CHAPTER 10

The Responsibilities of Engineers and Scientists

". . . One characteristic of a professional is the ability and willingness to stay alert while others doze. Engineering responsibility should not require the stimulation that comes in the wake of catastrophe."

—Samuel C. Florman

With the advent of modern industrial society, it has become increasingly evident that engineers and scientists, through their work, largely define the course of our technological civilization that is radically altering our world. Yet, while colleges and universities strive to provide their students with the technical and scientific skills necessary to master complex technologies, they rarely prepare them for the potential role they play as agents of social transformation. Most engineers, according to Nandagopal, leave college uninformed and unconcerned about the societal issues relevant to the practice of engineering (Nandagopal, 1990). This predicament arises because of the narrow scope of engineering curricula: social and ethical implications of engineering are, for the most part, ignored. Since the students' education is predominantly technical, students often come to believe that engineering is divorced from human values and the larger societal impacts of technology (Durbin, 1989). Engineering education fails to help engineers become self-conscious and responsible social actors because both educators and practicing engineers often view engineering education and practice in restricted terms (Wacker, 1990).

THE ROLE OF ENGINEERING SCHOOLS

There is a growing need to inculcate, through engineering education, an awareness of the complex set of interrelated issues of engineering design, public safety, and ethics—in particular the potential dysfunctional effects of engineering and technology on society (Glagola, Kam, Loui, and Whitbeck, 1997). For many engineering professors, "engineering is essentially the application of technical expertise to technical problems, and education is primarily the process by which this expertise is reproduced for new generations of engineers" (Glagola *et al.*, 1997). Contrary to this conventional wisdom, engineering is a social as well as a technical practice, and engineering education should promote an understanding of *both* dimensions. Since technology creates potential risks as well as great benefits, engineers, as experts in technology, should assume a more positive stance toward their social responsibilities. They should "not adopt the stereotypical hyper-rational, calculating character of the technocrat, but should apply humanistic values along with technical insights" (Wacker, 1990).

Most engineering educators would agree that two important steps need to be taken: (1) a reevaluation of the role of design and safety in engineering curricula, and (2) the introduction of a comprehensive engineering ethics program in engineering curricula. These two steps are closely related; engineering design courses, as opposed to theory courses, can more readily incorporate ethical and social factors—the social aspects of design—into their curricula (Unger, 1982; Carpenter, 1984; Vanderburg, 1995).

Responsibility for Safety in Engineering Design

The first step engineering schools can take to mitigate the effects of technological disasters is to successfully integrate ethical and social issues in courses dealing with engineering design. According to a study by Lichter (1989), engineers in their educational experiences, in professional societies, and in actual employment are inclined to consider safety only as a necessary constraint on efficient engineering decisions. Such a constraint tends to be viewed *reactively* rather than *proactively*. In his investigations, Lichter found that concern for engineering safety is "tacked on" to a primary concern for "technical" design; safety-related activities are viewed as essentially "non-productive" (Lichter, 1989). As Lichter points out, "this is best reflected in the budgeting of engineering projects where safety is seen as an added cost which, in the absence of a public mandate or evidence of profitability, would normally be avoided in order to maintain a competitive position in the marketplace" (p. 217). Because of such economic constraints, the design engineer might be tempted to use an unconventional technology in order to comply with financial constraints. It has finally come to the attention of engineering educators that unwarranted pressures are often placed on the young engineer in industry. Now, more than ever, educators should stress safety as a central element in all engineering designs (Moonashingha, 1996). Designs must be infused with safety and ethical values, not just with financial values.

Albert Flores has documented the general failure of engineering education to expose future engineers to any serious treatment of safety-related topics (Flores, 1982). Approximately 250 engineers responded to a survey on a wide range of safety-related issues. Three-quarters of those engineers reported never having had a course on safety, and, for those who had been exposed to some treatment of safety, most claimed that the treatment was superficial and rarely the primary focus of the course. Similar results were obtained from a survey of 450 engineers at Otis Elevator, Boeing, and NASA (Flores, 1982).

The fact that Flores's survey was conducted in 1982 ought not lead readers to suppose that the current status of design safety in engineering curricula has changed significantly. While researchers recognize that design safety is becoming more and more important to engineering education, they also point out that engineering schools still have a long way to go to increase the salience placed on design safety (Bryan, 1999; Lau, 1998; Slaymaker and Bates, 1993; Vesilind, 1992).

Rapid developments in engineering innovation are constantly being introduced into engineering materials, structures, and systems. Because of these rapid advances, which often stretch the limits of engineering knowledge and lead into relatively unknown and untried areas of research and development, Bryan argues that "all aspects of the design stage should be examined closely for possible safety and health hazards" (Bryan, 1999: 34). Prominent examples are nuclear power, telecommunications, computer networking, refineries and industrial chemicals, and bioengineering. One field of engineering, however, has begun to take the lead in focusing on the central role of design safety in classes and laboratories. This field is chemical engineering (Akgerman, Anthony, and Darby, 1999; King, 1998; Willey and Piece, 1998). The relatively new field of bioengineering would be the next likely area to start integrating ethical and social values into engineering safety design courses (Grundfest and Scott, 1998).

Stephen Unger was one of the first engineer-ethicists to stress the need to promote design safety in the engineering curriculum (Unger, 1982). In his 1982 publication, Unger outlined the nature of the responsibility that engineers bear for producing safe designs and safe products, both consumer and industrial. He suggests that engineering schools introduce ideas about safety and responsibility through courses on engineering ethics and technology-society studies.

In recent years, numerous engineers have faced ethical dilemmas in which engineering judgment ultimately led to technological disaster. What is more, these cases have received considerable attention and publicity (Pletta and Hon, 1987). Examples include the problem of safely positioning the gas tank in the Ford Pinto case, the accidents of the Bay Area Rapid Transit system in San Francisco, the cargo door latch on the DC-10 aircraft, the falsification of test data in the B.F. Goodrich aircraft brake case, technical miscalculation in the Hyatt Regency walkway collapse, and faulty risk assessment and flawed decision making in the Challenger disaster. All of these cases involved engineers and/or engineering decisions and have become the subject of analyses by engineers, educators, philosophers, and sociologists.

In the DC-10 case, design flaws in the rear cargo door were well known to top engineers and management, as well as to the Federal Aviation Administration. Neglect of safety and design issues in engineering practice, management decisions, and governmental regulation led to a few serious incidents, but the Paris crash was the most serious. All 346 passengers on board lost their lives due to the defectively designed door. In the B.F. Goodrich case, engineers were involved in a conspiracy to commit fraud in a cover-up that included the falsification of technical data to make an unsafe braking system appear safe. In the BART case, engineers were fired for speaking out against what, in their professional judgments, were serious design and safety defects in the newly installed and computerized Bay Area Rapid Transit System. In the Hyatt Regency case, engineers were found guilty by investigators for "failing to conform to accepted custom and practice of engineers for proper communication of the engineer's design intent."

In the Chernobyl case, engineers and other technical personnel, presumed to be competent, violated numerous operational safety rules, causing the worst nuclear power plant disaster to date. Moreover, the odd design of the Soviet reactor was also implicated as a secondary cause of the catastrophe. Long-term neglect of safety requirements at the Bhopal plant, as well as broken-down safety equipment, were partly responsible for the release of tons of deadly methyl isocyanate into the air. The Board of Inquiry in the Apollo I case found that there were "numerous examples of poor installation, design, and workmanship." After the fire, hundreds of modifications were made to improve the safety of the module to make it more fireproof.

Technological disasters sometimes occur when the engineer's judgment is overruled—as in the Challenger and Ford Pinto cases. Sometimes, however, crises arise when engineers fail to report hazardous practices—as in the DC-10 and B.F. Goodrich cases. Finally, some failures result from the direct actions of engineers—as in the Chernobyl and Hyatt Regency disasters. At a minimum, the engineer's obligation with respect to guarding against technological hazards is the conscious effort to produce effective and safe technology in their designs. Engineers are responsible for such technological hazards in many ways, and hence, they have individual and professional duties to design products and technologies that do not harm the public (Schinzinger, 1986; Unger, 1982).

How is it possible to restructure the activity of engineers so that design safety and human welfare, and not only efficient production, are the principal concerns of engineering practice? This would entail, according to Lichter, the modification of the "culture of engineering" as it relates to engineering pedagogy and numerous professional engineering organizations. To accomplish this difficult task, however, engineering educators would have to "institutionalize the notion that the practice of a merely technical activity cannot be divorced from a theory of the normative dimension of engineering activity that helps define the morally proper goals, obligations, and responsibilities of engineering" (Lichter, 1989: 217).

The American engineering profession took positive steps toward these ideals with the establishment of the Accreditation Board of Engineering Education and Technology's Engineering Criteria (ABET, 1998). To become accredited by ABET, engineering schools are required to have at least 24 credits of design content in the four-year undergraduate curriculum. In addition, more and more educators are realizing the importance of introducing ethical and social issues into engineering design courses. However, as Vesilind points out:

> Engineering ethics is often neglected in engineering design because most faculty do not see the value of ethics in engineering. On the contrary, there are many instances in engineering practice when values will be involved and engineering students and professionals will be faced with ethical problems. (1992: 215)

Clearly, what is needed are courses that incorporate and integrate problems of safety, design, and ethics (Manion and Kam, 2000; Rabins, 1998; Unger, 1995; Vanderburg, 1997). Such courses would draw upon actual experiences of practicing engineers to illustrate the social factors of design—aesthetic, economic, political, ethical, environmental, and usage—along with technical factors (Vanderburg, 1995; Whitbeck, 1995). Some engineering schools have recently experimented with such courses. Lau (1998) describes a course that is multidisciplinary and "attempts to increase engineering students' awareness of the relationships between technology and society, and how they can design technology that improves people's lives." McLean (1993) develops a rationale for an ethics of engineering course that "tries to incorporate design, systems management, ethical theory, and insights from sociology and psychology that are completely integrative and interdisciplinary" (p. 20).

Engineering as a Social Practice

Engineering should be understood as a social "practice" for a number of reasons (Wilson, 1990: 117). First, it is through engineering that new technologies are embodied in products and sys-

tems developed in order to satisfy the needs and problems facing society. Technology and industry, one might say, fuel the "wealth of nations." Engineering is practiced in corporate organizations that are embedded in larger social structures of economic and power relations. Corporate organizations are critical to the implementation, operation, and maintenance of technological systems. As Wilson points out, "social and economic relations are found at all levels of engineering practice and technology development, hence making engineering a genuine social practice" (1990: 117).

Second, the products of engineering are used in diverse social contexts. To be effective, these products must be designed with their social context in mind. Hence, responsibility for safety and avoidance of public harm are two social goals that make engineering central to almost all social contexts. In fact, the moral imperative to "do no harm" is embedded in many codes of engineering ethics. Identifying this ethical mandate in the very conception of engineering underscores the importance of understanding engineering as a social practice.

Third, engineering has an impact on society in both intended and unintended ways. "New technologies often alter social relations, power relations, working and living conditions, and cultural values" (Wilson, 1990: 118).

Finally, engineering is a social practice because it is often used to tackle and ameliorate social conditions such as urban slums, world hunger, illiteracy, disease, and pollution (Wilson, 1990: 117).

The roots of an engineer's duties and responsibilities to society can be said to be derived from a "social contract" that holds, at least implicitly, between the engineering profession and society. Harris, Pritchard, and Rabins (1995) argue that this social contract between the engineering profession and society at large contains at least four provisions. On the one hand, engineering professionals agree (1) to devote themselves to rendering service to society or to advance the public good and (2) to regulate themselves in the provision of these services. On the other hand, society agrees (3) to give professionals a place of honor and above-average livelihood and (4) to allow them an unusual degree of autonomy in the performance of their professional duties (Harris, Pritchard, and Rabins, 1995). In fact, professional codes have an important role to play in establishing the social contract between the engineering profession and society at large. The code of ethics stands as a "promissory note," made by the engineering profession, to uphold its part of the contract.

Strong commitments to the social contract can be found in almost all contemporary engineering codes of ethics, such as those of the National Society of Professional Engineers (NSPE), the Institute of Electrical and Electronic Engineers (IEEE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), and the American Institute of Chemical Engineers (AIChE), as well as other professional societies. In fact, the emphasis on the obligations to the public—the hallmark of the social contract professional societies model—seems to be accorded an increasingly prominent role in engineering codes of ethics. In 1974, the code of the Engineering Council of Professional Development was revised to state that "engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties." Within the last 20 years, this "paramountcy" provision has been adopted by all of the major engineering societies.

The Role of Engineering Societies

Engineering societies have an important role to play in managing and controlling hazardous technologies (Unger, 1987). These professional societies can perform at least three major functions in facilitating the management of technological risk and disaster: (1) the advancement of engineering knowledge; (2) the protection of ethical engineers; and (3) the promotion and enforcement of codes of ethics.

The Advancement of Knowledge

As with engineering schools, one important way professional engineering societies can help guard against the hazards of technology is by advancing safety in design. This is accomplished by facilitating the development and dissemination of engineering knowledge, thereby bolstering the engineer's capacity for building safer devices, structures, and systems. In the past, engineering societies have, for the most part, almost exclusively focused their attention on the advancement of technical knowledge. Undoubtedly, the major function remains to promote the discovery of technical knowledge and its dissemination. To this end, engineering societies publish scholarly journals and organize meetings at which technical papers are presented and discussed. The sharing of important knowledge is made possible through the actions of professional engineering societies, such as the Institute of Electrical and Electronics Engineers (IEEE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Institute of Chemical Engineering (AIChE), and the National Society of Professional Engineers (NSPE). For example, relatively recent advances in electronics resulted in improved instrumentation for airlines, thus contributing to safer air travel. A better understanding of materials science has given us more rugged automobile tires, thereby eliminating a major cause of automobile accidents nationwide (Unger, 1987).

An important function of engineering societies that promote the dissemination of engineering knowledge about safety is the development of industry standards. The establishment of the boiler safety codes in the 19th Century set the stage for the role engineering societies have come to play in the development of safety standards. The ASME, for example, administers the National Elevator Code. All in all, more than 200 organizations—professional societies, trade associations, and safety organizations—develop and promulgate voluntary engineering standards in the United States (Sherr, 1982).

Moreover, these standards, voluntarily formulated by the professional organizations, become the de facto standards in industry, in virtually all governmental regulatory agencies, even in legal disputes over technological issues. Professional engineers are responsible for almost all of the technical standards that undergird our entire sociotechnical infrastructure—from telecommunications to computerized networking to the entire built urban environment. This places a huge responsibility for public safety and welfare on the shoulders of professional engineering societies.

The fact that engineering standards are produced voluntarily—that is, they are developed and promulgated by professional organizations themselves—is an example of a self-regulated professional practice. This creates the necessity for institutional trust between engineers, the citizenry, and the government. Hence, this is also part of the social contract existing between engineers and society. Society places high trust in the engineering profession and permits it to develop and abide by its own technical standards, which, as we have noted, become the de facto norms for industry, government, and society at large. The citizenry receives the technological systems it so eagerly adopts, with the tacit promise that the technology will be safe and reliable. In return, engineers are accorded the principle of professional autonomy—at least as far as technical standards are concerned. Thus, a "social compact" is created between the profession of engineering and the citizenry.

Engineering societies coordinate their activities through a loosely organized entity known as the American National Standards Institute (ANSI). For the most part, the ANSI standards are well defined and categorized by technological areas. These areas are as follows:

(1) American Society of Mechanical Engineers (ASME)—Mechanical, Pressure Vessels, Boilers
(2) Institute of Electronic and Electrical Engineers (IEEE)—Electrotechnology, Communications, Power Apparatus and Generation, Nuclear Instrumentation and Control
(3) Society for Automotive Engineering (SAE)—Automotive and Aeronautics
(4) National Fire Prevention Association (NFPA)—Fire and Safety
(5) The American Society for Testing and Materials (ASTM)—Materials and Testing (Sherr, 1982).

Some professional societies have produced literally hundreds of standards. For example, the IEEE has more than 400 standards in print. The American Society for Testing and Materials (ASTM) has published more than 48 volumes of technical standards (Sherr, 1982).

What has been consistently missing from the traditional function of reporting and advancing engineering knowledge, however, is *the reporting and advancing of engineering knowledge about failures.* Lack of established channels of communication, misplaced pride in not asking for information, embarrassment at failure, or fear of litigation often impede the flow of such important information and hence lead to many repetitions of past mistakes.

In a series of influential books, Henry Petroski (1985, 1994) argues that knowledge about failures is essential for good, sound engineering design practices. Failing to present information about failures is a critical deficiency, both for engineering schools and engineering societies. More attention needs to be paid to research and knowledge of failures and disasters in engineering societies' professional conferences and professional trade journals.

Protection of Ethical Engineers

Engineering societies seek to provide support for engineers who come into conflict with corporate management over issues involving the development and management of hazardous technologies. Engineering societies could assist ethical professionals whose conduct has led to retaliation by employers. They could establish funds to pay legal expenses of engineers who are contesting discharges or other types of lawsuits. These funds would not only assist engineers in times of financial and emotional stress but would also signal the support of their professional colleagues. Professional societies could even assist engineers, who have been unfairly dismissed from their jobs, to find new employment. They could support engineers who take strong positions on behalf of worker and public safety, thus leading to greater workplace safety and, in turn, to a safer society. Hence, professional support for socially responsible conduct, the "right" to be an ethical engineer, could play a crucial role in mitigating the effects of technological risk and harm (Unger, 1994). After considering the most likely objections to professional societies supporting individuals and speaking out in the public interest, Unger concludes that:

> Providing support for the ethical practice of engineering is a very worthwhile and appropriate endeavor for engineering societies . . . It is up to engineers, standing together in their professional societies, to see to it that they are no longer subjected to agonizing choices between sacrificing either conscience or career. (1987: 20–21)

The exemplary actions of the Institute of Electric and Electronic Engineers (IEEE) on behalf of the three engineers dismissed at the Bay Area Rapid Transit system (BART) during the 1970s serves as a good example of how engineering societies can come to the aid of ethical engineers.

Two engineers working on the BART project, systems analyst Holger Hjortsvang and programming analyst Max Blankenzee, became concerned with what they perceived to be major design defects in the Automated Train Control (ATC) system, deficiencies they thought would almost certainly compromise public safety. In addition, a third engineer, Robert Bruder, an electrical engineer monitoring various phases of the construction, also became concerned about the unprofessional manner in which the installation and testing of control and communications equipment was being conducted (Unger, 1994: 22). They brought their concerns to management, but management was not responsive to their apprehensions and professionally based judgments concerning safety.

In November 1971, after many attempts to communicate their concerns to their superiors, the three engineers decided they must express their concerns in order to protect the public interest. They contacted Daniel Helix, a sympathetic member of the BART Board of Directors. Unbeknownst to the three engineers, however, Helix released their complaints to the press. When BART management identified all three dissenting engineers as the source of the complaint, they were given the option of resigning or being fired. All three engineers refused to resign, so they were all fired. Some time after their dismissal the three engineers brought a lawsuit against BART, charging breach of contract and violation of their constitutional rights. An extensive report of the BART case was published in the *newsletter* of the IEEE Committee on Social Implications of Technology in September 1973. This report, and many others, including findings of an independent contractor, confirmed the charges made by the three engineers. Extensive redesigns of the ATC and higher safety standards of construction and maintenance were instituted after the BART investigation (Unger, 1994).

Following the publication of the BART report, the case was discussed extensively within the IEEE. In March 1974, a resolution was passed to set up procedures to support engineers who, acting in compliance with ethical principles articulated in the society's code of ethics, may find themselves in professional jeopardy. This resolution eventually led IEEE to file an *amicus curiae* brief on behalf of the three engineers in their civil suit against BART. The brief deals not only with the facts of the case, "but with the broad ethical principles involved; it urged the court to rule that an engineer's employment contract includes an implicit provision that he or she will protect public safety and that discharging an engineer for adherence to this provision constituted a breach of contract by the employer" (Unger, 1994: 26). In other words, IEEE implored the court to acknowledge that engineers have a professional right to implement the provisions of their code of ethics.

One unfortunate consequence of the BART case was that the chance to establish a legal precedent that professionals have a right to implement provisions of their code of ethics was thwarted since the three engineers, because of financial hardships, eventually agreed to an out-of-court settlement with BART management.

Promotion and Enforcement of Codes of Ethics

One of the principal functions of engineering societies has been the promulgation and enforcement of codes of ethics. Professional codes present an image of what professionals understand as their ethical and social obligations. Hence, in analyzing such codes, we can acquire an understanding of how the profession perceives its own purpose as regards its social responsibilities.

The increasing promotion of codes of ethics in professional engineering societies and their growing role in lending support for the right to be a responsible engineer—as is evident in the BART case—demonstrates that engineering professionals *do* indeed have reciprocal responsibilities and rights as regards the functioning of engineering in society. Recognizing the importance of such reciprocal responsibilities and duties to serve the public in their professional practice, physicians long ago developed the Hippocratic Oath. It is noteworthy that not all medical schools require their graduates to take the Hippocratic Oath. According to a study by Orr and Pang (1993), in 1928 only 26 percent of medical schools administered some form of the oath. However, in 1993, the percentage had markedly risen to 98 percent of all medical schools administering some form of the oath.

Requiring that all engineers, upon graduating from engineering schools, take the equivalent of the medical profession's Hippocratic Oath would perhaps provide the clearest statement possible of an engineer's self-proclaimed social responsibilities. Such an "Engineer's Hippocratic Oath" has, in fact, been articulated. The Oath reads as follows:

> *I solemnly pledge myself to consecrate my life to the service of humanity. I will give to my teachers the respect and gratitude which is their due; I will be loyal to the profession of engineering*

and just and generous to its member; I will lead my life and practice my profession in uprightness and honor; whatever project I shall undertake, it shall be for the good of mankind to the utmost of my power; I will keep far aloof from wrong, from corruption, and from tempting others to vicious practice; I will exercise my profession solely for the benefit of humanity and perform no act for a criminal purpose, even if solicited, far less suggest it; I will speak out against evil and unjust practice wheresoever I encounter it; I will not permit considerations of religion, nationality, race, party politics, or social standing to intervene between my duty and my work; even under threat, I will not use my professional knowledge contrary to the laws of humanity; I will endeavor to avoid waste and the consumption of nonrenewable resources. I make these promises solemnly, freely, and upon my honor. (Susskind, 1973: 118)

In addition to such oaths, almost all engineering societies have formulated a code of ethics for their members. For example, the first canon of the NSPE Code of Ethics states: "The engineer shall hold *paramount* the health, safety, and welfare of the public in the performance of his professional duties" (National Society of Professional Engineers, 2000). This requires members to adopt this concern not as something over and above the profession's requirements and not as remedial, but as integral to the requirements of the profession *per se*—integral to what the profession is all about. As we have seen, this provision is found in almost all engineering codes. Embedded in such prescriptions is the assumption that the goal of engineering is to uphold the values of public health, safety, and welfare above *all* other values. On this view, values such as safety, health, and welfare are overriding values. They "trump" other values such as market competitiveness, profit, efficiency, cost, and benefit-burden trade-offs.

How should engineers interpret the paramountcy clause? If we choose to interpret it as establishing the "do no harm" principle, this is consistent with present engineering practice. Hence, one responsibility engineers owe to society is to design and build safe products, machines, and systems. As Flores (1980) points out: "It is clear that the products, bridges, dams, computer systems, etc. that engineers design should be safe enough to avoid unnecessary harm to life and limb, and perhaps to liberty and property" (p. 212). Moreover, developments in tort law providing for strict product liability have, in many ways, helped to establish this principle in a more formal way (Tribe, 1971a, 1971b). In sum, engineers must abide by the do no harm principle. This entails a duty to always make products and systems that are safe and reliable.

However, no engineering project is totally free of risk, and hence most engineering projects can be interpreted as "experiments" carried out on human subjects. Martin and Schinzinger (1996) argue for such a view. They characterize engineering as social experimentation and, on the analogy with medical experimentation, they argue that the doctrine of informed consent must be recognized and honored between the experimenters (engineers and their corporations) and their subjects (the general public). On this model, an engineering project is seen as an "experiment"—that is, a potentially risky undertaking—on a societal scale (Long, 1983).

Inasmuch as people will be affected by the experiment, their well-being should be considered in the decision-making process of engineering projects. From this it follows that the moral relationship existing between engineers and the public should be grounded along the lines of an ethic of informed consent. Knowledge about technology must be disclosed and discussed. Not just technical knowledge *per se,* but knowledge of the risks and the potential harms, as well as of the benefits, need to be debated in a public forum.

What are we to make of engineers who believe they function as merely applied physical scientists operating in an environment where decisions are made objectively and values do not enter the decision-making process? The hazards associated with the experimental nature of engineering projects—as opposed to the controlled and often less complex nature of scientific investigations, for example—present challenges distinct to engineers, creating for them certain ethical obligations and social responsibilities unique to their profession.

For one thing, safety and risk are crucial variables for engineers, variables from which the purely theoretical scientist is generally immune. To render scientific judgments is, for all intents and purposes, to make decisions based on sound, law-like principles. Making engineering judgments, as opposed to scientific judgments, is to make judgments about safety and risk, namely, seeing the prospective engineering design project in terms of trade-offs between costs and benefits (Lowrance, 1976).

Hence, engineering design judgments cannot always be grounded in sound scientific theory. Engineering methodology consists not of scientific principles alone but of scientific principles along with a constellation of nonscientific "heuristics." Engineers often do not have all of the scientific facts on hand when problems are to be solved and cannot always perform full-scale controlled tests. They extrapolate from proven principles using engineering heuristics and engineering judgment. Sometimes, unfortunately, the extrapolations and judgments fail.

Comparing engineering with science helps us identify some of the social responsibilities of engineers and their profession. What of the people who have a stronger claim to objectivity, disinterestedness, and value neutrality, namely scientists who have been involved in engineering, applied science, and research and development?

THE ROLE OF SCIENCE AND SCIENTISTS

Unlike engineers, who see their role as technological innovators, scientists, concerned with contributing to a body of scientific knowledge, are inclined to develop an "ivory tower" conception of their role. Pursuing knowledge for its own sake is an intrinsic value for scientists. Up until World War II, scientists tended to view their work as value-free and morally neutral, and hence they were generally oblivious to the social consequences of their discoveries. The only norms ideally guiding their research are those identified by Merton, a world-renowned sociologist:

1. Universalism: empirically verified knowledge transcends national boundaries.
2. Organized skepticism: a scientist is obligated to subject his or her research results as well as those of other scientists to the most rigorous scrutiny.
3. Communality: a scientist is obligated to share his or her research results with others since scientific progress requires the free flow of ideas.
4. Disinterestedness: a scientist pursues science for "its own sake." Knowledge and discovery should be pursued for their own sake and not to enhance a scientist's prestige or authority (Merton, 1973: 267–278).

While these ideal norms describe the role of academic scientists engaged in basic research, they clearly do not describe the role of applied scientists employed in government or industrial laboratories operating with explicit missions. The latter are concerned with *instrumental,* as opposed to *intrinsic,* values of knowledge; they are also governed by norms pertaining to proprietary and classified information.

Developments in 20th Century science, however, have tended to blur the distinction between pure and applied research. Examples from atomic and nuclear physics will bear out this point. In the first decade of the 20th Century, Niels Bohr, the renowned Danish physicist, was pursuing atomic research when he formulated his "planetary" model of the atom. In the late 1930s, Hahn and Strassmann conducted experiments on neutron-irradiated uranium, which yielded the surprising result that the uranium nucleus had split into two smaller nuclei (Beckman et al., 1989: 20–26). These basic research findings eventually paved the way for an applied research project to develop an atomic bomb, known under the code name of the "Manhattan Project."

Knowledge and Power

Francis Bacon, the apostle of modern science, anticipated the relationship between basic and applied research when he formulated his well-known aphorism: "Knowledge is power."

Unlike some other values human beings create that are perishable, scientific knowledge tends to endure and to accumulate, enriching the lives of succeeding generations. This is indeed the premise upon which universities were first founded in the Middle Ages and the reason they have flourished for centuries, whereas many other types of organizations have been ephemeral.

Valuable as scientific knowledge may be, is it powerful? In other words, does knowledge guide the fateful decisions taken at national and international levels that affect the lives of millions of human beings? Does knowledge contribute to the wise use of power? In uttering his aphorism, was Bacon describing reality at the dawn of the 17th Century, or was he projecting a vision of a utopia in which knowledge *would* be power, as he subsequently did in his *New Atlantis?* These questions point to the uneasy and perplexing relationship between knowledge and power. On the one hand, knowledge may be entirely divorced from power; it may be pursued and developed without any concern for its impact on the exercise of power. On the other hand, knowledge may be cultivated for the express purpose of undergirding the exercise of power.

When knowledge is applied—that is, converted to power by public policy decision makers—it is never a direct or an automatic process: intervening between knowledge and power are an implicit or an explicit affirmation of values and a commitment to specific interests. Moreover, the values prompting the application of scientific knowledge may be benevolent as well as malevolent, altruistic as well as selfish, humane as well as inhumane. Since the social roles of knowledge producers—scientists—and the public policy decision makers are distinct, there may or may not be consensus among the people performing these roles regarding the values and interests underlying the use of knowledge (Evan, 1981: 11–13).

Examples of the Relationship between Knowledge and Power

The Manhattan Project provides ample data on the complexities of the relationship between knowledge and power. Leo Szilard, a Hungarian physicist, upon learning of the Hahn-Strassman experiments in 1938, quickly inferred that bombarding a uranium nucleus would trigger a chain reaction releasing an immense amount of atomic energy. He further inferred that Nazi Germany would exploit this knowledge by developing an atomic bomb in order to win the forthcoming world war. He thus decided to travel to the United States to confer with his fellow Hungarian physicists of great renown, Eugene Wigner and Edward Teller. Convinced of the political urgency of their knowledge, they met with Albert Einstein and drafted a letter, which Einstein signed, and which they then forwarded, through an intermediary, to President Franklin Roosevelt in 1939. After several years of a feasibility study initiated by President Roosevelt, the Manhattan Project was established in 1942. This is indeed a historic example of a successful linkage between knowledge and power.

Two unsuccessful examples of the relationship between knowledge and power will now be considered. By the time the first nuclear weapon was successfully detonated on July 16, 1945, at Alamogordo, New Mexico, Nazi Germany was already defeated, thus eliminating the primary motivation of many scientists who were recruited to the Manhattan Project. Some of these scientists now had moral misgivings about using the bomb to force the Japanese to surrender. James Franck, a refugee German Nobel Laureate in chemistry, chaired a committee of concerned scientists, including Leo Szilard, which urged that the United States conduct a demonstration test of an atomic bomb on an unoccupied Japanese island. In addition, the scientists advocated putting such weapons under international control to prevent their use and to forestall the emergence of a nuclear arms race between the United States and Soviet Union. The committee submitted its proposal to President Harry Truman, who rejected it.

Niels Bohr also made an effort to link knowledge with power. Convinced that nuclear weapons would challenge the traditional concepts of national sovereignty and concerned about the possible outbreak of a nuclear weapons arms race, he urged Winston Churchill and Franklin Roosevelt in 1944 to inform Stalin of the Manhattan Project and to negotiate a mutual security pact. "The only security from the bomb would be political: negotiation toward an open world, which would increase security by decreasing national sovereignty and damping out violence that attended it. The consequence of refusing to negotiate would be a temporary monopoly followed by an arms race" (Rhodes, 1988: 783). Bohr's scenario of the postwar world, ushered in by the invention of the atomic bomb, was, however, rejected by Winston Churchill and Franklin Roosevelt as "dangerously naïve" (Rhodes, 1988: 783).

These failures on the part of the Manhattan Project scientists to translate knowledge into power prompted them to establish the Federation of Atomic Scientists, whose mission is to end the worldwide arms race, to achieve complete nuclear disarmament, and to avoid the use of nuclear weapons. In cooperation with the members of the Federation of Atomic Scientists, the atomic scientists of the Metallurgical Laboratories of the University of Chicago established in December 1945 *The Bulletin of the Atomic Scientists*, dedicated to addressing the problems of the nuclear age.

Given the foregoing cases of the relationship between knowledge and power, is Francis Bacon's proposition valid? Does knowledge lead to power? As stated, it is generally *not* true. Knowledge *does* indeed lead to power provided three essential resources are available: human, organizational, and financial. The Manhattan Project is an exemplary manifestation of the validity of our revised proposition about knowledge and power.

In the 1930s, nuclear physics attracted the most gifted scientists in the world such as Bethe, Fermi, Feynman, Oppenheimer, Rabi, Rotblat, Teller, and Wigner (Zuckerman, 1977). The scientists recruited to the Manhattan Project by Oppenheimer were truly outstanding, many of whom became Nobel Laureates or were their intellectual peers (Bernstein, 2000).

The organizational structure of the Manhattan Project was also functionally well designed, with Oppenheimer, a nuclear theoretical physicist, appointed as the technical director and General Groves appointed as the administrative director with liaison functions with the War Department.

As for the third essential resource—financial—for a successful relationship between knowledge and power, Roosevelt, in the interest of safeguarding the security of the Manhattan Project, bypassed Congress in his decision to allocate $2 billion—probably one of the largest budget allocations for a single federal project in the first half of the 20th Century.

Professionalization and Internationalization of Science

In the course of developing bodies of knowledge, scientists tend to form professional societies or organizations as mechanisms for disseminating their theories and research findings. These societies give rise to formal and informal networks of communication and a "scientific community" based on a set of shared values and norms.

In the early stage of development of scientific fields, national societies tend to emerge. As sciences grow and develop in different countries, the tendency is for international scientific societies to arise, encouraging the further growth of informal and formal communication networks. These networks stimulate professional collaboration across national boundaries and accelerate the growth of scientific knowledge. The more developed a scientific field, the greater the probability that the values and norms are internalized by its members and the higher the frequency of international collaboration (Evan, 1975: 386–387).

As early as 1847, the American Association for the Advancement of Science (AAAS) was founded for the purpose of furthering the work of scientists, facilitating cooperation among them, improving the effectiveness of science in the promotion of human welfare, and increasing public understanding of the role of science in human progress. By the late 20th Century, AAAS represented all the major fields of science; its annual conferences continue to coordinate the activities of approximately 300 scientific societies. It is also noteworthy that in 1976 the AAAS established the Science and Human Rights Program, the objectives of which include protecting the human rights of scientists and fostering greater understanding of and support for human rights among scientists throughout the world (Rogers, 1981).

With the growth of the scientific community and the multiplication of specialties in the 19th Century, international scientific societies have proliferated. One of the oldest international scientific associations, the International Meteorological Committee, was founded in 1872. Numerous other international associations were subsequently founded, so that by the end of World War I there was a perceived need for a new association to coordinate the multitude of scientific societies, thus giving rise in 1919 to an umbrella organization called the International Council of Scientific Unions. After World War II, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) was instrumental in coordinating the activities of all the social sciences under another umbrella organization known as the International Social Science Council.

Notwithstanding the proliferation of professional societies at national and international levels, there has been a dearth of organizational developments focused on the social responsibility of scientists, namely their ethical concerns about the social impact of technological innovations. In addition to the pioneering work of the Federation of American Scientists mentioned previously, several other organizations deserve consideration.

A kindred national organization in the United States is the Union of Concerned Scientists (UCS). The purpose of this organization of approximately 50,000 concerned scientists is to combine rigorous scientific analysis with citizen advocacy for "a cleaner, healthier environment and a safer world" (Union of Concerned Scientists: www.ucsusa.org). Founded in 1969 by faculty members of the Massachusetts Institute of Technology, its mission is to redirect scientific research to environmental and social problems. Its members collaborate on technical studies on renewable energy options, the impact of global warming, risks of genetically engineered crops and related problems. Results of technical studies are shared with policy makers, news media, and the public.

In 1955, at the height of the Cold War, Bertrand Russell and Albert Einstein issued a humanist manifesto for peace addressed to the participants of the first Pugwash conference:

> We are speaking . . . not as members of this or that nation, continent, or creed, but as human beings, members of the species Man, whose continued existence is in doubt. . . .
>
> We have to learn to think in a new way. We have to learn to ask ourselves, not what steps can be taken to give military victory to whatever group we prefer, for there no longer are such steps; the question we have to ask ourselves is: what steps can be taken to prevent a military contest of which the issue must be disastrous to all parties?
>
> There lies before us, if we choose, continual progress in happiness, knowledge, and wisdom. Shall we, instead, choose death, because we cannot forget our quarrels? We appeal, as human beings, to human beings: Remember your humanity, and forget the rest. If you can do so, the way lies open to a new Paradise; if you cannot, there lies before you the risk of universal death. (Pugwash: 1978: 10–12)

Signed by a number of internationally-distinguished scientists, the manifesto urged scientists, regardless of political persuasion, to assemble for the purpose of discussing the threat to civilization posed by thermonuclear weapons. The first meeting was held in 1957 in the Village of Pugwash, Nova Scotia—hence the name "Pugwash Conference." Meeting as private individuals rather than as government representatives, Pugwash participants explored alternative strategies to arms control and other global problems. The results of the Pugwash Conferences are communicated as policy recommendations to national governments around the world.

> It has . . . been reliably stated that . . . (Pugwash Conferences) made a very significant contribution to decisions by governments on such a major issue as the Partial Test-Ban Treaty. They have also contributed new ideas towards the control and limitation of armaments such as 'nuclear-free zones' and the 'black-box' methods of monitoring underground test-explosions. They may have been useful in preparing the ground for the recent 'SALT' negotiations. (Pentz and Slovo, 1981: 177)

In 1979, the first Student Pugwash Conference was convened at the University of California, San Diego. This offshoot of the Pugwash Conference seeks to foster dialogue among student participants about major global problems (Leifer, 1979: 3–11).

Professional scientific societies, at national as well as international levels, suffer from several fundamental weaknesses. First is a lack of adequate financial resources to launch scientific studies and disseminate their findings to policy makers and the public. Second is a lack of funds to protect the human rights of scientists who choose to act as whistleblowers in government agencies and private corporations. Andrei Sakharov, the father of the Soviet hydrogen bomb, who, after its development, then foreswore participation in any subsequent military research, became a celebrated dissident and an advocate of human rights. As a result of his courageous challenge to the Soviet totalitarian system, he was harassed by the KGB and eventually banished from Moscow to Gorky. During the years of his privation, national and international scientific organizations were unable to prevail upon the Soviet authorities to release him from internal exile.

Yet another deficiency of professional scientific societies is the lack of funds to establish research institutes to study global problems and provide employment for scientists who choose not to work on military and national security projects.

Finally, professional societies, especially at the international level, lack a code of ethics affirming the principle of "do no harm" embodied in the Hippocratic Oath. In a recent lecture entitled "Science and Humanity at the Turn of the Millennium," Sir Joseph Rotblat, a physicist and Nobel Laureate in Peace, addressed this problem:

> The time has . . . come for some kind of Hippocratic Oath to be formulated and adopted by scientists. A solemn oath, or pledge, taken when receiving a degree in science, would, at the least, have an important symbolic value, but might also generate awareness and stimulate thinking on the wider issues among

young scientists . . ." The text of the pledge adopted by the US Student Pugwash Group seems to me highly suitable. The Pledge reads:

> *"I promise to work for a better world, where science and technology are used in socially responsible ways. I will not use my education for any purpose intended to harm human beings or the environment. Throughout my career, I will consider the ethical implications of my work before I take action. While the demands placed upon me may be great, I sign this declaration because I recognize that individual responsibility is the first step on the path to peace."* (Rotblat, 1999: 7)

Apart from the individual expression by scientists of their social responsibility, there is a need for organizations of scientists to articulate such a commitment collectively (Lakoff, 1979).

If these four fundamental problems of international scientific societies are ever to be solved, they presuppose the growth of transnational loyalties in the scientific community to promote the well-being of humanity rather than the interests of nation-states (Evan, 1997: 987–1003).

Rotblat, upon leaving the Manhattan Project, made a fundamental career decision based on ethical considerations:

> Work on the atom bomb convinced me that even pure research soon finds applications of one kind or another. If so, I wanted to decide myself how my work should be applied. I chose an aspect of nuclear physics that would definitely be beneficial to humanity: the applications to medicine. Thus I completely changed the direction of my research and spent the rest of my academic career working in a medical college and hospital. (Rotblat, 1986: 21)

A Nobel Laureate in physics, I.I. Rabi has articulated a similar conception: "Wisdom is the application of knowledge for the benefit of mankind" (Lederman, 1999: 15).

Conclusion

To ensure that the inventions of engineers and the discoveries of scientists promote the "benefit of mankind," both professions will have to abandon their stance of ethical neutrality. Through their role in institutions of higher learning, they can help inculcate future generations of engineers and scientists with a social responsibility perspective. Through their participation in professional societies, engineers and scientists can potentially implement the principles embodied in their codes of ethics. By translating codes of ethics principles into their everyday work experience, they can help significantly reduce the incidence of technological disasters.

References

Accreditation Board of Engineering Education and Technology (ABET). (1998). Engineering criteria 2000. Available on the World Wide Web at: www.abet.org/eac/EAC_99-00_Criteria.htm#EC2000

Akgerman, A., Anthony, R.G., and Darby, R. (1999). "Integrating process safety into ChE education and research," *Chemical Engineering Education* 33 (3): 198–204.

Beckman, Peter R., Campbell, Larry, Crumlish, Paul W., Dubkowski, Michael N., and Lee, Steven P. (1989). *The nuclear predicament.* Englewood Cliffs, NJ: Prentice Hall.

Bernstein, Jeremy. (2000). "Creators of the bomb," *The New York Review of Books,* May 11; 47: 19–21.

Bryan, Leslie. (1999). "Educating engineers on safety," *Journal of Management in Engineering* 15 (2): 30–34.

Carpenter, Stanley. (1984). "Redrawing the bottom line: The optimal character of technical design norms," *Technology in Society* 6: 329–340.

Durbin, P. (1989). "The challenge of the future for engineering educators." In A. Flores (Ed.), *Ethics and risk management in engineering.* Washington, DC: University Press of America.

Evan, William M. (1975). "The International Sociological Association and the internationalization of sociology," *International Social Science Journal* XXVII: 385–393.

Evan, William M. (1981). "Some dilemmas of knowledge and power." In William M. Evan (Ed.), *Knowledge and power in a global society.* Beverly Hills, CA: Sage Publications.

Evan, William M. (1997). "Identification with the human species: A challenge for the twenty-first century," *Human Relations* 50 (8): 987–1003.

Flores, Albert. (1980). "Problems with technology: Social responsibility and the public's trust." In Albert Flores (Ed.), *Ethical problems in engineering.* Troy, NY: Center for the Study of the Human Dimensions of Science and Technology: 211–214.

Flores, Albert. (1982). "Designing for safety: Organizational influences on professional ethics." In A. Flores (Ed.), *Designing for* *safety: Engineering ethics in an organizational context.* Troy, NY: Rensselaer Polytechnic Institute.

Glagola, C., Kam, M., Loui, M., and Whitbeck, C. (1997). "Teaching ethics in engineering and computer science: A panel discussion," *Science and Engineering Ethics* 3 (4): 463–480.

Grundfest, Warren, and Scott, Andrea. (1998). "Ethical issues in the development of medical devices: The role of education and training in the evaluation of safety and efficacy," *Critical Reviews in Biomedical Engineering* 26 (5): 378–383.

Harris, C., Pritchard, M., and Rabins, M. (1995). *Engineering ethics: Concepts and cases.* San Francisco, CA: Wadsworth Publishing Co.

King, Julia. (1998). "Incorporating safety into a unit operations laboratory course," *Chemical Engineering Education* 32 (3): 178–184.

Lakoff, Sanford. (1979)."Ethical responsibility and the scientific vocation." In Sanford A. Lakoff (Ed.), *Science and ethical responsibility.* Reading, MA: Addison-Wesley Publishing Company: 19–31.

Lau, Andrew. (1998). "Broadening student perspectives in engineering design courses," *IEEE Technology and Society Magazine* 17 (3): 18–25.

Lederman, Leon M. (1999). "The responsibility of the scientist," *The New York Times,* July 24: A15.

Leifer, Jeffrey R. (1979)."The origins and objectives of Student Pugwash." In Sanford A. Lakoff (Ed.), *Science and ethical responsibility.* Reading, MA: Addison-Wesley Publishing Company: 3–11.

Lichter, B. (1989). "Safety and the culture of engineering." In A. Flores (Ed.), *Ethics and risk management in engineering.* Washington, DC: University Press of America: 211–221.

Long, Thomas. (1983). "Informed consent in engineering: An essay review," *Business and Professional Ethics Journal* 3: 59–66.

Lowrance, William. (1976). *Of acceptable risk: Science and the determination of safety.* Los Altos, CA: William Kaufmann.

Manion, Mark, and Kam, Moshe. (2000). "Engineering ethics at Drexel University." *Proceedings of the American Society of Engineering Education (ASEE) 2000 Conference,* March 24: 45–63.

Martin, W., Mike and Schinzinger, Roland. (1996). *Ethics in engineering.* New York: McGraw-Hill.

McLean, G.F. (1993). "Integrating ethics and design," *IEEE Technology and Society Magazine* 12 (1): 19–30.

Merton, Robert K. (1973). *The sociology of science: Theoretical and empirical investigations.* Chicago: University of Chicago Press.

Moonashingha, Ananda. (1996). "Design—cornerstone of your career: Advice for young engineers," *Journal of Professional Issues in Engineering Education and Practice* 122 (3): 135–138.

Nandagopal, N.S. (1990). "Why and how should students in technical programs be exposed to ethical and international issues." In *A delicate balance: Technics, culture, and consequences.* The Institute of Electrical and Electronics Engineers. Catalog Number 89CH2931-4. Los Angeles: California State University: 87–93.

National Society of Professional Engineers. "NSPE code of ethics." Available on the World Wide Web in September 2000 at: www.nspe.org

Orr, R., and Pang, N. (1993). "The use of the Hippocratic oath: A review of 20th century practice and content analysis of oaths administered in medical schools in the U.S. and Canada." Available on the World Wide Web June 6, 2001 at: www.imagerynet.com/hippo.ama.html

Pentz, Michael J., and Slovo, Gillian (1981). "The political significance of Pugwash." In William M. Evan (Ed.), *Knowledge and power in a global society.* Beverly Hills, CA: Sage Publications: 175–203.

Petroski, Henry. (1985). *To engineer is human: The role of failure in successful design.* New York: St. Martin's Press.

Petroski, Henry. (1994). *Design paradigms: Case histories in error and judgment in engineering.* Cambridge, England: Cambridge University Press.

Pletta, Dan, and Hon, M. (1987). " 'Uninvolved professionals' and technical disasters," *Journal of Professional Issues in Engineering* 113 (1): 23–32.

Pugwash Conferences on Science and World Affairs. (1978). *The Pugwash movement at twenty-one.* Basingstoke, Hampshire: Taylor and Francis Ltd.

Rabins, Michael. (1998). "Teaching engineering ethics to undergraduates: Why? what? how?" *Science and Engineering Ethics* 4: 291–302.

Rhodes, Richard. (1988). *The making of the atomic bomb.* New York: Simon & Schuster.

Rogers, Carol L. (1981). "Science information for the public: The role of scientific societies," *Science, Technology and Human Values* 6 (36), Summer: 36–39.

Rotblat, Sir Joseph. (1986). "Leaving the bomb project." In Len Ackland and Stephen McGuire (Eds.), *Assessing the nuclear age.* Chicago, IL: 15–22.

Rotblat, Sir Joseph. (1999, July). "Science and humanity at the turn of the millennium," *Student Pugwash USA's 20th Anniversary*

International Reunion Conference, held at the University of California, San Diego.

Schinzinger, Roland. (1986). "Technological hazards and the engineer," *IEEE Technology and Society Magazine* 11 (1): 12–19.

Sherr, Sava. (1982). "Societal aspects of engineering standards," *IEEE Technology and Society Magazine* 1 (3): 13–16.

Slaymaker, Robert, and Bates, Christine. (1993). "Today's challenge in training new engineers," *IEEE Transactions on Industry Applications* 29 (1): 26–34.

Susskind, Charles. (1973). *Understanding technology.* Baltimore, MD: The Johns Hopkins University Press.

Tribe, Lawrence. (1971a)."Towards a new technological ethic: The role of legal liability," *Impact of Science on Society* 21 (3): 215–222.

Tribe, Lawrence. (1971b). "Legal frameworks for the assessment and control of technology," *Minerva,* October: 243–255.

Unger, Stephen. (1982). "The role of engineering schools in promoting design safety," *IEEE Technology and Society Magazine* 7 (1): 9–12.

Unger, Stephen. (1987). "Would helping ethical professionals get professional societies into trouble?" *IEEE Technology and Society Magazine* 6 (3): 19–21.

Unger, Stephen. (1994). *Controlling technology: Ethics and the responsible engineer* (2nd ed.). New York: John Wiley & Sons.

Unger, Stephen. (1995). "Engineering ethics: What's new?" *IEEE Technology and Society Magazine* (Fall): 4–5.

Vanderburg, Willem. (1995). "Preventive engineering: Strategy for dealing with negative social and environmental implications of technology," *Journal of Professional Issues in Engineering Education and Practice* 121 (1): 155–160.

Vanderburg, Willem. (1997). "Rethinking end-of-pipe engineering and business ethics," *Bulletin of Science, Technology & Society* 17 (93): 141–153.

Vesilind, Aarne. (1992). "Guidance for engineering-design-class lectures on ethics," *Journal of Professional Issues in Engineering Education and Practice* 118 (2): 214–219.

Wacker, G. (1990). "Teaching impacts of technology/professional practice in an engineering program." In *A delicate balance: Technics, culture, and consequences.* The Institute of Electrical and Electronics Engineers. Catalog Number 89CH2931-4. Los Angeles: California State University: 79–83.

Whitbeck. C. (1995). "Teaching ethics to scientists and engineers: Moral agents and moral problems," *Science and Engineering Ethics* 1: 397–408.

Willey, Ronald, and Piece, John. (1998). "Freshman design projects in the environmental health and safety department," *Chemical Engineering Education* 33 (3): 198–204.

Wilson, G. (1990). "Education for the social practice of engineering," *IEEE Spectrum* 25 (4): 117–122.

Zuckerman, Harriet. (1977). *Scientific elite: Nobel laureates in the United States.* New York: Free Press.

CHAPTER 11

The Role of Corporations in the Management of Technological Disasters

"The distinguishing mark of the executive responsibility is that it requires not merely conformance to a complex code of morals but also the creation of moral codes for others."

—Chester J. Bernard

If one wishes to identify the social, political, and moral dimensions of technological disasters, one must focus on the organizational context in which the failed technology is embedded. An analysis of the corporate environment surrounding many technological disasters often reveals a structure and pattern of corporate misconduct in the management and control of potentially hazardous technologies.

CORPORATE MANAGEMENT VERSUS MISMANAGEMENT

Research on "white-collar crime" and "organizational deviance" (Ermann and Lundman, 1992) has identified at least three hypothetical explanations, inferred from the investigation of dozens of cases, that help account for how and why corporations "socialize individuals into evildoing" (Darley, 1991). From this research we can gain some insight into the dynamics of corporate mismanagement and, hence, corporate responsibility and accountability for technological disaster. In the course of analyzing factors con-

ducive to corporate *mismanagement* of hazardous technologies, we also uncover factors concerning the proper corporate *management* of technological crises.

One factor that can result in corporate mismanagement of technology is the diffusion and fragmentation of information in large organizations, as illustrated in the Challenger case (Vaughn, 1996). When it is discovered that a product that has been designed, manufactured, advertised, and sold is harmful to consumers, we find that knowledge of the product's potential for harm tends to be dispersed in various divisions of a corporation. This is because corporate divisions are often not in adequate communication with each other on issues of risk and safety.

The Challenger case provides a clear illustration of the compartmentalization of information and the failure of communication within a large corporation. Morton Thiokol engineers wrote a series of memoranda, even presenting data about potential failures of the O-rings the night before the fateful flight, but the information was never passed up from Level III to Level II or to decision makers at Level I during the all-important preflight readiness review process.

A second factor that can lead to corporate mismanagement of technology is the prior commitment to courses of action by corporate elites who establish norms and rewards that may encourage conduct leading to technological disaster. The Ford Pinto case, as we shall see, is a telling example of this. A third factor is that technological disaster may be the result of deviant actions by corporate top management, as illustrated in the Dalkon Shield case and in the Johns-Manville case. These cases of technological disaster were, for the most part, the result of management misconduct—which Lerbinger calls "crises of malevolence" or "crises of deception"—clearly the result of distorted management values (Lerbinger, 1997).

These three particular disasters, the Ford Pinto, Dalkon Shield, and Johns-Manville cases, are prime examples of a failure that spiraled into a "crisis," a situation that can threaten the very existence of a corporation. Such behavior by top management can have untold negative effects on its environment as well as on multiple stakeholders or constituencies. In the case of the Exxon *Valdez*, a major technological disaster, the spillage of millions of gallons of oil into the pristine waters off the coast of Alaska, turned into a crisis because the Exxon executives, by

Westin, Alan. (1981). *Whistleblowing: Loyalty and dissent in the corporation.* New York: McGraw-Hill.
White, Joseph, Power, Steven, and Aeppel, Timothy. (2001). "Death count linked to failure of Firestone tires risen to 203," *The Wall Street Journal,* June 19: A3.
Williams, David E., and Olaniran, Bolane A. (1994). "Exxon's decision-making flaws: The hypervigilant response to the *Valdez* grounding," *Public Relations Review* 20 (1): 5–18.

Endnote

1. A kindred managerial response occurred in the Merck pharmaceutical company in the 1980s. Following the discovery of Mectizen, a drug effective in a killing parasite that causes river blindness—a disease afflicting millions of people in sub-Saharan Africa and Latin America—scientists at Merck discovered that one could treat this disease by giving victims one tablet of Mectizen once a year and thus completely preventing the progression of the disease. However, this discovery posed a quandary for Merck because the victims who could benefit from the drug were completely unable to pay for it. Hence, a debate raged within the ranks of management as to whether to shelve this miracle drug or to embark on a philanthropic venture to produce and distribute the drug free of charge. Under the imaginative leadership of Dr. Roy Vagelos, the then CEO of Merck, he embarked on an effort to elicit the cooperation of the World Health Organization, various foundations, and other organizations to distribute the drug free of charge—at considerable cost to Merck—in the interest of curing approximately 20 million people suffering from the river blindness disease.

   In 1987, Merck announced that it would donate Mectizen for the treatment of river blindness as long as needed (www.merck.com/overview/philanthropy/mectizan/p12.htm).

   Merck's decision was based on a simple, yet profound Credo, articulated by George W. Merck, the company's President from 1945–1950. In a 1950 address at the Medical College of Virginia, George Merck stated, "Medicine is for the people. It is not for the profits. The profits follow, and if we have remembered that, they have never failed to appear."

CHAPTER 12

The Role of the Legal System in Technology Policy Decisions

"Justice can be attained only by the careful regard for fundamental facts, since justice is but truth in action."
—Justice Louis D. Brandeis

The case studies of technological disasters presented in Chapters 5, 8, and 11 raise questions about the ability of our legal system to cope successfully with the negative consequences of technology. The most general point to be made is that lawyers, judges, and politicians are rarely in a position to assess the risks of complex technology about which they make decisions. Technology policy is made by politicians who—although a large proportion may have a legal background—are nevertheless mostly innocent of technical matters. It is because of these inadequacies that the need for independent, objective, and expert advice arises at every level of the legal system.

The legal system in the United States consists of four subsystems, each of which performs a lawmaking function that bears on technology policy decisions: the executive, legislative, administrative, and judiciary branches.

The Executive Branch

The executive branch consists of a complex of organizations reporting to the president and responsible for assisting him in dealing with

United States of America v. Microsoft Corporation, State of New York, et al. v. Microsoft Corporation, 97 F. Supp. 2d59 (2000).
United States of America v. Microsoft Corporation, 2001 U.S. App. P73, 321 (June 28, 2001).
U.S. Census Bureau. (1999). *Statistical Abstract of the United States* (119th ed.). Washington, DC: Author.
U.S. Government Manual. (1997–1998). Washington, DC: Government Printing Office.
Wald, Patricia M. (1995). "Technology and the courts." In William T. Golden (Ed.), *Science and technology advice to the president, Congress, and judiciary.* New Brunswick, NJ: Transaction Publishers: 484–488.
Whiteman, D. (1982). "Congressional use of technology assessment." In D. O'Brien and D. Marchand (Eds.), *The Politics of technology management.* Toronto: Lexington Books.
Wiesner, J. (1989). "On science advice to the president," *Scientific American* 260: 34–40.

CHAPTER 13

Assessing the Risks of Technology

"In all traditional cultures . . . human beings worried about the risks coming from external nature . . . very recently . . . we started worrying less about what nature can do to us, and more about what we have done to nature. This marks the transition from the predominance of external risk to that of manufactured risk."
—Anthony Giddens

The prevalence of technological disasters points to deficiencies in the way technology is assessed—the way technologies are determined to be or not to be risky. In this chapter we focus on two prominent methods for assessing risk: probabilistic risk assessment (PRA) and risk-cost-benefit analysis (RCBA). If we find the standard methods deficient, then it should not be surprising that we have more disasters than we can expect. The overall lesson is that, if we want to reduce the number and magnitude of technological disasters, we must reform our methods of evaluating the potential impacts of technology—PRA and RCBA—and develop more effective methods.

Experts attempt to separate risk assessment techniques into two independent procedures—the risk identification or risk estimation level, which is supposedly factual, scientific, objective, and value-neutral, and the risk assessment or risk management level—which is supposedly normative, political, subjective, and value-laden (Humphreys, 1987). This rigid demarcation into the "factual" or scientific measurement of risks vs. the "normative" management of the social acceptability of risks is thought to secure for risk assessors a level of scientific objectivity and value neutrality.

We will argue, however, that the factual/normative split is no longer adequate for the proper identification, assessment, and management of technological risk. Consequently, the so-called objective activities of risk identification or risk estimation need to be integrated with the normative and evaluative aspects of risk evaluation and risk management.

PROBABILISTIC RISK ASSESSMENT

Probabilistic risk assessment (PRA), or quantitative risk assessment (QRA), attempts to provide a model of the causal interactions of the technological system under study. The goal of PRA is to supply a mathematical technique for estimating the probability of events that cause physical damage or loss of life (Thompson, 1982: 114). A comprehensive probabilistic risk assessment involves three steps: (1) the identification of events that lead to, or initiate, unwanted consequences; (2) the modeling of identified event sequences with respect to probabilities and consequences; and (3) the determination of the magnitude of risks and harms involved (Bier, 1997).

PRA has become one of the standard methods used by engineers for determining the likelihood of an industrial accident or a technological disaster. This method makes use of technical procedures called *fault-tree analysis* and *event-tree analysis*. Fault-trees and event-trees generate diagrams that trace out the possible ways a malfunction can occur in complex technological systems. They enable design engineers to analyze in a systematic fashion the various failure modes associated with a potential engineering design (Henley and Kumamoto, 1981: 24–28). Failure modes are the ways in which a structure, mechanism, or process can malfunction.

In an event-tree analysis one begins with an initial event—such as a loss of electrical power to a nuclear power plant—and, using inductive logic, reasons *forward,* trying to determine the state of the system to which the event can lead (Henley and Kumamoto, 1981: 24–28). Figure 13–1 illustrates an event-tree analysis of the probability of radiation release from a standard nuclear power plant. The diagram is based on the authoritative reactor safety study, WASH 1400, the so-called "Rasmussen Report," commissioned by the U.S. government in 1975 (*Reactor Safety Study,* 1975).

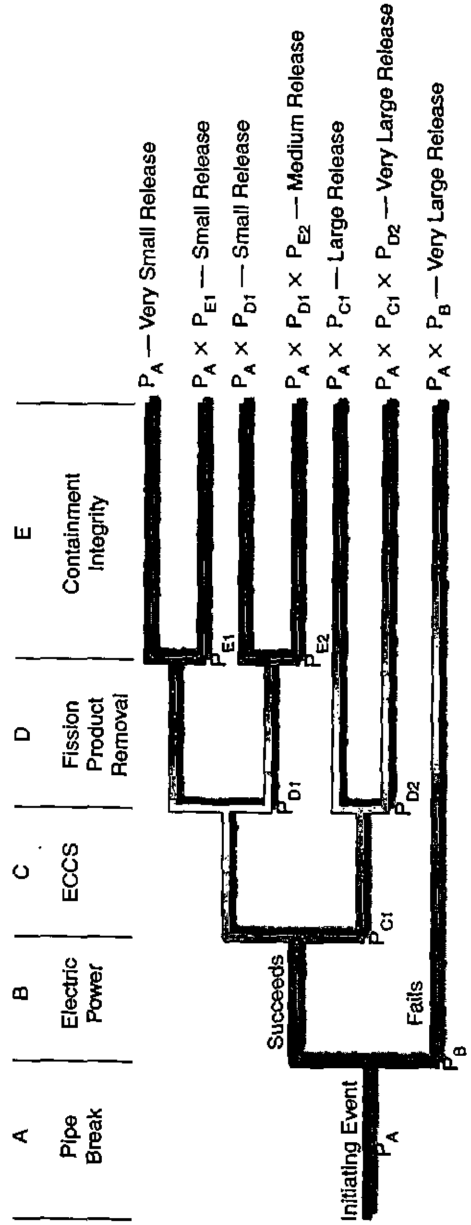

Figure 13–1
Event-tree analysis of a possible fission product release from a nuclear power plant.
Source: Henley, Ernest and Kumamoto, Hiromitsu (1981). *Reliability engineering and risk assessment.* Englewood Cliffs, NJ: Prentice Hall: 25.

The Reactor Safety Study was performed to determine the public risks associated with existing and planned nuclear power plants. The simplified event tree begins with a definite accident-initiating event and tries to identify all the safety systems that can be called upon to mitigate the consequences. The study determined that the failure of the reactor cooling system is the most critical component that could lead to a radiation release. The analysis therefore begins with the initiating event that a (coolant) pipe might break. If the pipe breaks, without any other system failing at the same time, then the probability that there would be a radiation release is P_A, a very small release, as shown in Figure 13–1. Possible failures are next defined for each system; and accident sequences are constructed, consisting of the initiating event with specific systems failing and specific systems succeeding. For example, the probability of both a pipe breaking and a corresponding loss of electrical power to the plant ($P_A \times P_B$), would lead to a very large release of radiation. Keep in mind that a probability of 1 means that an event is certain to happen. Therefore, the probability that P_A occurs is less than one. In fact, all of the assigned probabilities will be less than 1, and, as the probabilities are multiplied, the total probability will diminish. For example, if the probability of P_A occurring is 0.01 and the probability of P_B occurring is 0.001, then the overall probability that a pipe will break per day and the electrical power will fail is 0.01×0.001, which equals 0.00001 or one in 100,000 events. Even though the probability of a pipe breaking at the same time as the electrical system failing is rather low, the potential consequences are very high.

If electric power does not fail during the pipe break, the analysis moves to determining the relationship between the breaking pipe and the emergency core coolant system (ECCS). The ECCS could either succeed or fail. The probability that ECCS fails at the same time that a pipe breaks would lead to a large release, namely, ($P_A \times P_{C1}$). If the ECCS succeeds, then the probability that the fission product removal is inhibited and that a pipe breaks would lead to a small release, namely, ($P_A \times P_{D1}$). Likewise, the probability of a pipe breaking and a failure of the ECCS as well as the fission product removal being inhibited would lead to a very large release, namely, ($P_A \times P_{C2} \times P_{D2}$). In the end, each possible system state (failure or success) is connected through a branching logic to give all the specific accident sequences that can arise. The event tree is particularly useful when many individual systems and subsystems interact.

In a fault-tree study, the analyst begins with a hypothetical undesirable event, then, using deductive logic, reasons *backwards* to determine what might have led to the event. Fault-trees follow a cause-and-effect model and can be used whenever hypothetical events can be resolved into more basic, discrete units for which failure data exist or for which failure probabilities are generally easily calculable. Figure 13–2 illustrates a fault tree for analyzing the possible causes of why a car would not start. For example, a good mechanic would, more than likely, already be aware of all of the possible reasons of why a car will not start. The mechanic would then construct a fault tree as illustrated in Figure 13–2, checking each subsystem as a possible cause of why the car will not start. An insufficient battery charge is the most likely cause of a car not starting, so the mechanic would begin there and proceed to check whether there was a faulty ground connection, the battery terminals were loose or corroded, or the battery charge was weak, etc. If, for example, it is determined that the terminals are not loose or corroded or the battery charge was not weak, then the mechanic would check to see if there was rust on the ground connections, the connections were corroded or otherwise dirty, or the ground connections were loose. If the battery checks out, the mechanic would move to an analysis of the starter system, checking each related subsystem. If this checks out, then the mechanic would move to the fuel system and each of the other related subsystems. The mechanic reasons step-by-step through the fault tree until the cause of the car not starting is identified.

Since the first comprehensive application of probabilistic risk assessment in 1975—the U.S. Reactor Safety Study—more than 15 large-scale PRAs have been carried out for nuclear power plants in the United States. In addition, large-scale PRAs have been carried out in Sweden and West Germany and have also been used in determining levels of safety in such varied industries as chemical production, liquid gas transport and storage, oil-drilling rigs, transport of toxic chemicals, and the aerospace and nuclear industries (Linnerooth-Bayer and Wahlstrom, 1991: 240). Even though PRA has been used extensively, there are substantial methodological problems, some of which we will now consider.

The first set of methodological problems in PRA arises when experts attempt to determine which factors to include and which to exclude. The second set of problems arises when scientific uncertainties appear in the modeling process (Rowe, 1994). Thirdly, there are

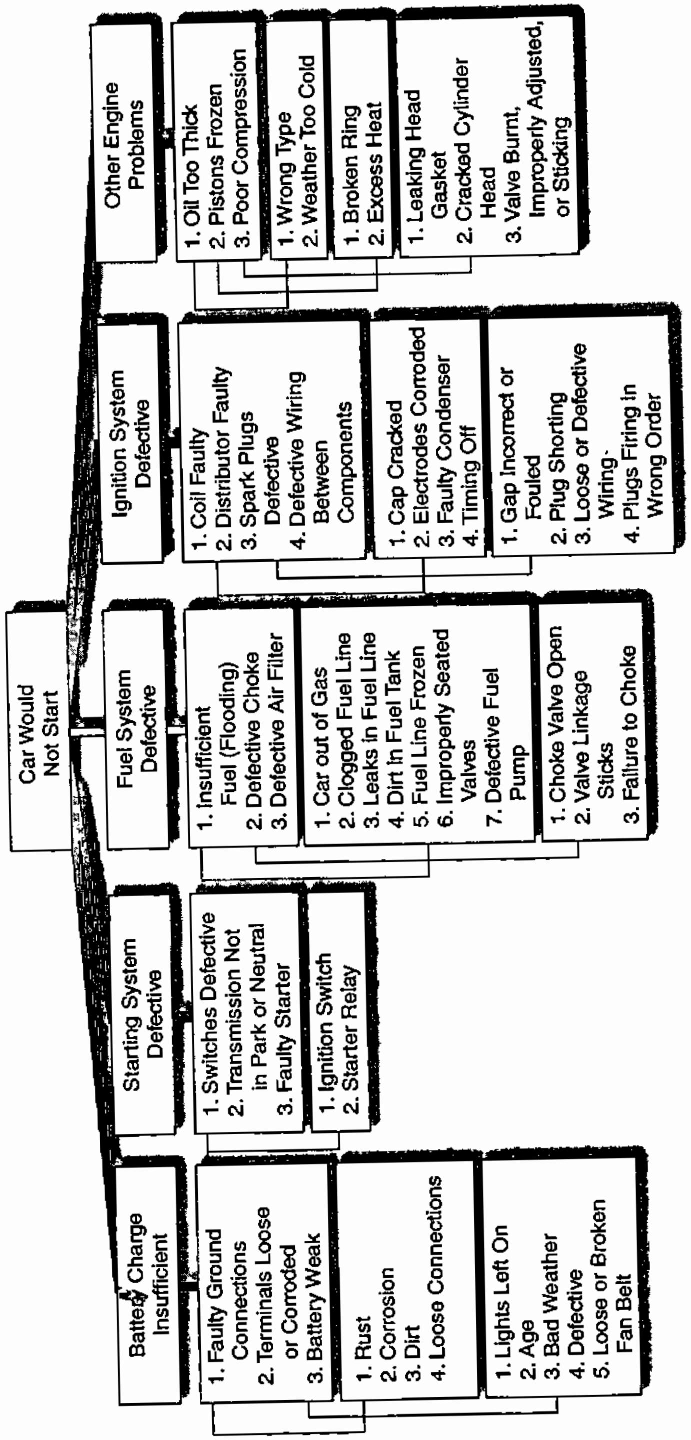

Figure 13–2
Fault-tree analysis of the failure of an automobile to start.
Source: Fischoff B., Slovick P., and Lichtenstein S.A., "Fault trees: Sensitivity and estimated failure problem representation," *Journal of Experimental Psychology: Human Perception and Performance*, 4 (1978). Copyright © 1978 by the American Psychological Association. Reprinted with permission.

reservations about the adequacy of the method due to uncertainties that arise in attempting to trace out unknown cause-and-effect relationships. A fourth deficiency of the method is its inability to account for uncertainties that inevitably arise due to operator error and other human factors. Fifth, the very complexity of many large-scale technologies renders the PRA method inadequate as the sole source of assessing risks and adequate safety levels. Figure 13–3 lists the five problems pertaining to PRA and the associated issues that arise with each problem.

The first set of problems with PRA methodology arises when experts are confronted with difficulties in taking into account all of the ways the components of a system are interrelated. Furthermore, risk or reliability analysts can fail to foresee all of the interactions among individually-separated problems. Methodological uncertainties abound, causing large knowledge gaps in how systems operate and how systems fail. Such uncertainties arise if fault trees or event trees are inaccurate, incomplete, or inappropriate (Bier, 1997: 72–73).

The second set of difficulties of PRA methodology arises when researchers inadvertently construct, select, and validate an

Problems	Issues
1. Problems of identifying all potential risk factors	1. Uncertainties arise when experts attempt to anticipate all of the mechanical, physical, electrical, and/or chemical factors to be included in a fault-tree or an event-tree analysis.
2. Problems with uncertainties in the modeling of systems	2. Uncertainties arise from the failure to incorporate in the model important characteristics of the process under investigation.
3. Problems associated with determining cause-and-effect relationships	3. Direct cause-and-effect relationships between potential hazards and consequent harms are often not demonstrable.
4. Uncertainties due to human factors	4. Potential errors are associated with human operators, which often cannot be "modeled" and hence are rarely anticipatable.
5. Problems of complexity and coupling	5. Tight coupling and interactive complexity between system components disallow any complete modeling of potential system failures.

Figure 13–3
Problems and issues with probabilistic risk assessment.

inaccurate or faulty modeling of the system under analysis. "Models are simplified representations of real world processes; as such, they make certain assumptions concerning the true state of nature" (Haimes, 1998: 240). Model uncertainty arises from the failure to incorporate important characteristics of the process under investigation. "If this uncertainty is improperly understood, it can be potentially the largest contributor of error, leading to significant misrepresentations of processes" (Haimes, 1998: 240).

The third set of methodological shortcomings of PRA arises because the probabilities assigned to various failure modes are, by and large, conjectural and based on analyses that often cannot be corroborated by experimental testing. This is especially true of uncertainties that arise due to hidden or unknown cause-and-effect relationships (Bougumil, 1986). For example, researchers often come upon uncertainties when inferring risks to humans from animal experimentation models.

The fourth set of problems associated with the PRA method is its inability to anticipate all of the opportunities for human error that could lead to failure. As we have pointed out in Chapter 5, such human factors include cognitive processing of information; insufficiencies in human perception, memory retention, or an individual operator's capacity for stress; cognitive and emotional overload; and worker burnout. All of these factors may lead to bad judgments and/or inaccurate perceptions. Simple human inattention, carelessness, or even negligence can lead to operational failure. Such factors were evident in the TMI, Bhopal, Chernobyl, USS *Vincennes*, and *Titanic* cases. In spite of decades of research on human-factors problems, we still have a long way to go to understand adequately human-machine interactions. Other human-factors problems that render PRA insufficient as a method for determining risks were operating in the Ford Pinto case and in the B.F. Goodrich brake scandal case. Risk assessors may, on occasion, underrate risks in a risk assessment report or fail to see the significance of risks that are present. The Challenger disaster is a case in point.

In fact, a research survey of about 1,500 members of the Society of Risk Analysis found that such human factors as data fabrication and bias in research design are more common in the risk assessment process than one would think. As the researchers put it:

> Surveys of almost 1,500 members of . . . professional societies that do risk analysis (e.g., environmental economics, epidemiology, exposure assessment, industrial hygiene, toxicology) found that 3 in 10 respondents had observed a biased research design, 2 in 10 had observed plagiarism, and 1 in 10 observed data fabrication or falsification. Respondents with many years in risk analysis, business consultants, and industrial hygienists reported the greatest prevalence of misconduct. These respondents perceived poor science, economic implications of the research, and lack of training in ethics as causes of misconduct. (Greenberg and Goldberg, 1994: 223)

The fifth and final set of problems with PRA is the increasing complexity and interdependence of technological systems. Large-scale risk assessments, such as those in the nuclear industry, for example, encompass a myriad of different systems requiring the involvement of expertise from numerous areas. As Perrow points out, the description of possible chains of events is so complex and open to multiple interpretations that there is often room for dispute after an accident as to whether the destructive chain of events was even described in the initial PRA.

Given the methodological deficiencies of PRA discussed above, it is safe to assume that technical methods alone, no matter how sophisticated, cannot be the only way to assess the benefits and burdens of technology. Moreover, exclusive focus on probabilities leads analysts to ignore *low-probability but high-consequence events.* In other words, PRA often ignores the category of "catastrophe," because catastrophes entail low-probability, high-consequence events. Ignoring low-probability, high-consequence events is unwise, given the immense complexity of many technologies, especially large-scale sociotechnical systems. No matter how detailed a fault-tree or an event-tree analysis may be, the methodology simply cannot begin to capture all of the common mode failure events that are possible. The inadequacy of PRA in treating low-probability, high-consequence events is glaringly evident in the Three Mile Island, Chernobyl, Challenger, and Bhopal cases. As Lanthrop puts it, "deciding that, say, a nuclear power plant is safe because it is only expected to fail once in every 10,000 successful usages does not rule out that a catastrophe may happen tomorrow, or next year, or the next" (Lanthrop, 1982: 171). This is exactly the kind of assessment failure that happened in the Three Mile Island case.

Even if PRA were an effective method for determining the risks of technology, which it is not, it would not be enough in any event. As we have seen in numerous cases discussed previously, beyond technical factors, human, organizational, and socio-cultural factors are often at the root of technological disasters.

Risk-Cost-Benefit Analysis

Along with PRA, cost-benefit analysis (CBA) and risk-cost-benefit analysis (RCBA) arose as the preeminent methods of assessing the risks of technology during the late 1960s and early 1970s, as Congress began to enact legislation on the regulation and monitoring of technology and its social and environmental impacts. RCBA is a variant of CBA in which human health and welfare are brought into the equations, along with the material costs and benefits of a proposed technology.

Comprehensive statutes such as the National Environmental Policy Act of 1970 (NEPA), the Federal Water Pollution Control Act Amendments of 1972, the Consumer Protection Act, and the Clean Air and Clean Water Acts require a government agency to consider technical and economic feasibility characteristics and health and environmental effects when contemplating a technological intervention. In order to accomplish these goals, organizations turned, and continue to turn, to CBA and RCBA in an effort to comply with statutory and judicial requirements (Baram, 1977). The National Aeronautics and Space Administration (NASA) uses RCBA in its feasibility and safety studies. The Nuclear Regulatory Commission (NRC) has followed NASA's lead in employing RCBA almost exclusively in setting "acceptable" radiation standards and in decisions concerning the licensing of nuclear facility construction and operation (Kneese, Ben-David, and Schultze, 1983: 60–61).

RCBA has also been the leading method used by experts as a basis for policy choices concerning controversial problems surrounding the storage and disposal of nuclear waste (Grossman and Cassedy, 1985). In addition, RCBA is utilized frequently in medical economics for assessments of medical interventions and other health-care contexts (Gewirth, 1990: 222). RCBA is also used widely in analysis of and policy making concerning environmental toxins (Baram, 1976). Finally, RCBA is used frequently in large-scale water and waste management technologies.

In order to set up a risk-cost-benefit analysis, one begins by trying to enumerate all adverse consequences that might arise from the implementation of a given technology. Next, one attempts to estimate the probability that each of these adverse consequences will occur. The third step is to estimate the cost or loss to social and individual health and well-being should any or all of the projected adverse consequences come to pass. Fourth, one tries to calculate the expected loss from each possible consequence. Finally, one attempts to compute the total expected losses from the proposed project by summing the expected losses for each of the various possible consequences. One follows a similar procedure to calculate the benefits. In the end, one subtracts the overall costs from the overall benefits. If the benefits outweigh the costs, the project is generally described as feasible.

However, there are significant methodological deficiencies in the RCBA method, especially those that raise ethical problems. Our analysis has identified five methodological deficiencies. They are: (1) problems of identification, (2) the value-of-life problem, (3) the commensurability problem, (4) problems associated with values and market mechanisms, and (5) problems of social and ecological justice. These problems and associated issues are listed in Figure 13–4.

The first methodological problem associated with RCBA is the unquestioned assumption that *all* significant consequences can be enumerated in advance. The assumption is that all of the costs and benefits of a particular implementation of a new technology or extension of a "known" technology can be clearly identified and catalogued, that meaningful probability, cost, and benefit values can be obtained and assigned to them, and that often disparate costs and benefits can somehow be made comparable to one another. Such judgments are grounded in unrealistic assumptions about the availability of the data needed to complete the analysis.

As with probabilistic risk assessment, not all of the crucial questions regarding the nature, estimation, or acceptability of the risks, costs, and benefits can be answered with quantitative analysis alone. Conscious normative judgments arise in determining what will be included and what will be excluded. In other words, at least as far as the "problems of identification are concerned, the same problems associated with PRA also arise with RCBA (or CBA). As Martin (1982) points out:

Problems	Issues
1. Problems of identification	1. It is almost impossible to arrive at a complete enumeration of *all* risks and benefits because one can never know all of the variables that need be assigned diagnostic values, let alone be able to calculate all the costs and benefits.
2. The value-of-life problem	2. A fundamental moral problem arises in assigning a monetary value to human life, a necessary requirement of RCBA.
3. The commensurability problem	3. The erroneous assumption that disparate costs and benefits are quantifiable according to an identical metric leads analysts to believe that all values are commensurable with one another.
4. Human values and market mechanisms	4. Utility maximizations fail to provide satisfaction for all crucial human needs and values.
5. Problems of social and ecological justice	5. RCBA fails to take into account issues of fairness in the distribution of risks and harms across social groups, between different generations, and throughout the natural environment.

Figure 13–4
Problems and issues with risk-cost-benefit analysis.

> PRA and CBA are different techniques, but they have important similarities. Both attempt to translate seemingly incomparable sorts of considerations into a quantifiable common denominator of some sort (whether dollars or mathematical formulae), then tallying up the results for various options, and finally presenting this information in a form that can be readily digested by decision makers . . . [However] . . . cost-benefit analyses, as well as probabilistic risk assessment are value-laden, both in what they count out (usually, for example, considerations of rights and justice) and in what they count in (for example, assumptions about what sorts of things constitute costs and benefits, whose costs and benefits are to be weighed, and how relative values are to be assigned to them). (p. 147)

Uncertainties as to how one should define "harm" or "risk" of a particular action force analysts to make judgments that are value-laden. For example, one contested assumption of both PRA and RCBA is that mortality rates—ignoring morbidity rates—are usually chosen as the focus of analysis.

The second methodological problem with RCBA is a hotly debated issue: the assignment of a monetary value to human life, a necessary requirement of a robust risk-cost-benefit analysis (Byrne, 1988; Kahn, 1986; MacKinnon, 1986; Rescher, 1987). As MacKinnon puts it, "of all the difficulties that surround the attempt to calculate the economic 'value of a life' one of the thorniest is a moral one, namely whether it is morally permissible to place any 'price' on a human life" (MacKinnon, 1986: 29).

Of course, certain practices are used by insurance companies, economists, and risk assessors that demonstrate that society does place some implicit monetary value on human lives (VOL). As one philosopher argues, "If it is permissible to forego life-saving treatment due to its cost, life has a monetary price" (Bayless, 1978: 29). On the other hand, there is a long and venerable tradition in our philosophical attitudes toward the VOL problem, perhaps best articulated by the Enlightenment philosopher Immanuel Kant (1785), when he wrote:

> In the realm of ends everything has either a price or a dignity. Whatever has a price can be replaced by something else as its equivalent; on the other hand, whatever is above all price, and therefore admits of no equivalent, has a dignity.

Of course for Kant, human persons are such creatures who exhibit "dignity." As Rescher puts it "How much is it worth to prevent the death of a person? . . . the question has no answer . . . it assumes that 'life' and 'risk to life' is some measurable quantity that actually exists in a stable and determinable way" (Rescher, 1987: 226). But, since this is false, Rescher concludes: "The question of value of life pushes beyond the proper limits of cost-benefit analysis in its insistence on quantifying something that is inherently unquantifiable" (Rescher, 1987: 226).

Byrne's analysis reveals three general methods to assess the value of life that are used in RCBAs: insurance-based, earnings-related, and willingness-to-pay (WTP) strategies (Byrne, 1988). Unsurprisingly, each one of these methods has serious limitations and deficiencies. Rescher (1987) points out the limitations of the earnings-related method. As he puts it:

> One study that examined salary as a function of occupational risk concluded that a premium of about $200 per year (1986) was sufficient to induce workers in risky occupations to accept an increase of 0.001 in their annual probability of accidental

death, a finding that was interpreted to indicate a life-valuation of around $200,000. . . . The linearity assumption involved in such calculations is questionable—the man who accepts a 1% chance of death for $10,000 may well balk at accepting $1,000,000 for certain death. (p. 227)

In other words, the supposedly higher or lower wages people accept for different types of hazardous jobs are interpreted as a valid measure of the cash value people are thought to place on their own lives. All too frequently, however, when lives are valued based on such criteria as economic worth or expected earnings, this turns into "life is cheap" in poorer neighborhoods or less developed nations. This issue is clearly illustrated in the Bhopal case. Life in Bhopal was implicitly valued less than life in the United States. Therefore, the safety equipment and emergency preparedness at the Bhopal plant in India were far less adequate than those at a similar plant operated by Union Carbide in Institute, West Virginia.

Barbour (1980) states the consequences of following the valuation of life principle to its logical conclusion:

> If applied consistently, the method would require that the lives of the elderly would be valueless. If future earnings are discounted, a child's life would be worth much less than an adult's. . . . I would maintain that there are distinctive characteristics of human life that should make us hesitant to treat it as if it were a commodity on the market. Life cannot be transferred and its loss to a person is irreversible and irreplaceable. (p. 73)

The third methodological problem of RCBA is how to deduce the value attribution of all the identified risks, costs, and benefits. Analysts automatically assume that often disparate costs and benefits can somehow be compared with another—that is, that all values are commensurable and can be fully quantified to reasonably determine whether the benefits of the proposed technological intervention or policy do, in fact, outweigh the risks and costs. Such calculations are necessary for RCBA so that disparate values can be compared and traded off, one against the other. Money becomes the common metric so that "goods" and "bads" can be compared with one another, and price becomes the medium through which all alternatives are evaluated, even those that are not normally perceived to have a market value (Kelman, 1981). This is evident in the "willingness-to-pay" criterion of a free-market economy: what a willing buyer will pay a willing seller. Take, for example, our aesthetic relationship to nature. How much is a beautiful view worth in monetary terms? How much is a landscape worth? A sunset? How much would someone be willing to pay to avoid having a toxic waste dump, a power plant, or an oil refinery built in his or her community?

The fourth methodological deficiency of RCBA becomes visible when one begins to probe the unquestioned assumption that market values provide the best opportunities for human beings to advance their life goals (Kelman, 1981). In other words, an RCBA methodology makes the assumption that the decisions people make in the marketplace are rational with regard to price, needs, and wants. However, it must be admitted that even in the open market the notion of utility maximization does not fully satisfy the variety of human needs and purposes. Notions such as freedom, equality, justice, and aesthetics also matter (Hausman and McPhearson, 1996: 77). In other words, one cannot always trust the market to satisfy all of our preferences and sustain all of our values. This became all too evident in the case of the Ford Pinto (see Chapter 11). The public was outraged when they were informed, perhaps for the first time, as to how decisions like this are made. In the end, the problem is that:

> By regarding human happiness, human well-being, human life, and non-human life as mere commodities, cost-benefit analysis ignores the non-market value of these things and the central role they should play in public policy. (Anderson, 1993: 190)

These sentiments are reflected in a sign that Albert Einstein is reported to have had hanging in his office. The sign read: "Not everything that counts can be counted, and not everything that can be counted, counts" (Diwan, 2000). After everything is said, Einstein's aphorism perhaps best sums up the problems that beset using risk-cost-benefit analysis as the preeminent method for assessing the risks of technology. The aphorism also points to why risk-cost-benefit analysis fails as the sole method of determining the appropriate and equitable level of acceptability of those risks. This is no more evident than in RCBA's neglect of social values that contribute to our idea of justice, qualities that one can be sure Einstein would consider among those things that "count, but cannot be counted."

The fifth set of problems that beset the RCBA method are the well-known criticisms that RCBA fails to address adequately issues of fairness associated with the equitable distributions of risks and harms. For one thing, RCBA places exclusive focus on aggregate benefits and cannot address the ways in which those benefits are distributed. It is *not* designed to pay attention to the ethically crucial question: "Who pays the costs, and who gets the benefits?" Typically, such analysis reaches its "bottom line" by aggregating all costs, all risks, and all benefits. Its goal is to determine, within its limited definition of the goods and harms involved, the *net* good, or harm that a technological intervention will produce. In other words, risk-benefit analysis is concerned only with the amounts of "goods" and "bads" in society, not with their fair or equitable distribution. For example, if the oil refinery in a neighborhood can be calculated to allow millions of distant persons to benefit from the gasoline and other products of that refinery, this can be multiplied into a major benefit. On the other hand, if the refinery results in higher cancer rates, greater medical costs, and residential property devaluation in the immediate neighborhood, this can also be calculated as part of the net costs, or harms, and subtracted from the "greater good." Although the net benefit may greatly outweigh the overall costs, the distribution of goods and harms may not be fair, because as Ferre (1995) puts it: "the principle of beneficence, to create greater good, is satisfied, but the principle of justice has been overlooked" (p. 83).

Justice across geographical, economic, and social space is one crucial set of values that RCBA leaves out of its calculations and equations. In addition, justice across time is almost totally neglected. Since RCBA is geared toward favoring short-range exploitation of opportunities and resources, it tends to ignore what Barbour (1980) calls "intergenerational justice" (p. 173). In other words, RCBA fails to address questions about the duties, obligations, and responsibilities one generation has to the next. Given recent concern over questions of ecological sustainability, resource depletion, and harm to future generations, this constitutes a major ethical flaw in the RCBA method of risk assessment.

In addition to overlooking questions about our duties and obligations to future generations, economists and policy makers seem to either ignore or deny that the market process in general, and cost- and risk-benefit analysis in particular, systematically undervalue irreplaceable natural assets. RCBA tends to ignore considerations of what Ferre (1995) calls "ecological justice" (p. 84). The scarcity of nonrenewable resources, the irreversibility of habitat and land destruction, the extinction of endangered species, the depletion of the ozone layer, global warming, etc., are all pressing concerns that RCBA fails to address.

Technology Assessment

PRA and RCBA are not the only ways to assess the risks and harms of technology. Another approach is called *technology assessment* (TA). As originally conceived, TA was sensitive to the problems and issues previously discussed. Take, for example, the definition of TA given by one early theorist:

> Technology assessment is the process of taking a purposeful look at the consequences of technological change. It includes the primary cost-benefit balance of short-term localized market-place economics, but particularly goes beyond these to identify affected parties and unanticipated impacts in as broad and long-range fashion as is possible . . . both 'good' and 'bad' side-effects are investigated since a missed opportunity for benefit may be detrimental to society just as an unexpected hazard. (Coates, 1976: 141)

This definition introduces two ideas: the first points to a feasibility analysis performed so as to determine whether a proposed technology would maximize public utility. The second idea calls for mechanisms that focus on second- and higher-order (noneconomic) consequences, which are to be balanced against first-order (economic) benefits. Only with the aid of such an analysis is it possible to take account of unanticipated impacts of technology and also identify how they affect different stakeholders or constituencies. These two different but complementary concerns give voice to two general models, a "narrow" and a "broad" definition of technology assessment.

The narrow definition tends to restrict the meaning of TA to basically an operational analysis of particular technologies defined as concretely as possible (as in PRA):

> Technology assessment is viewed as a systematic planning and forecasting process which encompasses an analysis of a given production method or a line of products . . . it may be considered as a natural follow-up to systems engineering . . . (Coates, 1976: 142)

The broad definition, on the other hand, tends to consider technology assessment as a framework for societal analysis. This requires a systematic and interdisciplinary analysis of the impacts of technological innovation on the social, political, ethical, and medical aspects of life.

CONCLUSION

To enhance our capacity to prevent technological disasters, a broad concept of technology assessment is in order, the features of which are as follows:

1. *Social impacts.* TA should be concerned with second-, third-, and higher-order impacts such as impacts on human health, society, and the environment, as distinguished from economic utility of exclusively first-order concerns.
2. *Multi-disciplinary analysis.* TA should require that all pertinent aspects—economic, social, ethical, cultural, environmental, and political—be taken into account. Diverse methodologies and inputs from all disciplines are to be employed.
3. *Multi-constituency impacts.* TA should consider the widest range of stakeholders that may be affected by the proposed technology. Comprehensive TAs should require the informed consent of all affected stakeholders, inviting their active participation in the decision-making process.
4. *Policy-making tool.* TA should not be concerned with just technical expertise but, more essentially, with the socio-political problems associated with the impacts and consequences of a proposed technological innovation.

Such principles for a broad technology assessment can only be realized if risk assessment becomes a democratic process rather than one that is dominated by a technocratic and power elite. This critical issue will be the subject of our final chapter.

References

Anderson, Elizabeth. (1993). *Value in ethics and economics.* Cambridge, MA: Harvard University Press.

Baram, Michael. (1976). "Regulation of environmental carcinogens: Why cost–benefit analysis may be harmful to your health," *Technology Review,* July/August; 78: 40–42.

Baram, Michael. (1977). "An assessment of the use of cost-benefit analysis." In Joel Tarr (Ed.), *Retrospective technology assessment.* San Francisco, CA: San Francisco Press: 15–30.

Barbour, Ian. (1980). *Technology, environment, and human values.* New York: Praeger.

Bayless, Michael. (1978). "The price of life," *Ethics* 89 (1): 28–39.

Bier, Vicki. (1997). "An overview of probabilistic risk analysis for complex engineered systems."In Vlasta Molak (Ed.), *Fundamentals of risk analysis and risk management.* Boston, MA: Lewis Publishers: 67–85.

Bougumil, R.J. (1986). "Limitations of probabilistic assessment," *IEEE Technology and Society Magazine* 24 (8): 24–27.

Byrne, L.J. (1988). "The value of life: The state of the art." In Larry Martin (Ed.), *Risk assessment and management: Emergency planning perspectives.* Waterloo, Canada: University of Waterloo Press: 79–101.

Coates, Joseph. (1976). "The role of formal models in technology assessment," *Technological Forecasting and Social Change* 9: 140–146.

Diwan, Romesh. (2000). "Relational wealth and the quality of life," *The Journal of Social Economics* 29 (4): 305–322.

Ferre, Frederick. (1995). *Philosophy of technology.* Athens, GA: University of Georgia Press.

Gewirth, Alan. (1990). "Two types of cost-benefit analysis." In Donald Scherer (Ed.), *Upstream/downstream: Issues in environmental ethics.* Philadelphia: Temple University Press: 205–232.

Greenberg, Michael, and Goldberg, Laura. (1994). "Ethical challenges to risk scientist exploratory analysis of survey data," *Science, Technology, and Human Values* 19 (2): 223–241.

Grossman, P.Z., and Cassedy, E.S. (1985). "Cost-benefit analysis of nuclear waste disposal: Accounting for safeguards," *Science, Technology, and Human Values* 10 (4): 47–54.

Haimes, Yacov. (1998). *Risk modeling, assessment, and management.* New York: John Wiley & Sons.

Harris, Charles E., Pritchard, Michael S., and Rabins, Michael J. (2000). *Engineering ethics: Concepts and cases.* Belmont, CA: Wadsworth.

Hausman, Daniel, and McPhearson, Michael. (1996). *Economic analysis and moral philosophy.* London: Cambridge University Press.

Henley, Ernest, and Kumamoto, Hiromitsu. (1981). *Reliability engineering and risk assessment.* Englewood Cliffs, NJ: Prentice Hall.

Humphreys, Paul. (1987). "Philosophical issues in the scientific basis of quantitative risk analyses." In James Humber and Robert Almeder (Eds.), *Quantitative risk assessment: Biomedical ethics reviews.* Clifton, NJ: Humana Press: 205–223.

Kahn, Shulamit. (1986). "Economic estimates of the value of life," *IEEE Technology and Society Magazine,* June: 24–29.

Kant, Immanuel. (1785). *Groundwork for the metaphysics of morals.* Translated by James W. Ellington. (1981). Indianapolis, IN: Hackett Publishing Company.

Kelman, Stephen. (1981). "Cost benefit analysis: An ethical critique." Reprinted in Thomas Donaldson and Patricia Werhane (Eds.), *Ethical issues in business* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Kneese, Allen, Ben-David, Shaul, and Schultze, William. (1983). "The ethical foundations of cost-benefit analysis." In Douglas MacLean and Peter Brown (Eds.), *Energy and the future.* Totowa, NJ: Rowman and Littlefield: 59–74.

Lanthrop, John. (1982). "Evaluating technological risk: Prescriptive and descriptive perspectives." In Howard Kunreuther and Eryl Levy (Eds.), *The risk analysis controversy: An institutional perspective.* Heidelberg, Germany: Springer-Verlag: 165–180.

Linnerooth-Bayer, Joanne, and Wahlstrom, Bjorn. (1991). "Applications of probabilistic risk assessments: The selection of appropriate tools," *Risk Analysis* 11 (2): 239–248.

MacKinnon, Barbara. (1986). "Pricing human life," *Science, Technology, and Human Values* 11 (2): 29–39.

Martin, Mike. (1982). "Comments on Levy and Copp and Thompson." In Vivian Weil (Ed.), *Beyond whistleblowing: Defining engineers' responsibilities.* Chicago: Center for the Study of Ethics in the Profession, Illinois Institute of Technology: 146–152.

Reactor safety study—An assessment of accident risks in U.S. commercial nuclear power plants. WASH-1400, NUREG-75/014, October 1975. Washington, DC: U.S. Nuclear Regulatory Commission, 1974.

Rescher, Nicholas. (1987). "Risk and the social value of a life." In James Humber and Robert Almeder (Eds.), *Quantitative risk assessment: Biomedical ethics reviews.*Clifton, NJ: Humana Press: 225–237.

Rowe, William. (1994). "Understanding uncertainty," *Risk Analysis* 14 (5): 743–750.

Thompson, Paul. (1982). "Ethics and probabilistic risk assessment." In Vivian Weil (Ed.), *Beyond whistleblowing: Defining engineers' responsibilities.* Chicago: Center for the Study of Ethics in the Profession, Illinois Institute of Technology: 114–126.

CHAPTER 14

Technology Decisions and the Democratic Process

"I know of no safe depositor of the ultimate powers of society but the people themselves; and if we think them not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it away from them, but to inform their discretion."

—Thomas Jefferson

We now turn to the question of how technological decisions in a democracy are made and how they might be made, especially when there is a discrepancy between the experts' judgment of risk, policy-makers' judgments, and the public's perception of risk. The separation into "expert" and "lay" judgments has polarized society's understanding of risk and has created two schools of thought, which Fiorino and others call the "technocratic" and the "democratic" modes of risk interpretation (Funtowicz, 1983; Lathrop, 1982; Fiorino, 1989; see also Spangler, 1982).

Technocratic versus Democratic Assessments of Risk

Mitcham (1997) expresses the difference between these two approaches to risk assessment as follows:

> . . . sociologists and political scientists have analyzed technology as harboring within itself fundamental anti-democratic

> possibilities and tendencies. The general name for such tendencies is 'technocracy,' rule by technical elites or technical information rather than by the people (demos). . . . (p. 40)

The unexamined assumption of the technocratic approach is that "scientific" risk analyses yield totally objective, factual, value-free assessments of risk, whereas the lay public's assessments of risk are thought to be subjective and value-laden. Because of this bias, technical experts often view the judgments of laypeople as capricious and unreasonable, sensitive to irrelevant factors and insensitive to relevant ones. This leads experts to assess the risks of technologies completely divorced from the public's perception, assessment, and understanding of technologically induced risk and harm. Technocrats argue, for example, that since public perceptions of risk are supposedly derived exclusively from their subjective opinions, which can differ substantially from person to person, only objective risk assessments can protect an uniformed public from the dangers of technology (Slovic, Fischoff, and Lichtenstein, 1980).

Traditionally, the risks and failures of technology have mainly been perceived as a technical problem, a problem relegated to experts, not to public debate. But controversies have politicized the issue of risk. Risk assessment is no longer seen as simply an exercise in the technical measurement of risk. Questions of risk can no longer be defined simply in technical terms; they must also be defined in political and social terms, because the real question is not how safe it is, but how safe is safe enough for individuals and society? Moreover, since technical risk assessors are no more qualified than the general public to assess value judgments such as those involving welfare, fairness, social justice, and informed consent, they should not be the only ones who participate in the assessment of the risks of technology that affect us all.

It is often true that the public's interpretation and assessment of risk differs considerably from the interpretations and assessments of technical experts. However, the view that the public perception of risk is distorted by subjective biases and that only experts can define the "real" risks is overly simplistic. As we have argued in Chapter 13, experts are also subject to biases in interpreting quantitative data, especially when objective uncertainties are present. Many so-called objective assessments