CHAPTER 14

HIERARCHY OF CONTROLS: SECTION 5.1.2 OF Z10

Section 5.1.2 of ANSI/AIHA Z10-2012, the *Occupational Health and Safety Management Systems* standard, deals with the hierarchy of controls. The opening sentence in that section states: "The organization shall establish and implement a process for achieving feasible risk reduction based on the following order of controls." A prescribed hierarchy of controls immediately follows that provision.

The hierarchy in Z10 is the base for decision making when action is taken to resolve occupational health and safety issues. Those issues are "defined as hazards, risks, management system deficiencies, and opportunities for improvement," as in the Planning Section (4.0).

Application of a hierarchy of controls is of such importance that a separate chapter is devoted to it. Thus, in this chapter we:

- Comment on the evolution of hierarchies of control
- Discuss the hierarchy of controls in Z10
- Provide guidelines on the application of a hierarchy of controls
- Establish the logic of taking steps in the hierarchy of controls in the order given
- Place the hierarchy of controls within a good problem-solving techniques, as in The Safety Decision Hierarchy

Advanced Safety Management: Focusing on Z10 and Serious Injury Prevention,
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EVOLUTION OF THE HIERARCHY OF CONTROLS

Z10's hierarchy of controls has six elements. Hierarchies in other published standards and guidelines have three to nine elements. Z10's hierarchy of controls is the outcome of the work of a large number of safety professionals over many years. All of the contributors cannot be recognized here. A limited review of the evolution of the hierarchy of controls follows.

AT THE NATIONAL SAFETY COUNCIL

The third edition of the National Safety Council's *Accident Prevention Manual* was published in 1955. Section 4, "Removing the Hazard from the Job," provides a three-step "order of effectiveness and preference," This is taken from the *Accident Prevention Manual*.

> The engineer should include in his planning and follow-through such measures as will attain one of the accident prevention goals listed as follows (in the order of effectiveness and preference):
>
> - Elimination of the hazard from the machine, method, material, or plant structure.
> - Guarding or otherwise minimizing the hazard at its source if the hazard cannot be eliminated.
> - Guarding the person of the operator through the use of personal protective equipment if the hazard cannot be eliminated or guarded at its source. (p. 4–1)
>
> Company policies should be such that safety can be designed and built into the job rather than added after the job has been put into operation.

Establishing the concept that risk reduction actions should be taken in an order of effectiveness and preference was an important step in the evolution of the practice of safety. It implies that some steps in the process are preferable since they achieve greater risk reduction than others. Declaring that safety policies should require that safety be designed and built into the job rather than be dealt with as an add-on is also a premise that influenced later versions of hierarchies of control.

THE COUNCIL OF THE EUROPEAN COMMUNITIES

Although the excerpts taken from the Directive issued in 1989 on workplace safety by the Council of the European Communities are not labeled a hierarchy of controls, that's what they are: a nine-element list of "principles of prevention." It is intriguing

of individuals, gives prominence to the design of the workplace and the choice of work equipment; and advises employers "to take account of changing circumstances and aim to improve existing situations."

The full title of the bulletin is "Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work." It is available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31989L0391:en:HTML.

The following general obligations on employers is from Article 6.

1. Within the context of his responsibilities, the employer shall take the measures necessary for the safety and health protection of workers, including prevention of occupational risks and provision of information and training, as well as provision of the necessary organization and means. The employer shall be alert to the need to adjust these measures to take account of changing circumstances and aim to improve existing situations.
2. The employer shall implement the measures referred to in the first subparagraph of paragraph 1 on the basis of the following general principles of prevention:
   a. avoiding risks;
   b. evaluating the risks which cannot be avoided:
   c. combating the risks at source;
   d. adapting the work to the individual, especially as regards the design of work places, the choice of work equipment and the choice of working and production methods, with a view, in particular, to alleviating monotonous work and work at a predetermined work-rate and to reducing their effect on health.
   e. adapting to technical progress;
   f. replacing the dangerous by the non-dangerous or the less dangerous;
   g. developing a coherent overall prevention policy which covers technology, organization of work, working conditions, social relationships and the influence of factors related to the working environment;
   h. giving collective protective measures priority over individual protective measures;
   i. giving appropriate instructions to the workers.

ANSI/PMMI B155.1-2011

The Packaging Machinery Manufacturers Institute is the secretariat for the standard *Safety Requirements for Packaging Machinery and Packaging-Related Converting Machinery*. A revision of B155.1 was approved by ANSI in 2011. It replaced a version issued in 2006. In effect, this is an eight-element process within three classifications.

lecting the most appropriate risk reduction measures, apply the following
iples in the order in which they appear.

lassification—Design Out
Elimination or substitution
lassification—Engineering Controls
Guards and safeguarding devices
lassification—Administrative Controls
Awareness devices
Training and procedures
Personal protective equipment

hierarchy of controls repeats the elements in the hierarchies in other standards,
e close to the provisions in MIL-STD-882E, comments for which follow.

TD-882E-2012

partment of Defense *Standard Practice For System Safety, MIL-STD-882*, issued
, was a seminal document at that time. Four revisions of 882 have been issued
pan of 43 years. This standard has had considerable influence on the development
assessment, elimination, and amelioration concepts and methods. Much of the
g on risk assessments and hierarchies of control in safety standards and guide-
sued throughout the world is comparable to that in the several versions of 882.
fifth edition, issued in May 2012, is designated MIL-STD-882E. It is available
Internet at http://www.systemsafetyskeptic.com/yahoo_site_admin/assets/
IL-STD-882E_final.135152939.pdf. It can be downloaded at no cost. Scroll
nd click on the 882E indicator on the right-hand side.
system safety design order of precedence" is outlined in 882E. *Precedence*
priority in order, rank, or importance. In 882D, the design order of preference
ir elements. This latest version has five. (p. 13)

system safety design order of precedence identifies alternative mitigation
roaches and lists them in order of decreasing effectiveness.

Eliminate hazards through design selection.
Reduce risk through design alteration.
Incorporate engineered features or devices.
Provide detection and warning devices.
Incorporate signage, procedures, training, and PPE.

ruction is given in 882E to assure that:

Mitigation measures, if necessary, are selected and implemented to achieve an
cceptable risk level.
Implementation measures are evaluated to verify that they have achieved the
isk reduction expected.

HIERARCHIES OF CONTROL: PREMISES AND GOALS

A *hierarchy* is a system of persons or things ranked one above the other. The hierarchy of controls in Z10 is to provide a systematic way of thinking, considering steps in a ranked and sequential order, to choose the most effective means of eliminating or reducing hazards and the risks that derive from them. Acknowledging that premise, that risk reduction measures should be considered and taken in a prescribed order, represents an important step in the evolution of the practice of safety.

A model of hierarchies of control may give examples of the types of actions to be taken for each of its elements, as does Appendix G in Z10. But little is written about the purpose and the goals to be achieved in applying a hierarchy of controls. An attempt to do so follows.

A major premise to be considered in applying a hierarchy of controls is that the outcome of the actions taken is to be an acceptable risk level, defined as follows.

> Acceptable risk is that risk for which the probability of a hazard-related incident or exposure occurring and the severity of harm or damage that could result are as low as reasonably practicable in the situation being considered.

That definition requires taking into consideration each of the two distinct aspects of risk as risk reduction actions are decided upon:

- Avoiding, eliminating, or reducing the *probability* of a hazard-related incident or exposure occurring
- Reducing the *severity* of harm or damage that may result if an incident or exposure occurs

The definition of acceptable risk also requires reflection on the feasibility and effectiveness of the risk reduction measures to be taken and their costs in relation to the amount of risk reduction to be achieved. The following appears in the "shall" column as a part of section 5.1.2 of Z10.

> Feasible applications of this hierarchy of controls shall take into account:
>
> - The nature and extent of the risks being controlled
> - The degree of risk reduction desired
> - The requirements of applicable local, federal and state statutes, standards, and regulations
> - Recognized best practices in industry
> - Available technology
> - Cost effectiveness
> - International organization standards

Decision makers should understand that with respect to the six levels of action

> The ameliorating actions described in the first, second, and third action levels are more effective because they
>
> - Are *preventive* actions that eliminate or reduce risk by design, substitution, and engineering measures
> - Rely the least on personnel performance
> - Are less defeatable by supervisors or other employees
>
> Actions described in the fourth, fifth, and sixth levels are *contingent* actions and rely greatly on the performance of personnel.

What Kepner and Tregoe wrote in *The New Rational Manager* about taking preventive and contingent actions in the problem-solving process fits precisely with the risk elimination and amelioration concepts set forth here.

> Two kinds of actions are available to anyone conducting a Potential Problem Analysis: preventive actions and contingent actions. The effect of preventive actions is to remove, partially or totally, the likely cause of a potential problem.
>
> The effectiveness of a contingent action is to reduce the impact of a problem that cannot be prevented. Preventive actions, if they can be taken, are obviously more efficient than contingent actions. (p. 147)

As decisions are made in applying each step in the hierarchy of controls, the following should be considered as goals:

- Avoiding work methods that are overly stressful, taking into consideration worker capabilities and limitations
- Keeping the probability of human error as low as reasonably practicable by designing workplaces and work methods that are not error-provocative, meaning that they do not (as in Chapanis, p. 119):
  - Violate operator expectations
  - Require performance beyond what an operator can deliver
  - Induce fatigue
  - Provide adequate facilities or information for the operator
  - Present unnecessarily difficult or unpleasant requirements
  - Include unnecessarily dangerous methods
- Designing systems so that human interaction with equipment and processes is as low as reasonably practicable
- Designing systems so that use of personal protective equipment is as low as reasonably practicable

THE HIERARCHY OF CONTROLS IN Z10

We said in Chapter 1 that although Z10 is a management system standard and not a specification standard, the provisions pertaining to a hierarchy of controls are the exception. Rather than present a performance statement relating to the outcomes to be achieved through a risk reduction process, a specifically defined hierarchy of controls is outlined in section 5.1.2.

> The organization shall establish a process for achieving feasible risk reduction based upon the following preferred order of controls:
>
> A. Elimination
> B. Substitution of less hazardous materials, processes, operations, or equipment
> C. Engineering controls
> D. Warnings
> E. Administrative controls
> F. Personal protective equipment

This hierarchy of controls contains six elements. The first step, Elimination, is separated from the Substitution element. In reality, undertaking separate processes is required to accomplish what is needed. Those subjects were combined in some hierarchies issued previously.

THE LOGIC OF TAKING ACTION IN THE DESCENDING ORDER GIVEN

Comments follow on each of the action elements listed in Z10's hierarchy of controls, including the rationale for the listing in the order given. Taking actions as *feasible and practicable* in the prescribed order is the most effective means to achieve risk reduction.

A. Elimination

Use of the term *elimination* as the first step in applying a hierarchy of controls is a bit simplistic. My experience requires that it be replaced with such as: "Eliminate or reduce hazards and risks through system design and redesign." (In Chapter 16, "Prevention through Design", Avoidance precedes Elimination.)

The theory is stated plainly. If the hazards are eliminated in the design and redesign processes, risks that derive from those hazards are also eliminated. But the complete elimination of hazards by modifying the design may not always be practicable. Then the goal is to modify the design, within practicable limits, so as to limit the:

- Probability of personnel making human errors because of design inadequacies
- Ability of personnel to defeat the work system and the work methods prescribed

Examples include designing to eliminate or reduce the risk from:

- Fall hazards
- Ergonomic hazards
- Confined-space hazards
- Noise hazards
- Chemical hazards.

Obviously, hazard elimination or reduction is the most effective way to remove or reduce risk. If a hazard is eliminated or reduced, the need to rely on worker behavior to avoid risk is diminished.

B. Substitution of Less Hazardous Materials, Processes, Operations, or Equipment

Methods that illustrate substituting less hazardous methods, materials, or processes for that which is more hazardous include:

- Using automated material-handling equipment rather than manual material handling
- Providing an automatic feed system to reduce machine hazards
- Using a less hazardous cleaning material
- Reducing speed, force, amperage
- Reduce pressure, temperature
- Replacing an ancient steam-heating system and its boiler explosion hazards with a hot-air system

Substitution of a less hazardous method or material may or may not result in equivalent risk reduction in relation to what might be the case if the hazards and risks were reduced to an acceptable level through system design or redesign.

Consider this example. Considerable manual material handling is often necessary in a mixing process for chemicals. A reaction takes place and an employee sustains serious chemical burns. There are identical operations at two of the company's locations. At one location, a decision is made to redesign the operation so that it is completely enclosed, fed automatically, and operated by computer from a control panel, thus greatly reducing operator exposure.

At the other location, funds for doing the same were not available. To reduce the risk, a substitution took place in this manner:

- It was arranged for the supplier to premix the chemicals before shipment.
- Some mechanical feed equipment for the chemicals was also installed.

The risk reduction achieved by substitution was not equivalent to that attained by redesigning the operation.

C. Engineering Controls

access to a hazard by workers. They are to separate hazardous energy from the worker and deter worker error. They include such devices as:

- Machine guards
- Interlock systems
- Circuit breakers
- Startup alarms
- Presence-sensing devices
- Safety nets
- Ventilation systems
- Sound enclosures
- Fall-prevention systems
- Lift tables, conveyors, and balancers

D. Warnings [Warning Systems]

Warning system effectiveness, and the effectiveness of instructions, signs, and warning labels, rely considerably on administrative controls, such as training, drills, the quality of maintenance and human reaction capabilities. Further, although vital in many situations, warning systems may be reactionary in that they alert persons only after a hazard's potential is in the process of being realized (e.g., a smoke alarm). Examples are:

- Smoke detectors
- Alarm systems
- Backup alarms
- Chemical detection systems
- Signs
- Alerts in operating procedures or manuals

A comment is necessary on my preferred use of the term *warning systems* rather than *warnings* or *warning signs*. The latter terms appear in some published hierarchies of control, as in Z10. The entirety of the needs of a warning system must be considered, for which warning signs or warning devices alone may be inadequate.

For example, the NFPA Life Safety Code 101 may require, among other things, detectors for smoke and products of combustion; automatic and manual audible and visible alarms; lighted exit signs; designated, alternate, properly lit exit paths; adequate spacing for personnel at the end of the exit path; proper hardware for doors; and emergency power systems. Obviously, much more than merely "Warnings" is needed.

E. Administrative Controls

Administrative controls rely on the methods chosen being appropriate in relation to the needs, the capabilities of people responsible for their delivery and application, the

- Personnel selection
- Developing appropriate work methods and procedures
- Training
- Supervision
- Motivation, behavior modification
- Work scheduling
- Job rotation
- Scheduled rest periods
- Maintenance
- Management of change
- Investigations
- Inspections

Achieving a superior level of effectiveness in all of these administrative methods is difficult, and not often attained.

F. Personal Protective Equipment

The proper use of personal protective equipment relies on an extensive series of supervisory and personnel actions, such as the identification of the type of equipment needed, its selection, fitting, training, inspection, maintenance, and so on. Examples include:

- Safety glasses
- Face shields
- Respirators
- Welding screens
- Safety shoes
- Gloves
- Hearing protection.

Although the use of personal protective equipment is common and necessary in many occupational situations, it is the least effective method to deal with hazards and risks. Systems put in place for their use can easily be defeated. In the design process, one of the goals should be to reduce reliance on personal protective equipment to as low a level as practicable.

APPLICATION OF THE HIERARCHY

For many risk situations, a combination of the risk management methods shown in the hierarchy of controls is necessary to achieve acceptable risk levels. But the expectation is that consideration will be given to each of the steps in a descending

order, and that reasonable attempts will be made to eliminate or reduce hazards and their associated risks through steps higher in the hierarchy before lower steps are considered. A lower step in the hierarchy of controls is not to be chosen until practical applications of the preceding level or levels are exhausted.

ATTACHING THE HIERARCHY OF CONTROLS TO PROBLEM-SOLVING TECHNIQUES

The following observations are a reflection of my experience: encompassing the design and engineering, the operational, the post-incident, and the post-operational aspects of the practice of safety:

- Safety practitioners often recommend solutions to resolve hazard/risk situations before they define the problem: that is, before they identify the specifics of the hazards and assess the associated risks
- Rarely are safety management systems in place to determine whether the preventive actions taken achieve the risk reduction intended

Those observations led to research into the feasibility of encompassing the hierarchy of controls within a sound problem-solving technique which:

- Begins with problem identification and analysis
- Requires measurement of results of the actions taken to determine their effectiveness
- Necessitates taking further preventive measures if the residual risk is not acceptable

The initial step in this research was to review what is proposed in several texts regarding the basics of problem solving. The problem-solving methods the authors propose have great similarity. A composite of those techniques is presented in Table 14.1.

In every problem-solving method reviewed, the first steps are to identify and analyze the problem. Also, they end with a provision requiring that evaluations be made of the effects of the actions taken. Figure 14.1, the Safety Decision Hierarchy, presents a logical sequence of actions that safety professionals should consider in resolving safety issues: identify and analyze the problem; consider the possible solutions; decide on and implement an action plan; and determine whether the actions taken achieved the intended risk reduction results.

TABLE 14.1 Problem-Solving Methodology

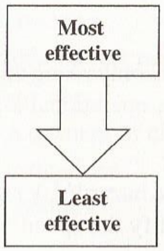
1. Identify the problem.
2. Analyze the problem.
3. Explore alternative solutions.
4. Select a plan and take action.
5. Examine the effects of the actions taken.

The Safety Decision Hierarchy

A. Problem identification and analysis:

1. Identify and analyze hazards.
2. Assess the risks.

B. Consider these actions in their order of effectiveness:



1. Avoid, eliminate, or reduce risks in the design processes.
2. Reduce risks by substituting less hazardous methods or materials.
3. Incorporate safety devices.
4. Provide warning systems.
5. Apply administrative controls (work methods, training, etc.).
6. Provide personal protective equipment.

C. Select risk-reduction measures and implement them.

D. Measure for effectiveness.

E. Accept the residual risk, or start over if it is unacceptable.

FIGURE 14.1 The Safety Decision Hierarchy

The safety decision hierarchy depicts a way of thinking about hazards and risks and establishes an effective order for risk avoidance, elimination, or amelioration. Why propose that safety professionals adopt a safety decision hierarchy? This quote from *The New Rational Manager*, reflecting the real-world observations of Kepner and Tregoe in dealing with many clients, makes the case:

> The most effective managers, from the announcement of a problem until its resolution, appeared to follow a clear formula in both the orderly sequence and the quality of their questions and actions. (p. vii)

It makes sense to apply a safety decision hierarchy encompassing methods in an orderly sequence of effectiveness to resolve safety issues.

ON PROBLEM IDENTIFICATION AND ANALYSIS

In utilizing the safety decision hierarchy, the goal in the problem identification and analysis phase is to identify and analyze the hazards and assess the risks. Hazard and risk situations cannot be dealt with intelligently until the hazards are analyzed and assessments are made of the probability of incidents or exposures occurring and the severity of their consequences are estimated.

Chapter 11, "A Primer on Hazard Analysis and Risk Assessment," is a resource for this problem identification and analysis phase.

EXPLORING ALTERNATIVE SOLUTIONS

The action steps shown in The Safety Decision Hierarchy under the caption "Consider These Actions, in Their Order of Effectiveness" provide a base for considering alternative risk avoidance, elimination, or reduction measures. They are similar to items A through F in the preferred order of controls outlined in section 5.1.2, the hierarchy of controls, in Z10. The logic in support of those steps and the order in which they are listed were given earlier in the chapter.

DECIDING AND TAKING ACTION

All facets of the safety decision hierarchy apply when considering the hazards and risks in a specific facility, process, system, piece of equipment, or tool in its simplest form. Also, they are broadly applicable in all four of the major aspects of the practice of safety:

- In the design processes, pre-operational: where the opportunities are greatest and the costs are lower for hazard avoidance, elimination, or control
- In the operational mode: where, integrated within a continual improvement process, hazards are eliminated or controlled before their potentials are realized and hazard-related incidents or exposures occur
- Post-incident: through investigation of hazard-related incidents and exposures to determine and eliminate or control their causal factors
- Post-operational: when demolition, decommissioning, or reusing/rebuilding operations are undertaken

MEASURING FOR EFFECTIVENESS

Provisions in the Management Review Process – Section 7.1 of Z10, require that systems be in place to measure the effectiveness of the risk reduction measures taken. Those provisions are relative to the measuring for effectiveness and re-analyzing steps in The Safety Decision Hierarchy.

Assuring that the actions taken accomplish what was intended is an integral part of the PDCA process. Follow-up activity would determine that:

- The problem was resolved, or only partially resolved, or not resolved.
- The actions taken did or did not create new hazards.

ACCEPT THE RESIDUAL RISK, OR START OVER IF IT IS UNACCEPTABLE

If the follow-up activity indicates that the residual risk is not acceptable, the thought process set forth in the safety decision hierarchy would be applied again, beginning with hazard identification and analysis.

CONCLUSION

The hierarchy of controls in Z10 derives from work that has evolved over many years. As management "implement(s) and maintain(s) a process for achieving feasible risk reduction," the hierarchy presents the actions to be considered in a logical order.

Encompassing a hierarchy of controls within a sound problem-solving technique furthers the ability of management and safety professionals to achieve effective risk avoidance, elimination, or reduction, and to meet the requirements of certain provisions in Z10. Adopting established problem-solving techniques to address hazard and risk situations is a fundamentally sound approach. That is the purpose of The Safety Decision Hierarchy.

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CHAPTER 15

SAFETY DESIGN REVIEWS: SECTION 5.1.3 OF Z10

Requirements for design review and management of change are addressed jointly in Section 5.1.3 of Z10. Although the subjects are interrelated, each has its own importance and uniqueness. Comments on the management of change concept and how to institute the management of change process are the focus of Chapter 19. Only the design review requirements of Z10 are addressed in this chapter.

Although the term *design review* appears in the title of Section 5.1.3, the "shall" requirement and the advisory comments indicate that much more than a design review is expected. The standard states that "The organization shall establish a process to identify, and take appropriate steps to prevent or otherwise control hazards at the design and redesign stages to reduce potential risks to an acceptable level."

A design review is one part of that process. For a design review to occur, there must be a design to review. As Bruce Main writes in *Risk Assessment: Challenges and Opportunities*: "A design review evaluates a design against the design criteria or requirements." (p. 27)

In the advisory column, E5.1.3 says: "The design review should consider all aspects including design, procurement, construction, operation, maintenance, and decommissioning." And E5.1.3.1 says: "The design process typically includes consideration of some or all of the following life cycle phases: Concept design stage; Preliminary design; Detailed design; Build or purchase process; Commissioning, installing and debugging processes; Production and maintenance operations; and Decommissioning activity.

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