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The constructive application of technology—engineering—is essential to the well-being and prosperity of present and future generations in all nations. Since the inception of the National Academy of Engineering in 1964, scientific discovery and technological innovation have provided many new benefits and produced some unforeseen risks. Much of the technology now enjoyed and taken for granted was scarcely dreamed of by the public 25 years ago. However, in the next 25 years, engineering must become even more forward-looking and more global in scope. Engineering will increasingly affect, and be affected by, issues in economic growth, national security, environmental quality, and public health and safety in the context of the political, social, legal, industrial and business systems, and public infrastructures that are evolving in this country and in others. As discussed by a panel of distinguished speakers at this symposium, the challenge to engineering is the development of technologies for the general welfare of all humankind.

9:00 a.m. **Welcome**
Robert M. White, Symposium Chairman
President, National Academy of Engineering

Opening Remarks
John H. Sununu, Chief of Staff, The White House

9:15 **Engineering and Changing World Relations**
Simon Ramo, Director Emeritus, TRW Inc.

10:00 **Technology and Economic Growth**
Koji Kobayashi, Chairman Emeritus and Representative Director, NEC Corporation

10:45 Break

11:15	**Engineering for the Future: Environmental Responsibility** Robert A. Charpie, Retired Chairman, Cabot Corporation
12:00	**Transportation Systems of the 21st Century: Breaking Gridlock** Alan S. Boyd, Chairman, Airbus Industrie of North America, Inc.
12:45 p.m.	Luncheon (West Lawn of the Building)
2:00	**Sovereignty** George Shultz, Professor of International Economics, Stanford University, and Honorary Fellow, Hoover Institution
2:45	**Engineering in an Age of Anxiety: The Search for Inherent Safety** Alvin M. Weinberg, Distinguished Fellow, Institute for Energy Analysis
3:30	Adjournment

Engineering and Human Welfare

25th Annual Meeting Symposium
National Academy of Engineering

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Engineering and Changing World Relations

SIMON RAMO

On the 25th anniversary of the National Academy of Engineering it is appropriate to look back at the impressive engineering achievements of the past quarter century. It is also desirable to look ahead to the challenges of the next 25 years. Further discoveries in science and advances in technology of course will enable engineers to exceed present capabilities enormously. At least as significant, however, is that different societal demands will be made of engineers as an altered world social-economic-political environment reshapes objectives, priorities, and the allocation of resources for pursuit of engineering.

In this paper I will make some predictions about the impact of changing world relations and engineering on each other, and offer some speculations on future possibilities that seem both probable of occurrence and of great consequence should they eventuate. Calling them out might help identify actions that could influence forthcoming developments for the betterment of the society.

THE COMING TECHNOLOGICAL SOCIETY

In a quarter of a century of further planetary aging, we will not yet have—perhaps we will never have—a single world government guaranteeing to people everywhere the same rights, privileges, protection, citizenship, and free movement. The globe will remain divided into sovereign states, each with a government attempting tight control over people, things, and information that cross its borders.

Despite this, every technology advance, wherever it might occur, will tend in the future to move to all nations that want it, organize to get it, and are willing and able to pay or trade for it. The adoption of the latest technology will be rapid and widespread because the twenty-first century will be intensely and pervasively technological, and all nations will share the firm conviction that engineering strength is an absolute requirement for economic growth, national security, and social stability.

In the period ahead, as in the past, every country will continue to characterize its problems as social-economic-political, not technological. However, the separate facets will intersect, and technology-based influences will be found plunk in the middle of each intersection. At times technology developments will give rise to problems or exacerbate them. Equally often technological advances will point the way to solutions. Almost always, an expanding technology frontier will uncover opportunities that, if grasped, lead to a more satisfying life. Overall, the technology status of a nation will come to be rated universally as the most powerful determinant of its standard of living.

With technological effort globally ubiquitous, the totality of advances produced by the entire family of nations in the next 25 years will greatly transcend the technology originating in any individual nation. No country will rely solely on its internal intellectual and physical technological resources as it competes in the world arena. Technology developments will become so vast that any nation failing to persevere in acquiring and employing technology from many sources will find the economic penalties intolerable. No country, not even the United States or Japan, will handicap its future by endorsing policies that assume superiority in virtually all technology.

To be sure, an individual engineer or scientist, a corporation, or a single country may happen upon a great discovery or invention, or opt to focus large resources on one technology. That entity might then possess an initial superiority—in that one specialty—exceeding the expertise or output of the rest of the world. But if the advance is truly significant, the centers of aggressive concentration will pop up immediately about the globe, creating a wave of advances that in combination will inundate the beginning contribution from the original source.

While political entities may be expected to seek strong regulation of technology transfer, the generation, dissemination, and application of technology advance will come to be seen as predominantly global, not local, phenomena. All nations, it can be predicted, will adjust their policies and operations to accord with this concept, tending to create an "open" world of technology. Of course, certain pivotal technology developments (for example, communication networks that link nations to their mutual advantage) will, by their inherent nature, be impossible to confine. Many synergistic influences will propel the technological society to an elevated plateau of openness.

THE FUTURE RELATION OF TECHNOLOGY TO SECURITY

Consider what is likely in the advancement of military technology, a field to which the superpowers and other nations have devoted a large fraction of their economic resources during the past half century. Substantial, even radical, deviations may be in the offing in the relation of technology advance to national security. While we cannot be certain that the recent acceleration in arms reduction negotiations will lead to large-scale decreases in offensive nuclear weapons, that possibility must be given serious consideration. The critical factor here is verification. The deeper the degree of arms reduction contemplated, the greater the importance of openness and inspection. Verification through indirect observation systems, like spy satellites, will undoubtedly expand, but the potential for cheating must be drastically reduced. This can only be accomplished through agreed-upon implementation of close-in, detailed verification by almost unrestricted human movement on land, sea and air, an unprecedented degree of international access. Without such openness, the danger of cheating, and hence the security risk, will be judged too severe to enable realistic initiation of truly major arms reduction, no matter how much we might invest in research to develop innovative verification systems.

Yet, strategic arms reductions must stand high on our speculation list as it is becoming widely accepted that neither the United States nor the Soviet Union is likely to launch an all-out nuclear attack against the other. Success in such an attempt would require that the blow eliminate the stricken nation's capability to retaliate and that the resulting nuclear fallout would not harm the aggressor.

No competent weapons engineer would expect near perfection in an operation of such unparalleled complexity, and one that is not rehearsable even once. Moreover, if a USSR raid were to destroy most of our land-based Intercontinental Ballistic Missiles (ICBMs), Russian blitz planners still would have to consider it likely that the unscathed ICBMs, including some launched during the attack, might knock out principal cities, killing many tens of millions. Each U.S. missile-launching submarine carries over 100 nuclear warheads. A single surviving submarine, targeting its payloads on Soviet industry, even imperfectly, might eliminate half of it. Strategic nuclear bombs are so destructive that a small deviation from perfection in an offensive strike might be expected to trigger intolerable retaliation.

The two superpowers have each spent trillions of current dollars—on everything from the first atomic bomb research to the creation and maintenance of manned bombers, ICBMs, and missile-launching submarines—to create strategic nuclear capabilities neither nation can justify using first, and whose function is solely to deter the other from executing an attack. If nothing changes, the superpowers could spend trillions more to ensure continued mutual deterrence. Meanwhile, in the United States, we have an untenable $200-billion annual deficit, they in the USSR a stagnant economy; we must strive to regain global technology competitiveness, they to develop their natural resources; we must struggle to maintain our standard of living, they to raise theirs. With the feeling growing that it possible to deter, distrust, scare, and fear each other adequately at a much lower cost, it is clear that powerful economic forces will drive both nations toward large-scale strategic force reductions.

Lowering present offensive forces by a factor of ten would change the way strategic nuclear warfare is regarded. With that large a decrease in offense, ensured by adequate verification, both nations could put in place defense systems at reasonable cost with the ability to shoot down nearly 90 percent of incoming missiles. Then the number of bombs surviving to arrive on target during the strike would be reduced to a tenth of a tenth of present inventories, so the idea of contemplating that strike would become obsolete. Moreover, strengthened defense systems would provide added security against cheating, an accidental launch, or a raid by a terrorist nation.

During the past 25 years, advances in strategic offensive weapons technology made total destruction attainable. This dominated peacekeeping. It was peacekeeping by deterrence. In the future, peacekeeping may reflect changed social-economic-political relations among the industrialized nations that will emphasize reduced offensive nuclear arms, verification, openness, and defense systems. For example, before the end of the next 25-year period we may adopt a global regulatory procedure to announce and verify beforehand every vehicle launching into space as peaceful and to shoot down any unverified launch vehicle. This would ensure the safety of countries with no desire to inflict nuclear warheads on others, and provide a sensible, cooperative guarantee that no country can launch a successful surprise attack.

Consider next the European theatre. The Western European nations and the United States will undoubtedly consider it mandatory to maintain a military force capable of opposing any attempts by the USSR to occupy Europe. At the same time, many Americans and many more Europeans view this prospect as unlikely. As a result, both Europeans and Americans want smaller military expenditures; both strongly reject a buildup of European armies to match Warsaw Pact forces. Further technology advance will encourage this thinking as European theatre military strength ceases to be measured in numbers of soldiers, tanks, and airplanes. Rated higher will be sophisticated technology for command, control, communications, intelligence, and reconnaissance, as well as smart robotic missiles that can spot and destroy enemy tanks, planes, and military concentrations.

Advanced electronics and robotry can make a defensive army more effective than a less well-equipped offensive army, even if it is much larger in man- and fire-power. For example, superior electronic equipment will enable the simultaneous blocking of offensive communications and protection of defensive communications; also, advanced electronic brainpower will permit high-speed processing of incoming data during battle for rapid situation analysis, such that NATO forces can be optimally employed in highly focused military actions, and attacking Warsaw forces can be befuddled. Such capabilities will hinge on high-volume production of advance computer networks, semiconductor microchips, computer gear, and precision electromechanical equipment, just where America, Western Europe, and Japan are strong and where the USSR is weak.

NEW ECONOMIC IMPERATIVES

These technologies are also needed to increase the productivity of civilian industry. Indeed, advanced computer networks, fast semiconductors, and electromechanical devices for automatic control, when well designed for defense and verification applications, will be close cousins to technological systems yielding more efficient manufacturing of commercial products and enhancing all manner of civilian industrial, governmental, and professional operations. Consequently, the resulting hardware, software, and process technology will be sought vigorously by all nations and become principal items in world trade.

The Soviet Union will undoubtedly work very hard to arrange to share in the benefits of these technologies. They will issue ever louder denials of having a plan or desire to start a war in Europe, and back these disclaimers with offers of major cuts in offensive forces. The West will find such offers attractive—if the arms reductions are verifiable, a condition requiring, again, more openness. As European offensive forces are diminished, the shift to defensive systems will drop the costs of attaining confident national security. The associated civilian technology will balloon as an item in East-West trade, feeding back to strongly buttress added openness in technology transfer.

Openness of a different kind, Mr. Gorbachev's "glasnost," has relevance here. Even though concerned mainly with added freedom in the Soviet Union, the underlying attitude of "glasnost" will encourage more peaceful world relations. Of even greater pertinence is the concept of "perestroika," which connotes the objective of USSR leadership to reorganize and strengthen its economy. We should expect this effort to include increasingly vigorous promoting of credit grants from, and joint ventures with, the capitalist countries even as the Soviets introduce new motivational measures internally somewhat akin to a free market and free enterprise.

The European Eastern Bloc and other Communist countries will expand programs already started along these lines. These countries will develop hybrid economies that combine rigid, total government control with substantial, novel, semi-private domestic activities. As a burgeoning array of deals develop between the Communist countries and the multinational technological corporations of the non-Communist states, technology transfer will accelerate and technology-based production in the Communist countries will increase, resulting in economic growth there dependent, they will be well aware, on their maintaining openness with the outside world.

These trends will sharpen and expand operating approaches favored by multinational technological corporations. These companies design products for the world market and must locate operations of all kinds—basic research, product development and design, manufacturing, purchasing of parts and materials, warehousing—wherever the combination of markets, human and physical resources, infrastructure, geography, and social-economic-political policies and environments yield cost and value-adding advantages. Their success in the international market—in producing automobile parts, microchips, or pharmaceuticals—will hinge increasingly on an ability to incorporate and exploit rapidly technological advances occurring anywhere, and to bring innovations to the market everywhere. As these companies seek to move technology, materials, equipment, people, and money about to maximize their operating and financial performance, they either will pass by investment opportunities in a country that erects barriers or press its government strongly to change its ways.

As the source of customers, suppliers, capital, and innovations becomes more internationally diffuse and dynamic, the competitive advantage will go to those companies that prove the most skillful at developing efficient geographical spreads of their operations, and to those countries most helpful in forming those patterns.

ECONOMIC GROWTH AND SOVEREIGNTY

The collective effect of some international technological systems will inherently lower national barriers and dilute national autonomy and sovereignty. Take the example of international electronic information networks. To attain lowest manufacturing costs and quickest marketing response, operating companies must arrange for the pertinent information to cross national borders without impediments and virtually instantaneously. This information will control the flow of materials and components; the scheduling of parts fabrication, assemblies and tests; the assigning of labor; and the distribution of finished products. Companies with access to such an information network will have conspicuous initial advantages over their competitors, who will act to possess equal capabilities posthaste, resulting in the network's expansion and near universal adoption. If a country presented barriers to network entry into its territory, it would chance being bypassed.

An even more startling example is the movement of funds electronically. Rapid handling of credits and cash transfers will become necessary to support ordering, selling, and moving of goods and materials. Continuous electronic money shifts also will be made in response to, and, in speculative anticipation of, currency exchange rate adjustments (which will come to include the communistic countries in time, difficult as the interchange now appears to be). These money shifts probably will exceed in quantity and speed those occurring in direct response to government actions, such as interest rate setting by the U.S. Federal Reserve, forcing National governments to adjust to new levels and types of global money supply and movement.

The foregoing speculations sum up to a shift from the firm and autonomous grip by each nation's government on its domestic activities and its interactions with foreign entities, to increasingly influential free-market and government-private arrangements. This shift will be partly the consequence of national imperatives to be technologically strong and globally competitive. It also will result from the implementation of technological systems that require more openness in international relations in order to operate.

GREATER ENGINEERING

The superior application of basic discoveries and innovative advances to meet societal demands in the future will require going well beyond handling scientific and technological components of the tasks. Because of changing world relations, the ability to harmonize technology with society will assume vastly increased importance: either the engineering profession will broaden greatly or the society will suffer because the matching of science and technology will be too haphazard. At present there is only a weak coupling between the science and technology opportunities available to society and the degree of social maturation to pursue them. Consequently, only a fraction of the benefits of our knowledge is being realized. Furthermore, the disbenefits of certain technology coupled with human behavior, such as those that seriously threaten the environment, are hardly being addressed.

It would not be realistic to redefine the engineering profession to encompasses every facet of the enormously complex social processes involved, from science and technology to economics, business management, sociology, politics, government, public psychology, and numerous other disciplines, and influences that together will shape the technological society of the future, and do so, moreover, on a global scale. Moreover, numerous professional, and nonprofessional groups will be in the act, some organized, others chaotic and hit or miss, some rational, others irrational.

A "greater engineering" needs to evolve in which more of the nontechnological realm associated with putting science and technology to work effectively is encompassed. The engineering profession clearly should handle fully some aspects and, on most of the others, it should provide the remaining team of players with timely, authoritative descriptions of potentials, costs, and consequences, both beneficial and adverse. The engineering profession should participate actively in allocating resources, setting priorities, and creating practical organizational units suitable for seizing technological opportunities. Today, engineering is perceived and practiced as a far narrower activity. I predict, however, that the next 25 years will see a great flowering of the profession. It will come to embrace much more of the issues at the technology-society interface for two reasons: (1) the need will become conspicuous to leaders in industry, government, academe, and engineering, who will rise determined to generate ways to fill it; and, (2) the economic rewards for enhancing the profession will impel and motivate such effort.

It is not enough to say that global enterprises will be somewhat more dependent on technology advance than now, or a bit more international in the scope of its operations. Rather, there will be an order of magnitude step-up, all at the same time, in every one of the following facets:

- speed of change
- number of factors important in decision making
- variety of ways to exploit technology
- international sources of new technology
- severity and kinds of international competition
- scope of considerations important in managing operations

While the risks of failure will be heightened by the necessity of dealing with such complex changes and interactions, the potential rewards for exceptional performance will zoom. The quality of the people designing systems that will operate on a global scale will make all the difference. Accordingly, the worth of people combining wisdom with imagination will rise.

Companies and governments that successfully employ technology-society matchers will excel in competition against those lacking these practitioners of greater engineering. The losers will be driven to identify, educate, and train enough engineers with the proper aptitudes for the interface problems, offer them the challenges, and encourage them to rise to the tasks. Gradually, the basic underlying intellectual disciplines will evolve and be taught in the universities. In the future, student engineers may elect to prepare for careers devoted to the technology-society interface much as students today specialize in computer, aeronautical, or materials sciences. As the return on investment for training these experts is realized, the profession will broaden and worldwide competition will accelerate the process of producing "greater engineers."

These optimistic predictions about the engineering profession are based on recognizing engineering competence as a foundation of national strength in a highly competitive world. As to the future of the United States, it is harder to be optimistic. We know we have been neglecting math and science education in our primary and secondary schools, and that the fraction of our college students choosing science and engineering has dropped below the corresponding ratio in competitive nations. It is clear that in the years ahead the United States will provide a much smaller portion of the globe's engineers than in the past.

As executives and politicians around the globe reshape their concepts about education and career development to match the needs of our increasingly technological society, fewer of those managing the affairs of the world successfully will be scientific illiterates as is common today. Those leaders educated in law, finance, political science, history, or economics eventually will come to have significant knowledge of science and technology or they will likely fail. This will enable better linkage with the technology-society engineers, as each profession becomes better prepared to reap the benefits of their coupling. If, indeed, this pattern of broadly educated leaders should develop into a general world trend, we can be forgiven if we harbor a concern that the United States may fall behind. Today, most of our universities still happily grant degrees to students who elect to take only one science course during their entire college experience, hardly a way to prepare Americans for a globally competitive technological society.

It has become commonplace for the captains of academic, industrial, governmental, and professional groups concerned with engineering matters to deplore our nation's loss of technology preeminence. Still, even as we have gone from surpluses to deficits in key areas of international trade, and entire U.S. industries have disappeared, bested by foreign rivals, concerted campaigns have not yet been organized to attack the roots of our nation's technology slip.

For example, manufacturing has been prominently labeled a relatively weak sector of the United States economy for at least a decade; however, government, industry, and the universities have only recently cooperated to establish manufacturing technology courses in engineering schools. Moreover, practically no attempts have been made to find ways to educate students in the art and technique of moving technological innovation toward marketable products where, again, our performance lags relative to competitive nations.

In recent years, action by certain leaders of industry, government, universities, and the National Academies, has lead to the creation of new engineering research centers and centers for interdisciplinary scientific research at several universities, where programs are operated jointly by industry professionals and academicians. Such programs will introduce students to true frontier areas and accelerate U.S. technology advance. But this effort alone is far from enough to stem the drop in America's technology stature or spearhead a drive to reattain preeminence. The total annual budget for these programs is in the low tens of millions, about one tenth of one percent of the funding for a major weapons system.

In the United States, experts at relating science and technology advances to society emerge through the workings of the system without much planning. Successful interface engineers typically start out as research scientists or conventional engineers. Then, as a consequence of career developments and natural talents and interests these individual acquire skill in handling matters of organization, personnel, financing, budgeting, and marketing, and rise to become industry or government executives or heads of major projects and laboratories. In some cases leading scientists with no initial thought of engaging in engineering become engineers, and no less scientists, as they design complex instruments and systems for scientific probing, be it spacecraft, nuclear bombs and reactors, particle accelerators, or genetic engineering machinery. They spend much time "selling" these projects to the Congress, the media, and any and all sources of funds, learning in the process how to compete against rivals.

There is nothing basically wrong with this way of producing American practitioners of greater engineering. But if we are going to train technology-society matchers entirely in the school of hard knocks, we should recognize that other countries have been knocking harder. This is evidenced by international competitors succeeding regularly in applying our early advances better and quicker to create and satisfy international market opportunities.

Should we look more to our universities to produce technology-society interface engineers? Today, a typical university education in engineering stands in wide contrast to real-world engineering. Engineering schools educate mainly in the science and technology underlying engineering. In comparison, real-world engineering involves activities with consequences barely touched upon in most universities. These include designing products and systems of quality that can be manufactured, implemented, and utilized in a cost-effective way; that will fill a true market need better than alternatives or generate new markets, be globally competitive, and provide a satisfactory return on the invested capital; and, that will meet social, economic, political, national security, and environmental requirements. Many engineering graduates leave college without realizing that such matters constitute the heart of their chosen profession. More importantly, they do not emerge with their innovative powers turned on, endowed with entrepreneurial zeal, knowing they are about to enter a tough world olympics of technology.

Real-world engineering as described above is intimately concerned with non-science and non-technology issues basic to the effective application of science and technology to fill societal requirements. Many of us in industry used to advise, and some still do, that university education need only cover the underlying science and technology. Industry experience, we claimed, would train efficiently in the art and technique of application. That such a viewpoint may have been carried too far is suggested by analogy to medical education and training. Suppose, although it may appear a bit exaggerated, we were to graduate physicians having completed university courses limited to biology, chemistry, physics, anatomy, and pharmacology. Furthermore, upon graduation, they begin work in hospitals under the tutelage of practicing doctors, where they first begin to learn about disease symptoms, diagnoses, and treatment and discover that what physicians mainly do is apply drugs and knives to the human body and rarely engage in research.

While it is clear that university programs should not be expected to provide the equivalent of years of experience in performing real-world engineering, engineering students should not graduate ignorant of social-economic-political systems that will exert decisive influences on what they will be assigned and privileged to do and on the degree of their success in their careers.

There are a number of other factors that limit America's competitive position beyond an overly narrow concept of engineering. Consider technological entrepreneurship. In the past, the United States has led the world in mating capital at risk with technology advances to produce innovative products. Alone among the nations, this country has a thousand venture capital firms that assemble funds from pension funds, bank trusts, insurance reserves, large and small individual investors, and other private sources to finance new companies; a nationwide brokerage system to market equity in start-ups; and a special stock market to trade these equities. Why is it, then, that technological entrepreneurship in the United States is not a more powerful vehicle for regaining world leadership in technology advance? For technological entrepreneurship to be effective, the economic environment must be more conducive to long-term investment. What is needed is a long, steady period of low cost of capital, low inflation, low real interest rates, high savings rates, and low taxes on capital gains. For two decades, the United States has performed poorly by these criteria. For us to realize these conditions is clearly difficult and surely unrealistic in the short term, but doing so would violate no law of economics. Japan and Germany have achieved all these conditions for years.

CONCLUSION

The United States government, in 1989, still finds it possible, and indeed acceptable, to muddle through decision-making about multi-billion dollar science and engineering projects with only limited input from the science and engineering fraternities of the nation. Asking for studies and reports is not the equivalent of defining, in a timely fashion, policies and programs to raise the nation's overall science and technology stature.

Some technological industry and government officials have risen above the preoccupation of most with short-term issues and attained limited success in fashioning industry-government cooperation to uplift U.S. performance in global competition. By comparison, however, with leading competitive countries, where such teaming is commonplace, U.S. government-industry relations remains largely adversarial.

At the beginning of this paper, I argued that the value of speculating about the next 25 years might be to identify actions worth taking in anticipation of likely developments. In my view, the engineering profession in the United States needs enhancing to match the needs and opportunities of the future. The existing trend favors the nation's competitors and needs changing, otherwise pessimistic predictions about our relative position in putting science and technology to work seem both easy and justified. Building and broadening engineering in the United States should be a priority issue for government, industry, academe, and especially the National Academy of Engineering.

Technology and Economic Growth

KOJI KOBAYASHI

On the occasion of the 25th Anniversary of the National Academy of Engineering, I think it is a meaningful exercise to try to imagine the course of technological development and economic growth over the next 25 years, as doing so may help us extract principles which might make our progress easier. In this rapidly changing world, forecasts are often embarrassingly far off the mark, so it requires some courage to predict what will take place in 25 years. However, I will take my chances with history and put my views on record.

This paper will deal with technology and its role in economic development in the area of information technology, the integration of computer and communications (C&C) technology. First there is a perspective on the development of information technology over the next 25 years and its role in economic development. Then there are some speculations on how this may affect economic development in several parts of the world, including Asia, the People's Republic of China, India, the USSR and Eastern Europe. And lastly, there is a list of minimum business conditions necessary in order for economic development in developing countries to proceed.

DEVELOPMENTS IN INFORMATION TECHNOLOGY

Quite recently Integrated Services Digital Networks (ISDN) have begun to be introduced in the industrialized countries of the world. In a simple example of its capability, ISDN enables us to use the telephone while sending or receiving facsimile messages or electronic mail by personal computer. Since ISDN is based on internationally agreed standards, it will be possible to interconnect the networks of different countries. It is expected that the use of the present, narrowband ISDN will spread first within the business community, then to homes, and eventually cover most of the world. Because in ISDN information is transmitted and received in digital form, it is less expensive than conventional analog networks, thanks to the advancement of technology. This advance makes it easier for developing countries to adopt state-of-the art systems (Kobayashi, 1989).

By the mid-1990s broadband ISDN technology, using optical fibers instead of copper wires, will also carry TV or video signals, enabling TV conferencing for businesses and high-definition television (HDTV) programs for the home. By the year 2000, integrated intelligent networks will provide a wide variety of new services (Kobayashi, 1989).

For example, before the year 2014, 25 years from now, I hope that my dream of an automatic interpretation telephone system can be realized. When this system is completed, I will be able to speak in Japanese over the telephone with my American friend talking in English, while the telephone system handles the perfect simultaneous interpretation of our conversation. In 1983 NEC Corporation demonstrated such a research prototype between Japanese and English, and English and Spanish at TELECOM 83 in Geneva, Switzerland. The demonstration attracted a huge crowd of people and helped to communicate what we wish to achieve. In the beginning this system may be large, but as the related technologies advance it will eventually become small enough to be incorporated in a telephone set. I regard the completion of this system as a benchmark for measuring the progress of information technology. It is my heartfelt wish that this automatic interpretation system will overcome language barriers and contribute to deepening the mutual understanding between the people of the world (Kobayashi, 1983; 1986).

ROLE OF INFORMATION TECHNOLOGY IN ECONOMIC GROWTH

In the developing countries, communication networks based on information technology are useful in expanding economic activities. For example, if the people involved have immediate access to the latest domestic and overseas market information through communication networks, they can profitably control the shipment and production of agricultural products, livestock, marine products, mineral products, and so on. If a country has communications networks in addition to other essential infrastructures such as harbors, airports, roads, and electricity, corporations from industrialized countries will be attracted there to build factories and use natural and human resources. This will not only help the local economy develop, but also serve to transfer manufacturing or processing technology to that country. Moreover, communication networks, including broadcasting, can be used to educate and train the local people, which will also attract more companies and create more employment. In this way, communication networks, supported by information technology, can have a snowballing effect in stimulating the economies of developing countries.

For developing countries, it is essential that they earn foreign currency in the international markets by exporting labor intensive products made using the surplus labor of farming communities. The foreign currency thus acquired can then be used to obtain the technology necessary for building heavy industry and the infrastructure required for further economic growth.

In industrialized countries, information technology already plays a central role in every aspect of life. It is no longer possible to pursue economic activities without its help. If we wish to develop our economic activities further, we must rely heavily on information technology.

SOME PERSPECTIVES ON ECONOMIC GROWTH

The economic growth of the NIEs (newly industrialized economies) and ASEAN (Association of Southeast Asia Nations), which are located on the western rim of the Pacific Ocean, has been remarkable during the past decade. American corporations first moved their manufacturing plants to these countries to employ inexpensive labor. Japanese corporations started direct investment in these countries in the early 1970s and greatly increased investment since 1986 as the rapid rise in the value of the Yen made it economically necessary for Japanese corporations to move production sites overseas. Most Japanese direct investment has been in the machinery industry, centered on household electrical appliances, semiconductors, and communication equipment.

It is important to note that the NIEs (the Republic of Korea, Taiwan, Hong Kong, and the Republic of Singapore) already have the industrial infrastructure in place to manufacture components, intermediate products and machines. Although they are competitors, their industrial production is complementary, each nation supplying goods not manufactured by the others. This horizontal supplemental relationship is further strengthened by NIEs investments in the ASEAN countries, as evidenced by a rapid increase in investments by Taiwan in the Kingdom of Thailand, Malaysia, and the Republic of the Philippines (Watanabe, 1988).

As western Pacific developing countries have expanded the base of their export industry and raised their income and living standards, their domestic markets have grown, much of this due to technology, in general, contributing to economic growth. Twenty-five years from now, the western

Pacific developing countries, which are presently in the midst of an industrial revolution, will be the force behind the balanced expansion of the world economy; it is also likely that present economic differences in Asia between Japan, the NIEs and ASEAN will greatly shrink because of the rapid economic growth of the latter two groups.

The Chinese Government has designated four coastal economic zones where foreign investment and technology are to be introduced. In these zones the labor-intensive processing industry operated by town and village enterprises imports raw materials from the international markets and exports value-added goods back to the international markets. These exports earn foreign currency which can be used to build heavy industry and economic infrastructure, and to absorb surplus farming labor. The Republic of Korea, Taiwan and Hong Kong have invested heavily in these coastal zones, and they are favored by good conditions in trade and investment (Watanabe, 1988). I hope such activities will help the People's Republic of China become one of the key players on the Asian economic scene in the next 25 years.

Since 1984 direct investment in India by the West has increased. The United States surpassed the USSR in 1986 as top trading partner and now also leads in the number of joint ventures with Indian companies. Electronics production has been growing and is estimated to expand by about 40 percent to $7.5 billion by 1990. An even more optimistic estimate sees it reaching $33 billion by the year 2000 (Rayner, 1989). With a long tradition of producing mathematical geniuses, India should provide an excellent environment for software creation and production, and large growth is expected in these areas. If the Indian government could remove the 40 percent equity ownership restrictions against foreign companies, much more advanced foreign technology would be introduced, which would increase the rate of growth of the Indian economy.

Thanks to Mr. Gorbachev's policies of "perestroika" and "glasnost," the people of the Soviet Union and the Eastern European countries will slowly gain exposure to the wealthier lifestyle of citizens in industrialized countries. This will stimulate the desire to improve their living standards, and hopefully create pressure to divert economic resources from producing weapons to creating consumer goods. If so, the next 25 years may see a flourishing of peaceful economic activities in this region that will eventually approach those of the industrialized nations.

ECONOMIC DEVELOPMENT IN DEVELOPING COUNTRIES

There are a number of minimum business conditions necessary in order for economic development in developing countries to proceed. Those that will attract foreign investment and technology to developing countries include the following:

Political stability. Without political stability, corporations in industrialized countries will hesitate to make any investment or provide any technology because they cannot guarantee any return on their investment.

Infrastructure. The country must also have established certain essential infrastructures, such as communication networks, harbors, airports, roads, electricity, and city water.

Work force. An educated or trained and diligent working force must be available.

Favorable government policies. The government should not be too strict in its restrictions on foreign investment and approval of licensing of patents and knowhow, and there must be adequate intellectual property laws to protect patents and copyrights.

Unhindered business transactions. Here the degree of bureaucratic red tape is a factor, as illustrated, for example, by the time it takes to approve an application for a joint venture with a local firm.

On the other side of the coin, I think that it is the duty of industrialized countries to extend assistance to developing countries in at least two areas: (1) cooperation and help to build those infrastructures required to allow a country to enter the economic development cycle; and (2) provision of facilities and software to educate and train children, students, and the young work force.

CONCLUSION

In each era there has been a guiding principle. During the next 25 years I believe that C&C technology will serve as such a principle and will greatly contribute to economic growth and human welfare. I sincerely hope it will help reduce or eliminate the gaps in living standards among nations which now prevail. This is most important as we direct our efforts toward the ultimate goal of prosperity for all the people on our planet and for true world peace.

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Transportation Systems of the 21st Century: Breaking Gridlock

ALAN S. BOYD

The National Academy of Engineering may seem an unlikely venue from which to explore transportation congestion. It is and it is not. It may appear a strange forum in the sense that the basic solutions are social and political with economic consequences. But in fact, the National Academy of Engineering provides a proper forum in that engineering solutions for the types of congestion we know today are at hand or can be developed within the existing state of the art.

CURRENT PROBLEM AREAS

Traffic congestion is not new. Ancient Rome had ordinances to deal with the problem. In 1900 there were complaints about the average speed on the streets of New York City—just about eight miles an hour—only slightly better than the average speed of crosstown travel in New York today! No doubt countless other examples could be recounted, but the fact is that we and our ancestors have been coming to terms with congestion for a long, long time. If we consider what has been done to solve the problem or to manage it, the short answer is that we have merely shifted congestion to other areas and transportation systems, notably to suburbs and airports, and the air traffic control system!

Automobile Congestion

Efforts have been made to restrict certain types of traffic on city streets, e.g., to prohibit deliveries and pickups of merchandise during certain hours. This has not proved feasible. The opposite approach has been to restrict curb areas for sole use by trucks and delivery vans during business hours.

Restrictions against parking cars on arterial streets during business hours has increased through-put capacity. Synchronized traffic lights have improved traffic movement. In some cities, major streets now include an extra lane, inbound during the morning rush hour and outbound in the afternoon. Certain major highway segments now reserve the inner lane for so-called High Occupancy Vehicles (HOV) where each vehicle must have two or more persons aboard during rush hour. Also, some companies have tried staggered working hours so that commuters are not all on the road at the same time.

Another approach has been the development of building code requirements for parking spaces within new buildings, commercial or residential, based on rentable area in each building. This is a retrograde movement in my view. Although it provides for off-street parking, it discourages the use of public transit.

Suburban areas trying to cope with mounting traffic congestion are adding new streets and roads with additional traffic lanes to the existing road system. The hypothesis that added capacity induces added traffic is being proved every day throughout the country.

The growth patterns and problems are essentially the same in other industrial countries. Paris is in the process of building highway tunnels under the city to move its traffic. In the United States there are 183 million motor vehicles, and approximately 5 million more vehicles are added each year. With rare exceptions the capacity of city streets cannot be expanded short of double decking, which is not considered feasible.

An environmental problem in connection with road and street congestion is air pollution. It has reached epidemic proportions in some conurbations and is spreading relentlessly to others. Its impact on health, property values, and quality of life is quite literally, breathtaking. Recent proposals for dealing with the problem in the Los Angeles area are revolutionary in concept and expense.

Airport Congestion

Meanwhile, that fantastic brainchild of Wilbur and Orville Wright has come into its own. The airplane has achieved a level of congestion in two dimensions—in the air and on the ground. The air traffic control systems in both Europe and the United States are barely coping with existing traffic. Deregulation and the controllers' strike dealt a body blow to the U.S. system. Liberalization of aviation economic and political controls in Europe in 1992 will have a similar though not so devastating an effect in that area. In the United States the Federal Aviation Administration is now five years behind schedule on a multi-year program instituted in 1981 to upgrade and expand the U.S. system, which is designed to rely heavily on automation. The problems in European are compounded by various factors: each nation generally controls its own airspace, and even though some European governments banded together to create Eurocontrol, its jurisdiction is severely limited; the level of investment in the various national systems varies greatly; and large areas of European airspace reserved for military activity prohibit the scheduling of direct flights among a number of major cities.

Air traffic congestion exists on the ground as well, and the problem of too few airports to handle the ever-increasing number of air passengers remains a difficult one. Today the average passenger capacity of a commercial aircraft is 181 seats. In the next 15 years air traffic is projected to more than double. To handle that increased demand using existing airports would require an increase in *average* aircraft size to accommodate 296 seats. And to achieve that average size there would need to be a substantial number of aircraft with a capacity of more than 500 seats. The thought of trying to move clumps of 500 or more passengers to, through, and away from terminals with assorted baggage, relatives, and friends is enough to cause apoplexy among transportation planners. Even more sobering is the prospect of a crash of such a leviathan and its impact on the public.

Obviously, more airports is the answer; however, people travel to and from already densely populated areas. Those of us with memories of 30 years or more may recall the futile quest of the Port of New York Authority for a site to locate the "fourth" New York Airport. The same situation exists for Chicago, Boston, and Los Angeles. The last major airport in the United States opened at Dallas/Fort Worth in 1974. Now, Denver, one of the few major U.S. cities *not* suffering from airport congestion, is the only city planning to build a new airport. No others are on the drawing board. The reasons are primarily objection to noise, congestion on streets and highways, and fear of accidents. These concerns are not likely to dissipate.

PROSPECTS FOR THE FUTURE

The National Academy of Engineering knows better than any other institution that the problems of congestion can be resolved or controlled if approached on a systematic basis. The remedies, however, involve a number of trade-offs. One requirement is for enormous capital investment. Whether the capital is derived from public or private sources, its use for transportation systems reduces the funds available for investment in other infrastructure activities.

A more intractable trade-off might be to impose constraints on the nearly absolute freedom of personal mobility. It will not be possible to deal effectively with congestion and still permit everyone the license to go wherever they wish at any time in any vehicle. This freedom of mobility is a highly cherished American value and there would be enormous difficulty impinging upon it. The reality is that unconstrained personal mobility and control of congestion are incompatible in the America of today and tomorrow.

It is clearly possible to impose some constraints. Minneapolis has closed a major street to vehicular traffic through the construction of a pedestrian mall. Munich, Germany, has done the same in the Old City Center. Such actions force vehicle traffic to the perimeters; they do not reduce congestion. Instead they displace congestion to other areas.

The architectural/engineering firm of Skidmore, Owings and Merrill developed an innovative approach to the problem of congestion in Chicago with the design of the Hancock Building. Their concept was that people should be able to live, work, and satisfy their needs in one location. So the building has offices, apartments, stores, restaurants, and recreational facilities under one roof. The Hancock Building is a financial success, but I do not know of any studies to validate the concept. Logic would seem to support the belief that clusters of such buildings in our larger cities would provide enough services and interaction to effect a measurable reduction in congestion.

Mass Transportation

The assertion that a well-utilized mass transit system in our major cities would reduce congestion seems unarguable. The Metro system in Washington, D.C., seems to support the proposition. It is clean, convenient, and cost-effective from a consumer point of view. This has been made possible through massive federal funding as well as large amounts of money invested by local jurisdictions, with continuing annual subsidies from those same local sources. In so doing county governments in Maryland and Virginia and the District of Columbia seem to have overcome one psychological barrier: the belief that the riders are the sole beneficiaries of the system and should, therefore, pay the full cost of the system.

The fact is there are multiple beneficiaries: building owners, employers, communities, and the general public. For building owners, it is a means to get people to and from their buildings. Employers are able to draw their work force from a dispersed regional population. Communities in close proximity to public transportation generate substantially increased tax revenues because it is possible to erect large buildings within walking distance of the system nodes. And the public benefits from a greater range of employment opportunities as well as reduction in congestion that comes from using the system.

To be successful, a transit system must be seen as a reasonable alternative to the private automobile. Those who have no automobile will ride whatever transit is available; they do not provide a critical mass. For a transit system to serve its purpose it must be a matter of choice for many, not just a matter of necessity for some. Again, the Washington Metro is a good model. Its rail cars and buses are clean, air-conditioned, and comfortable. One does not lose status in one's own or others eyes by riding public transportation in the D.C. area.

One broad objection to mass transit is that it does not solve "the" transportation problem. It is true that no matter how extensive a system is, it can serve only a limited percentage of the traveling public. It is also true that cortisone does not cure arthritis, but those who suffer from this affliction are better off with cortisone. No thoughtful person would suggest that transit is the solution to congestion. No thoughtful person would declare that there is *a* solution to congestion. Whatever is accomplished is done at the margin. The issues involve population densities, funds, incentives, and social values.

Balancing Social Goals

Since 1950 population density has been declining in metropolitan areas and growing in the suburbs. Suburban growth has dictated the need for one, two, or more cars per family. There is no reason to expect a change in these patterns. However, two major forces are in conflict with respect to the role of the automobile in congestion: (1) there is the growing concern about air pollution, which is not expected to diminish; and (2) it is fair to say that time has become the most important aspect governing modes of travel.

In the latter regard, as average wages increase lost time becomes more expensive. There are more and more women in the work force. Many are leading two lives—as members of the work force and as homemakers. Furthermore, as technology has accelerated the pace of economic activity it has placed a premium on speed with a consequent pressure on time.

During the depression I remember the unpleasant odor emanating from a nearby paper mill. When the breeze wafted this aroma to people's nostrils some would exclaim in picturesque fashion, "That smells like Hell!" The constant response was, "That smells like jobs to me." Attempting to deal with congestion and its consequent pollution is an exercise in economic trade-offs. For example, the efforts by environmentalists and government planners in Southern California to deal with congestion and pollution have created charges of increasing cost and declining economic activity.

It is difficult for one whose costs will be increased or whose activity will be constrained by congestion control efforts to accept that overall it may be a zero-sum game. Control efforts will clearly create new or expanded economic activity, even though it is not possible to predict a one- for-one substitution.

Another counter to congestion control efforts is that they will be expensive. Our old nemesis, taxes, is brought to the fore. This is certainly correct. Unfortunately, no one has yet found the free lunch in the provision of public services. Arguments against more taxes must be equated with current and future economic and social costs. Political courage is required to promote benefits versus costs.

It will be a bona fide disaster if government officials attempt to treat the problems of congestion as our federal government is currently dealing with the budget deficit. It is instructive that those entertainers who used to be billed as magicians now refer to themselves as illusionists. Reality may be obscured but it does not change any more than the budget deficit. Smoke and mirrors may prolong some political careers but it will ultimately reduce our mobility to gridlock! At that time draconian measures may be required to deal with congestion. One wonders if such measures can be imposed through democratic institutions.

So how do we deal with congestion? First, there must be an appreciation that it is a growing problem that affects the lives of a majority of the American people. Second, there should be the gathering of accurate data to quantify the economic and social expense of congestion. Third, it is important for everyone to understand that congestion and pollution are closely related.

In 35 of our 50 states most people live in or near metropolitan areas. Congestion is a local phenomenon with an impressive effect on interstate and foreign commerce. Despite the local character of congestion it has a universal characteristic: too much traffic for the capacity available. Therefore, solutions and amelioration in one area can be readily transferred to others.

The Role of Government

These facts lead to the conclusion that the federal and local government has a major role to play in dealing with the problem, with a lesser role for the states. First we need to acquire information sufficient to calculate the economic and social costs of congestion today and to extrapolate those costs to the future. Then the public must come to understand what the costs are, that the costs are intolerable, and that the situation can be improved.

Inherent in this understanding is a requirement that official bodies promote a basic concept: the greatest good for the greatest number. With a credible statement of costs it will then be necessary to achieve consensus through debate as to what values the public wants to achieve or to maintain. Once it is accepted that benefits come only as a result of costs planning, execution can begin.

It is necessary to review types and sources of funding. There is good reason to believe that an amalgam of public and private funds can be used to develop mass transit systems—and possibly even toll roads. Additionally, it appears to make sense for local or regional governments to use public funds appropriated for transportation in the fashion that is most likely to solve the local problems. Today, too many of these funds are categorical grants that severely limit their use.

What this implies is the need for a systematic approach to congestion that comprehends public goals, a schedule for accomplishments to achieve those goals, funding and the establishment of a set of priorities. If there is a broad understanding of the costs and benefits related to congestion; if there is an agreement on the values we hope to achieve; and if there is a systematic public/private approach to dealing with congestion it may be possible to maintain a level of mobility equal to that in New York City in 1900.

Engineering in an Age of Anxiety: The Search for Inherent Safety

ALVIN M. WEINBERG

Ours is an age of anxiety.[1] Though life expectancy (corrected for infant mortality) in the United States has increased by an astonishing 20 years since 1900, so has our fear of death. We no longer accept death, especially death from cancer, as "natural"—every death, even the inevitable deaths of old age, must be caused by some malign, and identifiable, outside influence. In this we seem to be reverting to a primitivism identified long ago by the French philosopher Levy-Bruhl, that primitive societies do not accept natural death.[2] Every death is attributed to a definite cause—if not to a hostile arrow, then to the malediction of a hated enemy.

Modern technology is viewed, by and large, as a prime source of our anxiety. A succession of spectacular technological failures: Three Mile Island, Bhopal, Challenger, Chernobyl—have shaken the public's confidence in our engineering. And hardly a month goes by without one or another pesticide being proscribed, and our fruits and vegetables being regarded as tainted.

Some of our anxiety is justified. Bhopal and Chernobyl were disasters: no rationalization after the fact can undo the enormous loss in public confidence that these incidents engendered. Moreover, our ever more interdependent technologies are more fragile because of their very complexity and reach: the Northeast power blackout demonstrated to the public just how vulnerable a highly interconnected system is to inadvertent collapse. On the other hand, our preoccupation with man-made environmental insults at levels far below those imposed by nature's pollutants is hardly rational.

All of this heightened concern, this dizzy oscillation from one fear to another, is amplified by our superefficient methods of mass communication. Had I the slightest idea of how to reduce the enormous amplification of public worry caused by television; had I a neat technological fix—an "inherently safe" television system that both guarantees our freedom yet avoids scaring us out of our wits—I would urge its development and adoption with the highest priority. Much of our efforts to develop inherently safe systems would then be unnecessary!

THE ENGINEERS' RESPONSE TO PUBLIC CONCERN

These public concerns, both those that are justified and those that are unjustified, place constraints on our technologies. Engineering always has required judgment as to how safe is safe enough; and more safety can always be bought at a price. Where an engineer places his design point in a plot of "safety" versus "cost" is a judgment that is powerfully influenced by the public's concerns. This is illustrated by the difference between Western and pre-glasnost Soviet attitudes toward containment around pressurized water reactors (PWRs). Containment shells have been standard practice on Western commercial pressurized water reactors since the first plant at Shippingport went critical in 1957. Soviet PWRs were largely uncontained until Chernobyl. This difference was attributed to the West being more sensitive to public opinion than was pre-glasnost Soviet Union. And of course the design point must always conform to regulatory standards, which themselves are sensitive to the public's concern. Thus we read in the February 1987 report from the U.S. Environmental Protection Agency (1988, p. xix) ". . . EPA's priorities appear more closely aligned with public opinion than with our estimated risks. . .", an extraordinary admission that EPA, apparently at the behest of Congress, takes into consideration not only those public concerns justified by the facts, but also those concerns that are not so justified!

I take as given then that the amount of safety a technology must provide is ultimately decided by the public; but the public is fickle, and at least as viewed by engineers, often ill-informed. Though public attitudes are distilled and codified through various regulatory bodies such as EPA, Nuclear Regulatory Commission (NRC), Federal Aviation Administration (FAA), conformance to standards promulgated by such bodies no longer guarantees acceptance by the public. Consider the Shoreham Nuclear Plant; the Nuclear Regulatory Commission has certified that Shoreham meets all regulatory standards, "that there is reasonable assurance that it can be operated without undue risk to the health and safety of the public."[3] Yet, the State of New York, perhaps more sensitive to the mood of the public than is NRC, has killed Shoreham.

Traditionally, engineers design devices so as to conform to safety standards established either by their own standards committees, or by government regulators. Perhaps the first such standards were those imposed on boilers by the Engineering Insurance Companies of Manchester, England, following a series of boiler explosions about 100 years ago (Nichols, 1987). The worst such catastrophe was the explosion of the boiler on the Mississippi River Boat, Sultana, on 27 April 1865 with the loss of 1500 lives. In the United States, the first American Society of Mechanical Engineers (ASME) boiler code was adopted in 1914. Designers were required to incorporate safety factors—that is, if the bursting pressure of a vessel was P, the vessel was certified for operation at, say, P/4. Safety factors, as customarily formulated, were regarded as conferring "absolute" safety: a component designed and built in conformance with the appropriate code will not fail—provided approved operating conditions are not exceeded. Before the "age of anxiety," the public trusted the engineer: devices designed according to code were "absolutely" safe—or at least did not engender public apprehension.

Unfortunately, failures occur, even in components designed according to code—either because operating conditions are exceeded through human error, or the component ages, or the component was defective in the first place—or because the code itself may be defective. In instances where failure can cause massive harm—as for example, in high-powered nuclear reactors—probabilistic risk assessment (PRA) has become an accepted tool for determining how safe a device is. In PRA one tries to identify all the sequences of component failures that can lead to failure of the system as a whole. The components are generally designed to code; their failure rates, which theoretically are zero, must be estimated from historical data. For each sequence that leads to system failure, one estimates the consequences of that failure—the consequences may be loss of life, damage to equipment or to other property, ecological insult, etc. Thus a probabilistic risk assessment results in a curve P(C), that is, the probability, P, of a failure (that causes consequences of magnitude C), as a function of C.

Probabilistic risk assessment became a recognized, and accepted technique with the Rasmussen Study (U.S. Nuclear Regulatory Commission, 1975). Rasmussen estimated that the median probability of a core melt for the Peach Bottom Boiling Water Reactor was 3×10^{-5} per reactor year, and for the Surry Pressurized Water Reactor, 6×10^{-5} per reactor year, with an uncertainty of a factor 5 to 10 either way. Most of these core melts would have few off-site consequences. The worst accidents involving some 3,300 immediate radiation-induced deaths, 45,000 long-term extra cancers, and property damage of $17 billion was estimated to occur once every 10^9 reactor-years.[4]

Since the Three Mile Island accident (TMI-2), PRAs on 44 of the 111 power reactors in the United States have been completed, and an equal number are under way. Although the NRC does not quite use PRA as a regulatory standard, PRAs have been very useful in revealing vulnerable elements in a plant. For example, sequences involving *small* pipe ruptures generally contribute much more to the overall probability of core melt than do sequences involving large failures. This has caused reactor engineers to focus much more on avoiding small loss of cooling accidents than had been the case before TMI-2. At that time, when incidentally, PRA was not used widely, a popular view seemed to be, if one takes care of the *worst* initiating event, say a guillotine rupture of a large pipe, then the smaller initiating events would automatically be handled.

Though PRA had its origins, even before Rasmussen, in the aerospace industry, curiously it was not used by National Aeronautics and Space Administration (NASA). Indeed ". . . early in the history of the Apollo program a decision was made not to use numerical probability analyses in NASA's decision making process" (National Research Council, 1988, p. 55). This rejection of PRA was justified on the ground that PRA cannot substitute for human judgment. PRA simply offers an estimate of the probability of a failure, but does not of itself say how safe is safe enough. Were this estimate of failure very high, say, 10^{-1} per launch, a decision maker could easily choose to abort. But ordinarily the probabilities of massive failure in a well-designed system are much lower, say, 10^{-3} or 10^{-4} per sortie. So ultimately the decision maker must rely on his own judgment that 10^{-4} is acceptable and 10^{-3} is unacceptable. In short, probabilistic risk assessment only provides options: for preassigned consequences, C, the probability of incurring C is P(C). The engineer or regulator must choose whether or not the P(C) curve characterizing a given system is or is not acceptable.

Despite this shortcoming, PRA is now used rather widely in technologies that can pose serious hazard. NASA, at the behest of its post-Challenger hazard audit, has taken steps to incorporate PRA in its shuttle program. The Cabot Corporation, before embarking on a plan to bring liquid natural gas into Boston, conducted a PRA of the operation. AT&T has used PRA to analyze components of its communication system. After Bhopal, many chemical companies have used PRA to estimate the hazards of plants that handle toxic or explosive materials. And in nuclear industry, many countries that had not adopted PRA now make such analyses. It seems to have taken tragedies like Bhopal, Challenger, and Chernobyl, to bring other technologies, both in the United States and in other countries, to the same degree of sophisticated hazard analysis as has been employed by the U.S. nuclear industry for more than 15 years.

As I have already said, PRA does not relieve the engineer or regulator of deciding how safe is safe enough: it simply presents him with a quantitative estimate of the safety of a system. What can one do with such estimates other than arbitrarily deciding a technical system is safe enough, or not safe enough? In short, how does one set safety standards? One possibility, and the one that has been adopted by the Nuclear Regulatory Commission, is to set the acceptable standards of safety at a level consistent with the standards established and accepted, de jure or de facto, for comparable technologies. Thus the NRC, in its safety goals of 1986, accepted a societal risk from nuclear power no greater than the risk from other modes of generating electricity. This translates into a core melt probability of 10^{-4} per reactor year; moreover, it accepts an additional risk of cancer from a nuclear plant, not greater than 10^{-3} of the natural risk.[5] Of course, any such judgment also has elements of arbitrariness—if the comparison is with natural background risks, what fraction of that background is acceptable; if the comparison is with other hazards incidental to a technology that achieves the same aim but which is already accepted, will the hazard of the new technology be accepted if it matches that of the accepted one? For example, dams fail at the rate of 10^{-4} to 10^{-5} per year. Does this mean that reactors should be accepted if their core melt probability is also 10^{-4} to 10^{-5} per reactor year?

The acceptable standard of risk depends on how widely the technology is deployed. This point was first stressed by the Swedish aeronautical engineer, Bo K. O. Lundberg (1963). He argued that although the probability of a crash per passenger was independent of the total number of airplane flights, as the number of flights increased so would the number of crashes in the entire system—*unless* the crash probability per flight were reduced as the system expanded. And if the number of crashes in the whole system became too great, the public would lose confidence in flying, even though the probability of any given passenger completing his journey without injury remained constant and at a level that was acceptable in 1965. As far as I know, this observation of Lundberg's was the first realization that acceptable standards of safety in our media-driven society are very sensitive to the public's perception.[6]

THE SEARCH FOR INHERENT SAFETY

Although PRA is now widely accepted by the engineering community as a means of assessing risk, I do not believe its use can allay the public's anxieties. The public understands consequences, not probabilities. To concede that a technology has the potential for causing a major disaster, even if the probability of such occurrence is minute, is unacceptable in the "age of anxiety." Faced with this stubborn reluctance by the public to accept probabilistic argument, several technologies have sought to develop systems for which the risk, if not zero, is so low, and so transparently low, that the skeptical elites, if not the public, will accept the technologies. This is the path urged by David Lilienthal, the first chairman of the Atomic Energy Commission. In his book, *Atomic Energy, A New Start*, which appeared in 1980, a year after TMI-2, Lilienthal urged nuclear technologists to redesign nuclear reactors so as to eliminate the chance of a repetition of TMI-2. In reviewing his book, I argued that a technical fix to achieve zero risk in a high-powered reactor was an oxymoron. Technologists could not eliminate the 15 billion curies in a 1,000-megawatt reactor, nor the 200 megawatts of afterheat which slowly decays, even after the reactor has been shut off. The approach to zero risk had to be through better training and better institutions. And somewhat wistfully I remarked at the seeming reversal of roles: the man of affairs, David Lilienthal, calling for a technical fix (inherent safety); the technologist, Alvin Weinberg, calling for a social fix (better training, etc.).

This was not the first time the idea of an inherently safe reactor technology had been suggested. Peter Fortescue of General Atomics had been arguing in favor of "forgiving" nuclear reactors even before Lilienthal's book appeared. And five years before TMI-2, on 1 June 1974, a cyclohexane plant at Flixborough in the United Kingdom blew up killing 28 persons (Parker, 1975). Had the explosion occurred during peak hours, many more would have perished. Soon afterward, Trevor Kletz, who was the safety adviser to ICI Petrochemical Division, coined the phrase "inherent safety" to connote chemical plants whose safety depended not on the active intervention of mechanical, electrical, or human agents, but rather depended on the inherent characteristics of the process itself. Kletz became a proponent, if not a propagandist, for a new approach toward chemical plant design—an approach in which safety, rather than being achieved by clever devices and interventions *after* the basic process and plant layout has been chosen, becomes an integral part, *ab initio*, of the design. In supporting this new ethic of chemical plant design, Kletz pointed out that changes in process had often been used in the past to bring the risk of at least certain accident sequences to zero. For example, thatch in new buildings in London was forbidden in 1212; airships now are filled with helium rather than hydrogen; and modern anesthetics and electric lighting eliminate the possibility of explosions from ether or poisoning from phosgene caused by the burning of chloroform in gas lights. Each of these process changes reduced to zero the risk of disaster from a particular accident sequence—but of course they did not eliminate all fires in houses, airship disasters, or deaths from overdoses of anesthetics.

Kletz used common sense in his approach to inherent safety in chemical plants. A primary principle was, *Never allow large accumulations of very toxic materials*. Had this principle been observed at Bhopal, the tragedy there would have been averted; the storage vessel that exploded contained around 15 tons of methyl isocyanate (MIC). Modern plants that involve MIC no longer allow accumulations of more than a few kilograms.

In his book, Kletz (1985, p. 34) describes several other common sense steps that designers of hazardous chemical plants ought to observe—generally aiming toward replacing active systems (pumps) with passive systems (gravity) where possible; replacing highly exothermic reactions with less exothermic ones; replacing conventional distillation with so-called Higee distillation; but above all reducing inventory of hazardous materials.

Although Kletz's views were quite well known among chemical engineers, I don't think inherent safety was taken fully seriously in the chemical industry until Bhopal. A disaster of this magnitude is simply unacceptable; will the mind-set of the chemical industry, which until the Bhopal accident had not subjected its extremely hazardous operations-like production of MIC to the same scrutiny nuclear energy was obliged to undergo, change enough to require inherent safety in its designs? As Robert Kennedy of Union Carbide, said, "An aroused public can put us out of business just like it put the nuclear industry out of business" (*Wall Street Journal*, 20 September 1988). Much activity within the chemical industry has now been directed toward safer plants. For example, the American Institute of Chemical Engineers (AIChE) with broad support from the chemical industry has established a Center for Chemical Process Safety. The Center, in some ways like the Nuclear Safety Analysis Center, carries out studies, and provides guidelines for improving the safety of chemical plants.

The strongest drive toward inherent safety has been in nuclear energy. From the earliest days, we realized that ours was a uniquely hazardous undertaking—the 15,000 million curies in a 1,000-megawatt reactor was an accumulation of radioactivity without precedent (and incidentally, violated one of Kletz's dictums, keep inventory low); moreover, the Hanford reactors as built had positive void coefficients (though the Dupont Company eliminated the possibility of a catastrophic progressive flashing of steam and burnout of a single tube by taking most of the pressure drop across orifices placed at the inlet to each tube).[7] The choice of the Hanford site was itself an implicit recognition of a principle of inherent safety: place hazardous operation far from people. And SIR, the submarine intermediate reactor, near Schenectady was housed in a containment sphere: an ultimate passive safety system that, it was believed, once and for all reduced the public risk to what the public would surely accept—*zero*. Thus the notion of inherent, or more accurately, passive safety in nuclear systems was to some degree implicit from the earliest days of nuclear energy.

But I do not think inherent safety was explicitly addressed in those days. After all, the PWR was an outgrowth of the nuclear submarine. A submarine reactor is designed primarily to be small, and to be simple—this dictated the use of water as both coolant and moderator. But compactness, and therefore, high power density, is incompatible with *inherent* safety. Thus when Rickover's navy was moved to dry land, safety had to be provided by a complex array of active elements: emergency core cooling systems, afterheat removal systems, fast acting shut-off systems, all of which require active mechanical and electrical interventions.

Three events brought inherent safety of nuclear plants to more prominence and explicitness: the rejection of nuclear energy in the Swedish referendum, Three Mile Island, and above all, Chernobyl. The two reactor accidents seem to have shown that some societies simply reject any probability, other than zero, of a reactor accident, especially one of the magnitude of Chernobyl. And the Swedish referendum, followed by de jure rejection of nuclear energy in Austria, Norway, Denmark, and most recently, Italy, demonstrates how public concern is translated into public, that is, political policy.

Kåre Hannerz of the Swedish atomic agency ASEA-Atom was perhaps the first to recognize that a reactor for which the probability of a meltdown was essentially zero, if it could be devised, might restore the public's confidence in nuclear energy. He thereupon invented the Process Inherent Ultimately Safe (PIUS) Reactor (Figure 1). PIUS is a pressurized water reactor in which the usual pressure vessel is replaced by a much larger prestressed concrete vessel. The reactor and its cooling system is immersed in a huge pool of water which contains boron. Should this borated water enter the core of the reactor, the chain reaction would stop. The pure water that cools the reactor and the borated pool water are kept separate during normal operation by two open hydraulic density locks. As long as the system is operating normally, the boron remains outside; any upset (boiling, loss of coolant) causes the locks to break automatically. The borated water bathes the reactor, shutting it down and providing automatic cooling for about a week with *no* external interventions.

PIUS is, as far as I know, passively safe; that is, no credible sequence has been identified that could lead to meltdown, and no intervention, mechanical, electronic, or human is needed to protect the system. Does this mean that PIUS is absolutely, or at least inherently, safe? If we equate inherently safe with *zero* probability of failure, I suppose the answer must be no. A small atomic bomb on PIUS could cause a meltdown as could, perhaps, an extremely powerful earthquake. But against lesser incursions, such as smaller earthquakes or conventional bombs by terrorists, PIUS reactors appear to be secure. On the other hand, PIUS is surely *transparently* safe: the principle on which its safety depends is easily grasped.

The modular high-temperature, gas-cooled reactors (HTGR) (Figure 2), first proposed by Reutler and Lohnert, represents another approach to passive, if not inherent safety. This reactor is a more-or-less conventional

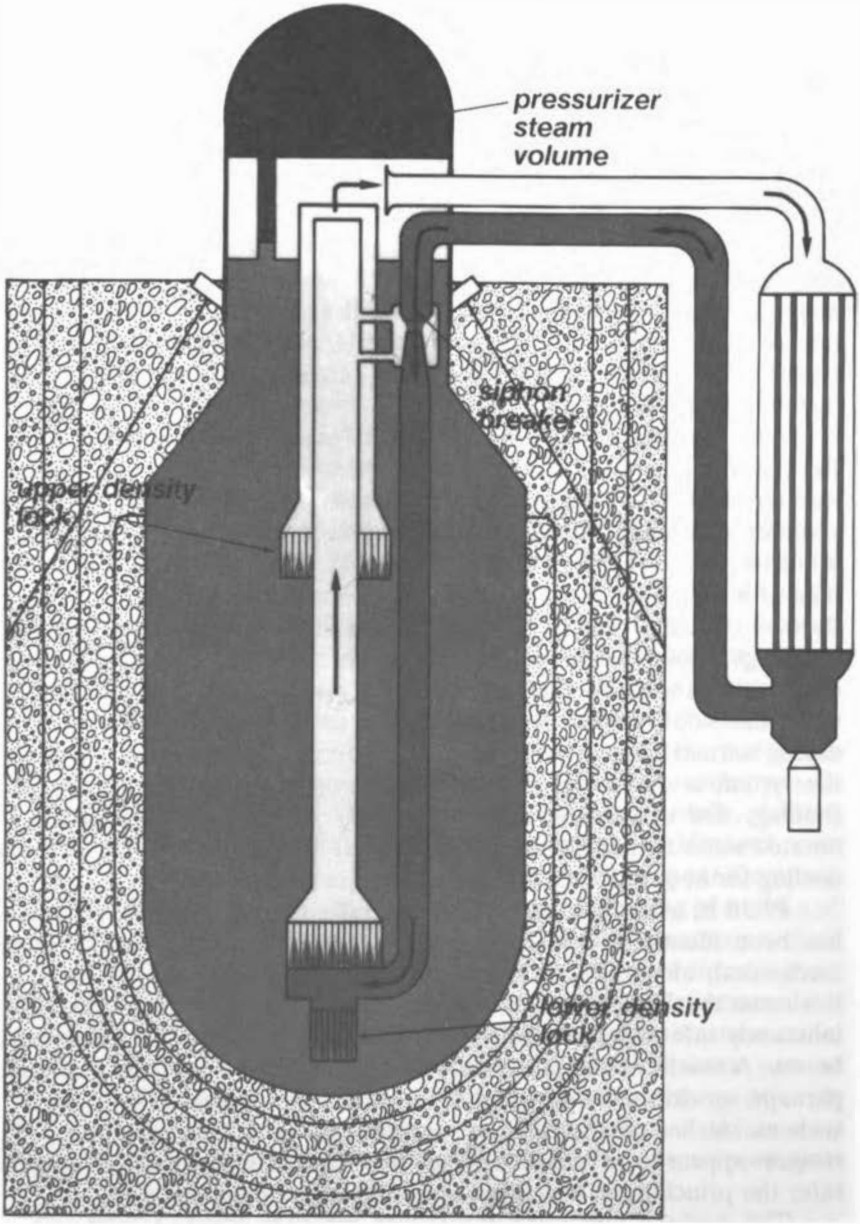

FIGURE 1 Process Inherent Ultimately Safe (PIUS) Reactor.

helium-cooled, graphite-moderated reactor, in which the fuel elements are microspheres of uranium dioxide coated with essentially impervious layers of silicon carbide and pyrolitic graphite. The reactor is shaped like an elongated cylinder and produces only about 250 megawatts of heat. By virtue of its very high ratio of surface to volume and its low power density, the reactor can dissipate all afterheat passively to its surrounding without exceeding the temperature at which the microspheres release fission products. The modular HTGR must therefore be regarded as inherently safe against major challenges such as caused damage at TMI-2 and at Chernobyl. At the present writing, modular HTGR is being considered by the U.S. Department of Energy (DOE) as one of the reactors for producing tritium for thermonuclear weapons; and, the Soviet Union and West Germany are planning to build such a reactor at the Lenin Research Institute for Atomic Reactors in Dimitrovgrad.

PIUS and modular HTGR are the reactors closest to being inherently safe, that is, having no identifiable or credible system failure modes. This statement is arguable: for example, is ingress of air into HTGR with burning of graphite credible? Or is inadvertent removal of boron from the large bath of borated water surrounding the PIUS reactor credible? Thus we see that inherent safety, in the sense of absolute safety, is itself hardly a credible concept when applied to large reactors. What is credible to a skeptic may be incredible to a designer. On the other hand, that both PIUS and modular HTGR depend for their safety on passive, not active, systems is undeniable; and perhaps even more important, their safety is relatively transparent, and scrutable, rather than being inscrutable, as is the case with reactors whose safety depends on the quick intervention of many backup auxiliary systems.

Between PIUS and modular HTGR, whose safety depends almost entirely on passive or inherent elements, and existing reactors, whose safety depends mainly on active elements, there are now several reactors, or reactor proposals. I mention the metal-fueled, sodium-cooled reactor, first proposed at Argonne National Laboratory. Because of the high heat conductivity of its fuel, this reactor is not subject to the loss of flow, the loss of external cooling, or transient overpower accidents of the standard liquid-metal fast breeder reactor (LMFBR); also there are the small advanced pressurized water reactor of Westinghouse, and the boiling water reactor BWR-600 of General Electric—essentially conventional light water reactors in which the emergency cooling system is activated by gravity, rather than by pumps. In case of a loss of cooling accident, the emergency core cooling system requires only the opening of a valve—an action that most would agree is reliable.

The nuclear establishment on the whole dislikes the designation "inherently safe." The argument is severalfold. First, if "inherently safe" is

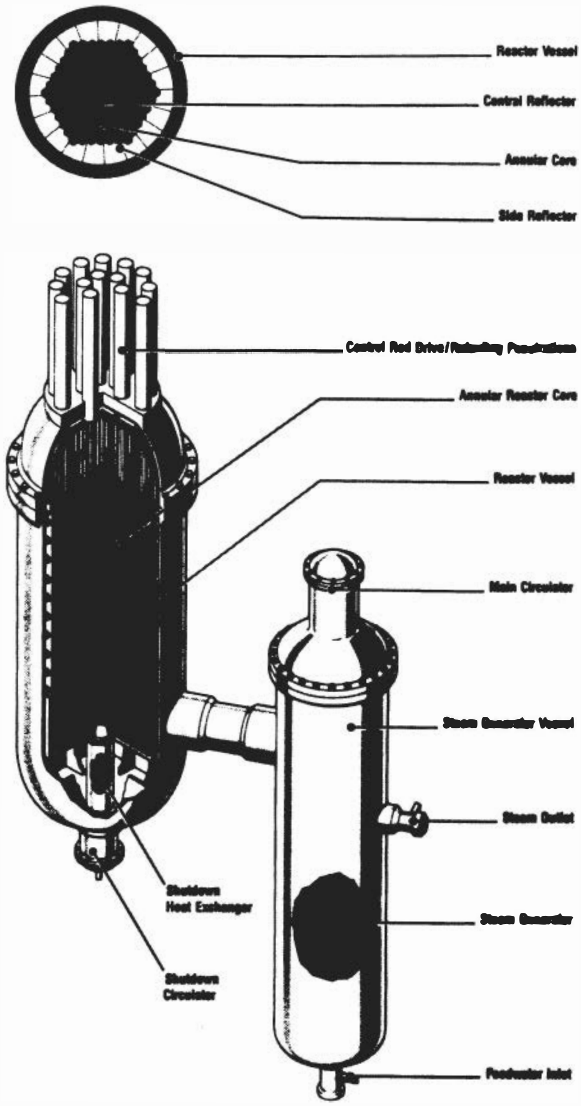

FIGURE 2 Modular high-temperature, gas-cooled reactor.

equated to "absolutely safe," this is impossible as no reactor that produces energy at a rate greater than some critical value can under *every* circumstance, conceivable and inconceivable, avoid a meltdown. Second, if a reactor advertised as being inherently safe actually suffered a meltdown, the entire nuclear enterprise would suffer an intolerable loss of confidence. And third, can inherently safe reactors and actively safe reactors coexist? Would not the pressure to shut down existing, actively safe reactors become irresistible were newer, safer reactors to be built?

To these objections, I offer the following: I do not regard "inherently" safe and "absolutely" safe to be identical. Inherent connotes to me only that the system's safety depends on inherent and passive characteristics. Under some all-but-incredible circumstances an inherently safe system can cause harm, for example, by malevolent act. As far as failure of an inherently safe reactor compromising the future of nuclear energy, I think the failure of *any* reactor, inherently safe or otherwise, would be disastrous for the nuclear business. As for the coexistence of devices of different vintage, and different levels of passive safety, we already accept this in commercial air travel. Modern jet aircraft are more reliable than are DC-3s, yet the public accepts both kinds of aircraft. Every technology improves, yet the introduction of a safer, newer technology generally does not cause the immediate shutdown of an older technology, provided the older technology has operated reliably and there is no better substitute available.

HOW SAFE IS SAFE ENOUGH?

I return to the central question: how safe is safe enough? From probabilistic risk analysis we judge that the mean core melt probability of light water reactors now deployed is between 10^{-4} and 10^{-5} per reactor year. With about 400 reactors now deployed, the probability of a core melt between now and 2000 is between 4 and 40 percent. Many of us in the nuclear business are uncomfortable with this result, especially since a nuclear accident anywhere is a nuclear accident everywhere.

Incremental improvements and backfits improve the odds. Thus the core melt probability for Sizewell-B, a large PWR under construction in England, and for the advanced PWR and BWR being built in Japan, is between 1 and 5×10^{-6} per reactor year. In a fleet of 5,000 such reactors, over their lifetime of 50 years, the probability of one such reactor suffering a core melt would be at least 25 percent. Is this good enough?

Having asked this question, I confess, I cannot answer it, especially since the answer depends so heavily on the public's perception of hazard, more so than it depends on the actual hazard. And here is why I think inherent, or at least transparent, safety will remain a tantalizing goal for engineers in the coming century.

The public's views are, in this age of television, strongly affected by skeptical and articulate elites. These are self-appointed spokesmen for the public interest as they conceive it. Though these elites are often antitechnological, many of them are sufficiently sophisticated to see tradeoffs in any assessment of a technology's risk. Thus, shortly after Chernobyl, Jan Beyea of the Audubon Society admitted before a Senate committee that in view of the greenhouse warming, nonfossil energy sources would be needed. Though solar was his favorite, he recognized that solar was expensive. He therefore urged development of inherently safe nuclear. Beyea is not the only skeptic who has voiced this view: the Union of Concerned Scientists, and the World Resources Institutes, though espousing conservation as the inherently safe alternative to nuclear, at least concede that they would be prepared to rethink nuclear were inherently safe embodiments to be developed.

So I think the nuclear community must address the skeptical elites. The engineering task is therefore to design reactors whose safety is so *transparent* that the skeptical elite is convinced, and through them, the public.

What the public requires by way of assurance will depend on the alternatives, and here the greenhouse effect may be decisive. To counteract the greenhouse effect, I have estimated that the world, by mid-twenty-first century, may have to deploy around 5,000 very large nuclear reactors. I assume here that total world energy increases to 500 quads per year from the present 300 quads per year; that the carbon from a fossil burn of 150 quads per year (75 million barrels of oil per day equivalent) will all be absorbed in the oceans, and that most of the remaining 350 quads is supplied by many thousands of nuclear plants.

I have already pointed out that the probability of a single core melt in so large a fleet of reactors is only .005 per year if the individual core melt probability is 10^{-6} per reactor year. This, however, leads to a probability of 25 percent over the 50-year life of the fleet. My own instinct therefore is to do better than this with transparently and passively safe reactors, rather than depend entirely on incrementally improved existing reactors.

The notion of inherent safety seems to have political appeal. For example, the Italian Parliament, though putting an end to nuclear power in Italy after Chernobyl, has authorized a five-year study of inherently safe reactors as a possible way to bring nuclear back to life. Mikail Gorbachev has called for the development of inherently safe nuclear reactors—and the Soviet Union has offered to cooperate with other countries in their development. And Michael Dukakis, governor of the Commonwealth of Massachusetts, promised to oppose construction of new commercial reactors "until a new generation of reactor design and safety control is developed."

Though the search for inherent, or at least passive, safety seems to be most evident in nuclear energy, the idea is catching on in the other technologies, and for pretty much the same reason. The state of New Jersey passed a Toxic Catastrophe Prevention Act in 1988 that places heavy restrictions on what kinds of chemical plants can be built there; and there is a chance that a Federal Toxic Catastrophe law may be enacted. Mr. Kennedy's warning—that a skeptical public may strangle the chemical industry as it has the nuclear industry—must be taken with some seriousness. Trevor Kletz's call for incorporating inherent safety wherever possible in all plants makes good sense whether or not the fate of the chemical industry is at stake.

CONCLUSION

William C. Clark (1979) reminded us in his famous paper, *Witches, Floods, and Wonder Drugs*, that much of today's anxiety over technology is as little justified as was the fear of witches that swept over Europe in the fifteenth, sixteenth, and seventeenth centuries. But people eventually overcame their fear of witches. According to Hugh R. Trevor-Roper (1969), the public relaxed after the intellectuals ("skeptical elites") of the time decided that witches were not as bad as their reputation, and then persuaded the public to regard witches as more or less benign. I do not say that today's technologies are always as benign as witches; the general anxiety, engendered in part by real catastrophes, in part by imagined catastrophes, has pushed the public's estimate of how safe is safe enough much further toward safety than most engineers would judge sufficient. But in this the public's voice is supreme; we as engineers have little choice but to respond to these concerns. Inherent or at least transparent and passive safety offers us a technical fix for the public's anxiety. I cannot guarantee that this technical fix will work, that the public will accept passively safe reactors, oil tankers, or chemical plants, when it rejects actively safe ones. That inherently, if not absolutely safe, technologies are feasible even in principle seems to me to be a remarkable existence theorem. I expect engineers of the coming generation will exercise their ingenuity, in the best engineering tradition, to reduce these exciting new ideas to commercial practice.

NOTES

1. Leonard Bernstein caught the essence of our times by entitling his Second Symphony "The Age of Anxiety."
2. As described in Douglas and Wildovsky (1982).
3. This is the statement that summarizes every approval of a reactor by the Advisory Committee on Reactor Safeguards.
4. Chernobyl, an uncontained, very different reactor caused only 31 immediate radiation casualties, but did cause property damage of the order estimated by Rasmussen.

5. Indeed, H. I. Adler and I have argued for a general standard of radiation exposures to be the standard deviation of the natural background, that is, about 0.2 millisieverts per year.
6. Lundberg's estimates, made in 1963, of number of accidents per year in civil aviation, and the goals he deemed necessary, follow.

Year	*Estimated Accidents/Year*	*Goal*
1980	120	approx. 10
1990	250	
2000	440	
2010	710	approx. 25

The actual number of accidents in commercial aviation in 1988 was 25.

7. From the very beginning, avoidance of criticality in handling of fissile materials was recognized as being essential. Codes governing the safe handling of such materials were developed, largely through the efforts of D. Callihan and H. Paxton.

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Speakers' Biographies

Alan S. Boyd is chairman of Airbus Industrie of North America, Inc. His career in the transportation sector in both private industry and government spans forty years. Before he joined Airbus Industrie, he served as president and chief executive officer of National Railroad Passenger Corporation (AMTRAK) from 1978 to 1982. He has held posts as chairman of the Civil Aeronautics Board in the 1950s, Under Secretary of Commerce for Transportation and first U.S. Secretary of Transportation in the 1960s, president, chief executive officer, and vice chairman of Illinois Central Railroad in the 1970s, and special representative of the President for United States-United Kingdom civil aviation negotiations in 1977. He recently retired as chairman of the National Trust for Historic Preservation. Mr. Boyd holds a law degree from the University of Virginia.

Robert A. Charpie is chairman of Ampersand Ventures. His career spans 40 years of research, technology management, business development, and general management with Union Carbide Corporation at the Oak Ridge National Laboratory and in New York, Bell & Howell Company from 1967 to 1968, and Cabot Corporation as president and chief excutive officer from 1969 to 1986 and CEO until 1988. Dr. Charpie is a member of the National Academy of Engineering and a director of Ashland Coal, Inc.; Cabot Corporation; Campeau Corporation; Champion International Corporation; Federal Department Stores, Inc.; and Northwest Airlines, Inc. He is also a Trustee of Carnegie Mellon University and Massachusetts Institute of

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Koji Kobayashi is chairman emeritus and representative director of NEC Corporation in Tokyo, Japan. He has been with the company since 1929. He was elected director of NEC in 1949, president in 1964, and chairman of the board and chief executive officer in 1976, and assumed his present position in 1988. Throughout his career Dr. Kobayashi has endeavored to bring about the development of a global telecommunications network through the supply of telecommunications systems and equipment, including satellite earth stations, microwave systems, submarine cable systems, and switching systems, and the commercialization, in Japan, of business computers and electronic equipment. He is a foreign associate of the National Academy of Engineering. Dr. Kobayashi is a graduate of Tokyo Imperial University where he received a Ph.D. in engineering in 1939.

Simon Ramo is a cofounder—the "R"—of TRW, Inc., one of the world's largest technological corporations. During his career he served as chief scientist in the development of the U.S. Intercontinental Ballistic Missile, chairman of the President's Committee on Science and Technology under President Ford, and and as a member of the Advisory Council to the Secretary of State on Science and Foreign Affairs, the White House Council on Energy Research and Development, the National Science Board, and the Council of Scholars of the Library of Congress. He is the author of widely used textbooks in science, engineering, and management. Dr. Ramo is a recipient of the Presidential Medal of Freedom, the nation's highest civilian award, and the first recipient of the National Academy of Engineering's award for statesmanship in national science and technology policy. Dr. Ramo is a member of the National Academy of Engineering.

George Shultz is honorary fellow of the Hoover Institution and professor of international economics at Stanford University. Mr. Shultz served as U.S. Secretary of State in the Reagan administration from 1982 to 1989. As a professor of economics in the 1950s and 1960s at the Massachusetts Institute of Technology and the University of Chicago, he served for the first time on the President's Council of Economic Advisors in 1955. From 1969 to 1974 he served consecutive government posts as Secretary of Labor, Director of the Office of Management and Budget, and Secretary of the Treasury. From 1974 until 1982 he was president and a director of Bechtel Group, Inc., and a member of the Stanford faculty. Mr. Shultz is a graduate of Princeton University and received his Ph.D. in industrial economics from the Massachusetts Institute of Technology in 1949.

Alvin M. Weinberg is a distinguished fellow of the Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee. Dr.

Weinberg was director of the Oak Ridge National Laboratory from 1955 to 1973; director of the Office of Energy Research and Development, Federal Energy Office, in 1974; and director of the Institute for Energy Analysis from 1975 to 1985. He has received numerous awards for his contributions to the design, development, and safety of nuclear reactors and the formulation of science policy. Dr. Weinberg is a member of the National Academy of Engineering and the National Academy of Sciences.