CHAPTER 9

MAKE IT SAFE AND LEGAL

Meeting Broader Community Expectations

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Learning Objectives

So that you can make students aware of their obligations as professional engineers, upon reading this chapter you should be able to

- Describe the concept of inherent safety and its implications for information across the life cycle of a new product or system
- Distinguish between a specification, a standard, and a regulation in the context of engineering design
- Locate and obtain relevant standards and regulations pertinent to your design project

INTRODUCTION

In addition to understanding user needs and contextual factors, the design team needs to consider issues of safety, legal constraints, and/or professional standards for performance or interoperability. These matters need to be addressed early on in the design process as part of clarifying the task. Safety is a paramount consideration that begins at the outset of a design project and which spans the entire life cycle of any product, process, or system. If the design team fails to take into account the need for certification to meet a required standard for safe use or issues of compatibility with other systems, then the design effort may be wasted. It is best to understand such design constraints and opportunities early in the design cycle. While a client may or may not know the relevant professional standards and regulations, the design team needs to be aware of them so that their solution is safe and legal.

Design failures can arise from very simple assumptions that are made early in a project, from issues that are taken for granted or are so obvious that no one thinks to ask or to check. On September 23, 1999, the Mars Climate Orbiter entered the Martian atmosphere rather than its planned higher orbit and was destroyed. During the flight to Mars, NASA engineers tried unsuccessfully to correct the trajectory. The failure was due to a very simple error—NASA planned the mission acceleration in metric units, while the builder of the orbiter used English units. As NASA explained, "The 'root cause' of the loss of the spacecraft was the failed translation of English units into metric units in a segment of ground-based, navigation-related mission software" (Isabell & Savage, 1999, para. 6). This failure was due to a very simple error, but the cost was high in dollars, effort, and prestige.

Clarity of information can avoid costly and sometimes deadly errors in engineering. As with the Orbiter, errors can be as basic as a unit of measurement mismatch or as complex as selecting the wrong materials for a particular environment. To address the need for clarity and specificity in engineering, a number of standards have been developed by various organizations with the goal of addressing conformity, reliability, compatibility, and safety. These include specifications, standards, codes, and regulations. While all share some commonalities, there are distinct differences among them—who creates and authorizes them, if they are mandatory or voluntary, and how they are promulgated—but in general they have some very important commonalities, such as providing guidance for the engineer to meet at least minimal levels of safety, structural integrity, and physical limits, among other requirements. In our increasingly global economy, they also provide the engineer and the consumer with some information on what level of confidence to place in a design solution. For example, the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.15 for wireless communication assures buyers of cell phones that, regardless of the location of manufacture or the name on the case, the phone will operate as they expect, wherever they are in the world (IEEE, 2002).

COMMON CHALLENGES FOR STUDENTS

Students often underestimate the centrality of safety in the design process and do not take into account relevant codes, regulations, and standards in the choices they make in designing a product. Examples of these challenges include the following:

- Considering safety as an integral part of the design process.
- Explaining how well-documented design specifications can improve safety in design.
- Finding, reading, interpreting, and applying the relevant information from standards, codes, and regulations with completeness, precision, and accuracy.
- Thinking globally rather than provincially when considering relevant standards and regulations.
- Considering concepts of standard sizes and interchangeability in components.
- Specifying with precision the composition and performance of materials, especially under different operating conditions.

SAFETY

Safety considers the avoidance, prevention, and diminishment of hazards and their potential impact on people and things. Most safety issues involve ensuring that a source of energy does not come in contact with a person or piece of equipment in an uncontrolled manner such as to cause injury or damage. The design hierarchy for ensuring safety is to (1) separate the energy source from the person or place where it can do damage; (2) reduce, restrict, or eliminate possible pathways for the energy to reach the person or place; and (3) as a last line of defense, protect the person or place from damage from the energy.

Safety should be designed in from the very beginning of a project rather than being added on at the end. In the context of chemical engineering, Trevor Kletz subscribes to the notion that "what you don't have, can't leak" (Mannan, 2012, para. 1). The basic idea is that the design solution should be one that is inherently safe even if something does go wrong. Reduction or elimination of hazards is the goal. Tragic instances of explosions, injuries, and death indicate the need for designing to minimize the hazardous materials and processes in a plant. While it is impossible to completely eliminate accidents, they can be decreased by limiting the amounts of hazardous materials used, substituting safer materials, simplifying design, and designing for projected worst cases. For example, limiting the amount of a caustic agent present, using a less caustic agent, moving the agent to a safer location, and constructing a containment system are examples of designing for inherent safety. While the concept is integral to chemical engineering, it can be applied to every engineering discipline.

To achieve inherent safety, it is critical to remember that safety should be a primary consideration at all stages of the product life cycle, from needs assessment, through design and manufacture to the use of the product, and ultimately to its disposal at the end of its useful life. It is a factor in concept development, selection of materials, detailed design of equipment and processes, design of training, and work conditions, and it must consider all people who might come in contact with the product at every stage of its life cycle. This includes the people who make it, move it, install it, operate or use it, maintain it, and repurpose or recycle it. Consideration of safety issues saves time and money in the long run, and avoids subsequent problems with product recalls and related legal issues.

Of increasing importance is safety after the useful life of a product is over. Safe, efficient recycling or disposal is a critical design consideration. While for some products and some countries or jurisdictions this is merely a desirable outcome, for other countries it is mandatory and enforced by law. All engineers should consider such life cycle safety within both the legal framework of the market and the ethical framework of the profession.

Inherent safety is the foundation upon which good engineering design rests. The most innovative product is worthless if the process to make it is dangerous or if its use is high risk for the consumer. The most efficient manufacturing is pointless if it cannot be done without harm to the workers. Understanding the basic aspects of safety and the appropriate standards and regulations—whether customized for a local facility or regulated locally, nationally, or internationally—is essential.

The question remains, what is safe or what is safe enough? According to Vesiland and Gunn (2011), "the key principle is that the level of safety be understood and fully communicated to the user, and that any deviance from this accepted level of safety without full understanding of the user is unethical conduct" (p. 162). For example, bungee jumping from a bridge into a rocky gorge is not advised for people who have particular medical conditions. However, if the jumping facility has been designed properly with adequate clearance from the platform; has equipment that meets all the appropriate standards for manufacturing, installation, and inspection; and has properly trained staff, there is a level of trust in the safety of the activity. Safety is about reducing the likelihood of something going wrong and the severity of the consequences to people or property if something does go wrong.

Safety in design applies to the things we use in our everyday lives—from the coffeepot we plug in for breakfast to the alarm clock we set at night—as much as it does to large, complex engineering projects.

DESIGN SPECIFICATIONS

A design specification describes a product or system in terms of what it is capable of doing, by using both a metric and a value (Haik & Shahin, 2011). In contrast to a design requirement (see Chapter 7), which focuses on needs or desires, the specification is a statement of expected performance. For example, "Product A will lift *x* number of pounds *y* feet in *z* seconds." With this precise information, the designer can begin to plan the development of the product. However, this is not a once and done process. As the product or system is developed and tested, new information is discovered and must be accommodated in the design specifications. Specifications often will be adjusted or refined as the design process develops and actual constraints and costs indicate that some specifications must be reconsidered. As an example, it is discovered that although Product A can easily lift the specified number of pounds the specified number of feet, doing so at the rate determined in the original specification would cause damage to the merchandise. Therefore, the rate needs to be adjusted, and the final specification would reflect that change.

The benefits of specifications are many, especially if careful documentation is kept of each aspect of the design process, including who is responsible and when the various aspects have been accounted for or changed. This itemization and accountability may limit errors, inefficiencies, and poor communication, especially of important changes. It also helps focus attention on specification targets and inclusion of individuals such as safety specialists, and it tracks progress on the project. For many projects a formal, written checklist is recommended, although there are instances when a less formal process is acceptable.

Analysis of the design specifications of previous products or systems can reduce risks and increase safety by carrying knowledge from past projects forward so that mistakes are not repeated. For example, if a pedestrian bridge is being designed, it is useful to know what issues and solutions have worked and what problems have been noted in the past. If specifications include a particular appearance and materials that have been known to cause problems in the past, it would be beneficial to already know about, for example, the wobbly bridge problem and alter the specifications to adjust for the vibration issues with dampers and vibration absorbers (Hales & Gooch, 2004).

STANDARDS

Standards are consensus documents that consolidate knowledge and best practices aimed at improving safety, reliability, quality, efficiency, interchangeability, and testing, and creating a consistent measurement, terminology, and use of symbols (see, e.g., de Vries, 1999). They are written by a group of subject matter experts and many are updated frequently, particularly after a problem or failure has been noted. Standards can apply to one specific company or to an entire industry. They can be created by local or national government groups, a collection of countries such as the European Union, or by nongovernmental organizations or professional societies. While adhering to standards is voluntary, it is good practice to take into account the standards that are relevant to both the location where the product or system designed will be used and the relevant professional organizations of the specific area of engineering. Box 9.1 contains the American Society of Mechanical Engineers (ASME) definition of a standard.

BOX 9.1

American Society of Mechanical Engineers (ASME) Definition of a Standard

A standard can be defined as a set of technical definitions and guidelines—"how to" instructions for designers, manufacturers, and users. Standards promote safety, reliability, productivity, and efficiency in almost every industry that relies on engineering components or equipment. Standards can run from a few paragraphs to hundreds of pages and are written by experts with knowledge and expertise in a particular field who sit on many committees.

Standards are considered voluntary because they serve as guidelines, but they do not of themselves have the force of law. ASME cannot force any manufacturer, inspector, or installer to follow ASME standards. Their use is voluntary.

Standards become mandatory when they have been incorporated into a business contract or incorporated into regulations.

There are standards that use the term *specification* or *spec*. These are different from design specifications and are usually interchangeable with those called *standards*. One of the most widely used are the Military Standards (MIL SPECs), which are standards set by the United States military for both engineering and nonengineering requirements.

Standards are a major source of information for designers, providing a look at best practices and successful design processes. Reviewing standards allows designers to benefit from the wisdom and experience of others, rather than reinvent the wheel each time. This results in time and money savings and the avoidance of unsuccessful or inefficient processes. Engineering, like so many other fields of endeavor, benefits from the accumulated wisdom of previous practitioners, and standards are a formal way of documenting those advances. Standards also allow for increased interchangeability and interoperability. For example, parts, tools, and training can be consistent across a system if the same standard is used for a product. Travelers are well aware of the variety of electrical plugs used in different countries and the need for bringing adaptors. Until recently most chargers were specific to each brand of cell phone, requiring the purchase of a new charger every time one bought a new phone. The move by many manufacturers to the USB standard has changed that.

An important source of information about standards can be found on the National Institute of Standards and Technology website (http://www.nist.gov/director/sco/index.cfm). The site has a number of useful links and an interactive map to check standards from around the world, including regulations, relevant news, and much more, including links to standards creators and providers.

The importance of standards is clear from the statement from the American Society of Civil Engineers, which states that "all engineering graduates should have at least a rudimentary knowledge of the standards system and standards development, standards as they affect engineering design and practice in general and some knowledge of standards specific to their specialized field" (Kelly, 2008, p. 159). The importance of standards cannot be overemphasized in the design process. They affect every aspect of our lives and bleed over into the popular media. News reports frequently document the tragic results of nonadherence to existing standards or the need for revised standards. Examples include poorly designed cribs with slats or spindles too far apart, toys containing lead, toys with parts that can cause choking, flammable clothing, and unsafe drug manufacture. Adherence to relevant standards and review and updating of existing standards is a critical engineering practice. Standards impact almost every aspect of our lives, from toy safety to strength of materials in airplane cockpits to materials used in medical procedures. While many standards can be searched in specific databases such as ASTM (American Society for Testing and Materials; http://www.astm.org) or IEEE Xplore (http://ieeexplore.ieee.org/xpl/standards.jsp), both commonly accessible in full text at academic libraries, a more general subject search can be done in the NSSN standards database (www.nssn.org), provided by the American National Standards Institute (ANSI). This resource searches U.S. and international standards from a wide range of sources and provides access information.

Finding appropriate standards can be a difficult task. While NSSN is an excellent source, students frequently have trouble discovering the correct terminology to search. For example, knowing that there is a standard used in the production of the Lego building block toy does not make it easy to find the ASTM standard, "Standard Consumer Safety Specification for Toy Safety" (ASTM F963). Local documentation, stated requirements from the customer, and utilization of a knowledgeable person to review the appropriate standard resources will help ease the process of locating the correct standard.

CODES AND REGULATIONS

The term *code* is commonly used interchangeably with the term *standards*, although there is a definite distinction between the two terms. ASME notes that "a code is a standard that has been adopted by one or more governmental bodies and has the force of law" (ASME, 2012, "What is a code?"). Examples are the ASME Boiler and Pressure Vessel Code, International

Building Code, the National Fire Protection Association's Fire Code (NFPA 1), and the National Electrical Code, among others. Adherence to the appropriate code is critical. Codes provide a level of dependability and reliability with wide acceptance. A product that meets or exceeds code specifications provides important information to those using or affected by the product. For example, the ASME Boiler and Pressure Vessel Code

> establishes rules of safety—relating only to pressure integrity—governing the design, fabrication, and inspection of boilers and pressure vessels, and nuclear power plant components during construction. The objective of the rules is to provide a margin for deterioration in service. Advancements in design and material and the evidence of experience are constantly being added. (ASME, 2013, "About the Code")

Utilization of this type of code provides a level of exactness and trustworthiness that is recognized, often internationally. The result of not adhering to codes can be fines, increased inspections, radical renovations, and lost business.

Regulations are the laws that require the adherence of a product to codes or other technical requirements. They ensure the health and safety of the product with consideration of consumer safety, environmental impact, and user safety, among other aspects, and are frequently based on standards. U.S. regulations are recorded in the Code of Federal Regulations (CFR). Regulations from other countries can often be found on the Library of Congress' Global & Comparative Law Resources website (http://www.loc.gov/law/find/global.php). The website link to the Guide to Law Online (http://www.loc.gov/law/help/guide.php) can be especially useful. However, finding the appropriate regulation might be difficult, or it may not be included in this resource. In that case, it is best to search the U.S. government websites for laws and regulations that might impact the design project (see Box 9.2).

BOX 9.2

U.S. Government Websites for Regulations

LexisNexis State Capital (fee database)
http://www.lexisnexis.com/en-us/products/lexisnexis-state-capital.page

NIST Regulations
http://www.nist.gov/standardsgov/regulations.cfm

Office of Information and Regulatory Affairs
http://reginfo.gov

Federal Register (1994–current)
http://www.gpo.gov/fdsys/browse/collection.action?collectionCode=FR

Code of Federal Regulations (1996–current)
http://www.gpo.gov/fdsys/browse/collectionCfr.action?collectionCode=CFR

Regulations.gov
http://Regulations.gov

INTERNATIONAL ISSUES

Designers need to know the market or markets that will use the product or system being designed, as the standards vary from jurisdiction to jurisdiction. While there are still standards unique to a particular country, increasingly standards are shared within cooperating groups of countries, such as the European Union. Major international standards organizations include the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the In-

BOX 9.3

Sources of Standards Information

Government provider:

NIST Global Standards (provides links to a number of resources)

http://gsi.nist.gov/global/index.cfm/L1-5/L2-44/A-171

Commercial providers:

Document Center

http://www.document-center.com

IHS Standards Store

http://global.ihs.com

SAI Global

http://www.saiglobal.com

Techstreet Store

http://www.techstreet.com

ternational Telecommunications Union (ITU). Also, there are a number of other organizations that focus on very specific areas, such as timber, aluminum, or illumination.

Whether a product designed by students is to be used internationally or if it is specifically for a given country, as is becoming common in service learning courses, attention must be paid to the standards and regulations that exist in the relevant market. A number of companies provide access to standards (see Box 9.3); however, there are instances in which the only way to obtain the relevant standard is to contact the appropriate government office directly, which can be a slow process.

LOCATING AND ACESSING STANDARDS

Identification of and access to the standards and regulations for student projects can take a number of paths (see Box 9.4 for examples). It may be as easy as consulting a list of databases subscribed to by the university's engineering library and conducting a subject search to obtain a downloadable copy of the appropriate full text standard. ASTM and IEEE Xplore are commonly held by most engineering libraries. In other cases it might entail a search of the catalog to find the call number of a print standard. Often a student will be searching by subject and either not know or not be concerned about the specific sponsoring organization. In this case the NSSN standards database (www.nssn.org) might be the best place to start the search, then once the standard is identified the library's catalog and databases can be consulted to determine whether a document is accessible. When a standard is not available locally, it can usually be obtained in minimal time via either interlibrary loan or a purchase request. The exception is for countries whose standards are not available from the major standard provid-

BOX 9.4

Standards Websites

ASTM International

http://www.astm.org

IEEE Xplore Digital Library—"Standards"

http://ieeexplore.ieee.org/xpl/standards.jsp

National Institute of Standards and Technology

http://www.nist.gov

NSSN Search Engine for Standards

http://NSSN.org

The Society for Standards Professionals—"National Standards Bodies"

http://www.ses-standards.org/displaycommon.cfm?an=1&subarticlenbr=54

Standards.gov

http://standards.gov/

World Standards Services Network

http://www.wssn.net/WSSN/index.html

REALITY CHECK 9.1

A class has been assigned to design playground equipment for a local park. The trustees of the park provided a list of requirements that include the types of equipment that they want and the age range of the children who will be using the park. With this information, the class needed to devise usable specifications for the requested equipment. Using the weight and height information from the Center for Disease Control growth charts (www.cdc.gov/growthcharts), the students created a specification for the weight and height and other pertinent physical parameters of the children for the various equipment to address the appropriate age groups. Searching the ASTM standards they then located appropriate national standards for playground equipment from the Consumer Product Safety Commission's Public Playground Safety Handbook (http://www.cpsc.gov/CPSCPUB/PUBS/325.pdf). State and local standards and regulations were then reviewed for the specific locale of the playground. Finally, the Americans with Disabilities Act of 1990 (http://www.ada.gov/2010ADAstandards_index.htm) was consulted to determine what specific accessibility issues needed to be addressed.

ers. In that case the best path is to use the SES—The Society for Standards Professionals website (http://www.ses-standards.org) and go directly to the country in question. Comparing standards on a particular topic is also a very good exercise for students to increase their understanding of the spectrum of expectations around the globe.

SUMMARY

While many aspects of safety are addressed in the standards, codes, and regulations, best practices and local knowledge all need to be considered as well. Safety is a critical aspect of all design and must be considered as integral at every level of the process. It is doubtful if any combination of standards and regulations can comprehensively address every aspect of the product or system being designed—its processes, location, and personnel—so other safety features must be incorporated into the design process. Documentation is important to memorialize the steps taken for increased safety, to inform those that follow, and to serve as an evolving template for future safety improvements. Safety builds on industry standards as well as local, learned knowledge.

Differentiating codes, standards, and specifications can be challenging. Understanding which are mandatory by law (regulations), what is mandated by customer (specifications), and what is voluntary but worthy of serious consideration (standards) can be a difficult task, and students need to practice thinking about the roles of regulations, specifications, and standards in their design projects.

By incorporating user needs (Chapter 7), context (Chapter 8), and best practices of the profession, students will create a much more robust problem statement that will help frame the potential solutions they will generate, using techniques discussed in the following chapter, and evaluate those solutions, as will be discussed in Chapter 11.

SELECTED EXERCISES

Exercise 9.1

Your students have been asked to design a waste disposal system for a rural village in Haiti devastated by the 2010 earthquake. What physical and financial issues will they need to address? What standards are relevant to this project from both the Haitian government and from professional standards governing this field of engineering?

Exercise 9.2

Failures can be instructive. Have students review of one of the following cases to stimulate discussion of the role of standards and regulations and their limitations. Discussion questions may include the following: Were standards followed? Were the standards adequate? How could the standards be changed? Have the standards been changed? What has been learned? Suggested topics include the following:

- Breach of the flood control system in Louisiana after Hurricane Isaac in 2012
- The London Millennium Footbridge (opened and closed in June 2000; reopened in 2002)
- Metal hip replacement implants
- Video recorders (VHS versus Betamax)

Exercise 9.3

Consider the scenario where students are designing a large-scale food dryer. They plan to use local materials and are seriously considering plastic piping. Have students investigate whether there are standards for the materials they can use, since the materials will be in direct contact with the food in the particular country in which they will be working.

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