RISK TREATMEN

Harmonizing the Hiera
& Inherently Safer Des

By Bruce K. Lyon and Georgi Popov

THE PRIMARY GOAL FOR AN OSH PROFESSIONAL is to reduce operational risk to a level that is considered as low as reasonably practicable (ALARP). ANSI/ASSP Z590.3-2011 (R2106), Prevention Through Design, defines ALARP as "that level of risk which can be further lowered only by an increase in resource expenditure that is disproportionate in relation to the resulting decrease in risk." Achieving and maintaining ALARP should be the goal, the state of being in all workplaces. One concept OSH professionals use to achieve the state of ALARP is the application of risk reduction strategies according to the hierarchy of controls.

Origins of the Hierarchy of Controls Concept

OSH professionals have traditionally ranked control measures according to their effectiveness and reliability in removing or controlling hazards. This concept has become known as the hierarchy of controls. It is thought to have its origins in occupational health and industrial hygiene beginning in the late 1940s. In *Advanced Safety Management*, Manuele (2008) cites the third edition of National Safety Council's 1955 *Accident Prevention Manual* as an early source of a hierarchy of controls.

The concept of ranking risk reduction strategies has developed over the years. Originally, the principle of the hierarchy of controls was to control the hazard as close to the source as possible, with 1) engineering as the top control measure and 2) PPE as the second option.

> Using engineering solutions to control hazards at their source or in the pathway of transmission is more reliable and less burdensome to the worker than personal protective equipment. Once installed, these controls work day after day with minimum routine intervention beyond maintenance and monitoring. (U.S. Congress, OTA, 1985)

JAMESTEOHART/ISTOCK/GETTY IMAGES PLUS

KEY TAKEAWAYS

- The primary goal of safety and risk management is to achieve and maintain a level of risk that is as low as reasonably practicable while accomplishing the organization's objectives. This is achieved by selecting and applying appropriate risk treatments using a hierarchy approach.
- A fundamental concept within operational risk management is the ranking of hazard controls and risk treatment strategies known as the hierarchy of controls.
- Various hierarchy of controls models exist, each having slight differences in control options and applications, presenting some confusion to the user. A new risk reduction hierarchy model is presented that incorporates inherently safer design strategies in a more comprehensive format accompanied by a decision tree.

NT STRATEGIES
rchy of Controls
ign Concepts

The concept was further advanced with the writings of William Haddon and his concepts of energy control. Haddon (1970) proposed 10 strategies for reducing and avoiding harm or damage based on a model of potentially harmful energy transfer. His strategies, which include preventing, reducing, modifying, separating, detecting and strengthening against energy transfer risk, have had a major influence on the thinking about safety and risk, and the concepts of risk treatment ranking and hierarchy.

In the present day, the hierarchy of controls concept provides 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 their associated risks. 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 (Manuele, 2008).

The Treatment of Risk

Risk treatment involves the selection and application of risk reduction measures for a risk that is judged to be unacceptable. The output of the risk assessment is a valuable input to the risk treatment process. The risk assessment results should be used to make important decisions on how to control anticipated and identified hazards, and reduce their risk. Without acting on the risk assessment's findings and treating risk, a risk assessment is of no value, and in fact may lead to negligence of the organization (Popov, Lyon & Hollcroft, 2016).

ISO Guide 73 (ANSI/ASSE Z690.1-2011) defines *risk treatment* as the "process to modify risk." For operational and hazard risks, the process to modify risk involves the selection and application of one or more treatment options to reduce risks to a level that is as low as reasonably practicable and acceptable

FIGURE 1
BOW TIE ANALYSIS DIAGRAM

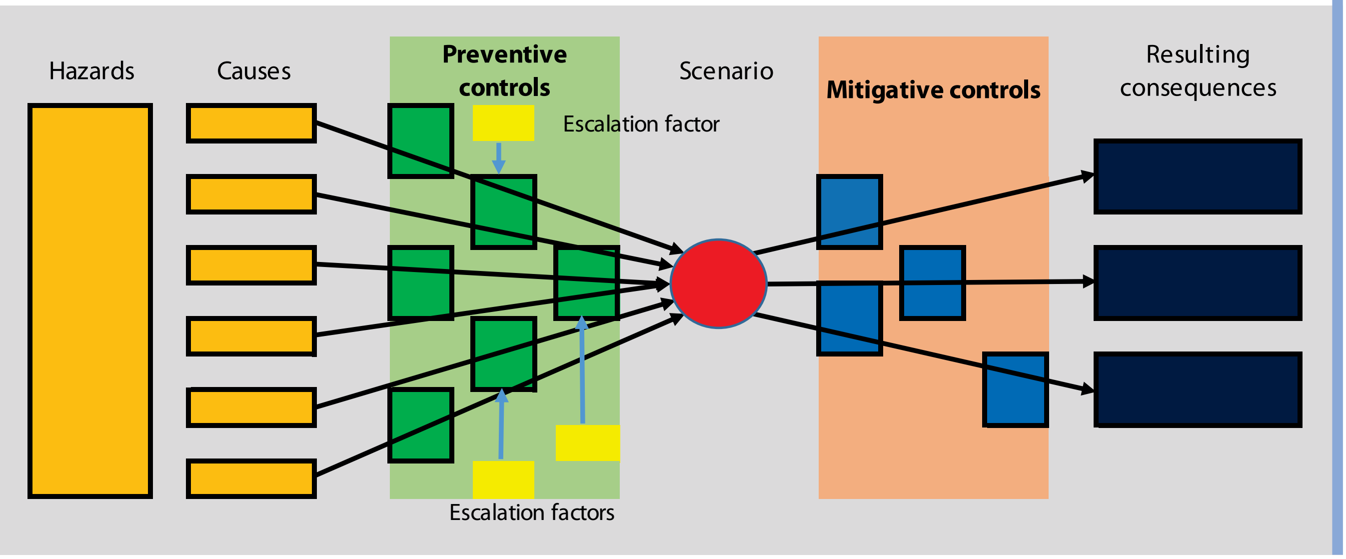
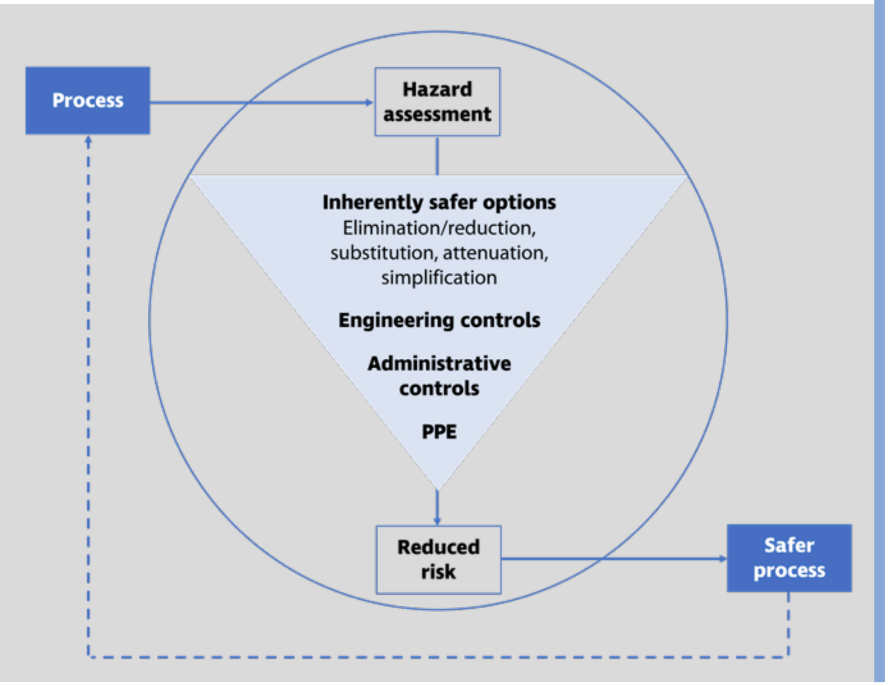


FIGURE 2
SAFER TECHNOLOGY & ALTERNATIVES ANALYSIS



to the organization. ISO Guide 73 provides several notes that further describe risk treatment options:

- avoid the risk by deciding not to start or continue with the activity that gives rise to the risk;
- take or increase risk in order to pursue an opportunity;
- remove the risk source;
- change the likelihood;
- change the consequences;
- share the risk with another party or parties, including contracts and risk financing;
- retain the risk by informed decision.

For the OSH professional, common terms used in association with operational risk treatment include *control, reduction, mitigation, protection* and *prevention*. These terms are often used interchangeably; however, there are some subtle, yet important distinctions to consider regarding these risk treatment terms.

Prevention: Risk prevention is the act of keeping something from occurring that would otherwise cause risk or harm. For example, a pressure relief valve on an enclosed tank or vessel prevents over-pressurization and explosion. *Preventive action* is defined as "an action taken to reduce or eliminate the probability of specific undesirable events from happening" and is described as generally less costly than mitigating the effects of negative events after they occur (BusinessDictionary.com, 2018). ANSI Z590.3 reinforces this in Section 9, Hierarchy of Controls, which states that the first four control levels of the hierarchy are more effective because they are preventive actions that eliminate or reduce risk by design, elimination, substitution and engineering measures.

Mitigation: This term has become more popular recently by some governmental agencies, organizations and groups. The term *mitigation* is generally defined as the action of reducing the severity or seriousness of something, thus making a condition or consequence less severe. Federal Emergency Management Agency (FEMA, 2017) defines *mitigation* as "the effort to reduce loss of life and property by lessening the impact of disasters." Rather than a preventive measure, mitigation is a reactionary measure used to reduce severity. An emergency action plan is a mitigation plan that is designed to limit damage and harm in response to an emergency-type event.

Protection: Similar to mitigation, protection is the act of shielding, covering or keeping an asset from harm. It is designed to limit the severity of harm or impact rather than prevent the event from occurring. Examples of risk protection include automatic fire suppression systems in buildings; cathodic protection for an underground storage tank; and PPE. Insurance (or risk transfer) could also be considered a form of protection measure for the insured parties or properties.

Control: *Risk control* is a more encompassing term meaning to manage risk by reducing likelihood and severity of an exposure. ISO Guide 73 (ANSI/ASSE Z690.1-2011) defines *control* as a measure that modifies risk and may include processes, policies, devices, practices or other actions. As indicated in the ISO standard, controls may not always exert the intended or assumed modifying effect. Some in the profession use the term *loss control*; however, management of risk involves controlling the risk rather than just controlling the resulting loss.

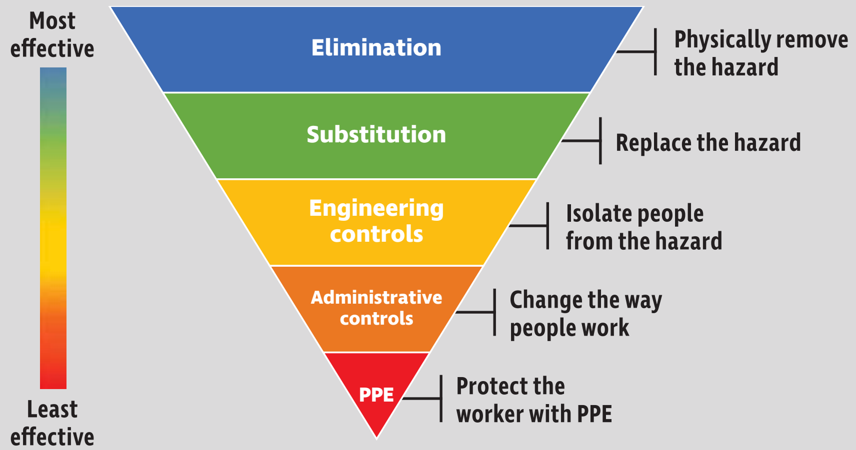
Reduction: Risk reduction, like risk control, seeks to minimize or reduce the likelihood and severity of an unwanted risk. Reduction is defined as making something smaller in size, amount or number.

A comprehensive approach to reducing risk to an acceptable level often requires layers of controls or defenses, or a combination of preventive, protective, mitigative and control measures (Lyon & Popov, 2016). For example, Figure 1 shows a bow tie analysis diagram, which identifies preventive measures on the left side of the bow tie (barriers positioned between the hazard-causes and the event) and the mitigation measures on the right side of the bow tie (reactive measures between the hazardous event and the consequences). Both preventive and mitigative measures are risk reduction treatment strategies.

OSH professionals should understand these differences and make use of all the available risk reduction strategies to properly manage operational risk.

FIGURE 3

NIOSH PTD HIERARCHY OF CONTROLS MODEL



Note. Adapted from "Hierarchy of Controls," by NIOSH, 2015, www.cdc.gov/niosh/topics/hierarchy.

FIGURE 4

ANSI/ASSP Z10 HIERARCHY OF CONTROLS MODEL

Most effective

Controls	Examples
1) Elimination	•Design to eliminate hazards, such as falls, hazardous materials, noise, confined spaces and manual material handling.
2) Substitution	•Substitute for less hazardous material. •Reduce energy. For example, lower speed, force, amperage, pressure, temperature and noise.
3) Engineering controls	•Ventilation systems •Machine guarding •Sound enclosures •Circuit breakers •Platforms and guard railing •Interlocks •Lift tables, conveyors and balancers
4) Warnings	•Signs •Backup alarms •Beepers •Horns •Labels
5) Administrative controls	**Procedures** •Safe job procedures •Rotation of workers •Safety equipment inspections •Changing work schedule **Training** •Hazard communication training •Confined space entry
6) PPE	•Safety glasses •Hearing protection •Safety harnesses and lanyards •Gloves •Respirators

Least effective

Note. Adapted from Occupational Health and Safety Management Systems [ANSI/ASSP Z10-2012 (R2017)], by ANSI/ASSP, 2017, Park Ridge, IL: ASSP.

Risk Treatment Plans

Risk treatment plans can involve a single control or multiple risk reduction measures to accomplish the risk reduction desired. Concepts such as inherently safer design, layers of protection, recognized and generally accepted good engineering practices, and safer technology and alternatives, along with the hierarchy of controls should be incorporated into the risk treatment plan. Risk treatment options can include the decision to 1) avoid the risk by choosing to not engage in the activity or exposure; 2) eliminate the risk by removing the risk source; 3) reduce the likelihood or reduce the severity; 4) share the risk among other parties such as contracts and risk financing; and 5) retain the risk such as self-funding or other risk-based decisions.

Risk treatment is a continuous process that involves the formulation, selection and implementation of treatment plans, evaluating the residual risk levels after treatment to determine acceptability, and for those that remain unacceptable, further treatment is required. For treatments

FIGURE 5

ANSI B11 SAFETY OF MACHINERY HAZARD CONTROL HIERARCHY

Most preferred

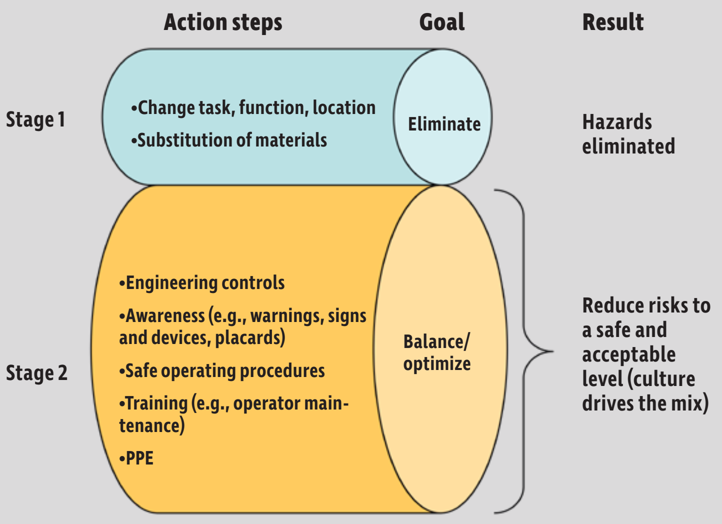
Least preferred

Risk reduction measures	Examples	Influence on risk factors	Classification
Elimination or substitution	•Eliminate pinch points (increase clearance) •Intrinsically safe (energy containment) •Automated material handling (robots, conveyors) •Redesign the process to eliminate or reduce human interaction •Reduced energy •Substitute less hazardous chemicals	•Impact on overall risk (elimination) by affecting severity and probability of harm •May affect severity of harm, frequency of exposure to the hazard under consideration, and the possibility of avoiding or limiting harm depending on which method of substitution is applied.	Design out
Guards, safeguarding devices and complementary measures	•Barriers •Interlocks •Presence sensing devices (light curtains, safety mats, area scanners) •Two-hand control and two-hand trip devices •Enabling devices	•Greatest impact on the probability of harm (occurrence of hazardous events under certain circumstances) •Minimal, if any, impact on severity of harm	Engineering controls
Awareness devices	•Lights, beacons and strobes •Computer warnings •Signs and labels •Beepers, horns and sirens	•Potential impact on the probability of harm (avoidance) •No impact on severity of harm	Administrative controls
Training and procedures	•Safe work procedures •Safety equipment inspections •Training •Lockout/tagout/verify	•Potential impact on the probability of harm (avoidance or exposure) •No impact on severity of harm	
PPE	•Safety glasses and face shields •Earplugs •Gloves •Protective footwear •Respirators	•Potential impact on the probability of harm (avoidance) •No impact on severity of harm	

Note. Adapted from Safety of Machinery (ANSI B11.0-2015), by ANSI/B11, 2015, Houston, TX: B11 Standards.

FIGURE 6

TWO STAGE ITERATIVE APPROACH TO THE HIERARCHY OF CONTROLS & RISK REDUCTION



Note. Adapted from Safety of Machinery (ANSI B11.0-2015), by ANSI/B11, 2015, Houston, TX: B11 Standards.

FIGURE 7

ANSI/ASSP Z590.3 PTD RISK REDUCTION HIERARCHY OF CONTROLS MODEL

Most preferred

Least preferred

Controls

Risk avoidance: Prevent entry of hazards into a workplace by selecting and incorporating appropriate technology and work methods criteria during the design processes.

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 (e.g., the organization of work, training, scheduling, supervision).

PPE: Provide PPE.

Note. Adapted from Prevention Through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes [ANSI/ASSP Z590.3-2011 (R2016)], by ANSI/ASSP, 2016, Park Ridge, IL: ASSP.

or controls that have been implemented, assessment of their effectiveness and reliability are required. This may require testing and verification of some degree to ensure that controls are working as expected. Also, it is important to determine that the implemented control measures have not created any unintended consequences or introduced new risks.

RAGAGEP

The term *recognized and generally accepted good engineering practices* (RAGAGEP) was introduced in 1992 by OSHA in the process safety management (PSM) standard (29 CFR 1910.119). RAGAGEP involves the selection and application of appropriate engineering, operating and maintenance knowledge when designing, operating and maintaining chemical facilities with the purpose of ensuring safety and preventing process safety incidents. This concept is in alignment with the prevention through design (PTD) concept of designing in such measures and managing risk throughout a system's life cycle. The use of applicable RAGAGEP as well as regulatory requirements should be one of the first considerations made when selecting available risk treatments.

STAA & Inherent Safety

Another risk reduction approach referenced in the OSHA PSM standard and U.S. EPA's risk management plan standard is the safer technology and alternatives analysis (STAA) concept. STAA (Figure 2, p. 36) is the concept of integrating various risk reduction strategies that work toward making a facility and its chemical processes as safe as possible (EPA, 2015; OSHA, 2017).

STAA follows a hierarchy of risk treatment options beginning with the use of inherently safer technology or inherently safer design applied at the process design stage (CCPS, 2008b; EPA, 2015). The concept of inherently safer design and inherent safety focuses on eliminating or reducing the hazards associated with a set of conditions and is closely aligned with the PTD concept. The concept of inherent safety requires designers to attempt to eliminate or reduce hazards that are identified at each stage in the system's life cycle, and design safety systems to control hazards rather than accept them. The theory is that a process is inherently safer if it reduces or eliminates the hazards associated with materials and operations used in the process. Such eliminations and reductions of risk are permanent in the system. It may not always be feasible to eliminate or minimize hazards, but the inherent safety concept requires that this first be attempted. An inherently safer process should not, however, be considered inherently safe or absolutely safe. There will always be some residual risk. While implementing inherent safety concepts will move a process in the direction of reduced risk, it will not remove all risks.

The hierarchical steps for managing chemical and process hazards and risk in the STAA approach are:

1) Avoid hazard. First-order inherent safety measures; measures that would avoid or eliminate the hazard altogether.

2) Reduce severity. Second-order inherent safety measures; measures that treat the hazard by reducing the hazard's intensity or severity.

3) Reduce likelihood. Second-order inherent safety measures; measures that reduce the likelihood of the event or exposure.

4) Passive safeguards. Layers of protection; measures that reduce the frequency or impact of the hazard without the need for external input or activation of the control. Examples include fixed guards, barriers, dikes and containment buildings.

5) Active safeguards. Layers of protection; measures that detect and respond to process deviations that require external input and activation of the control to provide safety.

6) Procedural safeguards. Layers of protection; measures such as operating procedures, management system procedures and administrative measures that rely on the human element to respond or perform.

Following the use of inherent safety measures, the remaining hazards and their residual risk are minimized through the use of layers of protection including passive, active and procedural safeguards to a level that is acceptable to the organization.

The Hierarchy of Risk Treatment Strategies

Risk treatment selection should always be linked to the concept of the hierarchy of controls to reduce risk to an acceptable level. Hazard and risk control measures vary in their degree of risk reduction, effectiveness and reliability. The hierarchy of controls concept is structured with the most effective and reliable risk reduction options at the top, descending to the least preferred option. The hierarchy model generally starts with avoidance of risk (excluded in some models), followed by elimination of risk, then substitution of risk. From there, residual risk is controlled using engineering controls, warning systems (also excluded in some models), administrative controls and PPE.

Various models exist. Unfortunately, OSH textbooks and others continue to refer to engineering controls as the highest level of control. It is important to recognize and understand the differences among the various hierarchy of controls models.

Jensen (2007) provides a unique review of several hazard control strategies. He lists nine strategies and shows their relationships with 1) Haddon's (1980) 10 strategies for reducing damage of all kinds originally based on his energy control theory; 2) Johnson's (1975) "The Management Oversight and Risk Tree"; 3) Asfahl's (2004) list from *Industrial Safety and Health Management*; and 4) Manuele's (2003) list of nine strategies from *On the Practice of Safety*. Jensen's proposed strategies, which closely align with Haddon's list, are well explained in his article and presented in the following order:

1) Eliminate the hazard.
2) Moderate the hazard.
3) Avoid releasing the hazard.
4) Modify release of the hazard.
5) Separate the hazard from that which needs to be protected.

FIGURE 8

HIERARCHY OF ERGONOMIC RISK CONTROLS

Control method	Stage/application	Control examples	Effectiveness
Avoidance	Conceptual stage New design	Prevent entry of hazard into workplace by design, selection of technologies, equipment and work methods.	**High**
Elimination	Operational stage Existing processes Redesign	Eliminate existing hazard by changes in design, technologies, equipment and methods.	**High**
Substitution	Conceptual stage Operational stage Existing processes	Substitute materials, sizes, weights and other aspects to a lower hazard severity or likelihood.	**Moderately high**
Engineering controls	Conceptual stage Operational stage Existing workstations Redesign	Reduce hazard by changes to workplace, tools, equipment, fixtures, adjustability, layout, lighting or work environment.	**Moderate**
Administrative controls	Operational stage Practices and procedures	Reduce exposure to hazard by changes in work practices, training, job enlargement, job rotation, rest breaks or work pace.	**Moderately low**
PPE	Operational stage Workers	Reduce impact of hazard to employee by use of protective equipment and materials such as vibration attenuation gloves.	**Low**

Note. Adapted from "Improving Ergo IQ: A Practical Risk Assessment Model," by B.K. Lyon, G. Popov and K. Hanes, 2013, *Professional Safety, 58*(12), pp. 26-34.

6) Help people perform safely.
7) Use PPE.
8) Improve the resistance of that which needs to be protected.
9) Expedite recovery.

Variations of control hierarchies exist, including those from NIOSH and ANSI standards, which are presented in Figures 3 through 7 (pp. 37-38). The B11 annex presents a unique and well-reasoned two-step approach to applying controls (Figure 6, p. 38). The theory is that risk treatment should first attempt to eliminate or substitute the hazard, then consider, in descending order, engineering controls, awareness devices, safe operating procedures, training and PPE (lower level controls) to reduce residual risk.

Among the established models, the ANSI/ASSP Z590.3 Prevention Through Design model (Figure 7, p. 38) is considered the most complete hierarchy of controls model since it includes risk avoidance and warning systems.

For risks associated with ergonomics, the authors have developed a hierarchy of ergonomic risk controls model based on the PTD hierarchy identifying application phases and control examples to aid the user (Figure 8).

A Hierarchy of Risk Treatment Model

The objective of operational risk management is to implement appropriate risk reduction plans to reduce risks associated with each decision made to achieve an acceptable risk level. OSH professionals should be able to effectively lead risk assessments, develop appropriate risk reduction strategies and advise decision-makers in making appropriate decisions. Risk treatments (i.e., risk controls) are designed to reduce the risk of a hazard's effects or reduce the likelihood of its occurrence. A risk treatment plan should include options and alternatives that eliminate the hazard or reduce its risk.

To provide OSH professionals a broader range of risk reduction strategies that include inherently safer design concepts, the authors have proposed a hierarchy of risk treatment (HORT) strategies hierarchy model (Figure 9).

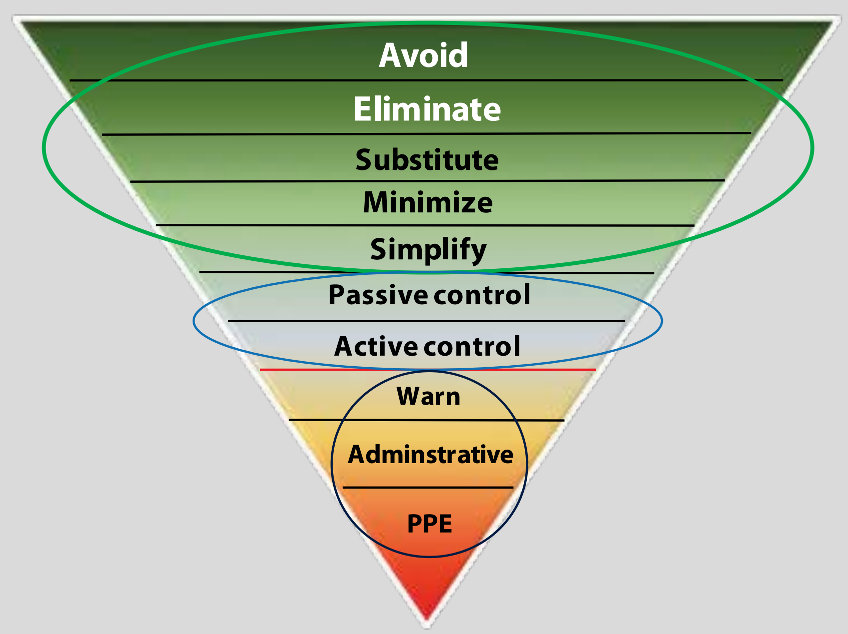
The model includes 10 risk treatment strategies, or tiers, which are divided into three categories: 1) design/redesign; 2) engineering; and 3) administrative controls. Design/redesign risk treatments, the first category, are the only risk treatments that are long lasting and typically do not degrade over time. Hazards avoided, eliminated or substituted through design will not change unless the design feature is changed. However, the second and third categories of risk treatments are less resilient. Engineering controls can be circumvented and, over time, tend to degrade, wear out or lose effectiveness. Such controls also require ongoing inspection, testing, maintenance and repair. Administrative controls are the least effective and degrade more quickly due to variations in the quality of training, application and management, as well as organizational influences and human fallibility. For these reasons, administrative controls are considered the last resort in the hierarchy. Following are brief descriptions and examples of each risk treatment strategy:

1) Avoid. New hazards/risks are intentionally avoided in new designs, as well as in redesigns, additions and modifications to existing systems and workplaces. Example: In a new facility, design all walking and working surfaces at the same level to avoid falls from heights.

2) Eliminate. Existing hazards/risks are eliminated or removed from systems/workplaces through

FIGURE 9

A HIERARCHY OF RISK TREATMENT INCORPORATING INHERENTLY SAFER DESIGN CONCEPTS



Note. Adapted from "Risk Management Tools for Safety Professionals" [Webinar], by B.K. Lyon and G. Popov, Sept. 6, 2018, Park Ridge, IL: ASSP.

redesign. Example: Eliminate a hazardous chemical process from the workplace by redesigning the process or remove it from the workplace and isolate it away from workers.

3) Substitute. New or existing hazards/risks are intentionally replaced with less hazardous materials that meet the needs of the system or workplace. Example: Replace a highly hazardous chemical such as pure sulfur dioxide with a less hazardous chemical such as potassium meta-bisulfite.

4) Minimize. The amount or quantity of a particular hazard is minimized to a level that presents a lower severity risk. Examples: Minimize the size and weight of materials to a level that workers can easily handle; use the smallest quantity of hazardous materials feasible for a process; use the lowest voltage or energy required; reduce operating temperatures and pressures.

5) Simplify. The likelihood of error or occurrence is reduced through simplifying the systems or workplace processes and controls. Examples: Eliminate unnecessary complexity in controls and displays; reduce the number of steps to complete a critical task; incorporate human factors engineering design into systems to reduce human error potential.

6) Engineer with passive controls. Hazards are controlled or contained by passive engineering controls that protect/function without activation. Examples: Install a containment dike around a hazardous material storage tank; install a fixed/permanent guard on a machine; use hard/fixed barriers.

7) Engineer with active controls. Hazards are controlled by active engineering controls that require activation to protect or function. Examples: Presence sensing devices on machines; process controls and safety instrumented systems (SIS); automatic fire suppression systems and sprinkler systems.

8) Warn. Awareness device that informs or warns of residual risks by sight, sound or touch. Examples: Forklift backup alarms; perimeter warning tape and signage; highway rumble strips to indicate drifting off road.

9) Administrative. Hazards are managed by applying work procedures and worker training for safe operation of the system or workplace. Examples: Written standard operating procedures and protocols; employee orientation and training; behavior-based safety efforts.

10) PPE. Hazards are managed by donning and wearing protective clothing and equipment to prevent or reduce contact, exposure, and impact or harm from hazards. Examples: Respiratory protection; flame-resistant clothing; fall protection harness and lanyard.

Table 1 (p. 42) compares five hierarchy of controls models and their listed risk treatment strategies discussed in this article. The models range from five to 10 strategy levels or tiers. OSH professionals should evaluate and consider which models and risk reduction strategies best serve the needs of their organizations and applications to achieve ALARP.

Risk Reduction Strategies Decision Tree

Risks should be prioritized to allow decision-makers to act on the most important risk first so that appropriate resource allocations can be made for risk avoidance, elimination, reduction or control. For more complex situations, a risk treatment or implementation plan may be required to document the reasons for selecting control options, their expected benefits and the methods of implementing the controls. Such a plan should identify who is responsible for implementing controls, the timeframe and resources necessary, and the key performance measures, reporting and monitoring requirements of the implementation.

Selection of the most appropriate risk reduction strategies to achieve ALARP can be achieved by using a decision tree. Figure 10 (p. 42) illustrates such a risk reduction strategies decision tree (Lyon & Popov, 2018b) that can be used in the risk treatment planning process.

A case example for applying risk reduction strategies follows:

> A manufacturing organization plans to expand operations by doubling the size of the main facility. As part of the planning process, a design and build team that includes OSH professionals is assembled. Upon the scoping and development of the conceptual designs, the OSH professionals lay out safety specifications that support the organization's acceptable risk levels and business objectives. The design team develops and uses a design safety specifications checklist.

TABLE 1

HIERARCHY OF CONTROLS MODELS: STRATEGY TIERS

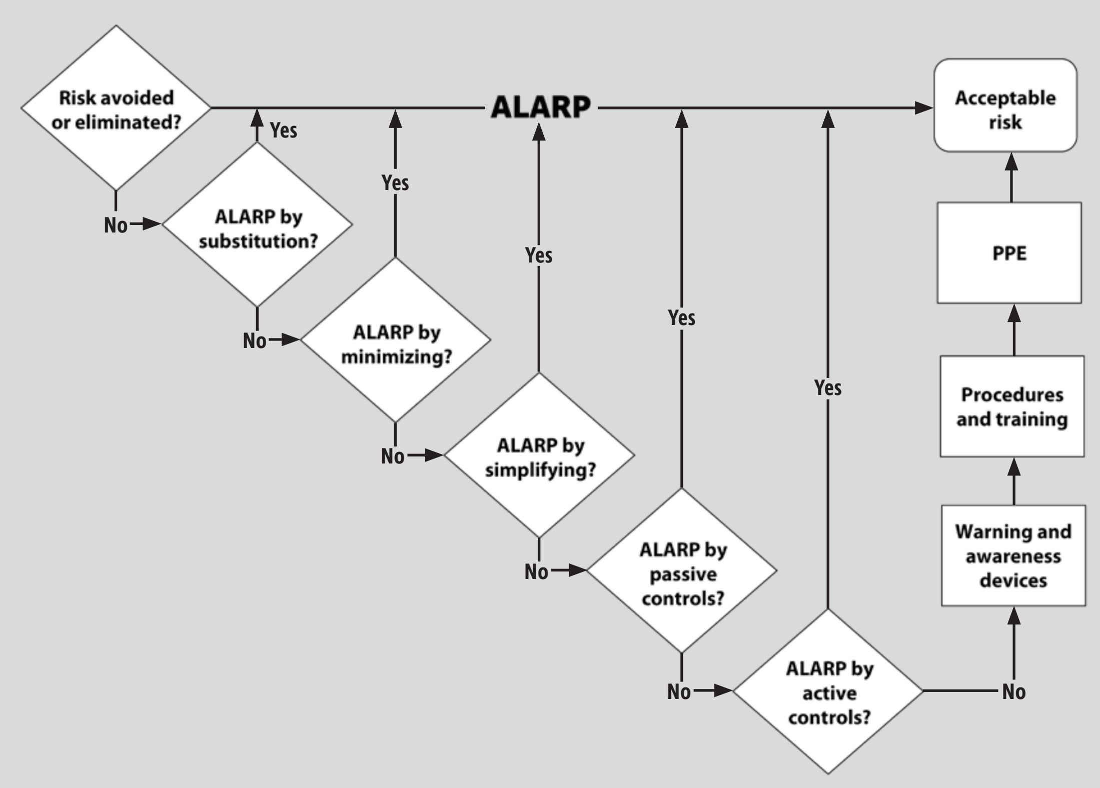
Most effective

Least effective

	Hierarchy of controls models				
Risk treatment strategies	***NIOSH PTD***	***ANSI/ASSP Z10***	***ANSI B11***	***ANSI/ASSP Z590.3***	***HORT model***
Avoid	--	--	--	1	1
Eliminate	1	1	1	2	2
Substitute	2	2	2	3	3
Minimize	--	--	--	--	4
Simplify	--	--	--	--	5
Engineer: Passive	--	--	--	--	6
Engineer	3	3	3	4	--
Engineer: Active	--	--	--	--	7
Warn	--	4	4	5	8
Administrative	4	5	5	6	9
PPE	5	6	6	7	10

FIGURE 10

RISK REDUCTION STRATEGIES DECISION TREE



For each hazard identified or anticipated, the team, led by the OSH professionals, determines its risk level and whether it is acceptable to the organization, or if it requires further treatment. For risks that are unacceptable, the following process using the risk reduction decision tree is used.

Beginning with highest level risk reduction strategy, avoidance/elimination, the team tests its feasibility. The team considers the risk level, what is possible, the anticipated costs and potential trade-offs.

If avoidance/elimination is not possible, the team formally considers substitution with a less hazardous material or method. The team reviews alternative materials, chemicals or methods for their risk levels, perceived benefits, costs, ability to satisfy operational objectives, and makes a determination whether ALARP can be achieved.

If further risk reduction is required, the team looks at the next strategy of minimizing the "quantity" of the hazard. Certain materials, weights, sizes, chemicals or energy forms (e.g., voltage, pressure, temperature) can be reduced to ALARP.

For risks that can be reduced through simplified designs, controls or methods, the team identifies acceptable solutions.

The team selects engineering controls based on their effectiveness as well as their reliability beginning with passive devices followed by active-type controls. The risk reduction strategies at this stage are considered higher level controls. However, the team is unable to reduce all risks to an acceptable level.

The team incorporates warning devices and administrative measures such as job hazard analyses, inspections, work procedures, training and PPE into the risk reduction plan.

The plan is presented and discussed with management decision-makers for approval, modification and implementation.

Conclusion

A large part of the OSH professional's role is to advise and influence the organization in operational risk issues. In the event of serious-injury-or-fatality-level risks, the OSH professional should make clear to decision-makers the importance of immediate risk treatment and reduction. Cost-benefit analysis and other justification tools may be needed to help make the proper case, as well as an alternate plan to present to decision-makers in the event that the primary plan is declined. Any such plans should be integrated into the organization's management processes and discussed with stakeholders. Decision-makers and stakeholders must understand the residual risk levels resulting from the risk treatment plan, and its level of acceptability. Residual risk levels should be documented and monitored for any further treatment and continual improvement as part of the safety management system.

The use of the hierarchy of controls models, such as those discussed in this article, should be standard practice for OSH professionals when developing risk reduction strategies to achieve ALARP. Considering expanded models such as those that include additional higher-level risk reduction options such as simplification, minimization, and other inherently safer design concepts can prove beneficial to OSH professionals and their organizations in their quest to achieve and maintain ALARP. **PSJ**

References

ANSI/ASSP. (2011). Vocabulary for risk management (National adoption of ISO Guide 73:2009; ANSI/ASSP Z690.1-2011). Park Ridge, IL: ASSP.

ANSI/ASSP. (2016). Prevention through design: Guidelines for addressing occupational hazards and risks in design and redesign processes [ANSI/ASSP Z590.3-2011 (R2016)]. Park Ridge, IL: ASSP.

ANSI/ASSP. (2017). Occupational health and safety management systems [ANSI/ASSP Z10-2012 (R2017)]. Park Ridge, IL: ASSP.

ANSI/B11. (2015). Safety of machinery (ANSI B11.0-2015). Houston, TX: B11 Standards.

Asfahl, C.R. (2004). *Industrial safety and health management*. Upper Saddle River, NJ: Pearson Prentice Hall.

BusinessDictionary. (2018). Prevention. Retrieved from www.businessdictionary.com/definition/prevention.html

Center for Chemical Process Safety (CCPS). (2008a). *Guidelines for hazard evaluation procedures* (3rd ed.). Hoboken, NJ: Wiley.

CCPS. (2008b). *Inherently safer chemical processes: A life cycle approach* (2nd ed.). Hoboken, NJ: Wiley.

Federal Emergency Management Agency (FEMA). (2017). What is mitigation? Retrieved from www.fema.gov/what-mitigation

Haddon, W., Jr. (1970). On the escape of tigers: An ecologic note. (Strategy options in reducing losses in energy-damaged people and property). *MIT Technology Review, 72*, 44-53.

Haddon, W., Jr. (1980). The basic strategies for reducing damage from hazards of all kinds. *Hazard Prevention, 16*(5), 8-12.

Jensen, R.C. (2007, Jan.). Risk reduction strategies: Past, present and future. *Professional Safety, 52*(1), 24-30.

Johnson, W.G. (1975). The management oversight and risk tree. *Journal of Safety Research, 7*(1), 4-15.

Lyon, B.K. & Hollcroft, B. (2012, Dec.). Risk assessments: Top 10 pitfalls and tips for improvement. *Professional Safety, 57*(12), 28-34.

Lyon, B.K. & Popov, G. (2016, March). The art of assessing risk: Selecting, modifying and combining risk assessment methods to assess risk. *Professional Safety, 61*(3), 40-51.

Lyon, B.K. & Popov, G. (2017, Nov.). Communicating and managing risk: The key result of risk assessment. *Professional Safety, 62*(11), 35-44.

Lyon, B.K. & Popov, G. (2018a). *Risk management tools for safety professionals*. Park Ridge, IL: ASSP.

Lyon, B.K. & Popov, G. (2018b, Sept. 6). Risk management tools for safety professionals [Webinar]. Park Ridge, IL: ASSP.

Lyon, B.K., Popov, G. & Hanes, K. (2013, Dec.). Improving ergo IQ: A practical risk assessment model. *Professional Safety, 58*(12), 26-34.

Manuele, F.A. (2003). *On the practice of safety*. Hoboken, NJ: John Wiley & Sons.

Manuele, F.A. (2008). *Advanced safety management: Focusing on Z10 and serious injury prevention*. Hoboken, NJ: John Wiley & Sons.

NIOSH. (2015). Hierarchy of controls. Retrieved from www.cdc.gov/niosh/topics/hierarchy

OSHA. (2017). Process safety management for petroleum refineries: Lessons learned from the petroleum refinery process safety management national emphasis program (OSHA 3918-08 2017). Retrieved from www.osha.gov/Publications/OSHA3918.pdf

Popov, G., Lyon, B.K. & Hollcroft, B. (2016). *Risk assessment: A practical guide to assessing operational risks*. Hoboken, NJ: John Wiley & Sons.

U.S. Congress, Office of Technology Assessment (OTA). (1985, April). Preventing illness and injury in the workplace (OTA-H-256). Retrieved from https://ota.fas.org/reports/8519.pdf

U.S. Environmental Protection Agency (EPA). (2015, June). Chemical safety alert: Safer technology and alternatives (EPA 550-F-15-003). Retrieved from www.epa.gov/sites/production/files/2015-06/documents/alert_safer_tech_alts.pdf

Bruce K. Lyon, P.E., CSP, ARM, CHMM, is vice president with Hays Companies. He holds a B.S. in Industrial Safety and an M.S. in Occupational Safety Management from University of Central Missouri (UCM). He is a board member of Board of Certified Safety Professionals (BCSP), advisory board chair to UCM's safety sciences program and vice chair of ISO 31000 U.S. Technical Advisory Group. Lyon is coauthor of *Risk Assessment: A Practical Guide to Assessing Operational Risk* and *Risk Management Tools for Safety Professionals.* In 2018, he received the BCSP Award of Excellence. Lyon is a professional member of ASSP's Heart of America Chapter, and a member of the Society's Ergonomics and Risk Management/Insurance practice specialties.

Georgi Popov, Ph.D., QEP, SMS, ARM, CMC, is a professor in the School of Geoscience, Physics and Safety (GPS) Sciences at UCM. He holds a Ph.D. from the National Scientific Board, an M.S. in Nuclear Physics from Defense University in Bulgaria, and a post-graduate certification in environmental air quality. In 2001, he graduated from the Command and General Staff College at Fort Leavenworth, KS. He is coauthor of *Risk Assessment: A Practical Guide for Assessing Operational Risk* and *Risk Management Tools for Safety Professionals.* Popov is a professional member of ASSP's Heart of America Chapter, a member of the Society's Risk Management/Insurance Practice Specialty, and serves on ASSP's Risk Assessment Committee. He received the Heart of America Chapter's Safety Professional of the Year (SPY) Award in 2015, the ASSP Region V SPY Award in 2016, and ASSP's Outstanding Safety Educator of the Year Award in 2017.