Professional Development

Safe Designs

A challenge to SH&E professionals

By Wayne C. Christensen

A CHALLENGE, OR PERHAPS A MISSING LINK in the application of SH&E program activities is seeking an acceptable level of risk (ALOR) for workers and the public in design (or redesign) of facilities, equipment, processes and products. Engineers of all types (civil, mechanical, electrical, etc.) and SH&E practitioners should be leading the charge toward increased safety of workers and the public. However, despite contributions from these groups, statistics reflect that workers and members of the public continue to die, be seriously injured or suffer illness as a result of design shortcomings (NIOSH, 2007, p. 1). These incidents also result in heavy consequences to production, schedules and operational costs.

Instead of seeking safe designs, both professions persist in performing rituals of retrofitting, training, requiring PPE, code compliance and attempting to change employee behavior to eliminate incident causes. The goal should be design for safety instead of continuing the practice of retrofitting for safety and its increased cost, time and possible human suffering. The knowledge and practices of identifying accident potential, conducting risk assessment, instituting risk mitigation and related actions remain minimal performance factors in both groups (Christensen & Manuele, 1999).

Industry has moved forward from the era of emphasis on nonsafety total quality management and similar programs. Today, many new efforts to grab management attention include lean, green and sustainability, yet safety is not in the equation. Each topic has a useful focus, but generally does not consider SH&E. If pursued without consideration of safety and related areas during the design or remodeling phase, such efforts can overlook potential risks for workers and the public.

For example, consider the following projects:

- **Green:** Using skylights for energy conservation without considering the hazard of skylight exposure to those who may access the roof.
- **Sustainability:** Using nonpotable water in automatic sprinkler systems may introduce potential people/operation contamination from leaks or when the system functions in its intended manner.
- **Lean:** Eliminating waste may introduce various risks, including removal of guards, decreased lighting and ergonomic problems.

Many injuries and illnesses could be prevented if SH&E practitioners and engineers took the opportunity to develop a strategy to incorporate safety (including fire, ergonomics, health, environmental) and risk assessment and mitigation into the design engineering phase of projects, whether facilities, equipment, processes, materials or products. Having expressed that thought and because of current economic conditions, it is reasonable to indicate that efforts must be redoubled or quadrupled to incorporate safety into design engineering with the idea of reducing fatalities, injuries and illnesses.

Today, some indications suggest that manufacturing and other operations which moved out of the U.S. in recent years are returning. Combined with the near-term future potential recovery from the economic recession, this may be an ideal time to consider developing plans to incorporate safety into design engineering. Such plans could help decrease time from concept to production as well as save money.

Toward the goal of "SH&E designs that seek ALOR for workers and the public," this article explores the history of safety in design, concepts of incorporating SH&E into design engineering, and knowledge and skills required by engineers and SH&E practitioners, and offers thoughts on developing an implementation strategy and a policy.

Abstract: *This article focuses on the history and concepts of incorporating SH&E issues early in the design process. It also challenges the misleading notion that code compliance results in an acceptable level of risk. The knowledge and skills needed by both engineers and SH&E practitioners are reviewed as is information on developing strategies to institute organizational culture and policy.*

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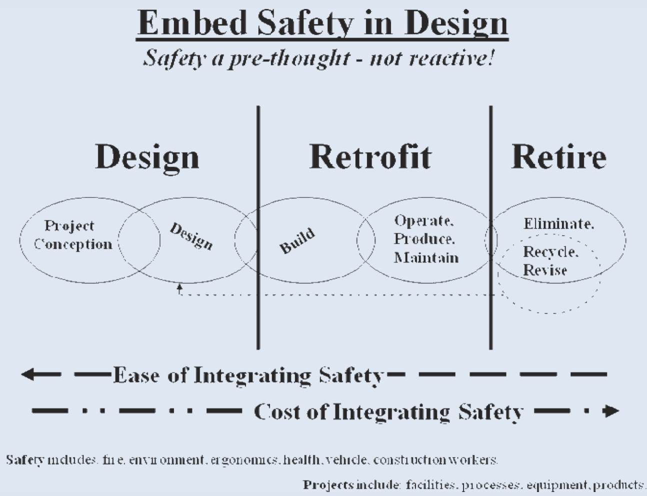
The safety through design model promotes the idea that safety should be considered in the earliest stages of design, not after the design is complete or after incidents occur.

Figure 1

Safety Through Design



Note. *Adapted from* Safety Through Design *(p. 4), by W.C. Christensen and F.A. Manuele (Eds.), 1999, Itasca, IL: National Safety Council.*

History of SH&E in Design Engineering

One cannot review the past 200 years of history without recognizing that SH&E has received substantial consideration, including in the design phase, but definitely not enough. Much of this improvement resulted from public outcry over not considering SH&E in designs. In fact, many codes and standards are the result of deaths or serious injuries. One example of lengthy activity in codes and standards is American Society of Mechanical Engineers (ASME), which has promulgated standards for 125 years. Many ASME standards have a safety basis, such as the boiler and pressure vessel codes and elevator codes.

As ASSE nears its 100th anniversary, it is noteworthy that it was formed just months after the Triangle Shirtwaist fire. In discussing this fire and subsequent events, Coleman (2009) states:

> Everybody keeps talking about the fact that we have done a better job of protecting life and property. But everyone forget(s) . . . that for almost all of the advances made in modern fire protection there was a body count before that occurred . . . Winecoff Hotel, Atlanta, GA, Barnum and Bailey's Ringling Brothers, Hartford, CT, Coconut Grove, Boston, Our Lady of the Angels, Chicago. . . . What is common . . . most . . . occurred a long time ago . . . they still occur . . . includ(ing) . . . the Station Night Club. . . ."

The first edition of the *Accident Prevention Manual* (NSC, 1946, p. 1) advocated safety in the design phase, stating that "safety must be included in the design and layout." The third edition (1955, p. 4-2) stated, "When safety is properly inculcated in the planning of new operations or processes there will be little need to secure management's backing for incorporating safety features before operations are started." Both are appropriate statements and recognize a need. Yet, in the intervening years, safety modifications primarily have occurred after designs were complete or after additional incidents—in other words, retrofitting.

Although consideration of safety in the design phase has been initiated by individuals and companies in recent decades, no concerted movement has occurred across industry in general or within a single industry. In the 1970s, NIOSH had project SHAPE (S&H Awareness for Preventive Engineering). ASSE (1994) adopted a position statement on designing for safety. NSC established the Institute for Safety Through Design (ISTD) in 1995, which endeavored to foster programs in companies, and initiate activities to incorporate necessary knowledge and skills in all engineering undergraduate curricula. ISTD also produced the text *Safety Through Design*, but its activity ceased in 2002.

In 2007, NIOSH launched a long-term research initiative entitled Prevention Through Design (PTD), which is progressing, as research does, at a modest pace. The PTD plan for national initiative was opened for public comment. It remains to be seen how the initiative will fare in the new administration and with the economic picture.

In 2009, ASSE issued Prevention Through Design: An ASSE Technical Report (TR-Z790.001-2009) and in January 2010 launched the Z790 initiative to develop a national voluntary consensus standard on PTD.

To date, the preceding activities have had minimal effect on the incorporation of significant, risk-based, SH&E activity into design engineering. Thus, all SH&E practitioners need to become involved for the sake of workers and the public. ASSE's (2002) Code of Professional Conduct states, "Membership . . . evokes a duty to serve and protect people, property and the environment . . . inform . . . when professional judgment indicates there is an unacceptable level of risk."

Similarly, the preamble of engineering societies' ethics codes specifically challenge engineers regarding SH&E as follows: "Engineering is an important and learned profession . . . has a direct and vital impact on the quality of life for all people. Accordingly . . . services provided by engineers . . . must be dedicated to the protection of the public health, safety and welfare. . . ."

Despite ethics codes and the cited activities, engineers, SH&E practitioners and their employers have done little to ensure that safety is considered in the design phase, as evidenced by the quantity of corrective actions reported throughout industry. Lack of such consideration by corporations and executives may be due to failure to bring these matters to their attention, or it may be that their eyes were fixed on other activities such as lean, green and sustainability. Coupled with this is the fact that the necessary SH&E-related knowledge and skills are not included in undergraduate engineering curricula, professional engineer licensing examinations or in available engineer continuing education (Christensen & Manuele, 1999).

At this time, there is little top management knowledge or concern in view of current economic, legal priorities and numerous other pressures. Another issue is the need to break down silos (groups that do not/will not exchange information within an organization) that exist between engineering, manufacturing, human resources, purchasing, safety and others to permit constructive development of safe designs.

Another factor to be recognized, based on the author's observations and discussions, as well as on input from other professionals, is that many engineers spend little time on the production floor observing how their designs are turned into useful products, or how equipment or processes developed are implemented. This impedes their ability to develop safe designs in the future.

Finding knowledgeable talent in the engineering field may become increasingly difficult in the future. By 2020, P.E. licensing may require that engineers possess a master's degree or equivalent, instead of the current baccalaureate degree; this would mandate additional education, yet still not require necessary SH&E knowledge and skills (National Council of Examiners for Engineering and Surveying, 2009).

With the present decline in U.S. engineering graduates (ASEE, 2009) and lengthening degree programs to 5 years, it is increasingly possible that many design engineering activities will be outsourced to engineers around the world. These individuals may know even less about the SH&E features desired to be incorporated into a project. These factors provide more reasons to advocate changes in policy as well as increased knowledge and skills among staff engineers and SH&E practitioners.

A growing number of standards are requiring risk assessment, yet there is little evidence that SH&E practitioners and engineers are obtaining commensurate education to perform this function. ANSI standards that require risk assessment include Z244.1, Control of Hazardous Energy Lockout/Tagout and Alternative Methods; the B11 machine tool series; B155.1, Requirements for Packaging Machinery and Packaging-Related Converting Machinery; and R15.06, Industrial Robots and Robot Systems: Safety Requirements. In addition, ANSI/AIHA Z10, Occupational Health and Safety Management Systems, specifically calls for SH&E, including risk assessment, to be considered in designs.

Concepts of Incorporating SH&E Into Design Engineering

Workers and the public continue to suffer since seeking an ALOR is not a regular practice. Current indications are that because of economic pressures and other factors (e.g., lack of technical ability), SH&E practitioners are not involved in the design phase; that engineers have poor guidance in considering SH&E; and that safety activities such as necessary maintenance or retrofitting of operations is not taking place. Thus, there is a need to initiate thinking about ALOR and to develop plans to ensure appropriate consideration when economic recovery starts.

Several years ago, Chapanis (1986) stated, "To err is human. To forgive, design." He later asked, "Are you good enough, ingenious enough and dedicated enough to meet the challenge?" The question remains appropriate today. Engineers and SH&E practitioners must ask themselves: "Will you design whatever you design with adequate consideration of safety, or will you hope it is caught before an incident, so you can spend time and money to retrofit?" Consider that retrofit costs (e.g., additional time and money) are in increasingly short supply. The sidebar below notes several broad concepts to consider when incorporating SH&E into design engineering.

Knowledge & Skills

It is recognized and documented that most engineers currently practicing as well as those who have recently graduated have learned little about hazard recognition and risk mitigation in their undergraduate or subsequent continuing education (NIOSH). Similarly, a large number of SH&E practitioners have obtained little education in hazard recognition, risk assessment, risk mitigation, and related knowledge and skills. Manuele (2008, p. 28) offers excellent guidelines for obtaining such education.

Engineers and SH&E practitioners generally know of OSHA regulations and may be familiar with some NFPA, ASME, ANSI, ASTM and similar standards and codes. One also must consider that many have been trained or have otherwise fallen

Concepts of Incorporating SH&E Into Design Engineering

1) Incorporating SH&E during conceptual or design stages (or in redesigns after a project is operational) provides benefits in time, cost and ease of completion. Mitigation after designs are complete is retrofitting and should be eliminated.

2) Design encompasses facilities, equipment, materials, processes, work methods and products from concept stage to the end of life (recycling/disposal/recommissioning).

3) Design SH&E objectives must be developed and subsequently evaluated. Designers must have a systematic approach to identify hazards, perform risk assessments, conduct risk mitigation and achieve an ALOR, recognizing that all risk cannot be eliminated.

4) SH&E is not a function solely of practitioners in these fields after designs take place; rather, substantial involvement other than in "SH&E reviews" or "post-project reviews" is necessary. Teamwork (collaboration) of engineering and nonengineering personnel in the design process is critical.

5) Corporate culture from the CEO to all employees must foster the concept of SH&E being incorporated in designs. Compliance with codes/regulations/standards does not ensure an ALOR.

6) Hierarchy of controls (Table 1, p. 32) must be utilized in achieving risk mitigation. Root-cause information from incident investigations must be communicated to engineering and other departments.

7) Knowledge to achieve SH&E in design requires skill development in designers (any engineering/design specialty, as well as architects), and others in the organization. Documenting safety actions in designing is necessary and audits must be conducted.

Table 1

Hierarchy of Controls

Effectiveness [most (A) to least (G)]	Examples of measures to implement hierarchy item
A) Elimination	• Remove hazard in design process
B) Elimination by redesign	• Reduce hazards to an ALOR by eliminating in design (i.e., need to enter confined spaces); manual material handling; conditions conducive to falls
C) Substitution or reduction	• Substitute less hazardous material • Reduction of energy—lower speed, force, amperage, pressure, temperature, noise
D) Engineering controls	• Ventilation systems; sound enclosures or absorbers • Machine guarding; platform guard rails • Circuit breakers; interlocks
E) Warning systems	• Automatic systems to warn in event of: over-pressure, loss of pressure, temperature change, vehicle beepers or back-up alarms • Manual warning systems—horns and buzzers • Warning signs and labels
F) Administrative controls	• Safe job procedures • Rotation of workers; changing schedule of work • Inspections—equipment and safety equipment • Training: HazCom; confined space entry and rescue; electrical lockout
G) PPE	• Eye, respiratory and hearing protection • Head, body, foot protection, face shields and gloves • Safety harnesses and lanyards

Note. *Adapted from ANSI/AIHA Z10 Appendix G.*

To achieve safety through design, the hierarchy of controls must be utilized in achieving risk mitigation. Root-cause information from incident investigations must be communicated to engineering and other departments.

into the trap of believing that conducting risk assessments is not necessary because compliance with codes, regulations and standards has been achieved. This is a fallacy.

Standards and codes generally are based on reaching a consensus, which in effect may be a minimum on which all participants can agree. In addition, not all situations or occupancies are covered in the specifications developed. Therefore, risk assessments are vital or the level of risk achieved via compliance may be far from acceptable.

Brannigan (1986) offers another view on assuming that code compliance (in this case, in the fire protection field) means no problems exist:

> If a structure was built to the latest code, it shouldn't have any problems. Right? Wrong. Codes, in effect, represent written compromises between opposing viewpoints . . . some code provisions are inspired by influence exerted on and economic interest of code-making authorities . . . subjected to the political process. . . .

Another factor is the growing use and acceptance of performance-based codes and performance-based designs. Achieving them requires goals, objectives and techniques. This presents a need to perform risk assessments to determine whether the design achieves an ALOR. Recently, NFPA, ANSI and ASTM have recognized performance-based codes across a wide-ranging spectrum that includes elevators and escalators (ANSI A7.7/B44.7-2007), eye protection (ANSI Z87.1-2003) and many NFPA fire protection standards.

ANSI A14.3 for fixed ladders is one example of unacceptable risk in a standard. The standard continues to equate cages to ladder safety devices by allowing either in meeting requirements: "Cages: An enclosure mounted to the side rails of the fixed ladder to safeguard the employee climbing the ladder." Compliance could be achieved by installing a cage, yet the risk to an operation should not be acceptable since a cage is not a guard and does not prevent the fall or arrest a fall should a person slip. The cage only provides protection against climbing space encroachment. Some argue that a cage allows a climber to lean back and rest, but no ergonomic studies indicate the configuration would accommodate 95% of the adult population who may currently climb ladders equipped with cages. (*Note:* Activity is underway to modify this section but change may be several years away.)

Given this, what knowledge and skills for developing safe designs should engineers accumulate in their education in college, continuing education courses or company-sponsored courses? Following are several areas of need:

• Understand concepts of incorporating SH&E into design engineering.

• Recognize that there are myths considered truisms in safety and why they should be avoided (Manuele, 2002).

• Understand hazard recognition techniques such as SH&E checklists for engineers and what-if; energy approach to hazards (i.e., mechanical, electrical, thermal, radiation, chemical); fishbone (cause-and-effect diagram) application; specific hazard or specific design area/function checklists for engineers.

• Understand root-cause analysis and its value in designing and the potential impact of ANSI/AIHA Z10. Accident/incident data should not be used unless based on root-cause analysis.

• Assess incident-occurrence probability and severity of consequences.

• Be aware of design principles related to SH&E and the concept of ALOR.

• Have knowledge of and practice with risk assessment techniques such as failure mode and effects analysis, hazard and operability studies, and fault tree analysis.

• Understand the hierarchy of controls and risk mitigation approaches.

• Develop measurable design objective UARs (usability with acceptable risk).

• Recognize the need and techniques for teamwork, documentation and auditing.

• Identify SH&E items that can be embedded in computer-aided design (CAD) systems.

The need to increase SH&E practitioner skills and knowledge has been a topic for many years (Christensen & Manuele, 1999). During a panel discussion at Safety 2004, Hussain Tadayon stated that "safety professionals must market themselves within the company, maintain their knowledge base and keep learning" (Smith, 2003). Lawrence (2009) discusses the role, skills and competency of SH&E personnel in connection with implementation of the ANSI/AIHA Z10 standard.

Skills and knowledge that should be acquired from degree programs, continuing education or company-sponsored courses might include the following:

- Items on the engineers' list that are not currently in their knowledge base. Risk assessment and mitigation methodologies are prime areas.
- Recognize that designing software (CAD) and techniques are advancing at tremendous speed. SH&E practitioners need to become familiar (not fully knowledgeable) with these programs and their use in order to effectively interface with engineers and discuss SH&E concerns.
- Ability to develop strategy to foster adoption of these design concepts into corporate, facility or operational culture.

Special attention should be paid to gaining knowledge of CAD. Product lifecycle management (PLM) software is used extensively and produces significant savings. In addition, simulation programs are a major time saver that eliminates the need to construct prototypes and perform actual tests of models. PLM is used in all industries, including manufacturing (MSC Software, 2009):

> Whether designing factory equipment, specialized material handling equipment, or other machines and equipment, the engineering demands are similar. Make it perform faster . . . last longer . . . move more precisely or vibrate less. How will you be sure the product will meet these demands? The process of design, build and test with physical prototypes is the engineering approach . . . used for years. It is proven and reliable for designing machinery to meet specialized demands. . . . But the process takes too long and requires too many prototypes to "get it right." The new approach for all of engineering is to create virtual prototypes that can be tested in the computer, duplicating the conditions the entire machine will experience. In this virtual environment, the design can be changed, new prototypes can be built and virtual tests can be run in minutes instead of months. This new approach has been proven in demanding aerospace applications, and shown reliable in time-critical automotive applications.

Simulation is used as part of designing an entire building in CAD. The nuclear industry uses simulation to perform core and end drop tests of nuclear casks (MSC Software, 2009) to produce a Transportation Safety Analysis Report with respect to spent fuels storage and transportation. The design and maintenance of the Boeing 787 was done using CAD. These examples are good reasons to gain knowledge of the software that engineers use so that in working with them on designs SH&E practitioners will understand the considerations engineers have given to SH&E. In practice, it is also much easier than looking at a stack of blueprints.

Strategy Development

No master format is available for developing and implementing a strategy in specific areas of responsibility (company, plant, organization). It must be customized for individual situations. The following thoughts are offered to assist in that process.

- Develop a written document of what is desired to be accomplished, with due consideration of the operation's past achievements. Think outside the box.
- SH&E practitioners must lead and influence leaders. Leadership may be learned from others and is a component of directing power, but it also entails anticipating events or actions, and influencing others to follow the right course of action.
- Determine top management's style and business focus to identify the manner in which an approach that will be welcomed can be developed. Review how current organizational beliefs, habits and behaviors are communicated and demonstrated, and identify roadblocks to adding to that culture. Determine where the operation is heading and not if, but when, a safe design engineering program will fit.
- Seek others who would support the strategy defined including, if possible, a mentor in engineering or upper management. An engineering contact may provide information on current or new CAD programs that may identify unique opportunities for integration of strategies. An upper management mentor will provide access to others in top management, a key factor. Finding supporters and/or mentors will be easier if the proposer has a history of working with others to the organization's benefit. If no history exists, the practitioner must study the various individuals involved, their interests and operation philosophies to aid in determining the course to pursue.
- Evaluate the operation's goals and status to determine how the proposal would further the operation's objectives. What cost or savings or benefits will be created by the proposal? For example, the current economic situation may be difficult, yet some benefit may be derived in acknowledging that talented, experienced individuals are retiring or otherwise will not be available to assist in ensuring that future projects achieve ALOR. Top executives have a plethora of pressures so there must be a significant proposal to gain attention.
- Analyze personal/position accomplishments since becoming an SH&E practitioner or advisor. Identify contributions and dedication to improved management understanding of the concepts being proposed. Evaluate how well management recognizes from mutual experience and that safety levels above code, standard or regulatory compliance are advocated and in the operation's best interest.
- Recognize that silos must be eliminated and that teamwork is necessary. When a team is established, initial strategy ideas may change based on additional input. Consider including engineers and customers in brainstorming and collaborative design activity. Seek a mindset toward continuous improvement. Understand that culture change will not occur the day a policy is adopted, overnight or next week.
- Determine the level of effort and cost to implement the proposed strategy. Make sure information from every root-cause incident investigation is fed

Many injuries and illnesses could be prevented if SH&E practitioners and engineers developed a strategy to incorporate safety into the design engineering phase of projects.

back to engineering and other appropriate groups to preclude repetition of similar design errors.

•In culture development, a long-term item, recognize that employees are inspired by leaders who demonstrate a vision of how things should be improved and tend to perform at that level or above. Leaders must recognize the way things are, face facts and act quickly.

•Examine whether action can be initiated on small redesign or remodeling projects to build experience and realize benefits. Consider marketing with lean, green or sustainable initiatives, indicating that they cannot be accomplished without SH&E input.

Policy

A policy will vary for different organizations or environments. One must examine the arena in which the proposal will be offered in order to determine the hoops that must be entered or may be bypassed. Generally, it should be endorsed and supported at the highest level that can be attained in the operation. Some thoughts expressed about strategy also apply to policy development. In addition, the following are important:

•The focus must be on eliminating hazards—"to design (or redesign) and produce facilities, equipment, processes and products that provide employees a safe work environment" and to "permit visitors, vendors, users and customers to have an acceptable level of risk in facilities or using products."

•Ensure that designers comply with or exceed applicable standards and codes, and federal, state and local regulations, and recognize that meeting these may only mean that a minimal level of risk has been achieved that may not provide an ALOR.

•The goal is not to be a program, but rather to be a demonstrated SH&E culture integrated into the operations management systems that need to be developed. Consider ANSI/AIHA Z10.

•Ensure that the demonstrated culture includes multidiscipline teamwork.

•Evaluate systems and processes as well as tasks to ensure that an ALOR is achieved. Recognize that zero risk is not attainable.

•Follow the hierarchy of controls in risk mitigation.

•Identify benefits. These may include safer work environments; reductions in serious injuries, illnesses and property damage; increased productivity; reduced operating costs; decreased workers' compensation and business interruption costs; and reduced potential public and product liability.

Conclusion

Readers are urged to give thoughtful consideration to the concepts presented, as well as to the information on the skill, strategy and policy needed to lead the charge toward including SH&E considerations in the design engineering process. Visualize change(s) that may/will occur within the next year, both inside the organization and outside among vendors and subcontractors. Will they benefit the safety of workers and the public?

Many thoughts have been offered. As a result of the information on the need to incorporate SH&E in the design engineering phase, should "inside" be the strategy for your area of responsibility? Will you, as an SH&E practitioner, and your organization's engineers be able to look each other in the eye in future years and feel you have met the ethics of your professional organizations?

The answer is up to each individual SH&E practitioner or engineer. For the sake of workers and the public, it is hoped practitioners will choose to incorporate safety into design and be able to answer with an affirmative yes the question, "To err is human. To forgive, design. Are you good enough, ingenious enough and dedicated enough to meet the challenge?" ■

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