TECHNOLOGICAL RISK

What are the real dangers, if any, of toxic chemicals, the greenhouse effect, microwave radiation, nuclear power, air travel, automobile travel, carcinogens of all kinds, and other threats to our peace of mind?

H.W. LEWIS

Winner of the Science Writing Award of the American Institute of Physics

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H. W. Lewis

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Introduction

We are obsessed with risk, especially in the novel forms brought to us by science and technology. Risk has become a major political and social issue, provoking widespread uneasiness about scientific progress; demagogues thrive in such an atmosphere.

Yet the risk is real, as are the benefits. We live our lives surrounded by the miracles of modern chemistry, yet we are preoccupied with chemical contamination. We use clean electricity from nuclear power plants, yet fear the prospect of a nuclear accident. Our lives have been dramatically extended by vaccines against many of the former scourges of mankind, yet the few cases in which a vaccine has done more harm than good are widely publicized, and concerned parents often refuse to immunize their children against known diseases. Commercial aircraft speed increasing numbers of us across the country in a matter of hours, ten times more safely than we could drive the same distance, yet fear of flying lingers. Fluoridation of our drinking water is making tooth decay a thing of the past, yet fear of chemicals deprives much of the nation of the benefits of fluoridated water.

We are both beholden to technology for enrichment of our lives and suspicious of the associated risks—especially when they are unfamiliar. It is an uneasy cohabitation. It would be good to know the price, including risk, that we have to pay for the benefits, but both risk and benefits are hard to estimate, even for dedicated experts. In all those mentioned above there are genuine benefits and genuine risks. Because they are not easy to balance we often do the job badly, accepting unnecessary risk in some more familiar forms, while grossly exaggerating it in others. Most people would probably agree that there is no point in exposing ourselves to a risk for which we get nothing in return, and probably even agree that we ought to accept great risks if the stakes are high. The history of the human race would be dreary indeed if none of our forebears had ever been willing to accept risk in return for potential achievement. Risk is part of the price we pay for growth, as nearly all parents know.

Just as there are trivialities that scare us witless, so are there real risks that don't bother us. Many agonize over the possibility that, in a thousand years or so, high-level nuclear wastes in geologic storage may leak (the current EPA standard requires no leakage for ten thousand years), while paying almost no attention to the fact that, every year, about a thousand Americans are accidentally electrocuted. No mass demonstrations oppose electricity, no rock concerts ring with speeches clamoring for lower distribution voltages, even though reduced distribution voltages would make an accidental shock less harmful. (Most of the world uses higher domestic distribution voltages than our 110 volts, with consequent economic gains.) Lightning kills about a hundred Americans each year, yet the sale of lightning rods is far from a sure road to riches. The most egregious example of a risk only beginning to be taken as seriously as it ought to be is smoking, which kills nearly four hundred thousand Americans each year, well over a thousand a day, often unpleasantly. One out of five American deaths is from smoking. To be sure, in the more than twenty years since the Surgeon General issued the famous report that certified that smoking causes lung cancer, smoking rates in the United States have gradually turned around, peaking in 1971, but we are dragging our feet. Incomprehensibly, many doctors still smoke, along with nearly 30 percent of the adult population of the United States. If we spent as much per untimely death caused by smoking as we do on coal mine safety, there would be no money left in the United States for any other purpose—it would require the entire gross national product. We even cough up over $30 billion per year just to buy cigarettes. That's still less than the estimated $100 billion we spend on illegal narcotics, about which no more will be said.

In fact, cigarette smoking, though declining in the United States, is growing as a world problem. In the Third World it is growing at a faster rate than the population, and in Africa almost twice as fast. Perhaps the same social forces are at work that are present here, where smoking is more prevalent among the less well educated than among the more educated, among blue-collar workers than among white-collar workers, among blacks than among whites, and so on.

This book is meant to improve public appreciation of the difficulties of risk assessment and management, and to contribute to public understanding of the issues. It is aimed at intelligent readers, not specialists. Though there are many forms of risk, the book is confined to the risks connected with progress in science and technology. The other threats to life are important—they dominate the mortality (death) and morbidity (sickness) statistics—but they are not the subject here.

Many of the risk-related issues, like the value of life or the problems of the regulation of risk, don't depend much on the specific form of technological risk under consideration. These matters are dealt with in Part I. On the other hand, there is no better way to learn than by example, so Part II is a potpourri of specific cases, treated in greater detail, and grouped in families with common features. Part II is meant to satisfy the craving for real issues that has been built up in Part I. The collection is far from complete, but each example is chosen to be of current interest, and to illustrate some point made earlier. Finally we have to recognize the unfortunate fact that no deep appreciation of risk can be developed, particularly with respect to the likelihood of rare events, without some minimal knowledge of statistics and probability. Part III contains the necessary lore, aimed at an inquisitive reader with a grounding in high-school mathematics. No one should be ashamed of using numbers. Part III also contains a kind of summing up.

Something must be said about timeliness. It is tempting to seek timeliness, but research and legislative and regulatory change make it impossible to be entirely up to date. Further, there is an argument against going too far in the direction of currency, since newly discovered information that has not stood the test of time may later turn out to have been wrong—that happens routinely in science. To be up to date is to be quickly out of date. This book will be reasonably, but not entirely, up to date.

Concern about technological risk is a function of both location and time—it is a relative newcomer on the scene, most visible among the more developed nations. The point of departure here will be unabashedly American, both through the examples chosen and the discussion of the regulatory forces at work, though variants of the issues and the examples can be found throughout the world.

We should also be honest about the significance of risk compared to the other threats and challenges facing mankind. Though technological risk is important, it is far from the *most* important subject. When doom comes to our species it will not be from trace chemicals in our air or water, nor from a nuclear accident. As T. S. Eliot foresaw, the end is less likely to come with a bang than with a whimper. We should reflect occasionally on the implications of the fact that the earth is grossly overpopulated and becoming more so, especially in the Third World. The First World is not insulated from the economic and population problems of the Second and Third Worlds; we're all in this together. The term "spaceship Earth" has been coined to describe this state of affairs, and the time scale for solving the population problem is one or two generations. It cannot go on this way, and the die is already cast.

Part 1

Generalities

1
The Risks of Life

Fear and risk are different creatures. What some of us fear most—poisons in our drinking water, radiation in our air, pesticides on our food—pose hardly any real risk, while some we fear least—driving, drinking, and smoking—kill many hundreds of thousands each year.

And risk isn't all bad. Personal development is impossible without risk—how would anyone learn to ride a bicycle? On a larger scale, evolution would be impossible without the risks and challenges that strengthen species. For better or worse, we would never have become the creatures we are without the risks to which our forebears responded.

This chapter is devoted to collecting the known facts about the threats to life in the United States, to set the framework for the rest of the book. Later we'll concentrate on technological risk.

For now let's think of risk as the chance of death before our allotted time. Of course death is inevitable for us mortals, so it may seem odd to use a certainty as a measure of risk. Alternatives are sometimes used, like the number of years or days or minutes by which a life is unnaturally shortened. By the first measure, death ten years too soon is treated as no worse than death five years too soon; by the second, it is counted as twice as bad. Some contend that the early years are more valuable than the later years, while some (like Robert Browning) argue otherwise. Chapter 7 will deal more deeply with the contentious subject of the value of life. When a famous comedian reached the age of fifty, and people began to speak of him as middle-aged, he is alleged to have said that he would feel better about it if he knew a few more hundred-year-olds. In fact, about 1 percent of us will live to be a hundred, and more than 80 percent of those are likely to be female. For the moment, the chance of premature death is an adequate definition of risk.

The average expectation of life in the United States has been rising steadily for many decades. An American born in 1920 could expect a life span of fifty-four years—females a year more than males—while by 1985 the life expectancy had risen to seventy-five. The worldwide average is about sixty. The premium for being female in America is now seven years, and decreasing. Our life expectancy has therefore gone up over the last sixty-five years by about four months for each year. If this were to go on for the next seventy-five years, the average American would live to be a hundred, and the recent crisis over the solvency of the Social Security fund would appear in retrospect to have been child's play. The increase in longevity is mainly a result of the conquest of some real scourges of the young, through medical advances and public health measures. Infant mortality in the United States has been cut in half in the last twenty years, a dramatic improvement that still leaves us behind twenty other industrialized countries. There has been a smaller improvement at the more advanced ages, where the average remaining life at age fifty has only been going up at a rate closer to a month per year, and is now about twenty-eight years. To get to age fifty, the most important step is to get to age one; 95 percent of those who make it that far can expect to live the remaining forty-nine years.

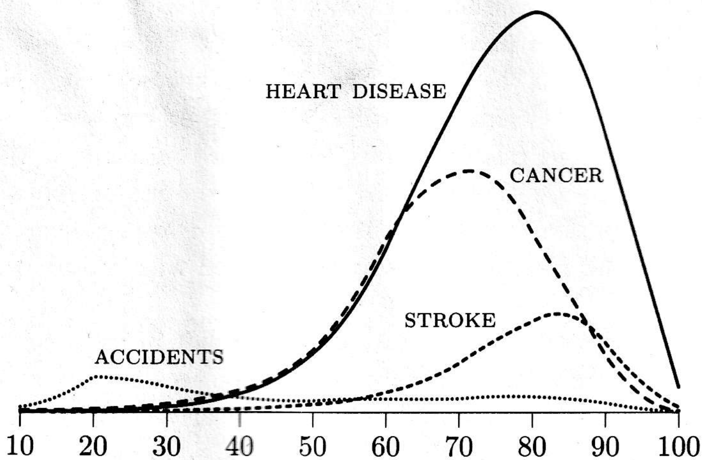
The difference between young and old in terms of improvement in survival prospects is even more evident if we go still further back in time. When the Constitution took effect in 1789, over two hundred years ago, life span data were kept in Massachusetts. At that time, and in that place, the expectation of life at birth was about thirty-five years, compared to seventy-five today. By contrast, the remaining life expectancy at age sixty was fifteen years in those days, and has now climbed to twenty. For old folks, the prospect of a long life ahead is not so much better now than it was then. Of course, people who made it to sixty in the late eighteenth century must have been pretty tough.

When we finally do pass on to the ultimate resting place, what is the cause? The table on the next page lists the leading causes of death in 1985, while the graph displays the age distribution of the major contributors. The items in parentheses in the table are the major subcategories of the previous item, so that, for example, nearly half of all fatal accidents are associated with motor vehicles.

The table reflects a kind of snapshot in time, and is not a prediction of the future, if only because our population mix is not stable. There are nearly twice as many births as deaths in the United States, so we are a young crowd, and will stay so for some time to come. That affects

Cause	Number
Cardiovascular diseases	978,000
(Heart disease)	(771,000)
Malignancies	462,000
(Lung, respiratory, etc.)	(127,000)
Accidents	93,500
(Motor vehicle)	(45,900)
Pulmonary diseases, chronic	75,000
Pneumonia	68,000
Diabetes	37,000
Suicide	29,500
Liver disease	27,000
Homicide (including police)	20,000
Other	. . .
Total	2,086,000

Major causes of death in the United States in 1985



Age dependence of various causes of death in 1985 the table by giving more weight to diseases that primarily afflict the young. For instance, the figure below the table shows the peak age for cancer deaths at seventy-two, while that for heart disease is eighty, so the latter will increase in importance as the population ages. (People don't think of cancer as a comparatively young persons' disease, but it is.) The accidental deaths are represented by the lowest curve on the figure, are dominated by traffic accidents, and peak at age twenty. (Suicide is the second-largest killer of Americans between fifteen and thirty-five.) As subcategories of non-auto accidents, though we haven't shown a chart for this, drownings and poisonings are most important in the twenties and thirties, while falls, the second most important cause of accidental death, are most important for those over sixty, peaking in the eighties. All of these age-dependent effects will affect the relative importance of the various causes of death in the future. So will medical research, which will conquer current diseases, and biological dynamics, which will create new ones. In 1900 the leading cause of death in the United States was tuberculosis, a disease that is now responsible for less than one death in a thousand. And AIDS was unknown.

Note also that the graph is a display of the total number of deaths of each type in 1985, and is not the death *rate*. The fact that all the curves show a peak followed by lower values at the more advanced ages doesn't mean that we develop an immunity to death as we get older, only that there are fewer of us left around to die. Only about 5 percent of our population is over the age of seventy-five, a proportion that would increase to 8 percent if we had a stable population with the current mortality rates. Yet the ratios shown on the graph tell us a great deal about relative risks. Thus, at age sixty cancer and heart disease kill about the same number of us, while by age ninety heart disease kills five times as many as cancer.

Not only do most of these causes of death depend on age, they are also specific to the United States at this time. The suicide rate in Austria is twice as high as ours, and that for Italy half as high. The death rate from heart disease is a third as high in France, and a fifth as high in Japan. The death rate for stomach cancer is almost four times as high for the Japanese. The table is truly a cut in both space and time, and not the permanent condition of the human race.

The obvious messages are that the real killers in our society are circulatory diseases and cancer (responsible for 47 percent and 22 percent of all deaths respectively in 1985), and that technology has contributed very little to the fatality rate. To be sure, handguns are used in about half of the murders in the United States, and one in a hundred of us is doomed (statistically) to be murdered, but handgun technology hasn't changed as much in recent decades as has handgun proliferation. Handguns don't represent technological risk in the way that possible chemical and nuclear accidents do. On the other hand, it is fair to ask whether technology plays a role in the increase in cancer rates in recent decades, or whether the aging of the population is responsible. We owe technology for much of that longevity. Even there, the age-adjusted fatality rate has been decreasing for some time for nearly all types of cancer. There are outstanding exceptions for lung and respiratory cancer, where the undoubted cause is smoking. Only fanatics and tobacco merchants continue to deny this. Just as an example, the death rate (per hundred thousand) for such cancers, for women aged fifty-five to sixty-four, has increased by more than a factor of five in twenty-five years, from seventeen in 1960 to ninety-four in 1985. These are women who started smoking after World War II, when it became fashionable to do so, and the risk was unclear. This is the price for that token of emancipation—lung cancer is now a bigger killer than breast cancer for such women. Of course, women still have a long way to go before they catch up with men in smoking mortality. The fraction of males who smoke has decreased about 35 percent in the last twenty-five years; for females the decrease is much smaller, about 15 percent for the same period. Among high-school seniors, more females smoke than males. For people without a high-school diploma, smoking has hardly decreased at all. There is a social aspect to smoking.

Technology contributes most to our mortality table through motor vehicle accidents, since they would certainly not have occurred if the automobile had not been invented. Yet travel by horse over comparable distances would have been riskier, so even the automobile probably saves lives. Of course, this cannot be proved, because people would never have traveled as much on horses or on foot. Even now, we are more likely to be killed by a car (per mile traveled) when walking than when we are driving. It has been observed that if we really want to save pedestrians' lives, we should put them in cars.

Other widely feared technological hazards, like nuclear power, simply don't appear in the table because they cause so few fatalities. In the case of nuclear power, the fear is of a catastrophic event, so the fact that no one was killed by nuclear power last year is not especially persuasive to the fearful. There is a whole class of risks which appear as the remote probability of a calamitous event, and the rational treatment of such risks—to neither overplay nor underplay them—is not trivial. We do rightly worry about a major nuclear accident, of which there has been at this writing just the one at Three Mile Island in this country, which killed no one, and the one at Chernobyl in the Soviet Union, which has killed thirty-one so far; we do worry about large airplane crashes, of which there are typically one or two per year; we do worry about devastating earthquakes, which occur less than once per generation in the United States; we do worry about the collapse of a large dam, and so on. Some even worry about visits from alien civilizations, less likely than any of the above. The challenge is to do our worrying constructively, without paralyzing our civilization.

In addition to all these rare but familiar eventualities, there are the truly apocalyptic technology-based risks, whose damage lies in the distant future. The burning of coal and oil has combined with massive deforestation of the earth, the latter to accommodate the spread of population (there are more of us, we need room to live, and we have an inclination to eat), to cause a steady and easily measurable increase in the carbon dioxide content of the atmosphere. No one doubts that this will affect the climate, but we are not sure by how much, or when, or what the effects of the climate change will really be. It may or may not be true, for example, that worldwide flooding of coastal regions, from the melting of the Antarctic and Greenland ice caps, is in the cards. Though some melting would inevitably accompany a worldwide warming trend, we cannot yet predict just how much.

The same is true of health effects from fluorocarbon-induced ozone depletion of the atmosphere, or the poorly quantified climatic effects of nuclear war (the so-called nuclear winter), or a number of other grand-scale risks. All are real, posing long-term threats to humanity, but all are sufficiently remote to give us a little time to get our act together. Whether we have the will and wisdom to do so is another matter.

2
The Measurement of Risk

Webster's Unabridged *New International Dictionary* (the revered Second Edition) says that risk is "hazard; danger; peril; exposure to loss, injury, disadvantage, or destruction." It distinguishes risk from hazard by suggesting that a risk is more often voluntary, a hazard the product of chance. Hazard itself is an old game, of which craps as we know it is a simplified form, and is defined in the (equally revered) *Oxford English Dictionary* as "a game at dice, in which the chances are complicated by a number of arbitrary rules." These definitions contain the essentials of risk, combining the idea of loss with that of chance or probability. The latter is crucial, since the inevitable may be unpleasant, but it lacks the element of chance and is not risk. Death and taxes are presumed to be inevitable. Only efforts to evade the latter are risky, though the risk is accepted by many in return for potential gain.

Mathematicians define probability as a number between zero and one (a fraction, if you like) that measures the chance that something will happen. A probability of one means an event is a sure thing, while a probability of zero means it is impossible. A probability of 1/2, or 0.5, means it is likely to happen about half the time, a tossup, or even money. In everyday life, people rarely speak of probability in this sense, but they do speak of odds, and they even gamble. To say that the odds are two to one that a given team will win a football game means that the chances of winning are two out of three, and of losing, one out of three. The probability of winning is thus two-thirds or 0.667, a number between zero and one. Odds and probability are always related in this way, so a probability of 0.01 can be thought of as ninety-nine to one odds against. Most people are more comfortable with the idea of odds than with probabilities, presumably because of the experience most of us have had with gambling. In fact the members of our society with the deepest practical knowledge of probability may well be the professional gamblers. They know far more than the amateur gamblers, who squander their substance on illusions like "winning streaks" at dice and lucky numbers at horse races. According to a recent poll, half of the American people believe in lucky numbers.

There are four broad categories of risk, covering most cases.

1. The familiar high risks, which exact a large toll, and on which we have good information. Driving and hang-gliding are reasonable examples.
2. Risks of low probability, whose consequences are so large that they must be taken seriously. An example might be a large earthquake.
3. This category might be considered an extension of the second—events whose probability is so very low that they have never happened at all, yet, but whose

prospective consequences are so awful that they deserve attention. An example might be a major destructive change in the climate, as a consequence of atmospheric pollution.

4. Finally a collection of substantial risks which, though real enough, are hard to evaluate because they show up as increases in naturally occurring hazards. Examples might be any of the cancers caused in part by environmental contaminants, where the additional incidence is hard to separate from the "natural" rate.

An example of the first category—familiar risk—might be the chance of demise in an automobile accident, while driving from Los Angeles to San Francisco and return. So many have done this, and so many have regrettably perished along the way, that the odds of survival are known. Average statistics show that there are about three trillion passenger-miles accumulated in the United States each year, in passenger cars, with about 45,000 fatalities due to all forms of motor vehicle travel. Only(!) about 25,000 of these are actually occupants of passenger cars—we'll see all the categories in Chapter 13—so the chance of getting killed is just about one in a hundred million miles of travel, for an average occupant.

The trip is about four hundred miles each way, so the risk of untimely death is about a chance in a hundred thousand. About one in forty thousand Americans dies each day, so the incremental risk of death from the trip is equivalent to the normal likelihood of dying in somewhat less than half a day. The risk seems acceptable, and there are mighty few who would make the risk estimate before setting out on the trip. Further, each driver is inclined to consider himself (or herself) so skillful that nothing can conceivably happen. Besides, when we have done something successfully for a long time we become complacent. It's a truism that no living driver has had the direct experience of being killed in an automobile accident, and lack of firsthand knowledge affects our attitudes.

We worked this out in some detail, just to show how this kind of well-known risk is calculated when there is long experience and a wealth of information. There was no need to even use the nationwide statistics, since that particular trip is taken so often that specific data are available. The calculation could even have been subdivided according to young drivers or old drivers, male drivers or female drivers, freeway or scenic route—all the relevant information is available. These common risks are easy to analyze, because we have the data.

Estimates of the *consequences* are more difficult, involving highly personal questions of value, which most people prefer to avoid. For example, a typical accident insurance policy available at airports doesn't only insure a passenger's life. It pays the same benefit for loss of life as for the loss of any two items from a list consisting of one's hands, feet, and eyes, but only half the benefit for the loss of one item from the list. While gruesome, that implies that someone has made a judgment about the value of these body parts to the average airline passenger, and has equated eyes to feet, etc. (People haven't always thought that such tradeoffs were appropriate. In Exodus, the Bible says, "life for life, eye for eye, tooth for tooth, hand for hand, foot for foot ....")

It is not easy to assign value to such losses. When dealing with tangibles, like property, it is useful to speak of replacement cost, or repair cost, or some such measure, but that kind of estimate tends to lose its cogency when applied to things that cannot be replaced or repaired. (It is relatively easy to replace people, but impossible to replace specific people.) A passionate debate therefore rages about the value of life, or even the value to be assigned to those irreplaceable items that contribute to the quality of life. What is the value of a beautiful sunset, or of an ancient redwood grove, or of Yosemite, or of Aunt Martha?

In any case, for the first category of risk—the common and familiar threats—the probabilities are available from statistical analysis of a surfeit of data, and assessment of the consequences is difficult only because matters of subjective judgment are often involved. Is a foot *really* equal to a hand or an eye? What is it worth to be able to walk across a street safely—more than eight thousand pedestrians get killed each year. Should there be traffic lights and crossing guards on every corner in each town with a population over ten thousand? A thousand? A hundred?

This question and the sunset question lead us to an important and widely misunderstood point. There are those who argue fervently that there is no limit to the resources we ought to expend to preserve life, and they take a dim view of risk analysts who try somehow to make an assessment of both sides of the equation. To do so does require putting a monetary value on a life, a limb, and on a beautiful sunset, so that we can judge how much to spend to preserve them. Money is, after all, our medium of exchange; its purpose is precisely to make it possible to trade in the value of things without bartering the things themselves. Yet analysts who try to set a value on life can expect a torrent of abuse for just making the effort. (When the Ford Motor Company did such an analysis for the threat of fire from collisions involving the Pinto fuel tanks, and decided that the value of the potential lives saved equated to an expenditure of about $11 per car, they were excoriated. It was not that the number they chose for the value of life—$200,000—was too small, it was that they had dared to set any value at all.) The standard expression used by opponents of risk/benefit analysis is that one is "comparing apples with oranges," which they believe impossible.

Actually, that unveils the flaw in the argument. Given a fruit bowl containing both apples and oranges, few of us will have much trouble making the choice. Given a shopping expedition to the supermarket, only the unusually indecisive shopper will have a problem. One could even test consumer response to different relative prices of apples and oranges, just to see which they like best, and indeed fruit merchants and supermarkets do that, so they can sell both commodities. The price represents a combination of relative cost to the seller and relative desirability to the buyer, as it should. Of course these value judgments are subjective; we are, after all, *not* machines. We make choices, and are often hard-pressed to defend them on logical grounds. So what?

The same point can be made about the need for traffic lights. Our society doesn't actually behave as if the lives of pedestrians were priceless. We allocate a certain level of resources to our democratic government, and that government allocates a certain fraction of those resources to traffic lights, after which we all accept the residual risk. Though the world is full of people who pontificate about the preciousness of life (and of course we all feel that way about the lives of those near and dear to us), we simply don't act accordingly.

The second category of risk is harder. Here the risk is real, but the probability so low that experience provides little guidance, yet the consequences are potentially so high that we are rightly concerned. Consider the chance of a major earthquake in Southern California, where this author lives. We know from occasionally exciting experience that we live in an earthquake-prone area, riddled with faults (cracks in the earth), and are smugly superior when visitors from the East are terrified by our routine small quakes. Major devastating quakes like the 1906 San Francisco disaster don't happen often, but are inevitable. Earthquakes are caused by the steady movement of the great tectonic plates of which the crust of the earth is made, and cannot be prevented. We can limit the damage they cause by building more resilient buildings, by research which can lead to improved understanding and perhaps even reliable warning, by improving emergency response capability, by public education, and so forth. All of those measures involve costs, and our willingness to incur these costs ought to depend on the probability that the event will occur in some reasonable time. We get our estimates of the probability from limited experience, and from theoretical understanding, neither of which is a precise guide. As a practical matter, we simply wait.

But we do try to expand our knowledge. We do as much research on the underlying causes as the country is willing to support, so that the sparse data can be used most effectively to make predictions. We have models, albeit imperfect, of earthquakes and floods and other natural phenomena, and reasonable estimates of their frequency. Since it has now been nearly a century since the last massive earthquake on the San Andreas fault in California, and since the internal stresses along the fault can be measured and are increasing, it is truly only a matter of time until there is a major event. (When this was first written, the California earthquake of 1989 had not yet occurred. It was small compared to the 1906 earthquake, and we are still waiting for the "big one.") We don't know where it will occur on the fault, when it will occur, or how much havoc it will wreak. Both the probabilities and the consequences are uncertain, and under those conditions we tend to do very little. At the University of California in Los Angeles a faculty committee estimated a few years ago that a number of the older buildings might not withstand a major earthquake, so there could be substantial loss of life if the event were to occur while those buildings were occupied by students. Yet there is no sense of urgency, and there are other demands on the scarce resources. The same can be said about the potential for dam collapse in the area.

The third major category of risk—things that have never happened at all, yet *could* happen—is even more remote. If they also don't do much harm we should forget about them, but if the results could be devastating, we ought to try to protect ourselves where we can. Examples abound, some technical and some not so technical. The consequences of a major nuclear war among the great powers would surely be so dreadful that we and the Soviets spend a substantial part of our gross national products on both equipment and activities designed to reduce the probability. It is unpopular in this country to try to do something about the consequences (like build shelters), because that is misinterpreted by some as accepting the inevitability of nuclear war.

This is the category that suffers most from misunderstanding of what is implied by a low probability. A low probability means only that; it does not mean that an event will never happen or can somehow be avoided. Acceptance of the fact that small probability doesn't mean zero probability is the beginning of understanding. In the case of nuclear war, one has to believe that the probability is precisely zero to insist that efforts to mitigate the potential consequences are misguided. Even though we all hope and work to avoid such a catastrophe, it is wishful thinking and a kind of arrogance to assume that success is guaranteed, and that we need not contemplate failure. According to the Rogers Commission report, that kind of misunderstanding of probability contributed to the loss of the space shuttle Challenger in 1986.

There are many more examples of events of high consequence, and either low (but not zero) probability or remoteness in time. The impact of a large meteorite on a city could kill millions, but since little can be done about it we don't even try. The steady increase in the atmospheric concentration of carbon dioxide has already been mentioned, with its potential to cause worldwide climatic catastrophe. Nuclear war itself.

This low-probability high-consequence category is in one way the most interesting of the four, since the estimates of *both* consequences and probabilities must be based entirely on theory. The probabilities come from probabilistic risk assessments (more later) with inevitable uncertainties, and the estimates are apt to generate disagreement and confusion. There is nothing intrinsically wrong with disagreement—democracies are supposed to thrive on it—and uncertainty itself is a legitimate and honorable feature of any scientific enterprise. Yet legitimate uncertainty provides an opening through which demagogues and technical charlatans can get into the act, and can exert disproportionate and ultimately destructive influence on public decision making. It is a source of great anguish to this author that so much of our public policy on technological risk is determined by lawyers acting as if they were technical experts, and by show business personalities trading on their commercial success in playing fictional roles. Both are out of their element.

There are many examples for this category, all different. We have not yet experienced a major commercial nuclear accident in this country, yet it is inevitable. Such are the laws of probability—if the probability is not zero, the event is ordained, given enough time. We need to know the probability, the likely consequences, and the best ways to reduce the probability *and* the consequences. We spend a great deal of money on regulation of the nuclear industry (the budget for the Nuclear Regulatory Commission alone is over $300 million annually), but continue to lack any agreed sense of "how safe is safe enough." Therefore we have no way to know when we've done enough, and should point our efforts elsewhere. The nuclear energy community is responsible for many of the most impressive advances in risk analysis in the last fifteen years, and also for much of the support for research in seismology (an earthquake can damage a nuclear power plant), but the probability of a major accident remains remarkably uncertain. That opens the door to the mischievous, who exploit uncertainty.

The fourth and last category—known risks that are increased slightly by technology—is often the most frustrating. It includes a whole menagerie of threats for which both probabilities and consequences are elusive. Not because the effects are unfamiliar, but because they are so familiar, and the extra damage is such a small increment in our already imperfect world. The classic examples are the health threats posed by low levels of natural or commercial chemicals, and the effects of low levels of radiation. The fear of contamination (for health, not æsthetic reasons) sometimes approaches the classic symptoms of a phobia, yet the threat is real, and we are well advised to do our best to understand it. Our problem in assessing the probability of harm from these contaminants is that the effects are so small, despite the clamor they often generate. We can make a few general comments here, but each is a separate case, and we'll go through some examples in Part II.

There is no doubt that certain chemicals in the environment, or in our food or drinking water, can cause cancer in people at some concentration, with exposure over some period of time. In no case do we know a magic exposure level below which a chemical is "safe" and above which it is dangerous. The important question in understanding chemical carcinogenesis is to determine the cancer induction rate for different exposures and exposure periods, so that public policy can be geared to reducing the risk to an acceptable level. It cannot be reduced to zero, especially since many of the worst offenders are in the natural environment. (Aflatoxins, found in peanuts, are among the most powerful carcinogens known, but who would think of banning peanuts at baseball games?)

The difficulty is that, since cancer is such a common disease (22 percent of us now die of some form of cancer), it is statistically almost impossible to determine just which cancer cases are due to what cause. Sometimes particular forms of cancer can be associated with identifiable exposures—that's how we know, beyond doubt, that smoking is by far the major cause of lung cancer in the United States—but we can't measure cancer induction directly at very low exposure levels. The chemical effects, if any, are swamped by the more than 400,000 "normal" cancer deaths in the population each year. (Some experts believe that oxygen is a culprit in the normal occurrence of cancer. It would be interesting to see an effort to purge the atmosphere of oxygen, or to make it illegal to breathe.)

It is the same with the effects of low levels of radiation. We know that large doses of radiation can cause cancer (or, paradoxically, sometimes cure it), but again have no way to learn whether that is true of the low doses that are associated with such things as the normal cosmic-ray background or competently delivered medical and dental x-rays. At low doses the effects are simply too small to be measured, and it may be that the lowest doses are harmless. But we don't know. If we wish to administer our society in such a way that we are not exposed to excessive risk, yet also don't overreact to small or negligible threats, we are in a pickle. Chapter 15 is devoted to this.

Finally, we have to deal with what the experts call risk aversion, relevant to all four categories. Up to now we haven't made any distinction in importance between the probability of an event and the consequences of that event, though risks that have *both* low probability and low consequences have been ignored—that is just common sense. It remains to ask whether a better measure of risk can be formed from some combination of the probability of an event and its consequences. Which matters more?

People running an insurance company find this easy. They multiply the probability of the event by the amount of the potential loss, call the product the expectation of loss, and use that as a final measure of risk. If an event has a chance in a thousand of happening, but would cause a loss of a million dollars, the expected loss is a thousand dollars. A non-profit insurance company, if one could be found, would charge that as a premium. This works because the fictitious insurance company might have a thousand such policies to cover, which would lead it to cover one loss on the average, using up the million dollars it had collected in premiums. Multiplying the probability by the value of the loss is good economics, and most reputable insurance companies function that way, adding to the premiums enough for overhead, profits, advertising, salesmen's salaries and commissions, and other perceived necessities. They would behave this way no matter how large the policy, provided the potential loss doesn't have the potential to bankrupt the company. (That would change the rules, as is known by many gamblers who have bet everything on the last roll of the dice.)

But people are not insurance companies, and there is a school of thought that holds that larger losses have to be considered worse than would be implied by the value of the loss, and therefore have to be held to even lower probabilities than the multiplication procedure would suggest. In that way of thinking, one large loss is worse than two smaller ones, even when they add up to the same amount of damage. An event that could destroy ten thousand homes would represent a higher risk than one that could only destroy a thousand, even if the probability were ten times smaller. This reasoning is what drives some companies to require that two high corporate executives not travel on the same airplane. (They often share a limousine to the airport, which can be riskier.) Though the probability that at least one will be killed is twice as high if they travel separately (either airplane can crash), the probability that both will be killed is much lower, and it's more important to avoid that catastrophe. Many people seem to think that way.

Much of the argument against nuclear power has risk aversion as its basis—though the probability of a major accident is extremely low, the consequences could be so severe that the technology is deemed unacceptable.

In the rest of the book we'll measure risk by the product of the probability and the value of the loss, the way of the ideal insurance company. Even some major insurance companies occasionally lose track of the familiar rules. In 1971 Lloyd's of London was asked to write an insurance policy to protect the Cutty Sark liquor company against the possibility that someone might catch the Loch Ness Monster that year. Cutty Sark had offered a prize, and was suddenly (and inexplicably) concerned that it might have to pay. Lloyd's had no way to judge the probability of capture, especially since the monster may not exist, but wrote the policy anyway, charging an outrageous premium that bore no relation to any reasonable probability of loss. Cutty Sark paid, apparently without haggling. Nobody made any pretense of calculating the product of probability and consequences. (It was pure profit for Lloyd's—the monster wasn't caught. Surprise.)

3
The Perception of Risk

We in the affluent societies are preoccupied with safety, while risk is recognized as a normal condition of existence by the less fortunate. Somehow the strange idea that the world owes us a risk-free life is a relatively localized and recent phenomenon, pretty much confined to the Western industrialized world. Even in the United States it tends to have regional emphasis—more in the West than in the Midwest, more in the North than in the South, and so on. Perception is very personal, and generalizations can be treacherous.

One perception of risk has a long history among primitive peoples, still flourishes in some segments of society, makes risk easier to accept, and appears in many of our insurance policies—denial of its existence. Insurance policies often refer to acts of God, implying that what happens is ordained by a higher authority, and is not just chance. It is a form of fatalism. Those who firmly believe that misfortunes are inflicted on us from above ought to go no further, because rational risk management won't help in that case. What is actually done to manage our exposure to risk depends, of course, on whether we think it threatening, and whether we think we can do something about it. The first of these is the subject of this chapter.

How, then, do people recognize risk? What criteria are used to determine whether a risk is acceptable? What makes us fear some threats while ignoring others?

In particular, what is meant by the word "risk" when dealing with the ultimate fear, loss of life? Up to this point it has been the likelihood of untimely death (when is death not untimely?), but there is more to risk than that. Insurers openly, and most people subconsciously, carry some sort of assessment of the relative values of life (both shortening and loss) and of various deformities or injuries. We mentioned airport insurance policies in the last chapter. We all have different values, based on such factors as early experiences, education, circumstances, personality, etc. Chapter 1 began with the observation that fear and risk are two different creatures, yet an individual's response to risk depends very much on the nature of his fears, rational or irrational. Consider some examples.

Looks, to some of the more fortunate among us, can assume such a central role as to be more important than life itself. In California, disfigurement through involuntary tattooing has been found by the courts to be equivalent to mayhem, a term encompassing loss of a limb or of some other vital part. Yet voluntary tattooing continues to thrive, so at least some feel otherwise. Of course it depends on the nature of the tattoo. Even in California it is illegal to tattoo a minor, voluntarily or involuntarily.

Some will jeopardize their lives to protect property, and most will do so to protect loved ones from injury. Many still cling to the old values, and will risk their lives to protect their country, while all too many will do so to promote their religion. The dictum (still adhered to, but now considered sexist) that in an emergency one ought to sacrifice the men to protect the women and children has its roots in a distant era, long forgotten, when there was a shortage of people. The world does not now suffer from such a problem.

We will deal with loss of life through two principal measures: the chance of untimely death itself and some version of the so-called YPLL, years of potential life lost. The latter is often used among risk analysts, most often counting only the years before age sixty-five as *really* lost. This gives expression to the view (shared by few senior citizens) that a risk imposed on old folks is somehow less damaging to society than if it threatened the young. It is sometimes assumed that the value of a person's remaining productive life is proportional to his or her remaining life expectancy, or to the remaining pre-retirement years. A person with twenty years remaining is then considered twice as valuable as one with only ten. Such a procedure actually overvalues the economic worth of the twilight years. In cold impersonal economic terms, the very old and the very young consume more than they produce, while those in the middle years support themselves and the others. Over a lifetime, we more or less break even, and neither productivity nor personal attachments are directly related to the number of years left. Yet medical statistics are commonly expressed in terms of YPLL, and the objective of medical procedures is life prolongation—not salvation, which is the responsibility of other specialists. In the version of YPLL in which only the lost years before age sixty-five are counted, the lives of those over that age are regarded as valueless—hardly a defensible position.

We'll use the term risk loosely, most often just in terms of life lost.

Even the term "untimely" poses problems when used to describe death. The Centers for Disease Control use the term premature to describe a death that occurs before the age of sixty-five, and publish death rates in all three forms: YPLL (before age sixty-five), premature deaths (again before age sixty-five), and crude total mortality rates. The table in Chapter 1 used crude mortality, and heart disease and cancer led the list of causes of death. But heart disease afflicts older people more than does cancer, as was illustrated through the graph in Chapter 1, so a comparable table for premature deaths will have these two causes nearly equal. (The graph shows that they run neck and neck up to about age sixty, at which point cancer levels off, before starting to decline in the years after seventy-two, while heart disease continues to increase. By age ninety, the vast majority of all deaths are attributable to either heart disease or stroke.) If we take the next step, and list causes of death in order of YPLL before sixty-five, both of these take a back seat to unintentional injuries, or accidents, which are the leading cause of death among the young. In terms of YPLL the four big ones are accidents, cancer, heart diseases, and suicide/homicide, in that order. At age twenty-one accidents are by far the leading cause of death, and three-quarters of those are motor-vehicle accidents. There are even regional and local differences—in terms of YPLL the District of Columbia is nearly twice as dangerous as the worst state in the union. Can one ask about the value of life without specifying *whose* life?

The elements most frequently mentioned as affecting an individual's perception of risk are:

1. Is the risk voluntarily assumed, or imposed by outside forces? Smokers often rely on this for part of the rationale for continuing to smoke. "It's my choice!" Risk is even easier to accept for a member of a group sharing the same situation, since mutual reinforcement can suppress any lingering doubts about the wisdom of the course. In the military world, this is known as *esprit de corps.*
2. Is the risk familiar or unfamiliar? Ghost story writers, carnivals, and demagogues exploit fear of the unknown. This is one reason why low-probability risks often seem worse than those of high probability—they are bound to be less familiar. The least familiar are, of course, those that have never shown their faces.
3. Does the risk lead to immediate harm, or is the day of reckoning far in the future? With apologies to Omar Khayyám, heed not the rumble of a distant drum.
4. How is the risk expressed? People are extremely vulnerable to verbal cues—this is known to risk analysts as the framing question.

The first of these requires little discussion. People are quite willing to assume risk, sometimes just for fun and sometimes as part of the job. When they do, it is often with little clear idea of the magnitude of the risk, provided they believe they control their own destinies. This stood out clearly in the mid-1970s, through the widespread resistance to compulsory seat belts. During the short-lived reign of automatic seat-belt interlocks (the pesky things that kept you from starting your car unless you were belted in), it was fashionable to disconnect them as soon as a new car was delivered. The dealer would offer the service as a freebie. In the end, the interlocks were so frequently disconnected that they had to be abandoned.

Both air bags and mandatory seat-belt laws have the same problem. Though the open argument about these unquestionably life-saving measures is about their cost and effectiveness (exaggerated by enthusiasts in the heat of the debate), the submerged issue of coercion *vs.* voluntarism is at least as important. Who likes the do-gooders who arrogate to themselves the right to protect us from ourselves? We didn't ask them to.

We've already mentioned the second item—familiarity of the risk. People exaggerate the risk in the unaccustomed. More people are still afraid of flying than of driving, though the fatality rate for commercial aviation is about one fatality per billion passenger-miles, with automobiles ten times worse. Xenophobia, the fear of other countries and cultures, has sometimes been justified by experience, but unfamiliarity plays an important role. Americans are notorious for their suspicion of those who don't speak English. The most exaggerated current fear is probably that associated with the storage of high-level nuclear waste, with deep roots in the unfamiliarity of radiation. Despite the essentially unanimous view of informed scientists and engineers that the risk is grossly overrated, the fear remains. Yet the radiation level in this room, as this is being typed, is higher (because of trapped indoor radon and its products) than it would be directly on top of a nuclear waste repository. Anyone who really fears nuclear radiation ought not to write a book indoors.

The third factor, timing of the consequences, is both more interesting and more subtle. Some risks pose immediate threats to life and limb—driving, mountain climbing, walking under ladders, entering a tiger's cage, and the like. For these we could in principle work out the chance of catastrophe and judge whether the activities carry, on balance, compensatory rewards. Bad luck carries consequences both timely and unmistakable. You take the chance, and pay the piper if you lose.

On the other hand, a person exposed to a dreadful disease (like AIDS or leprosy, or smoking-induced emphysema or lung cancer) may or may not contract the disease as a result of the exposure, and the consequences may be a long time coming. AIDS typically takes over ten years, while the consequences of smoking or radiation exposure or exposure to chemical carcinogens can be delayed twenty or thirty years, or even more.

At the far end of the time scale, there are risks whose damage lies in the distant future, affecting future generations. Major climatic change from the continued burning of coal and other fossil fuels (the greenhouse effect) is generally estimated to be twenty to a hundred years away (though it could come sooner), while the opponents of a nuclear waste repository speak animatedly of what might happen in a thousand to ten thousand years. (To see the futility of looking that far ahead, imagine the people of ten thousand years ago planning for our welfare. That would take us nearly back to Cro-Magnon. With the best of intentions they couldn't have known how to help.)

In this author's direct experience, the record for distant vision is held by a former governor of California, who worried about the welfare of the people who will live (we hope) a hundred thousand years in the future. If instead we think back a hundred thousand years, about the time *Homo sapiens* first appeared on earth, we might ask what those early ancestors could have done for us, other than survive. In the grand scheme of things, and assuming we wish well for the human race, survival is the single most important duty we have toward our descendants. Everything else, including the quality of life, comes after that. If we don't survive, they won't exist. It is pretentious to suppose that they will share our sense of values, or that we can predict their needs.

How then should we deal with risks that threaten future loss? There must be some outer limit for concern, a time beyond which there is just no point in fretting, whatever our sense of responsibility. The self-destruction of the sun is currently scheduled for a few billion years from now, but it makes no sense to prepare for it. We rightly pay less attention to risks whose day of reckoning is far far away. For most people the span of concern extends through their own lifetimes and those of their children—for some, not nearly that far. Of course we should prepare for and tend to the future, out of a decent sense of social responsibility, but should do so with humility and perspective.

Economists and bankers have no problem dealing with future contingencies—they do it every day—and the mechanism is discounting, as with an annuity or compound interest. The latter is more familiar to most people. With an annuity we make small payments now in the expectation of greater rewards (a comfortable retirement) in the future, while with compound interest we voluntarily give up the use of our money, so that it can build to larger amounts in the future. In both cases the value of something in the present is deemed to be higher than if it were deferred to a later time. (Bird in the hand, and all that.) No law of nature asserts that the future is less relevant than the present, but people have behaved for many centuries as if it were. Experience even provides a guide for the rate.

Given a choice between a calamity this year—say a broken leg—or one in ten years, few will decide to get it over with. Anything can happen between now and then, and even the Devil can be cheated of his due, if we are to believe Stephen Vincent Benét. Conversely, given a choice between a gift of a million dollars this year, or an inheritance of the same amount in ten years, it would take some kind of nut to opt for the latter. Deep in our hearts, we do know that we should discount the future, though the discounting rate depends very much on psychological factors like our sense of security. Banks and investors make such discounting a practice, and it is possible to learn about our collective wisdom from their experience. Judging from the rates used for savings accounts, investment returns, and similar trades of present wealth for future benefits, the rate at which we have historically discounted the future seems to be between 5 and 10 percent per year (over inflation, of course).

This practice goes both ways. We are willing to give up present good for even greater rewards later, which is called investment, and we insist on paying less now for something to be delivered in the future, which is called discounting. They are in principle the same. It is only one step from there to the concept called insurance, which means that the policy holder doesn't wait for loss, but pays premiums now as a hedge against a future cost. A trust fund is the same as investment; resources are squirreled away (with interest) for future withdrawal. If the future withdrawal is to deal with a future contingency, and is made available at the time of the contingency, it is called insurance, and the investment is called a premium.

All of these financial shenanigans are based upon the same concept—anything destined for the future is worth less now, whether it is good or bad. As was said earlier, this doesn't have the status of a law of nature, but is simply an observation about millennia of human behavior. (Incidentally, none of this is to be confused with inflation, which simply devalues the unit—money—in which things of value are measured. Allowance for inflation is an additional consideration when using money as the medium for future planning.)

To put it more explicitly, suppose the discount or interest rate is 10 percent, and an investor wants to have $10,000 at the end of a year. It would be necessary to invest $9,090.91 now, so that the accrued interest of $909.09 would bring the total to the needed $10,000 after the year. If the investor could wait two years, the needed investment would be $8,264.46, and so forth, so that the accumulated compound interest and principal would add to the $10,000 after the proper time. Ten years would reduce the needed investment to $3,855.43, and twenty years to $1,486.43, which is beginning to look like a bargain. Less than 73¢ will do it in a hundred years. (This is not investment advice.)

So the systematic way to deal with future risk is to treat it as if it were a business loss, and to determine its current value by discounting it at a rate of 5 to 10 percent per year. In 1972, the United States Office of Management and Budget (OMB) ordered all federal agencies to use a discount rate of 10 percent when calculating the costs and benefits of any intended actions. That was OMB's assessment of the proper level at that time. The order is still in effect, but widely ignored.

Most will agree that discounting is the logical procedure for dealing with the future (though some deny vigorously that it is relevant to questions of human life and health), but there is considerable controversy about the "right" rate. Reasonable people may differ, reflecting their different views of the value difference between the future and the present. Once the principle is accepted, however, there are dramatic consequences for decision making on risks; one will always devote more effort and resources to dealing with immediate problems. The future will be treated fairly, neither overrated nor underrated—both errors are common.

This issue of future loss will return in Part II, but a simple grand example can illustrate the point. The gross world product in 1986 (total of goods and services produced anywhere on earth) was recently estimated at something like $15 trillion, $15,000,000,000,000. Suppose we knew of an impending disaster (say, due to carbon dioxide buildup) which threatened to reduce this by one-third, a loss of $5 trillion, and a major setback for the human race, but the event was not due for two hundred years. Accepting the OMB recommendation of 10 percent as an appropriate discount rate, we could now ask how much should be spent today to avert such a tragedy. The answer turns out to be about $25,000, as a one-shot investment. That amount can either be spent now to avert the disaster, or invested in a savings account, so the $5 trillion will be waiting in the bank when it is needed. (What bank, you may well ask, but bank is just a figure of speech.) A discount rate of 5 percent would have led to an answer near $300 million, and a reasonable number probably lies somewhere between. Neither of these appears to be particularly expensive as the cost of prophylaxis or cure for a misfortune of that magnitude—a single airplane can cost $300 million these days—and most of us would probably want to make the investment, out of an unquantifiable sense of responsibility for future generations. We can think in terms of two hundred years. If we were talking about a thousand years into the future, that might be a different matter. The cost would be negligible, far less than one cent, but that is pretty far off, and we might simply not care.

This is all relevant to the perception of risk because, though all the above is economically beyond reproach, we don't all understand economics or compound interest, so we tend to waste current resources on distant threats. The billions being squandered on the quest for an absolutely safe nuclear waste repository provide a classic case, as we will see later. To make it worse, we also often err on the other side in this age of instant gratification, and both government and corporate leaders are reluctant to invest in the future. Very few of our major industries now support basic research, even in their own areas of interest. Marketing of today's products is deemed more important than the development of tomorrow's. It is a curious paradox that aversion of future harm seems more important than the promise of future benefit. That was not always true. Those who are unwilling to invest in the future haven't earned one.

The fourth important contributor to the perception of risk is the way the risk is portrayed—the framing question. It is easy to illustrate by asking people to make decisions on risk questions, when the same questions are alternately framed in terms of either benefits or losses. It turns out that they will usually take chances to minimize or avert a loss, risking a greater loss, but are more likely to go for a sure thing to secure a gain. Obviously, as all observers of gambling casinos know, there are variations among people, but these are the most common patterns.

One way to make the point consists of offering people a chance to flip a coin for a prize of $1,000, with no loss if they fail, but offer them a chance before the toss to suggest a settlement payoff. That would be a kind of settlement out of court. It's a clear winner, a possible gain with no chance of loss, but what is it worth? Since an even-money chance of winning $1,000 gives an average expectation of gain of $500, one would expect people to be willing to sell the opportunity for about that much. Yet tests show that they will settle for about $350, on the average. They want the sure thing, even if they don't get as much, and are willing to pay for it. This is the gain case.

If, on the other hand, the rules are changed just a bit, so the player is *given* $1,000, and asked to toss the coin to decide whether he has to give it back, his decision changes. It's of course the same thing, except that now he has the money in hand, and the coin flip is for a loss, not a gain. The probability is again that he will get to keep the money about half the time, so the expectation of gain is still $500 (the $1,000 in hand, minus the 50-50 chance of having to give it back). The big difference is that he already has the $1,000 and can savor it, so the gamble seems to be to avert loss, not to win. A mathematician should still offer to settle by paying back $500 to forego the toss, or, if he is consistent with the previous choice, he should be willing to pay $650 to assure the net gain of $350. But no, players still offer only about a $350 settlement, preferring to gamble everything on the chance of not losing anything. To a mathematician or statistician, or even to a professional gambler, this makes no sense at all. A professional gambler should lick his chops at the chance of meeting someone like this.

So people will generally gamble to avoid loss, but are conservative about potential gains. There they prefer to take the bird in hand. This assumes, of course, that they know the odds—very low-probability events, like lotteries and catastrophic accidents, are dominated by lack of information and understanding, as well as by superstition. In some tests, people who have just bought lottery tickets for one dollar have been unwilling to sell them back for two dollars. The bird in the hand is, in this case, no bird at all.

It is worth noticing that the very use of the term "risk" to define the subject of this book biases the issue. Had we used the term "safety," the psychological tone would have been different. This is recognized in the naming of federal agencies, all of which are devoted (at least in name) to assuring safety, and none to reducing risk. The Department of Defense, despite its name, is meant to wage war if necessary. The Department of Health and Human Services deals more with sickness than with health. The Department of Justice runs the FBI. The Department of Energy spends more on nuclear weapons than on energy. But the Centers for Disease Control, bless them, do exactly what the name implies. Still, euphemisms are the rule rather than the exception.

Sensitivity to the way in which questions are framed extends far beyond risk evaluation (where it helps to explain the routine exaggeration of low levels of risk) to other areas like amateur gambling and amateur (and some professional) investment strategies. Framing bias is unavoidable in connection with risk, since risk is rarely expressed in terms of how many people have escaped it. Imagine describing a day in the life of the airline industry by saying "Yesterday a million passengers rode the commercial airlines, the vast majority of whom were eventually deposited alive at some destination." Not much chance of seeing that on a billboard.

But what does our citizenry think of all this? About ten years ago an Oregon-based research organization asked four different groups of people—members of the League of Women Voters, college students, members of a business and professional club, and finally experts—to rank thirty reputedly risky activities in order of risk. Just comparing college students with experts, they found that the college students rated nuclear power public threat number one, while the experts put it in the twentieth spot. The experts rated motor vehicles number one, while the students rated it fifth (after nuclear power, handguns, smoking, and pesticides). And so forth. These discrepancies between fact and fancy carried across to the other groups, perceived risk often more dependent upon media coverage than on actual risk.

We mentioned in the Introduction a particularly egregious example of priority confusion, the decades-old question of fluoridation. By now, after a whole generation has grown up with drinking water to which a trace (about a part per million) of sodium fluoride has been added, many also using fluoridated toothpaste and mouthwashes, the results are in and are clear. Fully 50 percent of all children between the ages of five and seventeen have not had a single cavity in their permanent teeth. In the last decade alone, the number of children's cavities has gone down by about 40 percent. Further, the dire predictions for public health because fluorides are poisonous (true, in large enough doses, of many of the things we eat regularly, including fluorides) have not been borne out. Fluoridation has been as close to an absolute winner as can be found, nearly all benefit at minimal cost, with no detectable down side.

Yet the political pressures are such that, despite near unanimity among experts, about 40 percent of the American people live in areas in which the water has less than optimal natural fluoride concentrations, and none is added. Three of the ten largest cities don't adjust their water. In the entire Los Angeles Basin only two communities fluoridate their water, and the City of Los Angeles is not one of them. In effect, the anti-technology forces have made life so uncomfortable for the City Council that action in the public interest is bad politics. There is no vocal political constituency for good teeth, so a politician whose principal concern is to assure reelection cannot afford to waste goodwill on teeth. Fortunately, many of the deprived children use fluoridated toothpastes.

As an example of the quality of the debate, a recent anti-fluoridation publication asserted that most cases of AIDS are in cities that fluoridate their drinking water. It could just as easily have said that they occur in cities with a public library. Equally true—equally irrelevant.

Fluorides represent just one example of a familiar situation in which the common good is ill served by the democratic process. The problem is exacerbated by the emergence of groups of persuasive people who specialize in technology-bashing and exploitation of fear, make their livings thereby, and have been embraced by large segments of the media as experts. The next chapter deals, all too briefly and kindly, with this national problem, and with the distortion of priorities it brings with it.

4

The Politics of Risk

Since risk is a subject on which passions run high, it is necessary to say something about the players, and common decency requires that it be done as fairly as possible. Still, some of the participants exert a destructive influence on rational decision making, with consequent damage to all of us, and it would be disingenuous to pretend otherwise. This is a very short chapter devoted to recognizing the existence, in the United States and in Western Europe, of substantial and effective political forces that are simply opposed to technology, and use their political strength almost entirely for obstructive purposes. The German Greens are the most open about their platform, while the American equivalents are less well focused. They evoke in many of us a genuine nostalgia for a simpler life, a reaction to the fact that our technological world is simply harder to understand. The sense that we have somehow lost control of our destinies is certainly depressing, and an anti-technology posture can strike a responsive chord. Opposition to change, especially technological change, is a full-time profession for many, and the term "activist" is now used proudly, as if activism were honorable in itself, regardless of what one is active for or, more often, against.

The problem is exacerbated by a frightening trend in our society. Just as our lives are becoming more complex, interactive, computer-oriented, and—let's face it—technological, our population is declining in its educational level. It is no secret that the average scores on the standardized Scholastic Aptitude and Achievement Tests have been decreasing for many years, though the rate of decline seems to have been arrested in the early 1980s, and the scores have crept up a bit since then. Still, they are not even close to what they were only twenty years ago (they are fifty points lower), and the tests have not changed that much in their level of difficulty. To boot, the curricula in our schools have been greatly softened in the last few decades, academic achievement has been de-emphasized as a proper objective of education, science and mathematics have given way to more "relevant" material, and grade inflation has disguised the decline in standards from students and parents alike. All this has been documented in any number of reputable and solid studies, and railed against by any number of reputable scholars. In contest after contest in which our students are pitted against their foreign equivalents, we turn up near the bottom of the heap. All parents support—even demand—better education for their children, as long as it is in the abstract, but far fewer if it impairs the children's enjoyment of life, or faces them with the unthinkable—failure if they don't perform.

A partial consequence of this denigration of learning is that the fraction of our population that believes in UFOs and reincarnation is mind-boggling, less than half of us know that the earth goes around the sun once a year, and it is an unending struggle to keep the teaching of evolution legal in the schools. Americans are about evenly divided on whether evolution or creationism is more correct. Half the American people believe in lucky numbers. Finally, as a direct consequence, it has been estimated that American industry spends as much on remedial mathematics education each year as is spent on direct mathematics education in elementary schools, high schools, and colleges.

Many of us are dependent on television pictures and sound bites for our information, and formulate our positions on peace, war, the environment, risk, and the economy from the one-dimensional heroes and villains we see for a few seconds on the evening news. Those who have learned to dispose of complex points in five seconds or less appear on the talk shows, and all the television news programs have learned that their audience share depends almost entirely on their entertainment value.

It is worse among the young, who were raised in a television atmosphere. According to a National Opinion Research Center poll regular newspaper readership has decreased from 75 percent of the population twenty years ago to 50 percent now, while in the 18–29 age group it has decreased from 60 percent to 29 percent. In the 30–34 group it has gone from 75 percent to 45 percent. It is mainly the old folks, the over-sixty brigade, who still read newspapers. It has become an article of faith, encouraged in the schools, that anyone's opinion is as good as anyone else's, whether or not informed.

You, dear Reader, are in a distinguished minority—you are actually reading a book. Not only a book, but a book, however unworthy, that is meant to leave you somewhat better informed than you were before you read it. If it doesn't succeed it is truly the author's fault, not yours.

Our very literacy as a nation is in danger. The current estimates of the Department of Education are that a full one-third of us, seventy million Americans over the age of seventeen, are either functionally illiterate or only barely literate. The number is estimated to be increasing by about two million per year, even though the great majority of our children now graduate from high school. (More than 75 percent of the adult population has been through high school, compared to 25 percent in 1940.) Even more of us are functionally innumerate (the numerical equivalent of illiterate). Not only is this a work force which must be accommodated in an increasingly complicated and demanding job market, but it is also a population with rights and privileges, including the ancestral right to the pursuit of happiness. Above all it is a substantial electorate with a decisive voice in the ways in which our country responds to the challenges of technology. We are a participatory democracy and it is everyone's country, not just the educated. At the moment these words were first written, in March of 1988, not one of the eleven remaining candidates for the presidential nomination in the two major parties had had any scientific or technical training, and that was no accident. (The solitary one who did was one of the first eliminated from the race.) This is the backdrop against which the anti-technology forces work. The problems described in the last few paragraphs go so far beyond the subject of this book that we will leave them in a moment, despite their transcendent importance.

However, it is hard to resist mention of an interesting and perhaps even relevant story. We are told that in 1968 a poll was taken of a "representative sample" of German women, asking them what profession they would prefer in an ideal husband. At the top of the list was nuclear physicist. (Since this author is a male physicist with nuclear pretensions, that is heady stuff. Physicists, especially theoretical physicists, don't get many chances at a good fantasy.) Alas, in 1979 a similar poll produced a very different answer. Nuclear physicists didn't appear anywhere on the list of the first twenty choices—top of the heap was forest ranger. While the Germans love their forests, that is quite a change of preference, whose significance is too painful to pursue.

Technological risk provides a testing ground for the ability of a democratic society to manage its affairs in such a way as to assure the common good. Garrett Hardin, in his 1968 essay *Tragedy of the Commons,* made the point that a society can be badly served if each member of that society makes decisions aimed at serving his own perceived self-interest. The composite of individuals acting in their own interests can easily translate into a situation in which not only the society but each individual comes out badly. His example was a common pasture, in which each individual can appear to benefit by adding to his herd, leading to overgrazing and destruction of the pasture. We control such problems by accepting the strictures of government, balancing each individual's freedom of choice against the demands of the general welfare. The underlying logic breaks down when the government itself reflects no more than the sum of the individual choices, as is the case in a participatory democracy, and breaks down even more when the participants are ill-informed. Even a minority can then do real damage.

There is, of course, a history. In the early nineteenth century in England, as part of the Industrial Revolution, automatic machinery was introduced into the textile industry. This had the inevitable result that skilled craftsmen (with now obsolete skills) found themselves unemployed, through no fault of their own. Their resentment was originally directed at the machinery itself, especially the stocking-frames (machines used in the production of knitted stockings, which made it possible for relatively unskilled workers to produce stockings at more than ten times the historic rate), and the five years beginning in 1811 saw widening convulsions of rioting and destruction of machinery, at first only textile machinery, but later a wider variety. The rioters were called Luddites because their leader assumed the name General Ludd, after a perhaps mythical Ned Ludd who was alleged to have destroyed stocking-frames in 1779, and therefore to have been somewhat ahead of his time. The term "Luddite" has become opprobrious, and has come to mean anyone who is strongly opposed to machinery, or, by extension, to technology. It is quite appropriate here.

The Luddites finally generated a strong reaction in Parliament, which passed a law that made the destruction of stocking-frames a capital offense. After that a number of Luddites were hanged, and the movement crushed. The economic recovery that followed Napoleon's defeat at Waterloo, and the peace of 1815, probably also played a role in relieving the unemployment that fueled the riots.

An interesting sidelight of this miserable episode is the fact that Lord Byron's maiden speech in the House of Lords, at the age of twenty-three, was in opposition to the capital offense bill, and in defense of the Luddites. The distaste of poets for technology has a long history—read Walt Whitman's *Learn'd Astronomer* to get the flavor—but the cudgels have been taken up in modern times by the lawyers. There aren't enough poets to go around these days, and they can't be spared for this kind of work. On this one, however, technology won the next round. Byron's daughter Ada, Countess Lovelace, was one of the remarkable early figures in the history of computers, and a modern computer language is named after her. You can't keep a good gene down. Of course her mother was a mathematician.

Strangely, displaced workers do not form the core of the anti-technology movement today—it seems to be an upper-middle-class phenomenon. Such people are genuinely concerned that technology may be destroying the environment, and have presumably never seen the environment in other, less technically advanced, countries. (Mark Twain once said, "To be good is noble. To tell other people how to be good is even nobler, and much less trouble." With comparable relevance, H. L. Mencken once observed, "There's always an easy solution to every human problem—neat, plausible, and wrong.") It is a pity, since the environmental quality that is left to us does need vigorous and informed protection.

Up to this point, this chapter has probably (and not surprisingly) appeared one-sided, as if all the sins in the politicization of risk have been committed by the anti-technology elite. Unfortunately, that is not so. The counterpoint to the politics of ignorance is the politics of complacency, embraced by more than a few of the guardians and keepers of risky technology. The very low probabilities that go with some of the more unlikely threats to our health and welfare—nuclear accidents, nuclear war, the greenhouse effect (high probability in the future, but just beginning), etc.—can be misleading. The fact that the disaster has not yet come has led all too many to believe that it never will, and to relax. It is not easy to maintain vigilance when major accidents never occur, especially when the most strident prophets of doom are demonstrably uninformed, or even worse. Ignorance on the one side and complacency on the other (especially when combined with mutual contempt) are twin threats to the rational management of risk.