Program Development

Safety Through Design

Helping design engineers answer 10 key questions

By Wayne C. Christensen

IMAGINE THIS SCENARIO. XYZ Corp. has decided to consider safety early in the design phase of processes, equipment, facilities and products. The staff SH&E practitioner has been asked to facilitate a workshop with a small group of design managers and staff to initiate this effort. The plan is to involve designers in this process by having them develop "checklists" for the design activity. This will be the starting point for the company's initiative. During the workshop, the engineers will raise many questions—and the SH&E professional must be prepared to respond. Understanding the company's methodology for designing products and preparing manufacturing operations requires gaining insight into the design department's processes and procedures. Presented here are 10 questions the SH&E professional should be prepared to answer.

Wayne C. Christensen, P.E., CSP, *is head of Christensen Consulting for Safety Excellence Ltd. He is a member of three ASTM committees and the ANSI B11 TR3 Committee - Technical Report, "Risk Assessment and Risk Reduction." Consulting activities include seven years as project manager of the NSC Institute for Safety Through Design and as an adjunct instructor with the NSC Training Institute. A Fellow and former executive director of ASSE, Christensen has a B.S. in Fire Protection and Safety Engineering and is a member of the Society of Fire Protection Engineers and a professional member of the American Society for Engineering Education.*

Setting the Stage

Before discussing the questions, the conditions that precipitated the workshop must be established. The SH&E practitioner has realized several key facts:

1) Considering safety (which includes ergonomics, fire, health and environment) in the design phase of facilities, processes, equipment and products is beneficial and necessary to the company (Figure 1).

2) A company policy requiring safety unit involvement in the design phase of products or operations does not exist.

3) Sufficient company data on the benefits of safety through design is not currently available to help market this philosophy to top management in order to produce a policy and initiate development of a corporate culture.

4) The key factors of a safety through design activity have no specific sequence of action; it is possible to initiate the activity at points other than "adoption of a policy" and still achieve the desired result—safer operations.

5) Personal skills must be developed in unfamiliar technical/engineering territory.

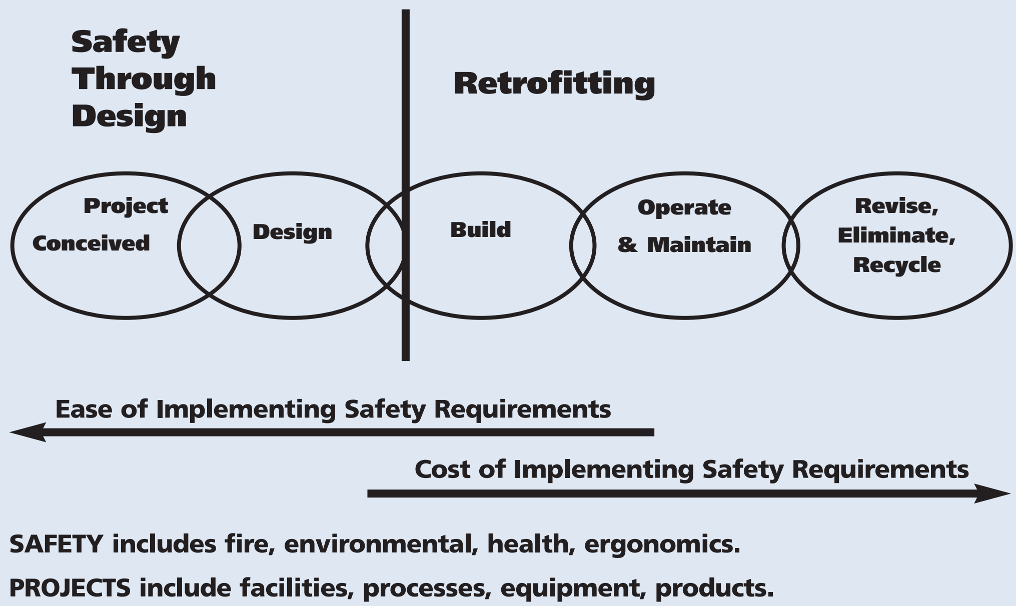
6) Prior contact with top design managers provided an opportunity to work with designers to develop a basic safety tool (checklists). A literature search revealed several checklists focused on inspections, but none related to design.

7) Participating engineers may represent many disciplines (e.g., mechanical, civil, chemical, electrical, industrial) involved in designing facilities, processes, products and equipment but with minimal focus on reducing employee or user injury.

Responding to the engineers' questions opens an opportunity to present information on the company's plans for the safety through design activity and to discuss safety problems. Depending on the company's markets and globalization, it will be helpful to share worldwide trends in this concept, such as growing recognition of the need for hazard analysis and risk assessment in various standards, laws and

Figure 1

Safety as a Forethought



countries, and by associations and companies in connection with products, equipment, processes and facilities (Main). Furthermore, as the time span from design to production continues to be compressed, the opportunity to retrofit just prior to production is being diminished.

The 10 Questions

Question 1: What root-cause data does the safety unit possess to indicate that the company could benefit from additional consideration of safety during the design process?

Engineers are interested in data that reflect deficiencies with a product's design, construction, maintainability, operation or other features which resulted in, or contributed to, anything from near-hits to serious incidents. Incident investigation results which indicate that workers ignored instructions, removed a guard, hurried or were inattentive, as well as similar information that does not focus on design needs or is based on the concept that 85 percent of injuries are caused by unsafe acts, will not enhance design efforts.

Engineers deal in facts; information that people are at fault makes it difficult to consider design modifications. As Chapanis stated:

> Everyone, and that includes you and me, is at some time careless, complacent, over-confident and stubborn. At times each of us becomes distracted, inattentive, bored and fatigued. We occasionally take chances, we misunderstand, we misinterpret and we misread. As a result . . . we sometimes do not do things or use things in ways that are expected of us. Because we are human and because all these traits are fundamental and built into each of us, the equipment, machines and systems that we construct for our use have to be made to accommodate us the way we are, and not vice versa. And that's what I . . . give in the form of a challenge—to err is human, to forgive, design.

Thus, a company needs an investigative system that thoroughly analyzes incidents and avoids faulting the worker. Investigations should include root-cause analysis, which can provide useful design information for engineers. According to Van Cott:

> So firmly entrenched is the belief that "to err is human" that, when a human error has been identified in an accident, further action is seldom taken once the perpetrator has been singled out, censured, given more training or otherwise dealt with. In many instances, however, had the investigators of accidents and injuries looked beyond the user or operator who made the error, product design features would have been found to be the real culprit because they had "set up" a design trap for a person to make an error. The question that should always be asked, What was the root cause of the human error, is often never raised.

Based on these observations, the system should also recognize that quality errors and incidents are similar to occupational injury incidents in that they reveal root-cause data concerning errors which produce defective or unsafe products. Those involved should also consider investigating customer product defect complaints to determine whether they might suggest safety considerations that would be useful to the design staff.

Question 2: What constitutes the safety through design process?

Engineers are interested in what the safety through design process is or will be within the company. The "Key Factors" sidebar (pg. 34) provides a good outline for discussion. It is often assumed that the task is accomplished when a policy simply states, "We will consider safety in the design of facilities, products, processes or equipment." Nothing is further from the truth. Developing policy is a small step; it is also important to emphasize the level of top management involvement. Therefore, the management status in developing policy, benchmarking and measurable project objectives should be shared.

Key Factors in Instituting a Safety Through Design Program

- Develop policy, implementation plans and marketing.
- Facilitate safety and engineering department cooperative efforts.
- Develop program benchmarks.
- Create a safety knowledge education program for engineers.
- Prepare engineering and design knowledge criteria for SH&E practitioners.
- Establish hazard analysis and risk assessment procedures to reach acceptable risk.
- Define project design criteria and measurable performance standards.
- Determine tools necessary to assist design engineers.
- Conduct design reviews before physical models are prepared.
- Develop methodology for SH&E practitioners to collaborate on outsourced projects.
- Prepare program evaluation audits and management of change procedures.

Depending on product complexity, several design departments—spanning various engineering specialties and involving possibly hundreds of designers—may be responsible for different components or systems. For example, in the aircraft industry, a partial list of systems involved might include avionics, dynamic loads, flight systems, fuel systems, interiors, payloads, propulsion and structures. The engineers will be interested in how the effort to develop design safety checklists will mesh among the various design groups.

Throughout the workshop, the SH&E practitioner should act as a facilitator and resource, letting the participants ponder the details, with discussions led by engineering managers; this will move the workshop away from being a program fostered by "safety" into engineering ownership.

The interfaces between the practitioner and the design team should also be identified. For example, how will project design objectives for safety be established and evaluated? How will they relate to individual engineer performance evaluations? It is also important to discuss how the safety unit will provide safety-related education to both practicing and new company engineers.

To be effective, the SH&E professional must establish credibility with the engineering staff through his/her education, experience, and the materials and tools shared during the workshop. In this regard, it will be valuable to learn—prior to the workshop—the type of computer-assisted design (CAD) software the company utilizes, then to work with the software vendor to begin to understand the software and its features. And, while engineering terminology may seem like a foreign language to the SH&E professional, many terms and concepts used in safety are equally foreign to engineers (e.g., incident, near-hit, risk assessment, acceptable risk). Therefore, discussions with engineers should start with an understanding of safety terminology used in the company.

Question 3: How does our company compare with other companies using or considering this process?

If the safety through design effort has been benchmarked against similar operations, those results should be shared. Even if no benchmarking has been performed, engineers will want any information available concerning competitor activities in this area. If others contacted are doing nothing, the SH&E professional will need to explain why this initiative is important to the company. Where benchmarks have been established, it is best to identify those involved in the process, describe the process used (or to be used) to develop benchmarks and explain how designers will be involved.

Engineers will want to know whether the effort to integrate safety into the design phase is related to products, manufacturing operations or both. They must also receive a description of the type and nature of involvement that is expected of them. The discussion must also relate how the process is to be applied to new designs as well as efforts to refurbish or modify past designs and operations (the design phase of retrofitting).

Outsourcing is another topic for discussion. Many companies now outsource to suppliers, so the engineers must understand the company's position on suppliers with respect to safety. To produce safer products and working conditions, engineers must share safety design criteria with suppliers. The SH&E professional should also share information on how suppliers' work will be audited.

In outsourced work, "collaboration" is becoming a significant part of efforts to design and produce a finished product. The brochure for one software package developed to facilitate this process says the software results in ". . . a virtual conference room where specialists from various disciplines can meet . . . to identify and solve design-related problems. Each participant . . . can view, manipulate and annotate a shared model in a real-time environment" (CoCreate). Through such group work, engineers in various organizations can discuss and modify designs online, resulting in substantial time and cost savings. According to Nichols, in the Joint Strike Fighter project, as many as 50,000 people would have access to various design components online (64).

Question 4: What is expected from us today (in the workshop) in developing these checklists?

The purpose of the workshop is to initiate creation of design checklists to serve as a reminder for engineers in future design activity. As a by-product, it may reveal areas where additional education and tools are needed to help designers understand hazards, assess risks and develop necessary controls. Engineers will be using basic knowledge brought to the discussion, supplemented by incident data presented by the SH&E practitioner.

A finished product is not expected at the end of the workshop. Instead, workshop results will be organized in a consistent format and submitted to participants for additional contributions. Other company engineering groups will also meet in order to gather their insights and develop checklists for their specialty areas. Workshop input from SH&E personnel will be mini-

Establishing Incident Prevention: Clues for Design Engineers

1) Clues should concern "potential." By nature they are to move beyond the realm of code and standard compliance.

2) Develop clues for various design functions first and subsequently review for consolidation.

3) Consider safety of a design from concept to the end of its lifecyle (recycling, disposal, decommissioning).

4) Clues should permit a systematic approach to consideration of hazards and risk assessment to determine if risk is acceptable or if mitigation is required.

5) Clues should lead to design systems that are failsafe, error-tolerant and forgiving. Consider that human operators are not 100-percent attentive.

6) In developing clues, improbable events, unexpected events and events that occur when people are not thinking must be considered; they occur for logical and scientific reasons.

7) Clues should guide systems to be stable, self-regulating, self-limiting, with robustness to resist environmental changes, inherently safe—low in energy or capacity to do harm.

Table 1

Examples of Clues That Might Be Utilized by Designers in Facility Design

Facility >> Exterior Structure

System/Condition		Clue for Potential
Transportation	Railroad	•Complex traffic patterns—tracks in relation to roads? •Tracks and parking, vehicles and employees entering/working? •Mainline trains blocking emergency vehicle access? •HazMat incidents or hazardous operations on adjoining rail spurs?
	Aircraft	•Landing patterns/activity of nearby airports, military facilities? •HazMat incidents from nearby aircraft flight patterns?
	Access and nearby roads	•Complex traffic between trucks and autos minimized? •HazMat incidents on nearby state/interstate highways? •Objects/structures block view of/by pedestrians/vehicles?
	Parking	•Safe haven for trucks incoming or awaiting loading?
Road/walkway surfaces	Opportunities to fall	•Surfaces subject to standing water? •Roads and walkways minimize accumulation of snow/ice?
Utilities	Electrical/gas	•Shutoff accessible in emergency? Remote shut-off?
Lighting	Work, access & security	•Adequate for night in elevated areas? •Adequate for inclement weather work? •Sufficient for worker access to parked cars?
Maintenance	Ease of access	•Motors and equipment in position for easy replacement?
Fire	Alarms	•Give outside audible and visual alarm in any emergency?
	Piping/pressure systems	•Effects of corrosion considered? •Effects of stress concentration considered?
	Windows	•Safe system for multi-story building window cleaning?
Weather	Wind—tornado	•In tornado area, shelter space 5 sq. ft. per person provided?
	Electrical storm	•Lightning protection necessary? •Structure, high points and equipment grounded?
Security—theft, terrorism	Perimeter	•Adequate space for emergency evacuees to be safe inside security fence? If no, ability to exit fenced area safely? •Evacuation assembly points identified/marked?
General	Isolated structures	•Test facilities or hazardous occupancies minimized? •No persons working alone?
	Nearby facilities	•Hazardous operations/occupancies (processes) pose threat?
	Roof access	•Regular maintenance access needed? If yes, consider stairs.

mized to avoid constraints in thinking and suppression of innovative ideas. In addition, the workshop facilitator should provide a timeline for results. For example, "All initial and any secondary engineering meetings will be completed in the next quarter and the initial checklists will be available 30 days after the end of the last meeting."

Developing checklists customized to company products, facilities, equipment or processes is not easy; therefore, flexibility is key. Checklists will vary from a product design group to manufacturing engineering, to maintenance and service operations, or even between portions of design operations when a product is complex. Participants must understand that although numerous checklists are available in various publications, most concern inspections of existing facilities or operations and result in retrofitting efforts. This effort (the workshop) is focused on helping participants develop clues or checklist items aimed at designing out or reducing hazards to an acceptable level of risk in new designs. Engineers should later be provided with risk assessment tools to be used to evaluate their designs. The SH&E practitioner must also set the stage so that when existing operations are to be modified or redesigned, each will be considered as if it were a new design and accorded all aspects of the safety through design process.

To achieve these outcomes, the workshop environment must be conducive to creating, with workspace for teams to easily share results periodically during their deliberations. In addition, "pump-priming" materials should be available, such as criteria for developing clues for design engineers ("Establishing" sidebar, pg. 35) and a sample checklist of clues (Table 1). These clues are not related directly to OSHA standards, codes or regulations, but reflect safety concerns that should be considered during facility design. The workshop should not become an exercise in converting standards into checklists; rather, it is an opportunity to focus on ergonomic, environmental, fire, safety and health concerns not necessarily covered by regulations, codes or company standards. Existing requirements must be considered, but the task is not to simply list chemicals that are not acceptable in company operations.

Usability with Acceptable Risk (UAR) Suggestions

1) All energy sources—meet or exceed OSHA and ANSI standards for energy lockout.

2) Permit-required confined spaces—minimized or provided alternative means for inspection, cleaning and maintenance.

3) Noise levels—facility/equipment/operation maintained below 82 dbA.

4) Ventilation—levels established to provide sufficient air:
- for occupant comfort;
- to maintain contaminants below respirator requirements.

5) Equipment disconnect control identification—readable from ____ feet.

6) Deliver ____ percent of supplies and equipment by direct unloading at point of use or conveyors.

7) Finished parts ____ percent moved by conveyors. Delivery/removal via pedestrian aisles by forklift trucks or similar devices is limited.

8) Ergonomics using CAESAR (SAE) study:
- Task strength requirements accommodate ____ percent of adult worker population.
- Workstation specifications accommodate adult worker (male/female) height and reach ____ percentile.

Question 5: Why start with a checklist rather than develop a policy?

At whatever stage the safety through design process is started—for example, with checklists—engineers must understand why this starting point was chosen and the steps to be taken from that point. The objective of the workshop is to enter the process at a midpoint in order to produce a quick return of information—the checklists—that will help to improve future designs. The workshop discussions will also indicate the SH&E practitioner's understanding of the CAD software and how checklists may be incorporated into it in the future.

Checklists are an excellent starting point because they are something those involved can discuss rationally. The resulting product can be used in engineering education activities and in efforts to eliminate hazards. A checklist is simply a reminder; the user must possess an understanding of its items and action necessary. Even if a company has no safety through design culture, working with engineers to develop checklists can be a superior tactic for three reasons:
- Engineers will obtain a useful tool.
- The concept of safety in the design process will be established.
- The SH&E practitioner will be established in the design stage and his/her retrofit mode image will be reduced (Figure 2).

After this workshop, each engineer should receive a thank you note or similar recognition from a top executive. Recognition will facilitate continued participation and acceptance of new safety challenges. It also lets the engineers know they are part of the team and that management, the engineering department and the safety unit are looking forward to continuous improvement of the resulting checklists.

Question 6: What education activities will be provided to engineers to improve their safety knowledge?

Engineers should readily recognize that their safety knowledge needs enhancement. Most undergraduate engineering programs offer little safety education. And, since it may be years before accredited curricula at most institutions reflect full implementation of changes to meet minimum safety requirements in "Engineering Criteria 2000" from the Accreditation Board for Engineering and Technology (ABET), it must be assumed that all company engineers and future hires will need further education to develop the level of safety knowledge determined appropriate for company design work.

Anecdotal evidence suggests that undergraduate engineers may never have been exposed to manufacturing facility operations except perhaps on a quick tour; the typical university-sponsored tour does not increase one's understanding of safety. And, while some students may serve an internship that can produce valuable manufacturing experience, an internship is generally voluntary and limited to available opportunities. Thus, most engineering students have no opportunity to acquire the knowledge needed to enhance their ability to contribute to company safety goals. It is entirely possible that some current company designers have never been on the manufacturing floor and, thus, have minimal knowledge of operations hazards and concerns for worker safety.

Engineers are information seekers. If presented good data regarding top management involvement in this initiative and given evidence which indicates that the process will produce improved designs, they will be eager to understand the process and how it can be implemented. It may be useful to develop measurable performance objectives in connection with a knowledge enhancement program for engineers—both practicing and new hires. The list of objectives and short courses needed to provide this knowledge could be lengthy and should be compiled based on company needs.

To ensure that all engineers receive the same material and testing, and that progress is documented, the system should be developed and administered on an internal network. Study courses may be delivered via this network or by an authorized vendor. To measure progress, it is best to prepare measurable performance objectives for the knowledge level defined as a base for making future safety interpretations. The tracking system should define requirements for each engineering group so that an employee transferring between groups can review records and identify the need for additional courses.

Measurable objectives can be established in many formats. For example, after completing the listed safety courses, the engineer should be able to perform the listed objectives.

- **Risk analysis principles.** Demonstrate acquired knowledge through application on four problems. Explain how "acceptable risk" is determined in the company.
- **The safety hierarchy.** Successfully categorize and explain 10 sample situations.
- **Preliminary hazard analysis (PHA).** Explain the process and analyze five problems.
- **Failure mode and effects analysis (FMEA).** Explain the process and analyze three problems.
- **Basic ergonomic knowledge and policy/practices regarding ergonomic injury prevention.** Explain company policy and methodologies. Demonstrate understanding of basic ergonomic techniques in three case studies.
- **Company basic electrical safety principles and requirements.** List five company requirements or principles and exhibit knowledge in two case studies.
- **Environmental safety policy and practices.** Explain company approach to environmental safety and respond to five situations, indicating the recommended action to be taken in each case.

Many of the suggested courses contain information specific to a given company and should be developed based on a company's internal philosophies and practices. Additional topics—such as guarding, basic electrical safety, energy lockout, confined spaces—are available from many web-based training organizations.

Programs for providing safety knowledge to company designers should be examined and a plan established. Each engineer's exposure to manufacturing operations should be evaluated. In some cases, a safety tour(s), guided by the safety unit, may be an appropriate educational activity. The previous safety knowledge of each engineering group must also be examined to determine the education its members should receive based on their design responsibilities. For example, all engineers should understand requirements for electrical safety, hazard recognition, risk assessment and the concept of acceptable risk; however, a product designer may not need to understand concepts of confined spaces, crane and hoist safety, or other OSHA requirements, unless such issues would be included in his/her design responsibilities.

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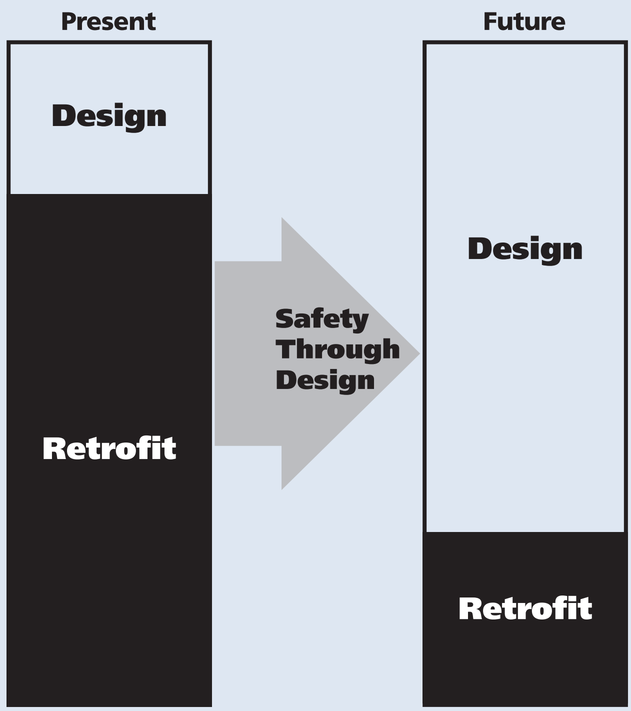
Figure 2

The Safety Through Design Evolution



Question 7: What other assistance will be provided to engineers?

The SH&E practitioner should participate in establishing measurable project objectives, as well as in the design review team, and in collaborative work to ensure that any changes do not adversely affect manufacturing or product safety. S/he should also participate in pre-startup evaluations and post-operational audits. Since the focus should be on reaching an acceptable level of risk, objectives could be defined as usability with acceptable risk (UAR) (“Usability” sidebar, pg. 36). Criteria for UARs could be related to employees and/or product users and include ergonomics, energy sources, safety, health, environmental and regulatory requirements.

A safety reference list should be provided to engineers and various texts should be available in a library for designers (“References” sidebar, pg. 37). The assistance provided may be as broad as the market for company products. Other services provided might include:

•bulletins on changes in U.S. and global regulations and standards regarding safety, hazard analysis and risk assessment;

•information on lessons learned from internal incident investigations or from outside sources that are pertinent to company products, processes, equipment or manufacturing operations;

•new hazard analysis and risk assessment tools that become available;

•refresher workshops and published articles on safety through design;

•progress on the company’s safety through design activities;

•education on application of new checklists developed and additions to the software safety knowledge base;

•safety benchmarks established for the company;

•results of design safety reviews, audits and program evaluations;

•supplier and contractor information on knowledge acquired and requirements with which they will comply.

Question 8: What tools will be provided for engineers to use?

The nature of tools provided will depend on the type, complexity and globalization of company products and/or manufacturing operations that engineers are responsible for designing. Safety-education modules for basic knowledge should be researched or developed based on company needs.

Workshop participants must understand that the checklists developed during the session are a starting point, not the end of consideration of safety. Any already available design-related checklists should also be shared (e.g., Manuele 137). These can enhance the set of checklists developed during the workshop.

Knowledge of computer software packages and their use will serve the SH&E practitioner well when designers move into the area of collaboration. Such knowledge enables the SH&E professional to determine add-ons or complementary products that would help the engineers accomplish safety objectives more easily. Topic areas might include:

•ergonomics (for product or manufacturing operations that involve substantial operator exposure to repetitive motion);

•animation (which permits observation of an individual using or manufacturing the product);

•hazard analysis and risk assessment;

•FMEA;

•designing machine safety systems (software offered by manufacturers of interlocks and related equipment that will guide engineers through complex directives and requirements).

Question 9: What is the future plan for safety through design and what, specifically, is engineering’s role in that process?

The SH&E practitioner should have clear objectives and a plan for the concept. That plan should be presented to help participants understand the potential company and engineering actions toward integration. If the engineers know in advance about the plan, they may take a greater interest and, as a result, learn more and be able to contribute more. While most designers recognize, in general, that safety is important, the advantages of considering safety early in the design process should be reiterated. Communication and follow-through must be excellent throughout this effort, otherwise engineers may lose interest. It should be emphasized that total implementation will not occur overnight.

Question 10: How will the checklist be integrated with the CAD technology?

The answer should be easy if the SH&E professional has done his/her homework and understands the principles of the features offered in CAD programs. What better way to share knowledge with engineers than to know something about the CAD program used? Most software suppliers offer overview sessions (full- or half-day training sessions), CDs describing a product's capabilities and perhaps webcasts to explain how the product is used. The SH&E professional would do well to take advantage of these opportunities.

Participants must also be informed that the company plans to incorporate a portion of the safety requirements into the CAD software; they will be interested in this initiative and how far downstream it may occur. A wide range of safety standards can be programmed into CAD software.

For example, CATIA v5 for facility design, one of many CAD programs available, contains a feature called Knowledge Engineering. According to product literature, it ". . . enables users to combine corporate expertise into their design process through an intelligent rule definition and checking function. Designers . . . can manage complex assemblies knowing that they comply with technical rules, safety regulations and company standards" (IBM). Through this feature, one can inquire whether the aisles as designed are wide enough to accommodate two-way forklift traffic and pedestrian movement. The software will assess the aisles throughout the entire facility and prepare a list of locations where the criteria is not met. Such a feature can also check the forward vision of a worker moving a large piece of equipment from one plant area to another to determine obstacles and hindrances to vision and equipment movement.

Obviously, it would be beneficial if substantial basic requirements were already in the software and each user did not have to develop his/her own (other than special company requirements). Imagine the benefit if a firm's entire checklist, as well as OSHA and other requirements could be incorporated. Unfortunately, industry demand is not yet sufficient to prompt developers to provide this as an integral feature.

Conclusion

To initiate an effective safety through design process, the SH&E professional must establish his/her professional competence through thorough preparation, informative materials and detailed information sharing. Every group of designers, even within a single company, will be unique based on its responsibilities, and individual and company experience. Any safety through design program will be distinct because of the range of products and engineering and manufacturing operations involved. For a plan to succeed, the SH&E practitioner must be prepared with relevant knowledge and data.

Responding to the growing interest in addressing safety during the design process and shortening of the concept-to-production cycle requires a change in management culture and in the knowledge of engineers and SH&E practitioners. SH&E practitioners must move from retrofitting to the design phase. Successfully incorporating safety into engineering knowledge and tools is vital if the total safety program is to benefit employees, the community, products and shareholders. Preparing for success will preclude management dissatisfaction with requests for retrofitting, which delay targeted production dates. SH&E practitioners must accept the challenge and move toward incorporating safety into the design phase. ■

Responding to the growing interest worldwide in addressing safety during the design process and shortening of the concept-to-production cycle requires a change in management culture and in the knowledge of engineers and SH&E practitioners.

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