. Openly discussing the potential hazards and their controls with all project team members can result in a multitude of options and the engineer should never limit the thinking by any member of the team. Even the most outlandish ideas may lead to the perfect solution for safety concerns encountered during the design process.

32.2.5 Machinery, Materials, and Equipment

From a safety standpoint, machinery, materials, and other equipment are frequent concerns. Materials can fall from storage racks, a machine can catch on clothing, hair, or limbs, and different types of equipment can result in a wide variety of accident-causing mechanisms, such as:

1) Narrow points where loose clothing and hair can get caught.
2) Sharp edges that can cause lacerations.

3) Motorized points of operation that can cause crush injuries and fractures.
4) High-temperature components that can cause burns.
5) Moving parts that can cause strike injuries such as contusions and fractures.

These hazards really need to be considered on two levels. First the designer of any machine must consider the hazards being built into the machine and create adequate controls to prevent injury, such as enclosures and point of operation guards. Second, the designer of a facility must consider the hazards and controls associated with the machinery to be placed in the facility, such as leaving enough clear space around electric boxes or the installation of light curtain guards around punch presses. The facility design must be done in such a way that machine hazards are not amplified and that new hazards are not introduced due to poor spacing and arrangement.

Machines provide a lot of benefit in getting jobs done quickly and correctly, but they can also cause some of the greatest safety concerns for a facility. In the author's experience, machines frequently present hazards such as:

1) Pinch points – these are areas where a body part could be pinched or nipped, such as automatic feeds with doors that open and close.
2) Impact points – these are areas where things are pressed, punched, or otherwise struck, such as punch presses and die cutting machines, and can crush or amputate limbs or digits.
3) Rotating parts – these are areas where clothing and hair can be drawn in, as in between rollers, and result in catastrophic, if not fatal, injury.
4) Power sources.
5) Fly-away pieces of product.

Machines are not all built, or used, in identical ways, so hazards will vary. The hazards listed above are the types of hazards that need to be addressed at the machine design level. Frequently, engineers employ things such as lockout/tagout and guards to control these hazards. These controls are discussed in Section 32.3. It is imperative, however, that the design engineer be aware of the controls used for the machines in a facility in order that enough space is allowed for proper configuration and the movement of personnel and supplies. So, what can the design engineer address?

In the example facility, forklifts will be used and a forklift charging station will be included. In addition, there will be a storage area for items to be shipped and having been received. Consider what hazards these items may present in the loading dock area. When you finish, refer to the sample worksheet in Table 32.3 to see a few of the hazards that need to be addressed.

The worksheet illustrated by no means identifies all potential hazards but it does give an idea of the types of things for which a design engineer must look. It also makes it easy to recognize what the designers can address and what must be left to operations personnel to consider and mitigate. For example, at the operations level personnel may need to develop specific work procedures and/or wear PPE to protect themselves from safety hazards that could not be engineered out. Such

Table 32.3 Design considerations – hazard identification.

Design consideration	Hazard(s)
Forklift	Limited visibility
	Difficult maneuvering
	Fuel
	Instability
Charging station	Acid vapor production
	Electricity
	Battery storage
Storage shelves	Falling materials
	Overloaded shelves
	Accessibility
	Conductivity

a worksheet is completed by the design team during brainstorming sessions and added to as new concerns are discovered. Using a worksheet such as this makes brainstorming easier and more organized.

From this worksheet, which hazards to address through design and how they could be addressed can be determined. Considering the above worksheet, identify what can be designed out and how it might be done. When finished, refer to Table 32.3 for further examples. In Table 32.4, note that not all of the listed hazards can be addressed, or should be addressed, in design. Some hazards need to be addressed through work process and procedures and will be handled at the operations level. The hazards that can be addressed through design show some potential controls, but probably not all available controls. As an engineer, you can likely think of several other possibilities. It is important to consider all possibilities that the team lists, as often the choice of controls will be guided by budget.

32.2.6 Power Sources

Another hazard that is often overlooked, and yet is common to all workplaces, is power sources. There are six recognized sources of power that safety professionals focus on:

1) electrical
2) mechanical
3) chemical
4) pneumatic
5) hydraulic
6) thermal.

Each of these has the potential to cause serious harm or fatality. We can tend towards complacency with power sources because we live with them every day in

Table 32.4 Design considerations – hazard control.

Design consideration	Hazard(s)	Can be addressed through design? (Y or N)	Possible control methods
Forklift	Limited visibility	Y	Provide aisles wide enough for forklift use
	Difficult maneuvering	Y	Provide space to allow forklifts to turn and move while loaded
	Fuel	Y	Eliminate fuel and use batteries
	Instability	N	—
Charging station	Acid vapor production	Y	Provide local exhaust ventilation (LEV)
	Electricity	Y	Provide easily accessible shut-offs and lockout capability
	Battery storage	Y	Provide storage fixtures that "lock" batteries in place
Storage Shelves	Falling materials	N	—
	Overloaded shelves	N	Limit shelf height
	Accessibility	Y	Provide aisles wide enough for forklifts
	Conductivity	Y	Install all wiring away from shelving Use non-conductive shelving material

all aspects of our lives. However, because of their potential to injure, they must be considered and controlled in order to protect employees.

Going back to our example, there are two types of power that we need to look at, electrical and chemical. Electrical is obvious: it is how we power our lights, dock levelers, computers, telephones, and so on. Chemical is limited to the batteries used for our forklifts. Forklift batteries contain acid that could, under the right circumstances, spray into an employee's face and on to clothing. We need to prevent injury from either of these sources.

A frequently used control method is a procedure that is required in OSHA regulations, lockout/tagout (29 CFR 1910.147) (OSHA, 2011f). This is generally an operational matter, meaning lockout/tagout is a procedure that will be used by machine operators and maintenance personnel, and it is discussed further from this standpoint in Section 32.3. There are, however, ways in which the design engineer can aid in the procedure and make compliance readily achievable. This can be done by considering positioning. Valves, outlets, piping, and so on, should always be placed and configured in such a way that an employee can reach them from the floor and manipulate them without having to contort into tight spaces and awkward positions. Awkward positions and tight spaces can lead to employee injury such as muscle strains or exposure to the energy source due to a lack of room to maintain a safe distance and move freely. When these items cannot be placed to be reachable from the floor, it is

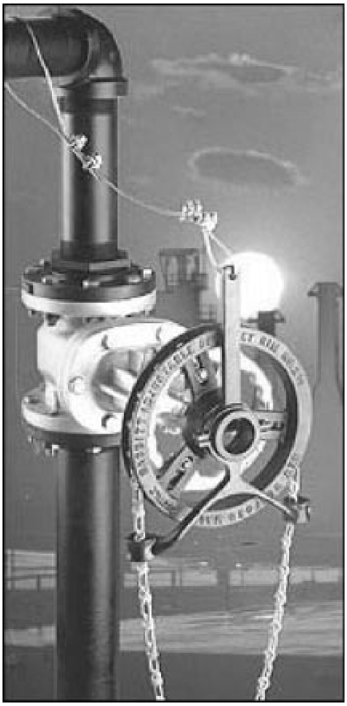

Figure 32.2 Chain wheels by Babbitt Steam Specialty (BoilerSupplies.com, 2012).

helpful for the designer to include a means of lowering the shut-off to the employee. For example, a chain could be attached to a valve, as shown in Figure 32.2, and configured to allow employees to use it to turn the valve to an open or closed position.

32.2.7
Temperature

Temperature can be a concern in a couple of ways. It can refer to the room temperature in which employees may work or it can refer to the topical temperature of an object or material. The design engineer can help in alleviating temperature concerns by controlling the temperatures to which employees can be exposed.

The loading dock will frequently be open to the outside and this will create difficulty in maintaining a comfortable temperature in the workplace. Perhaps also there is a steam line, used to provide heat to the facility, running through the vault space beneath the loading dock as in Figure 32.3.

This could create an undesirable ambient atmosphere in this vault and could be hot enough to burn the skin if it is touched. Human skin begins to burn at $\sim$55–60 °C (130–140 °F), depending on the duration of contact (Answerbag.com, 2012). There are a few engineering controls that can be put into place to protect employees from exposure to temperature extremes, such as:

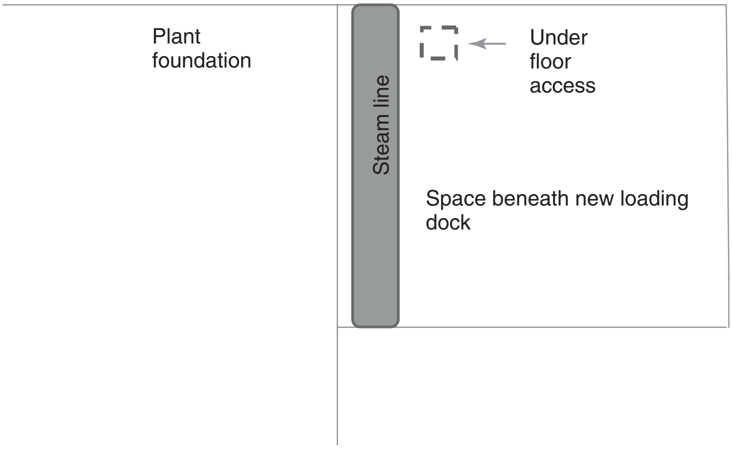

Figure 32.3 Illustration of steam line running beneath the loading dock.

Figure 32.4 Air curtain.

1) air curtains at dock garage entry doors (Figure 32.4) (Hankin Specialty Equipment, 2012)
2) plastic, slatted curtains at the dock edge (Figure 32.5) (Global Industrial, 2012)
3) insulated pipes (Figure 32.6) (Munster Insulation, 2012)
4) barriers constructed between pipes and vault space (Figure 32.7).

If considered within the design process, installing these controls will result in lower cost to the customer than if they had to construct retrofits, and ensure no interference with other systems or materials. The controls mentioned will provide separation of people from atmospheres and objects. Separation of people from

Figure 32.5 Plastic slat curtain.

Figure 32.6 Pipe insulation.

hazards is not only a relatively simple fix, it also has a marked effect on safety as it isolates the hazard and protects the employee.

32.2.8 Sound Levels

Sounds levels can be a major safety concern. It is important that employee hearing be protected. So how does this affect the design engineer? We need to look at what will be placed within a facility and how much sound will be produced, in other words, how many decibels of sound materials within the space will generate and how the facility structure will affect the transmission of sound (i.e., echoing, absorbing, and reverberating).

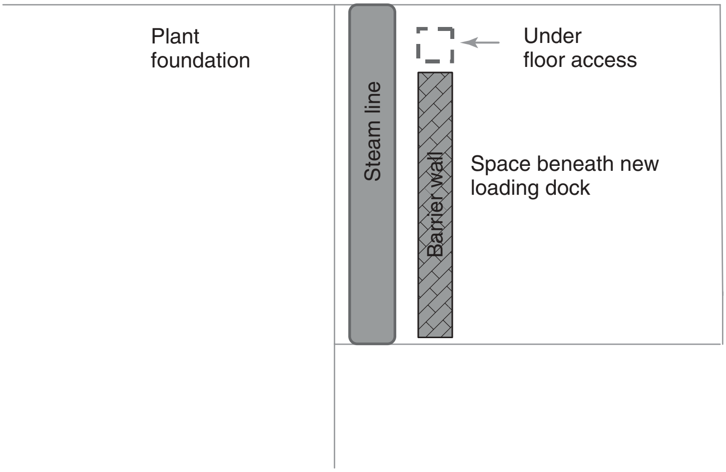

Figure 32.7 Physical barrier wall.

In our facility, a loading dock, sound (noise) will be introduced by the arrival and departure of trucks and the use of forklifts. When designing this space, we will need answers to the following questions:

1) What will produce noise in the work space?
2) At what frequency and decibel level will this noise be transmitted?
3) Will the noise be intermittent or constant?
4) What is the acceptable level of noise exposure?
5) What possible controls are available?

The answers to these questions will direct design efforts. Using the worksheet in Table 32.5, we can determine the following.

A new column has been added to the worksheet, Permissible exposure limit (PEL) (Table 32.5, shaded). This is the level of exposure permitted by OSHA during an 8 h workday. It is likely here that the exposure to noise will not be handled

Table 32.5 Design considerations – noise control.

Item	Hazard(s)	Can be addressed through design? (Y or N)	Permissible exposure limit (PEL) (dB)	Possible control methods
Tractor	Intermittent exposure for short durations	Possibly	90	Sound-damping room dividers
Trailer				
Engines				
Forklift	Intermittent to constant exposure based upon level of work each shift	N	90	Personal protective equipment (PPE)

Figure 32.8 Sound enclosure.

Figure 32.9 Noise and vibration damping sheets.

through design efforts, since noise is being created by moving vehicles that are not in place and running for extended periods, but there are instances in which design does have an effect. Machinery is often very loud and exposes employees to decibel levels exceeding the PEL. In this case it is sometimes possible to use machine enclosures (eNoise Control, Inc., 2012) (Figure 32.8) or sound damping devices (Industrial Noise Control, Inc., 2010) (Figure 32.9), such as acoustic walls, paint compounds, and so on, to reduce the exposure to employees.

Each of these controls needs to be considered during design as they will take up room and may affect the final layout of the facility.

Once the design team has completed the Design Considerations Worksheet, identified potential hazards, and developed possible controls, the team can progress into designing the necessary controls to maintain safety within the facility. Some typical controls are discussed in the next section. It should be noted that you may be able to find checklists, such as the Building Design Checklist in the *Safety Through Design* textbook (Christensen and Manuele, 1999) to help guide you through this evaluation, by searching the Internet for topics such as Safety or Prevention Through Design Checklists. These lists will help you to determine quickly the hazards that you will need to address in your design.

32.3 Control Methods

There is rarely only one way to control a given hazard and it is important that the control best suited to the situation be designed into the machine, facility, or process. There are a few controls worth discussing in more detail and with which it is a good idea for the design engineer to be familiar. These controls are discussed in detail below. It will be helpful to refer back to Section 32.2 and the worksheets completed earlier while going through this section.

32.3.1
Fall Protection

Every year, people are injured or killed due to falls from heights. Any method that we can employ to prevent such occurrences is a necessary part of safety in jobs throughout the world. It must be noted that fall protection is a highly specialized field and that it takes more than a degree in structural or mechanical engineering to prepare and engineer to design these complicated systems. There are companies that specialize specifically in this area and who may also offer Qualified Person courses to help prepare the engineer for specialization in fall protection design. Even OSHA states in the Construction Industry Standards, Subpart M, Fall Protection (OHSA, 2011b):

> 1926.502(d)(15) Anchorages used for attachment of personal fall arrest equipment shall be independent of any anchorage being used to support or suspend platforms and capable of supporting at least 5000 lb (22.2 kN) per employee attached, or shall be designed, installed, and used as follows:

1. as part of a complete personal fall arrest system which maintains a safety factor of at least two and
2. under the supervision of a **qualified person**.

A Qualified Person is one who has the necessary training and experience to design such a system considering all the appropriate factors to ensure that the final system meets all OSHA requirements.

Fall protection can be handled in a variety of ways, including:

1) personal fall arrest
2) personal fall restraint
3) safety nets
4) guardrails (Diversified Fall Protection, Ltd, 2012) (Figure 32.10).

The idea, ideally, is to prevent the fall from ever occurring. This is typically done using guardrails, but can also be accomplished through the use of fall restraint. Guardrails are familiar to everyone, but few people know that there are specific design requirements for a guardrail to be considered fall protection. Guardrails must be 42 in high with a mid-rail at ∼21 in. The top rail must be able to support a 200 lb load applied downwards and outwards on the rail. The mid-rail must be able to support a 100 lb load applied outwards. Hence not all railings can be considered guardrails for fall protection. Complete design requirements are outlined in OSHA 29 CFR 1926.502(b) and in 1910.23(e)(5) (OHSA, 2011b, d) as noted below.

Figure 32.10 Permanent hand guard railing in truck dock.

1926.502(b)

Guardrail systems.'' Guardrail systems and their use shall comply with the following provisions:

1926.502(b)(1) Top edge height of top rails, or equivalent guardrail system members, shall be 42 inches (1.1 m) plus or minus 3 inches (8 cm) above the walking/working level. When conditions warrant, the height of the top edge may exceed the 45-inch height, provided the guardrail system meets all other criteria of this paragraph.

Note: When employees are using stilts, the top edge height of the top rail, or equivalent member, shall be increased an amount equal to the height of the stilts.

1926.502(b)(2) Midrails, screens, mesh, intermediate vertical members, or equivalent intermediate structural members shall be installed between the top edge of the guardrail system and the walking/working surface when there is no wall or parapet wall at least 21 inches (53 cm) high.

1926.502(b)(2)(i) Midrails, when used, shall be installed at a height midway between the top edge of the guardrail system and the walking/working level.

1926.502(b)(2)(ii) Screens and mesh, when used, shall extend from the top rail to the walking/working level and along the entire opening between top rail supports.

1926.502(b)(2)(iii) Intermediate members (such as balusters), when used between posts, shall be not more than 19 inches (48 cm) apart.

1926.502(b)(2)(iv) Other structural members (such as additional midrails and architectural panels) shall be installed such that there are no openings in the guardrail system that are more than 19 inches (0.5 m) wide.

1926.502(b)(3) Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890 N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge.

1926.502(b)(4) When the 200 pound (890 N) test load specified in paragraph (b)(3) of this section is applied in a downward direction, the top edge of the guardrail shall not deflect to a height less than 39 inches (1.0 m) above the walking/working level. Guardrail system components selected and constructed in accordance with the Appendix B to subpart M of this part will be deemed to meet this requirement.

1926.502(b)(5) Midrails, screens, mesh, intermediate vertical members, solid panels, and equivalent structural members shall be capable of withstanding, without failure, a force of at least 150 pounds (666 N) applied in any downward or outward direction at any point along the midrail or other member.

1926.502(b)(6) Guardrail systems shall be so surfaced as to prevent injury to an employee from punctures or lacerations, and to prevent snagging of clothing.

1926.502(b)(7) The ends of all top rails and midrails shall not overhang the terminal posts, except where such overhang does not constitute a projection hazard.

1926.502(b)(8) Steel banding and plastic banding shall not be used as top rails or midrails.

1926.502(b)(9) Top rails and midrails shall be at least one-quarter inch (0.6 cm) nominal diameter or thickness to prevent cuts and lacerations. If wire rope is used for top rails, it shall be flagged at not more than 6-foot intervals with high-visibility material.

1910.23(e)(5) (OSHA, 2011d)

1910.23(e)(5)(i) A handrail shall consist of a lengthwise member mounted directly on a wall or partition by means of brackets attached to the lower side of the handrail so as to offer no obstruction to a smooth surface along the top and both sides of the handrail. The handrail shall be of rounded or other section that will furnish an adequate handhold for anyone grasping it to avoid falling. The ends of the handrail should be turned in to the supporting wall or otherwise arranged so as not to constitute a projection hazard.

1910.23(e)(5)(ii) The height of handrails shall be not more than 34 inches nor less than 30 inches from upper surface of handrail to surface of tread in line with face of riser or to surface of ramp.

1910.23(e)(5)(iii) The size of handrails shall be: when of hardwood, at least 2 inches in diameter; when of metal pipe, at least 1 1/2 inches in diameter. The length of brackets shall be such as will give a clearance between handrail and wall or any projection thereon of at least 3 inches. The spacing of brackets shall not exceed 8 feet.

1910.23(e)(5)(iv) The mounting of handrails shall be such that the completed structure is capable of withstanding a load of at least 200 pounds applied in any direction at any point on the rail.

1910.23(e)(6) All handrails and railings shall be provided with a clearance of not less than 3 inches between the handrail or railing and any other object.

Fall restraint also can be used to prevent the fall from occurring. Design requirements for such systems are found in 29 CFR 1926.502(e) (OSHA, 2011b). You can think of fall restraint as a dog leash, the user is held to a fixed distance that prevents falls over a roof edge or other leading edge (Figure 32.11).

In the event that preventing the fall is infeasible, the idea is to stop the fall quickly and avoid serious injury or death. This can be done by using safety nets that will catch a person or object that has fallen, or by using personal fall arrest systems. Each of these has design requirements that are laid out in 29 CFR 1926.502 with fall arrest being the most complex of the controls. There are several components to a fall arrest system:

1) anchorages (Figures 32.12 and 32.13) (Miller by Honeywell, 2012a)
2) lifelines (Figure 32.14) (Miller by Honeywell, 2012b)
3) lanyards (Figures 32.15 and 32.16) (Miller by Honeywell, 2012c)
4) snap hooks and D rings (Figures 32.17 and 32.18) (Miller by Honeywell, 2012d)
5) PPE (Figures 32.19 and 32.20) (Miller by Honeywell, 2012e).

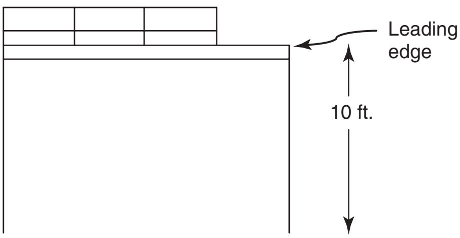

Figure 32.11 Illustration of leading edge.

Figure 32.12 Double D permanent roof anchor.

Figure 32.13 Claw permanent roof anchor.

Figure 32.14 Shock fusion horizontal lifeline roof system.

Figure 32.15 StretchStop lanyards with SofStop shock absorber.

Figure 32.16 Titan stretch tubular built-in shock-absorbing lanyards.

Figure 32.17 Miller snap hook.

Figure 32.18 Miller D ring.

Figure 32.19 Standard revolution full-body harness.

Figure 32.20 Revolution construction harness.

Each of these components has specific design and testing criteria that must be met in order to be compliant. Extensive criteria are outlined in 29 CFR 1926.502(d) (OSHA, 2011b) and ANSI/ASSE Z359 (ANSI, 2011b). The ANSI standard, although it is not enforceable under law, provides the most thorough and up-to-date criteria and is being voluntarily adopted by many people in the design of their fall arrest systems. The standards are not easily learned and have very detailed requirements in order to assure that a person who has experienced a fall will be stopped, mid-fall, and not suffer serious injury. This explains the need for specialization in fall protection design.

32.3.2
Guards

Industrial operations often employ the use of various machines, including such things as presses, furnaces, metal cutters, and others. Industrial machines present potential hazards that can result in serious or fatal injury to operators. For this reason, there are various types of machine guards that can be installed to keep operators away from points of operations and moving parts.

One method of guarding is to use devices known as light curtains to keep operators away from the machine's operating points and moving parts. These work by creating a curtain of light beams between stanchions set around the perimeter of the machine. When the light beams are on and uninterrupted, the machine is able to be operated. However, the slightest interruption in any of the beams will immediately shut down machine operation, thereby preventing an operator from contacting any operating parts, and preventing injury. Illustrations are shown in Figures 32.21 and 32.22.

Figure 32.21 Light curtain guard (ThomasNet, 2012).

Figure 32.22 How light curtains work (Machine Guard Solutions, 2012).

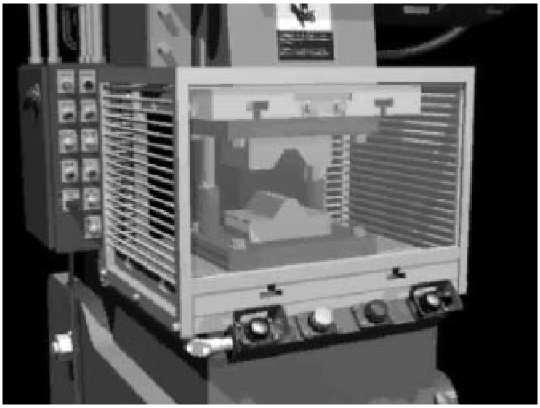

Figure 32.23 Barrier guard (OSHA, 2012a).

Another means of guarding is the use of barrier guards. These guards surround the point of operation or moving part to keep body parts and unwanted materials away from these areas. Lexan is a type of material used to construct such guards; however, as seen in Figure 32.23, wire, rods, or other solid material could be used to construct the guard as long as its strength and position are sufficient to keep unwanted things away from potential hazardous areas.

A third means of guarding is referred to as a pull-out or pull-back device. These devices operate with the machine to pull limbs away from the point of operation when it is engaged. Wrist straps are placed on both arms and these straps are tied back to a mechanical arm or lever that activates when the machine is initiated and pulls the hands away from the moving part. An example of a pullback device as shown on the OSHA website is shown in Figure 32.24. These devices are similar to positioning devices that are used for the same purpose. However, positioning devices hold the arms in a given area and will not allow the operator to reach into the machine.

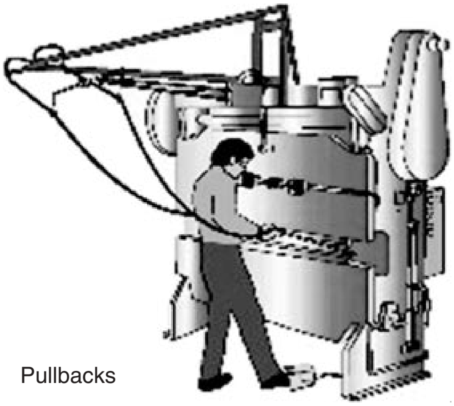

Figure 32.24 Pull-back device (OSHA, 2012b).

Finally, hazards can be guarded by additional means such as interlocks (Figure 32.25) and machine design. Interlocks are wired into the machine and the guard. When the guard opens or is removed from the point of operation, the interlock opens circuits to prevent machine operations until the guard is returned to a safe position.

Machines can also be designed in such a way that operating switches are placed far enough away from the point of operation that the operator must leave the operating area in order to initiate machine operation.

Despite the best efforts of designers and safety professionals, guards can fail or be defeated and rendered ineffective. To address this problem, emergency stop buttons (e-stops) should be placed so that the operator or another employee can find and hit the button easily, causing the machine to cease action immediately.

Figure 32.25 Barrier guard with interlock switch (Edson, 2012).

32.3.3 Ventilation

Ventilation is a means of controlling particulate and gaseous concentrations in the ambient air. Ventilation can be handled in one of two ways, general dilution ventilation and local exhaust ventilation (LEV). Dilution ventilation is accomplished by controlling the exchange of air in and out of the building (Figure 32.26). Calculations are done to determine the precise flow needed thorough air intakes and outlets. Fresh air coming through intakes and chemical vapor concentrations being exhausted result in the maintenance of safe ambient air concentrations within the workplace.

LEV is a means of attempting to capture the contaminant at its source. The basic premise is demonstrated in Figure 32.27.

LEV, also referred to as point source capture, is installed directly where the work is taking place and in such a way as to draw any fume, gas, or particulates away from the worker's breathing zone. The reader may recall this from laboratory hoods from high school or college chemistry courses. The hood was activated and exhausted any vapors emitted by the chemicals in order to maintain safe ambient air in a person's breathing zone. Industrial LEV works in a similar fashion to exhaust air at the source of contamination, away from the breathing zone, thereby preventing exposure to potentially harmful gas, vapor, or fumes.

Both types of ventilation result in the control of hazardous materials that could be inhaled by personnel. The type chosen will depend on the hazards present, the level of exposure, the size of the work environment, and other factors that help determine the most efficient and feasible means of controlling exposure to contaminants. For example, if welding is being used in a 100 ft^2 area located within a 10000 ft^2 facility, it probably makes sense to use LEV as the area to be controlled

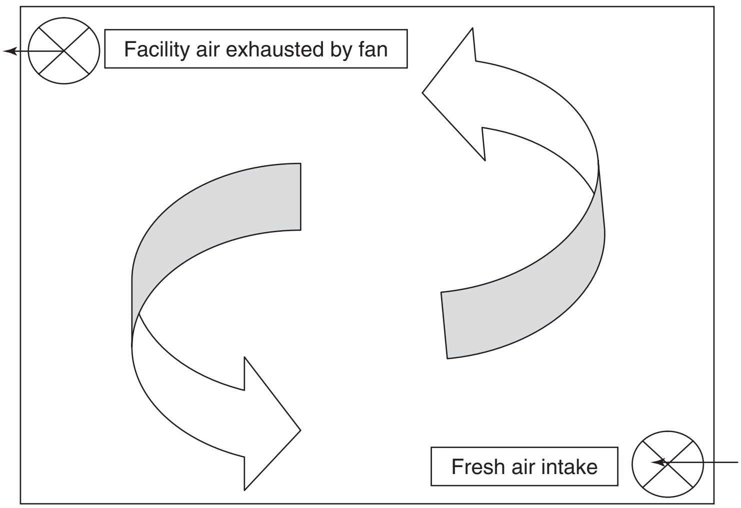

Figure 32.26 General dilution ventilation.

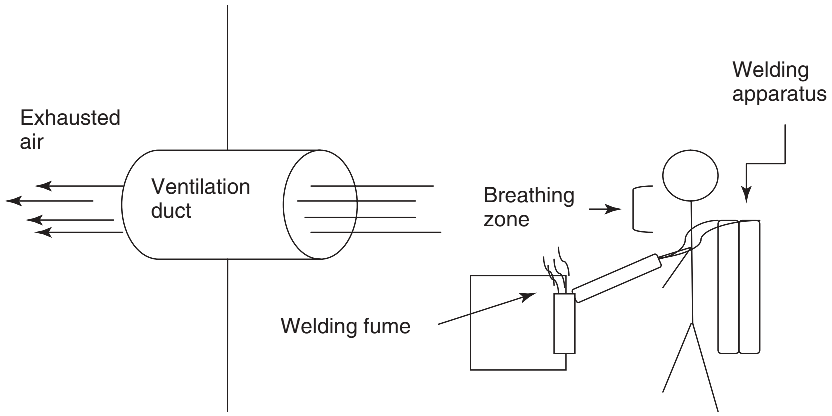

Figure 32.27 Local exhaust ventilation.

is localized to the welding operation and LEV can be designed to maintain safe air concentrations within the work area. This is done by sizing fans to achieve the appropriate number of cubic feet per minute at which a given contaminant will be captured and exhausted.

32.3.4 Lockout/Tagout

In the discussion of the hierarchy of controls, administrative controls were defined. As an example, lockout/tagout procedures were introduced. Lockout/tagout is a procedure by which workers can de-energize machines, rendering them safe to work on. Essentially it results in the isolation of all energy to the machine. To review, the six recognized sources of energy are:

1) electrical
2) mechanical
3) chemical
4) pneumatic
5) hydraulic
6) thermal.

These power sources are used to activate points of operation and other moving parts, parts that when in motion can pose an injury hazard to anyone working on the machine. Therefore, it is necessary to isolate the energy sources in order to prevent operation and avoid injury.

Remember that lockout/tagout is a procedure and therefore an administrative control which means that it must be used alongside other protections such as PPE. It is interesting to note that this is an administrative control, that is, actually required by law in the United States. OSHA 29 CFR 1910.147(c)(1) (OHSA, 2011f) states:

> *Energy control program.* The employer shall establish a program consisting of energy control procedures, employee training and periodic inspections to ensure that before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, startup or release of stored energy could occur and cause injury, the machine or equipment shall be isolated from the energy source and rendered inoperative.

In industry, there are a variety of devices available to employers for locking out different forms of energy. Some examples are shown in Figures 32.28–32.31.

By creating these procedures, employers protect their employees from unexpected injury and potentially even death. However, as noted earlier, procedures have the problem of relying on people to use them and to use them properly. So how does the design engineer fit in here? Design engineers should be aware of requirements for this procedure and be sure to design machines and work areas so that the energy source cut-offs are easily accessible by employees. The engineer taking the time to consider access for lockout will help to encourage people to use the procedure as intended and therefore reduce the risk of injury.

32.3.5
Layout

Working closely with consideration for lockout/tagout is consideration of the overall layout of machinery and equipment within the facility walls. Figure 32.32 shows a facility with four machines laid out along one wall. Each machine is powered by electricity and is plugged in behind the machine. These machines will need to be unplugged and lockout devices applied to the plugs to isolate the energy source. In the layout given, getting to the plugs is difficult as there is not enough room for a person to maneuver around the machine. Therefore, personnel may decide

Figure 32.28 Universal circuit breaker lockout device (DeEnergize, 2012a).

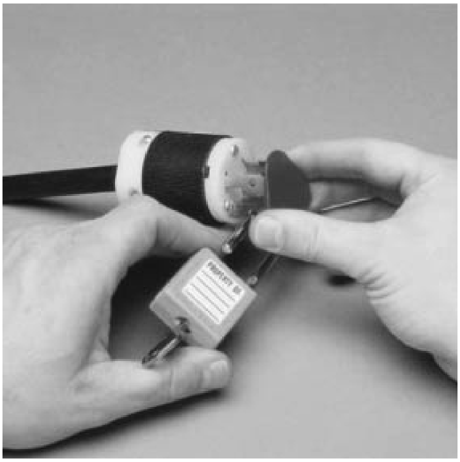

Figure 32.29 Universal plug lockout device (DeEnergize, 2012b).

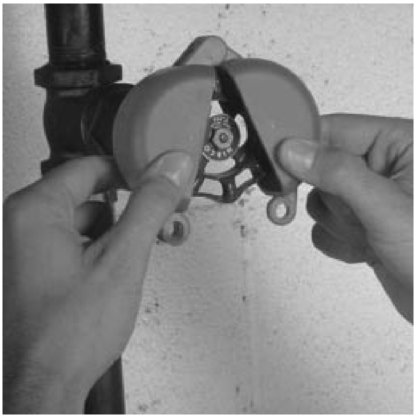

Figure 32.30 Gate valve lockout device (DeEnergize, 2012c).

not to bother with lockout and leave the machine energized while conducting maintenance activities. This will present an injury hazard should electricity contact the employee or someone start the machine because they do not know someone is working on it.

However, if the layout is changed to that shown in Figure 32.33, access is easier and the chance of employees adhering to the procedures and not taking short-cuts is improved. In this layout, employees have room to move around and behind the machinery so that all energy sources can be accessed and locked out.

Consideration of facility layout is important in order to assure a few aspects:

1) Room to run wire without overloading or creating wire bundles.
2) Room to move around electric junction boxes so that electricity does not arc to nearby equipment.

Figure 32.31 Pneumatic disconnect lockout (DeEnergize, 2012d).

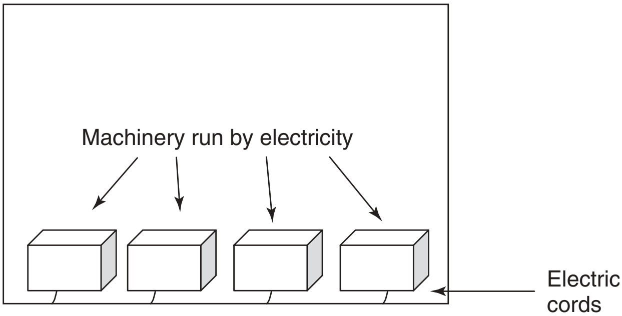

Figure 32.32 Tool room layout of machines run by electricity.

3) Room to provide for ample storage so that exits, aisles, machinery, and junction boxes are not blocked.

Assuring that ample room is planned for in design will therefore improve safety by reducing risks. Risks such as trip hazards, blocked exits, overloaded circuits, and confinement of personnel in tight spaces can all be avoided and thereby the potential injuries that might accompany these hazards.

32.3.6
Sensors

Sensors can be used to monitor the surrounding work environment for given hazards. Monitoring is generally the task of an industrial hygienist's (IH), but it can be incorporated into facilities with the help of an IH and using sensors. Sensors can be placed in key locations and set to monitor the surrounding environment for infiltration by contaminants. These would be similar to continuous air monitors such as the carbon monoxide monitors found in many homes.

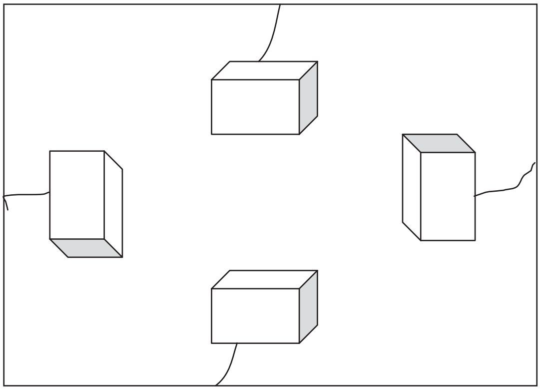

Figure 32.33 Improved tool room layout of machines run by electricity.

The purpose of monitoring is to keep abreast of the concentrations in a work area, which allows actions to be taken when concentrations reach flammability or personal exposure limits. These limits are levels that will be researched when preparing the design. Use of this type of control also requires the use of, or potential immediate access to, PPE and would therefore be a last-resort control. Monitoring should never be used as the sole or primary control for contaminant infiltrate hazards and exposures, but is a suitable means to check how engineering controls are performing.

32.4 Conclusion

A fair amount of information to aid in facility and equipment design and assurance of a safe work environment has been discussed in this chapter. However, this is only a brief sample of what can be learned regarding each of the topics.

It is the job of the project design engineer not only to create practical, effective, and efficient machinery, equipment, and facilities but also to construct such items so that they will not cause harm to people, property, or the environment. In this case, it is advisable for project design engineers to familiarize themselves with safety standards and regulations. It is also strongly advised that project design engineers actively pursue prevention through design by involving safety and environmental, professionals for the life of the project and beyond. The earlier in design that potential problem are caught, the easier it will be to correct them and the loss prevention engineer or safety professional will be able to aid in doing just that.

A project design engineer will not be expected to be an expert on safety and the regulations regarding safety, but will be expected to deliver a product that will not cause loss prevention-related concerns for the company. In designing machinery, equipment, and facilities, the design engineer must be thorough and carefully research the components and function of the end product; by doing so, the design engineer and the design team will build safe and effective products for accomplishing any number of tasks.

References

ANSI (American National Standards Institute) (2011a) ANSI/ASSE A10.1-2011. *Pre-Project and Pre-Task Safety and Health Planning*, ASSE, Des Plaines, IL.

ANSI (American National Standards Institute) (2011b) ANSI/ASSE Z359. *Fall Protection Codes*, ASSE, Des Plaines, IL.

ANSI (American National Standards Institute) (2011c) ANSI/ASSE Z590.3-2011. *Prevention Through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes*, ASSE, Des Plaines, IL, p. 24.

ANSI (American National Standards Institute) (2011d) ANSI A10.31-2011. *Safety Requirements for Steel Erection*, ASSE, Des Plaines, IL.

ANSI (American National Standards Institute) (2011e) ANSI/ASSE A10.26-2011. *Emergency Procedures for Construction and Demolition Sites*, ASSE, Des Plaines, IL.

Answerbag.com (2012) What Temperature Will Burn Skin?, *http://www.answerbag.com/q_view/2098645* (last accessed 21 February 2012).

ASME (American Society of Mechanical Engineers) (ASME, (2009a) ASME Y14.5-2009. *Geometric Dimensioning and Tolerancing*, ASME, New York, NY.

ASME (American Society of Mechanical Engineers) (ASME, (2009b) ASME B30.27-2009. *Material Placement Systems*, ASME, New York, NY.

ASME (American Society of Mechanical Engineers) (ASME, (2003) ASME B5.52-2003. *Power Presses: General Purpose, Single-Point Gap Type*, ASME, New York, NY.

BoilerSupplies.com (2012) Chain Wheels by Babbit Steam Supply, *http://www.boilersupplies.com/feature/chainwheel.html* (last accessed 21 February 2012).

Christensen, W.C. and Manuele, F.A. (1999) *Safety Through Design*, National Safety Council, Itasca, IL, pp. 227–239.

DeEnergize (2012a) Universal Circuit Breaker Lockout Device (PSL-CB), *http://www.deenergize.com/?target=Universal_Circuit_Breaker_Lockout_Device_(PSL-CB)* (last accessed 16 March 2012).

DeEnergize (2012b) Universal Plug Lockout Device (PSL-P), *http://www.deenergize.com/?target=Universal_Plug_Lockout_Device_(PSL-P)* (last accessed 16 March 2012).

DeEnergize (2012c) Gate Valve Lockout Devices, *http://www.deenergize.com/?target=Gate_Valves* (last accessed 16 March 2012).

DeEnergize (2012d) Pneumatic Disconnect Lockout Devices, *http://www.deenergize.com/?target=Pneumatic_Disconnects* (last accessed 16 March 2012).

Diversified Fall Protection Ltd (2012) OSHA Compliant Portable Guardrail Systems, *http://www.fallprotect.com/guardrails.html* (last accessed 21 February 2012).

Edson (2012) Safety Guarding, *http://www.edson.com/guarding_safety/index.html* (last accessed 16 March 2012).

eNoise Control, Inc. (2012) Sound Enclosures, *http://www.enoisecontrol.com/sound-enclosures.html* (last accessed 21 February 2012).

Global Industrial (2012) Energy Saving Strip Curtains & Strip Dock Doors, *http://www.globalindustrial.com/g/material-handling/dock-truck/doors-strip/energy-saving-strip-curtains-strip-dock-doors* (last accessed 21 February 2012).

Hankin Specialty Equipment (2012) What is an Air Curtain?, *http://www.hankinspecialty.com/aircurtain.html* (last accessed 21 February 2012).

Industrial Noise Control, Inc. (2010) Noise and Vibration Damping Materials. *http://www.industrialnoisecontrol.com/materials/damping-materials.htm* (last accessed 21 February 2012).

Machine Guard Solutions (2012) Light Curtains and Machine Guards, *http://www.*

machineguardsolutions.com/ (last accessed 21 February 2012).

Miller by Honeywell (2012a) Permanent Roof Anchors, *http://www.millerfallprotection.com/fall-protection-products/roofing-products/permanent-roof-anchors-3* (last accessed 21 February 2012).

Miller by Honeywell (2012b) Shockfusion Horizontal Lifeline Roof System, *http://www.millerfallprotection.com/fall-protection-products/horizontal-lifeline-systems/shockfusion-horizontal-lifeline-roof-system* (last accessed 21 February 2012).

Miller by Honeywell (2012c) Shock Absorbing Lanyards, *http://www.millerfallprotection.com/fall-protection-products/connecting-devices/shock-absorbing-lanyards* (last accessed 21 February 2012).

Miller by Honeywell (2012d) Miller Turbolite Personal Fall Limiters, *http://www.millerfallprotection.com/fall-protection-products/fall-limiters-self-retracting-lifelines/miller-turbolite-personal-fall-limiters-2* (last accessed 21 February 2012).

Miller by Honeywell (2012e) Harness Accessories, *http://www.millerfallprotection.com/fall-protection-products/body-wear/harness-accessories* (last accessed 21 February 2012).

Miller by Honeywell (2012f) Full Body Harnesses, *http://www.millerfallprotection.com/fall-protection-products/body-wear/full-body-harnesses* (last accessed 21 February 2012).

Munster Insulation (2012) Class 'O' Armaflex Selfseal Pipe Section, *http://munsterinsulation.ie/industrial-products/nitrile-rubber-products/class-o-armaflex-selfseal-pipe-section/index.html* (last accessed 25 April 2012).

OSHA (Occupational Safety and Health Administration) (2010) 29 CFR 1910, *OSHA General Industry Standards*, OSHA, Washington, DC, pp. 433–440.

OSHA (Occupational Safety and Health Administration) (2011a) 29 CFR 1910.1000, *Air Contaminants*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9991* (last accessed 25 April 2012).

OSHA (Occupational Safety and Health Administration) (2011b) 29 CFR 1926.502, *Fall Protection Systems Criteria and Practices*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10758* (last accessed 21 February 2012).

OSHA (Occupational Safety and Health Administration) (2011c) 29 CFR 1910.24, *Fixed Industrial Stairs*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9716* (last accessed 21 February 2012).

OSHA (Occupational Safety and Health Administration) (2011d) 29 CFR 1910.23, *Guarding Floor and Wall Openings and Holes*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9715* (last accessed 21 February 12).

OSHA (Occupational Safety and Health Administration) (2011e) 29 CFR 1910.146, *Permit-Required Confined Spaces*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9797* (last accessed 21 February 2012).

OSHA (Occupational Safety and Health Administration) (2011f) 29 CFR 1910.147, *The Control of Hazardous Energy (Lockout/Tagout)*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9804* (last accessed 21 February 2012).

OSHA (2012a) Machine Guarding eTool: Barrier Guards, *http://www.osha.gov/SLTC/etools/machineguarding/presses/barrierguards.html* (last accessed 16 March 2012).

OSHA (2012b) Machine Guarding eTool: Pullbacks/Pullouts, *http://www.osha.gov/SLTC/etools/machineguarding/presses/pullbacks.html* (last accessed 16 March 2012).

ThomasNet (2012) Safety Light Curtains Perform Complex Machine Guarding, *http://news.thomasnet.com/fullstory/Safety-Light-Curtains-perform-complex-machine-guarding-516470* (last accessed 16 March 2012).

Warmup, Inc. (2011) Electric In Slab Floor Heating System, *http://www.warmup.com/us/cable-in-slab-heating-system.phtml* (last accessed 21 February 2012).