UNDERSTANDING RISK

One of the worst stumbling blocks in gaining widespread public acceptance of nuclear power is that the great majority of people do not understand and quantify the risks we face. Most of us think and act as though life is largely free of risk. We view taking risks as foolhardy, irrational, and assiduously to be avoided. Training children to avoid risk is an all-important duty of parenthood. Risks imposed on us by others are generally considered to be entirely unacceptable.

Unfortunately, life is not like that. Everything we do involves risk. There are dangers in every type of travel, but there are dangers in staying home — 25% of all fatal accidents occur there. There are dangers in eating — food is one of the most important causes of cancer and of several other diseases — but most people eat more than necessary. There are dangers in breathing — air pollution probably kills 100,000 Americans each year, inhaling radon and its decay products is estimated to kill 14,000 a year, and many diseases like influenza, measles, and whooping cough are contracted by inhaling germs. These dangers can often be avoided by simply breathing through filters, but no one does that. There are dangers in working — 12,000 Americans are killed each year in job-related accidents, and probably 10 times that number die from job-related illness — but most alternatives to working are even more dangerous. There are dangers in exercising and dangers in not getting enough exercise. Risk is an unavoidable part of our everyday lives.

That doesn't mean that we should not try to minimize our risks, but it is important to recognize that minimizing anything must be a quantitative procedure. We cannot minimize our risks by simply avoiding those we happen to think about. For example, if one thinks about the risk of driving to a destination, one might decide to walk, which in most cases would be much more dangerous. The problem with such an approach is that the risks we think about are those most publicized by the media, whose coverage is a very poor guide to actual dangers. The logical procedure for minimizing risks is to quantify all risks and then choose those that are smaller in preference to those that are larger. The main object here is to provide a framework for that process and to apply it to the risks in generating electric power.

There are many ways of expressing quantified risk, but here we will use just one, the loss of life expectancy (LLE); i.e., the average amount by which one's life is shortened by the risk under consideration. The LLE is the product of the probability for a risk to cause death and the consequences in terms of lost life expectancy if it does cause death. As an example, statistics indicate that an average 40-year-old person will live another 37.3 years, so if that person takes a risk that has a 1% chance of being immediately fatal, it causes an LLE of 0.373 years (0.01 x 37.3).

It should be clear that this does not mean that he will die 0.373 years sooner as a result of taking this risk. But if 1,000 people his age took this risk, 10 might die immediately, having their lives shortened by 37.3 years, while the other 990 would not have their lives shortened at all. Hence, the average lost lifetime for the 1,000 people would be 0.373 years. This is the LLE from that risk.

Of course, most risks are with us to varying extents at all ages and the effects must be added up over a lifetime, which makes the calculations somewhat complex. We therefore developed a computer program for doing the calculations and used it to carry out a rather extensive study of a wide variety of risks. Some of the results of those studies are summarized in the next section.

A CATALOG OF RISKS

One widely recognized risk is cigarette smoking. One pack per day has an LLE of 6.4 years for men and 2.3 years for women — in the former case, this corresponds to an LLE of
10 minutes for each cigarette smoked. For non-inhalers, the lifetime risk from one pack per day is 4.5 years for men and 0.6 years for women, while for those who inhale deeply it is 8.6 years for men and 4.6 years for women. (The differences between male and female risks may involve how deeply they inhale, or some of their differences in lifestyle and physiology.) Giving up smoking reduces these risks after 5 years the LLE is reduced by one-third, and after 10 years it is more than cut in half. Cigar and pipe smoking do little harm if there is no inhalation, but with deep inhalation the LLE is 1.4 years for pipes and 3.2 years for cigars.

Further understanding of the risks in smoking comes from examining the diseases from which smokers die more frequently. The following figures are death rate ratios for 1-2 packs per day, smokers to nonsmokers in the 35-84 age range. This ratio is 17 for lung cancer (i.e., heavy smokers are 17 times more likely to die from lung cancer than nonsmokers), 13 for cancer of the pharynx and esophagus, 6 for cancer of the mouth, 11 for bronchitis and emphysema, 4 for stomach ulcer, 3 for cirrhosis of the liver, 2 for influenza and pneumonia, 1.8 for cardiovascular disease, our nation's No. 1 killer, and between 1.5 and 2 for leukemia and cancer of the stomach, pancreas, prostate, and kidney.

Much attention has recently been given to the risk of being near a smoker. The best evidence on this is that the added risk of lung cancer for a nonsmoker due to being married to a smoker corresponds to an LLE of 50 days. There are probably additional risks due to other diseases, since only 13% of the deaths attributed to smoking are due to lung cancer.

Another major risk over which we have some personal control is being overweight — we lose about 1 month of life expectancy for each pound our weight is above average for our size and build. In the case of someone 30-pounds overweight, the LLE is thus 30 months, or 2 years. To assess the effect of overeating, we note that our weight increases by 7 pounds for every 100-calorie increase in average daily food intake. That is, if an overweight man changes nothing about his eating and exercise habits except for eating one extra slice of bread and butter (100 calories) each day, he will gain 7 pounds (gradually over a period of about 1 year) and his life expectancy will be reduced by 7 months. This works out to a 15-minute LLE for each 100 extra calories eaten.

Any discussion of major risks must include the traditional leader — disease. Heart disease leads in this category with an LLE of 5.8 years, followed in order by cancer, LLE 2.7 years; stroke, LLE 1.1 years for men and 1.7 years for women; pneumonia and influenza, LLE 4.5 months; and cirrhosis of the liver and diabetes, LLEs of a little over 3 months each, the former found more in men and the latter more in women by about 3 to 2 ratios.

One of the greatest risks in our society is remaining unmarried. Statistics show that a single white male has 6-years less life expectancy than a married white male; his LLE from being unmarried is thus 6.0 years. This figure is based on data obtained before AIDS appeared, so that is not involved here. One might suspect that part of the reason for these differences is that sickly people are less likely to marry, but this is evidently not the main reason, since mortality rates are even higher for widowed and divorced people at every age. The LLE for a white male, female in parentheses, from being unmarried at age 55 and not later marrying is 3.2 (1.0) years if he (she) is single, 3.9 (2.7) years if widowed, and 6.2 (2.5) years if divorced. For blacks these...
LLEs are 3.5 (4.1) years if single, 6.2 (6.0) years if widowed, and 6.0 (4.0) years if divorced. Note that males generally suffer more than females from remaining unmarried, and blacks suffer more than whites.

Unmarried people suffer excessively from a variety of diseases, and in general the widowed and divorced suffer from them more than those who have never married. For example, compared to married people of the same age, widowed males die more frequently from tuberculosis by 117%, from stomach and intestinal cancer by 26%, from lung cancer by 26%, from cancer of the genital organs by 23%, from leukemia by 8%, from diabetes by 41%, from stroke by 50%, from diseases of the heart and arteries by 46%, from cirrhosis of the liver by 142%, from motor vehicle accidents by 99%, from other accidents by 127%, from suicide by 139%, and from homicide by 69%. To mention a few extremes, compared to a married man of the same age, a divorced man is 6.1 times more likely to die of tuberculosis, 2.1 times more likely from lung cancer, 6.2 times more likely from cirrhosis of the liver, 3.8 times more likely from motor vehicle accidents, 4.2 times more likely from other accidents, 4.1 times more likely from suicide, and 7.2 times more likely from homicide.

Perhaps the least appreciated of all major risks is that of being poor, unskilled, and/or uneducated. The best data on the "unskilled" factor are based on occupational groupings. Professional, technical, administrative, and managerial people live 1.5 years longer than those engaged in clerical, sales, skilled, and semiskilled labor, and the latter group lives 2.4 years longer than unskilled laborers. Corporation executives live 3 years longer than even the longest-lived of the above groups, a full 7 years longer than unskilled laborers. A similar study in England showed even larger differences, finding comparable differences among wives of workers; the wife of a professional person lives about 4 years longer than the wife of an unskilled laborer. This indicates that the problems are not occupational exposures but rather are socioeconomic.

In seeking to understand the reasons for these differences, it is interesting to consider the causes of death. If we compare unskilled laborers with professional, technical, administrative, and managerial people in the United States, their risk of early death from tuberculosis is 4.2 times higher, from accidents 2.9 times higher, from influenza and pneumonia 2.8 times higher, from cirrhosis of the liver 1.8 times higher, and from suicide 1.7 times higher. It is also 30% higher from cancer and 13% higher from cerebrovascular disease, but it is 8% lower from arteriosclerosis and diabetes. The large factors in this list are from causes associated with unhealthy living conditions, limited access to medical treatment, or unenlightened attitudes toward health care, and are thus generally preventable. This would seem to be a fertile field for social action.

A similar pattern appears in correlations between life expectancy and educational attainment. College-educated people live 2.6 years longer than the average American, while those who dropped out of grade school live 1.7 years less than average, a 4.3-year differential. These differences are about the same for men and women, which indicates that occupational exposures are not the basic problem here. Dropping out of school at an early age ranks with taking up smoking as one of the most dangerous acts a young person can perform. Even volunteering for combat duty in wartime pales by comparison; the LLE from being sent to Vietnam during the war there was 2.0 years in the Marines, 1.1 years in the Army, 0.5 years in the Navy, and 0.28 years in the Air Force.

The data on poverty are truly impressive. In one study, the Chicago area was divided into sections based on socioeconomic class. The difference in life expectancy between the highest- and lowest-class sections was 9 years for white males, 7 years for white females, and nearly 10 years for nonwhites of both sexes. A Public Health Service survey in 19 U.S. cities found that mortality rates in poverty areas were typically 70% higher than in non-poverty areas, which corresponds roughly to a 10-year difference in life expectancy. Incidentally, in this survey the differences were substantially less than average for Chicago, where the detailed study described above was made.

There is also an abundance of data from foreign sources. In one study, Montreal was divided into sections by socioeconomic class, and the difference in life expectancy between the highest-and lowest-class sections was 10.8 years for men and 7.3 years for women. A Canadian Ministry of Health Study in 21 cities divided the population into five equal parts (quintiles) by income, and found a difference in life expectancy between the
Within technologically advanced nations there are effective programs to provide poor people with reasonable medical care and an adequate diet, but such programs are much fewer and less effective on an international basis. This leads to much larger variations of life expectancy with socioeconomic level, as evidenced by correlations between life expectancy and per capita gross national product for various nations. In well-to-do countries like the United States, Western Europe, Australia, and Japan, life expectancy is about 75 years, whereas life expectancy in a sample of other countries is 72 years in Poland, Czechoslovakia, and Rumania; 67 years in Mexico and Central America; 64 years in Turkey, Brazil, and Thailand; 59 years in India, Iran, and Egypt; about 45 years in most central African countries; and 38 years in Afghanistan and Gambia. Lest these differences be ascribed to racial factors, it should be noted that Japanese have 10 years more life expectancy than other East Asians, and blacks in the United States have more than 20 years longer life expectancy than African blacks. The history of white versus black life expectancy in the United States is illuminating here: in 1900, there was a 18-year difference (50 years versus 32 years), whereas it is now reduced to 6 years, reflecting the improving socioeconomic status of blacks (but also showing that much progress remains to be made in that regard).

From all of this information, it is abundantly clear that wealth makes health, and poverty kills. Any action which might result in reducing our national wealth, or the wealth of segments of our population is fraught with danger. The LLEs we are dealing with here are about 10 years within the United States, and 30 years on an international basis.

Within the United States, life expectancy varies considerably with geography in ways not explainable by socioeconomic differences. For whites it is over a year longer than average in the rural north central states of North Dakota, South Dakota, Minnesota, Iowa, Nebraska, Kansas, and Wisconsin (all of which have lower than the national average income), while it is a year shorter than average in the rural southeastern states of South Carolina, Georgia, Alabama, Mississippi, and Louisiana. It is speculated that this may be connected with trace elements in soil. Areas at higher elevation have a few years longer life expectancy than areas near sea level. The differences are especially large for cancer. Note that radiation exposure increases with altitude, which would tend to cause the reverse situation. The rocks at higher elevation generally contain more radioactive material, and there is less atmosphere above to shield out cosmic rays. This is another demonstration that radiation is not an important cause of cancer.

The most highly publicized risks are those of being killed in accidents — the suddenness and drama of accidental death are well suited to the functions of our news media — although the actual danger is well below that of the risks we have discussed previously. The LLE from all accidents combined is 435 days (1.2 years). Almost half of them involve motor vehicles, which give us an LLE of 180 days — 147 days while riding and 33 days as pedestrians. Using a small car rather than a large car roughly doubles one's risk, and this would be true even if everyone used small cars. The difference between using a small and a midsize car is an LLE of 60 days, and there is a roughly equal difference between a midsize and a large car. Reducing the national speed limit from 65 to 55 miles per hour in 1974 increased our life expectancy by 40 days, and the recent increase back to 65 miles per hour on interstate highways in some states has had a substantial reverse effect.

On an average, riding one mile in an automobile and crossing a street each have an LLE of 0.4 minutes, making them as dangerous as one puff on a cigarette (assuming 25 puffs to a cigarette), or, for an overweight person to eat three extra calories. Note that if walking involves crossing a street more often than once per mile, it is more dangerous to walk a mile than to drive a mile.
The total LLE over a lifetime from various other types of accidents is 40-days each for falls (mostly among the elderly) and drowning, 27 days for fire and burns, 17 days for poisoning, 13 days for suffocation, 11 days for accidents with guns, and 7 days for asphyxiation. Men are more than twice as likely to die in accidents as women; in motor vehicle accidents the male/female ratio is 2 to 1 for both riders and pedestrians, and in drowning the ratio is 5 to 1.

Accidental death rates vary greatly with geography; they are 4 times higher in Wyoming than in New York, to give the two extremes; the Northeast is generally the safest area, while the Rocky Mountain states are generally the most dangerous.

We spend most of our time at home and at work, so that is where most of our accidents occur that are not related to travel. The LLE for accidents in the home is 95 days, and for occupational accidents it is 74 days. The latter number varies considerably from industry to industry, from about 300 days in mining, quarrying, and construction to 30 days in trade (e.g., clerks in stores). Nearly half of all workers are in manufacturing and service industries, for which the LLE is 45 days. For radiation workers in the nuclear industry, radiation exposure gives them an average LLE of 20 days.

Actually, these statistics cover up many high-risk occupations because they average over whole industries including white collar workers and many others in relatively safe jobs. Canadian occupational accident statistics are kept in much finer detail and elucidate some of these effects:

- In the mining industry, the LLE for those who sink shafts is 660 days versus 65 days for those involved in shop work and service.
- In the utility industry, the LLE for those who work with power lines is 820 days versus 58 days for mechanics and fitters.
- In forestry, the LLE for those who fell trees is 1,050 days versus 54 days for sawmill workers.
- In construction, the LLE for demolition workers is 1,560 days (more than 4 years) versus 38 days for those involved with heating, plumbing, and electrical wiring.

Some showmanship activities are widely advertised as having very high accident potential, but judging from statistical experience, these dangers are exaggerated in the public mind. Professional aerialists - tight-rope walkers, trapeze artists, aerial acrobats, and high-pole balancers - get an LLE of 5 days per year of participation, or 100 days from a 20-year career. The risk is similar for automobile and motorcycle racers of various sorts. The risk of accidental death in these professions therefore is less than in ordinary mining and construction work. The most dangerous profession involving thousands of participants is deep-sea diving, with an LLE of 40 days per year of participation.

In addition to accidents, occupational exposure causes many diseases that affect a worker's life span that in most cases are much more important than accidents. Coal miners, on an average, die 3 years earlier than the average man in the same socioeconomic status, and statistics are similarly unfavorable for truckers, fishermen, ship workers, steel erectors, riggers, actors and musicians (perhaps due to irregular hours), policemen, and firemen. On the other hand, there are occupational groups in which men live a year or more longer than average for their socioeconomic standing, such as postal workers, government officials, university teachers, and gardeners. Clearly, one's choice of occupation can have a large effect on one's life expectancy, extending to several years.

But by far the most dangerous occupation is no occupation — being unemployed. For this we use a study by Ray Marshall, former Secretary of Labor and now a professor at the University of Texas. Unemployment affects not only the worker himself, but his family and friends, and even those who remain employed because of stress caused by fear of losing their jobs. But if all of these effects were concentrated on the worker himself, the LLE from one year of unemployment would be about 500 days. This is about equal to the risk of smoking 10 packs of cigarettes per day while unemployed.

The unemployment rate in the United States frequently rises or falls by 1% or more. The estimated effects of a 1% increase for one year are 37,000 deaths, including 20,000 due to cardiovascular failure, 500 due to
alcohol-related cirrhosis of the liver, 900 suicides, and 650 homicides. In addition to the deaths, there are
4,200 admissions to mental hospitals and 3,300 admissions to state prisons. Clearly, any action, or inaction,
that can lead to increased unemployment is very dangerous. Importing oil rather than utilizing domestic
energy production is such an action, and having inadequate supplies of electricity or allowing electricity
costs to rise unnecessarily are such inactions.

Medical care is an obvious factor affecting life expectancy. If full use were made of available medical
technology, it is estimated that 75,000 cancer deaths and 125,000 deaths from cardiovascular diseases could
be prevented each year. Failure to achieve this performance by our medical care system is costing the
average American an LLE of about 1.4 years.

It is estimated that if all currently available technology were used to prolong life, including good dietary
practice, proper exercise and rest, and best available medical care, life expectancy would be increased by 9.5
years. Thus, sub-optimal lifestyles give us an LLE of 9.5 years. Over 20% of this is due to cigarette
smoking.

Averaged over the U.S. population, AIDS gives an LLE of 70 days. That disease is preventable by careful
sexual practices.

Homicide and suicide are significant risks in our society, with LLEs of about 135 days each for men, and 43
and 62 days, respectively, for women. Homicide is more common among the young, while suicide becomes
several times more likely among the elderly.

Judging by the media coverage they attract, one might think that large catastrophes pose an important threat
to us, but this is hardly the case. Hurricanes and tornadoes combined give the average American an LLE of 1
day, as do airline crashes. Major fires and explosions (those with eight or more fatalities) give us an LLE of
0.7 days, and our LLE from massive chemical releases is only 0.1 day.

The media have publicized the dangers of various individual substances from time to time. Broiling meat
converts some of it into carcinogenic compounds, and burning charcoal which is sometimes used in broiling
adds others; eating a half-pound of broiled steak per week throughout life gives an LLE of 0.15 days. Peanut
butter contains aflatoxin, which causes liver cancer; one tablespoon per day gives us an LLE of 1.1 days.
Milk also contains aflatoxin, enough to cause an LLE of 1.0 day from drinking one pint per day.
Chlorination of drinking water leads to formation of chloroform, which is a carcinogen; in Miami or New
Orleans where chlorination levels are particularly high, this gives an LLE of 0.6 days. Of course,
chlorination of water and drinking milk have benefits that far outweigh these risks. There is evidence that
coffee can cause cancer of the pancreas, giving an LLE of 26 days from drinking 2+ cups per day, the U.S.
average. Birth control pills can cause phlebitis, giving an LLE of 5 days to users. Diet drinks with saccharin,
which causes bladder cancer, give an LLE of 2 days from one 12-ounce serving per day, but this is a hundred
times less harmful than the weight gain from nondiet drinks if one is overweight.

Other things some of us use are much more harmful. Alcohol abuse is estimated to cause 100,000 deaths per
year due to cirrhosis of the liver, psychosis, accidents, suicides, and homicides, giving the average American
an LLE of 230 days. Abuse of other addictive substances is estimated to cause 35,000 deaths per year,
corresponding to an LLE of 100 days averaged over the population. Of course, the LLE is much larger than
these averages for those who indulge and much less for those who do not. However, it is still substantial for
the latter group, as they are often victims of homicides and of automobile collisions with drunk drivers.

Even very tiny risks often receive extensive publicity. Perhaps the best example was the impending fall of
our orbiting Sky-Lab satellite, which gave us an LLE of 0.002 seconds. Heavy publicity surrounded leaks
from radioactive waste burial grounds, although these have not given any single member of the public an
LLE as large as 10 seconds. It is shown in the Chapter 8 Appendix that the Three Mile Island nuclear
power plant accident gave the average Harrisburg-area resident an LLE of 2 minutes (0.0015 days). Our risk
of being struck by lightning gives us an LLE of 20 hours.
7/13/2017

Football seems like a dangerous sport, but the risk of being killed per year of participation is only 1 in 81,000 in high school and 1 in 33,000 in college, corresponding to LLE of 0.3 and 0.6 days, respectively. Many other sports are much more dangerous. The LLE per year of participation is 8 days for professional boxing, 25 days for hang gliding, 110 days for dedicated mountain climbers (10 days for all climbers), 0.9 days for mountain hikers, 25 days for parachuting, 9 days for sailplaning, 7 days for amateur scuba diving, 2 days for snowmobiling, and 0.5 days for racing on skis.

There are several very large risks that are so mundane that we often ignore them. Females live nearly 8 years longer than males, and whites live 5.5 years longer than blacks. One might therefore say that the LLE from being a male rather than a female is 8 years, larger than for almost any other risk we have considered, and the LLE due to being black is 5.5 years, although much of this may be due to socioeconomic factors.

For convenient reference, some of the LLEs we have discussed are summarized in Table 1, and shown graphically in Fig. 1.

**LOSS OF LIFE EXPECTANCY (LLE) DUE TO VARIOUS RISKS**

<table>
<thead>
<tr>
<th>Activity or risk</th>
<th>LLE (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living in poverty</td>
<td>3500</td>
</tr>
<tr>
<td>Being male (vs. female)</td>
<td>2800</td>
</tr>
<tr>
<td>Cigarettes (male)</td>
<td>2300</td>
</tr>
<tr>
<td>Heart disease*</td>
<td>2100</td>
</tr>
<tr>
<td>Being unmarried</td>
<td>2000</td>
</tr>
<tr>
<td>Being black (vs. white)</td>
<td>2000</td>
</tr>
<tr>
<td>Socioeconomic status low</td>
<td>1500</td>
</tr>
<tr>
<td>Working as a coal miner</td>
<td>1100</td>
</tr>
<tr>
<td>Cancer*</td>
<td>980</td>
</tr>
<tr>
<td>30-lb overweight</td>
<td>900</td>
</tr>
<tr>
<td>Grade school dropout</td>
<td>800</td>
</tr>
<tr>
<td>Sub-optimal medical care*</td>
<td>550</td>
</tr>
<tr>
<td>Stroke*</td>
<td>520</td>
</tr>
<tr>
<td>15-lb overweight</td>
<td>450</td>
</tr>
<tr>
<td>All accidents*</td>
<td>400</td>
</tr>
<tr>
<td>Vietnam army service</td>
<td>400</td>
</tr>
<tr>
<td>Living in Southeast (SC,MS,GAL,LA,AL)</td>
<td>350</td>
</tr>
<tr>
<td>Mining construction (accidents only)</td>
<td>320</td>
</tr>
<tr>
<td>Alcohol*</td>
<td>230</td>
</tr>
<tr>
<td>Motor vehicle accidents</td>
<td>180</td>
</tr>
<tr>
<td>Pneumonia, influenza*</td>
<td>130</td>
</tr>
<tr>
<td>Drug abuse*</td>
<td>100</td>
</tr>
<tr>
<td>Suicide*</td>
<td>95</td>
</tr>
<tr>
<td>Homicide*</td>
<td>90</td>
</tr>
<tr>
<td>Air pollution*</td>
<td>80</td>
</tr>
<tr>
<td>Occupational accidents</td>
<td>74</td>
</tr>
<tr>
<td>AIDS*</td>
<td>70</td>
</tr>
<tr>
<td>Small cars (vs. midsize)</td>
<td>60</td>
</tr>
</tbody>
</table>

Married to smoker 50  
Drowning* 40  
Speed limit: 65 vs. 55 miles per hour* 40  
Falls* 39  
Poison + suffocation + asphyxiation* 37  
Radon in homes* 35  
Fire, burns* 27  
Coffee: 2 cups/day 26  
Radiation worker, age 18-65 25  
Firearms* 11  
Birth control pills 5  
All electricity nuclear (UCS)* 1.5  
Peanut butter (1 Tbsp./day) 1.1  
Hurricanes, tornadoes* 1  
Airline crashes* 1  
Dam failures* 1  
Living near nuclear plant 0.4  
All electricity nuclear (NRC)* 0.04

*Asterisks indicate averages over total U.S. population; others refer to those exposed.

RISKS OF NUCLEAR ENERGY IN PERSPECTIVE

With the benefit of this perspective, we now turn to the risks of nuclear energy, and evaluate them as if a large fraction of the electricity now used in the United States were generated from nuclear power. The calculations are explained in the Chapter 8 Appendix, but here we will only quote the results.

According to the Reactor Safety Study by the U.S. Nuclear Regulatory Commission (NRC) discussed in Chapter 6, the risk of reactor accidents would reduce our life expectancy by 0.012 days, or 18 minutes, whereas the antinuclear power organization Union of Concerned Scientists (UCS) estimate is 1.5 days. Since our LLE from being killed in accidents is now 400 days, this risk would be increased by 0.003% according to NRC, or by 0.3% according to UCS. This makes nuclear accidents tens of thousands of times less dangerous than moving from the Northeast to the West (where accident rates are much higher), an action taken in the last few decades by millions of Americans with no consideration given to the added risk. Yet nuclear accidents are what a great many people are worrying about.

The only other comparably large health hazard due to radiation from the nuclear industry is from radioactivity releases into the environment during routine operation (see Chapter 12). Typical estimates are that, with a full nuclear power program, this might eventually result in average annual exposures of 0.2 mrem (it is now less than one-tenth that large), which would reduce our life expectancy by another 37 minutes (see Chapter 8 Appendix). This brings the total from nuclear power to about 1 hour (with this 37 minutes added, the UCS estimate is still about 1.5 days).

If we compare these risks with some of those listed in Table 1, we see that having a full nuclear power program in this country would present the same added health risk (UCS estimates in brackets) as a regular smoker indulging in one extra cigarette every 15 years [every 3 months], or as an overweight person increasing her weight by 0.012 [0.8] ounces, or as in raising the U.S. highway speed limit from 55 miles per hour to 55.006 [55.4] miles per hour, and it is 2,000 [30] times less of a danger than switching from midsize to small cars. Note that these figures are not controversial, because I have given not only the estimates of Establishment scientists but also those of the leading nuclear power opposition group in this country, UCS.
I have been presenting these risk comparisons at every opportunity for several years, but I get the impression that they are interpreted as the opinion of a nuclear advocate. Media reports have said "Dr. Cohen claims . . ." But there is no personal opinion involved here. Deriving these comparisons is simple and straightforward mathematics which no one can question. I have published them in scientific journals, and no scientist has objected to them. I have quoted them in debates with three different UCS leaders and they have never denied them. If anyone has any reason to believe that these comparisons are not valid, they have been awfully quiet about it.

It seems to me that these comparisons are the all-important bottom line in the nuclear debates. Nuclear power was rejected because it was viewed as being too risky, but the best way for a person to understand a risk is to compare it with other risks with which that person is familiar. These comparisons are therefore the best way for members of the public to understand the risks of nuclear power. All of the endless technical facts thrown at them are unimportant and unnecessary if they only understand these few simple risk comparisons. That is all they really need to know about nuclear power. But somehow they are never told these facts. The media never present them, and even nuclear advocates hardly ever quote them. Instead, the public is fed a mass of technical and scientific detail that it doesn't understand, which therefore serves to frighten.

When I started my investigations into the safety of nuclear energy in 1971, I had no preconceived notions and no "axes to grind." I was just trying to understand in my own way what the fuss was all about. Rather early in these efforts, I started to develop these risk comparisons. They convinced me that nuclear power is acceptably safe with lots of room to spare. If I am a nuclear advocate, it is because developing these comparisons has made me so.

To be certain that this all-important bottom line is not missed, let me review it. According to the best estimates of Establishment scientists, having a large nuclear power program in the United States would give the same risk to the average American as a regular smoker indulging in one extra cigarette every 15 years, as an overweight person increasing his or her weight by 0.012 ounces, or as raising the U.S. highway speed limit from 55 to 55.006 miles per hour, and it is 2,000 times less risky than switching from midsize to small cars. If you do not trust establishment scientists and prefer to accept the estimates of the Union of Concerned Scientists, the leading nuclear power opposition group in the United States and scientific advisor to Ralph Nader, then having all U.S. electricity nuclear would give the same risk as a regular smoker smoking one extra cigarette every 3 months, or of an overweight person increasing his weight by 0.8 of an ounce, or of raising the U.S. highway speed limit from 55 to 55.4 miles per hour, and it would still be 30 times less risky than switching from midsize to small cars. The method for calculating these numbers is explained in the Chapter 8 Appendix.

Some people think of radiation risks as somehow being different from other risks. Maybe they don't believe that scientists really understand health effects of radiation, or perhaps they view death from radiation as worse than death from other causes. For these people it is more meaningful to compare risks of nuclear power with another radiation risk, radon in homes. The average American gets an LLE of 35 days from radon, 800 times as much as from nuclear power (23 times as much according to UCS). Exposure from radon can be greatly reduced by opening a window, or by being outdoors. Thus, the radiation risk of nuclear power is equal to that of staying home an extra 8 hours per year, or of keeping windows closed an average of 2 minutes extra per day. There are also simple things one can do to drastically reduce radon levels, such as opening two windows in the basement and putting a fan in one of them. Even in cold climates this can be done with no problems for 6 months of the year, which would be 10 times more effective than eliminating nuclear power, even if one accepts the risk estimates of UCS (400 times more effective according to most estimates)

All of this applies to homes with average radon levels, but several million Americans live in homes with over 10 times this average. For them, reducing radon exposure would be more than 10 times as effective. For example, their radiation exposure from nuclear power is equal to that of spending an extra 45 minutes per year indoors or of keeping their windows closed an average of an extra 12 seconds per day.
The strange part of all this is that, for all of its concern about the radiation from nuclear power, the public has shown little concern about radon. Only 2% of Americans have even bothered to measure the radon level in their homes, despite repeated statements from the Surgeon-General's office and the Environmental Protection Agency that it should be measured in every home.

The purpose of the discussion presented above is to make the risks of nuclear power understandable. Risks are best understood when compared to other risks with which we are familiar. But we have not discussed the question of whether they are acceptable. Acceptability includes other factors than the magnitude of risks. People are more willing to accept voluntary risks like skiing, auto racing, and mountain climbing than involuntary risks like pollution. Opponents are quick to point out that nuclear power presents an involuntary risk to the public. On the other hand, most of the other risks we have discussed are involuntary or at least have an involuntary component. Poor people certainly are not poor by choice. Living in Southeastern states is no more voluntary than living near a nuclear plant. In many if not most cases, a person's occupation is determined more by circumstances than by voluntary choice; a boy who grows up in the coal fields often has not been exposed to other occupational options and has little opportunity to explore them, so his becoming a coal miner is far from voluntary.

Riding in automobiles is hardly voluntary for most people, as they have no other way to get to work, to purchase food, and to participate in other normal activities of life; even if one avoids riding in automobiles, one is still subject to accidents to pedestrians, which account for 20% of deaths from motor vehicle accidents. A large fraction of other accidents are largely due to involuntary activities. Most drownings are of children, but a parent cannot prevent her child from going swimming without risking psychological damage to the child. An appreciable number of drownings result from taking baths, which is hardly a voluntary activity. Deaths from fire, burns, falls, poison, suffocation, and asphyxiation are also not usually due to voluntary risk taking.

Some people are more willing to accept natural risks than manmade risks, but nearly all of the risks we have considered are manmade. Living with artificial risks is part of the price we pay for the benefits of civilization.

Some say that risks which occur frequently but kill only one or a few people at a time are far less important than occasional large catastrophes which kill the same total number of people. That is the prima facie attitude of the media since their coverage is certainly much greater for the latter than for the former. Based on this viewpoint, some people attribute greater importance to the very rare reactor meltdown accident in which there might be numerous deaths, than to air pollution which kills far larger numbers of people one at a time.

Actually this argument is highly distorted. The cancers from even the worst meltdown accident considered in the Reactor Safety Study (RSS) would not be any more noticeable than deaths now occurring from air pollution; it would increase the cancer risk of those exposed by only about half of one percent, whereas normal cancer risks are 20%, varying by several percent with geography, race, sex, and socioeconomic status. Noticeable fatalities are expected in only 2% of all meltdowns, and even the worst meltdown treated in the RSS is expected to cause only a few thousand such deaths. There has already been a comparable disaster from coal burning, an air pollution episode in London in 1952 in which there were 3,500 more deaths than normally expected within a few days.

Since reactor meltdowns are potential accidents, none having occurred, they should be compared with other potential accidents. There are dam failures which could kill 200,000 people within a few hours; they are estimated to be far more probable than a bad nuclear meltdown accident. There are many potential causes of large loss of life anywhere large numbers of people congregate. A collapse of the upper tier of a sports stadium, a fire in a crowded theater, and a poison gas getting into a ventilation system of a large building (some buildings house 50,000 people) are a few examples. Any of these are far more likely than the fraction of one percent of all nuclear meltdowns that would cause large loss of life. The idea that a potential reactor meltdown accident is uniquely or even unusually catastrophic is grossly erroneous.
But I have a deeper objection to the idea that a catastrophic accident is more important than a large number of people dying unnoticeably. To illustrate, suppose there are two technologies, A and B, for producing a desired product, that Technology A causes one large accident per year in which 100 people are killed, and that Technology B kills 1,000 people each year one at a time and unnoticeably. If Technology B is chosen to avoid the catastrophic accidents from Technology A, 900 extra people die unnecessarily each year. How would you like to explain to these 900 people and their loved ones that they must die because the public is more interested in large catastrophes? Moreover, any one of us might be one of these 900 that die unnecessarily each year. I therefore maintain that in choosing between technologies on the basis of health impacts, the total number of deaths or the LLE should be the overriding consideration.

If we are forced to accept the overblown importance of catastrophic accidents, at the very least it should be clearly recognized that sensationalized media coverage with no attempt to put risks into perspective is responsible for large numbers of needless deaths.

What risks are acceptable is not a scientific question, and I as a scientist therefore cannot claim expertise on it. I have merely represented the risks as they are, I hope in understandable terms. If any citizen feels that the benefits of electricity produced by nuclear power plants are not worth the risk to the average citizen of a regular smoker smoking one extra cigarette every several years, or of an overweight person adding a fraction of an ounce to his weight, or of raising the national speed limit from 55 to something like 55.1 miles per hour, he is entitled to that opinion. However, he is obligated to suggest a substitute for the nuclear electricity.

Nearly all experts agree that the most viable substitute is coal-burning power plants. In Chapter 3 we noted that air pollution is estimated to be causing about 100,000 deaths per year. These are generally among the sick and elderly who would probably have died within a few years without the air pollution. On the other hand, exposure to air pollution throughout their lives has contributed to their sickly condition. We therefore judge that lifelong exposure to air pollution has reduced the life span of an average victim by about 7 years. On this basis, it gives the average American an LLE of about 80 days.

In order to determine what fraction of the LLE is due to coal-burning power plants, we would have to know what components of air pollution are responsible for these deaths. The two principal sources of air pollution are coal burning and automobiles. The latter is important principally in areas with lots of sunlight, which is needed to convert the nitrogen oxides and hydrocarbons into damaging materials like ozone and PAN. This applies to cities like Los Angeles or Phoenix, and these places generally do little coal burning. All of the killer episodes mentioned in Chapter 3 were in areas where air pollution was dominated by coal burning, and the same is true of the cross sectional and time series studies on which the estimate of deaths is based. In fact, there is little evidence that Los Angeles smog, for all the discomfort and unpleasantness it causes, is responsible for any deaths. There can therefore be little doubt but that coal burning is responsible for most of the 100,000 deaths per year. Since somewhat over half of the coal burning is in power plants, we estimate that air pollution from coal-burning power plants is responsible for about 30,000 deaths per year, which means that it gives the average American an LLE of 30 days. It also means that a large coal-burning plant causes something like 70 deaths per year, or 3,000 deaths over its operating lifetime.

This estimate is highly uncertain. It could easily be twice as high or one-third as high. Opponents of nuclear energy have constantly used the uncertainty in radiation risks from nuclear power to imply that things may be much worse than usually estimated; they get a lot of mileage out of this ploy, but the uncertainties in health effects of air pollution from coal burning are very much larger.

In any case, there can be little question but that the LLE from air pollution due to coal burning is considerably larger than that due to all the radiation and accidents from the nuclear industry even if the claims of the nuclear power opponents are accepted — 30 days versus 1.5 days. According to the much more widely accepted estimates, the ratio of coal burning to nuclear LLE is 30 days versus 1 hour, a ratio of more than 700.

During the 1970s, there were numerous studies of the comparison of health impacts between nuclear and coal-burning electricity generation. At that time, effects of air pollution were estimated to be considerably
less serious and much more easily curable by simply reducing sulfur dioxide releases from coal burning. Moreover, the effectiveness of the emergency core cooling system in preventing a reactor meltdown was still in doubt, and the results of the Reactor Safety Study were still new and unverified by independent investigations. Nevertheless, every one of these studies concluded that nuclear power was less harmful to human health than coal burning. I know of no study that reached the opposite conclusion, that nuclear power is more harmful. In 1981, I published an offer of a $50 reward for information leading to my discovery of such a study, and that offer has been repeated several times in publications and over a hundred times in speaking engagements. All anyone would have to do to claim the reward is let me know how to get a copy of the report of such a study. Nevertheless, there have been no takers. I can only conclude that there are no studies which conclude that nuclear power is more harmful than coal burning.

The fact that nuclear power is less harmful to health than coal burning was conceded in a report by Union of Concerned Scientists, the leading nuclear power opposition organization, and by its president, Henry Kendall, in a scientific seminar at Carnegie-Mellon University. When I asked Ralph Nader about this, his reply was "maybe we shouldn't burn coal either." He didn't offer an alternative. Perhaps he thinks we don't need electricity.

Other than coal burning, the principal alternatives to nuclear power are oil, gas, solar energy, and conservation, i.e., reducing our energy use. We consider only their health impacts here, although these are by no means their most important drawbacks, and some of their other problems are discussed elsewhere in this book. Burning oil causes some air pollution, although not as much as coal burning; it is also responsible for fires, giving a total LLE of 4 days. Natural gas causes a little air pollution and some fires, but also kills by explosions and asphyxiation, giving an LLE of 2 days. The principal health impact of solar energy is in the coal that must be burned to produce the vast quantities of steel, glass, and concrete required to emplace the solar collectors; this is about 3% of the coal that would be burned to produce the same energy by direct coal burning, so the health effects are 3% of those of the latter, or an LLE of 1.0 day, if we obtained all of our electricity from the sun. This makes solar electricity far more dangerous to health than nuclear energy according to estimates by most scientists. The quantities of material used in other technologies are many times less than those required for solar technologies.

All electrical energy technologies bring with them the risk of electrocution, which has an LLE of 5 days for the average American. Note that this is far higher than the effects of generating nuclear electricity even if we accept the estimates of the nuclear power opponents. If solar electricity is generated and power conditioned in homes, it would probably multiply this effect manyfold.

The final alternative to nuclear power is conservation, doing without so much energy. Improvements in efficiency are, of course, always welcome, and there has been heartening progress on this in recent years. Waste is bad by definition. But while many people think that doing without energy is the safest strategy, it is probably by far the most dangerous. One energy conservation strategy is to use smaller cars, but we have shown that this has an LLE of 60 days, many times that of any other energy technology. The danger would be somewhat reduced if everyone used small cars, but most fatal accidents are from collisions with fixed objects, like trees or walls, and collisions with large trucks and buses are also important; the risk they pose is greatly increased by using small cars.

If fuel conservation doubles the amount of bicycling, the resulting LLE is 10 days for the average American. Bicycles are far more dangerous than small cars, and motorcycles are in between, both in danger and in fuel conservation. Another energy conservation strategy is to seal buildings more tightly to reduce the escape of heat, but this traps unhealthy materials like radon inside. Tightening buildings to reduce air leakage in accordance with government recommendations would give the average American an LLE of about 20 days due to increased radon exposure, making conservation by far the most dangerous energy strategy from the standpoint of radiation exposure!

Still another conservation strategy is to reduce lighting. Falls now give us an LLE of 39 days; thus if reduced lighting causes 5% more falling, it has an LLE of 2 days. If reduced lighting increases the number of
murders by 5%, this would give an additional LLE of 4.5 days. Most motor vehicle accidents occur at night, although most driving is done during the day; if reduced road lighting increases accidents by even 2%, this gives an additional 4 days of LLE. Note that each of these LLEs is larger than that due to nuclear power even if the estimates of its opponents are accepted.

An important potential danger in overzealous energy conservation is that it may reduce our wealth by suppressing economic growth. Just to keep up with our increasing population without increasing unemployment, we must provide over a million new jobs per year for the foreseeable future. We have been succeeding in keeping up for the past several years, but that requires increasing supplies of electricity. The tragic health impacts of unemployment were outlined earlier in this chapter.

We have also noted the health effects of a nation's wealth. Typically, life expectancy is 75 years in economically advanced nations versus 45 years in poor nations, a difference of 30 years.

From this it is evident that reduced national wealth can have disastrous impacts on health, amounting to hundreds of days of LLE. The greatest potential risk in overzealous energy conservation is that it may lead us down that thorny path toward becoming a poorer nation.

Since we have estimated the LLE from coal burning as only 30 days, that technology is much less risky than doing without the electricity we need. Coal burning is an acceptable method for generating electricity, but is far inferior to nuclear energy for that purpose.

Some people seem to believe that reducing our energy usage is unavoidable because we are running out of fuel, but that is most definitely not the case. We will show in Chapter 13 that nuclear fission can easily provide all the energy the world will ever need without any increase in fuel costs. No one favors wasting energy; waste is bad by definition. But there is no long-term reason to deny ourselves any convenience, comfort, or pleasure that energy can bring us, as long as we are willing to pay a fair market price for it.

**SPENDING MONEY TO REDUCE RISKS**

Another aspect of understanding risk is to consider what we are doing — or deciding not to do — to reduce our risks. Surely it is unreasonable to spend a lot of money to reduce one risk if we can much more cheaply reduce a greater risk but are not doing so.

It may seem immoral and inhumane even to consider lifesaving in terms of money, but the fact is that a great many of our risks can be reduced by spending money. In the early 1970s, air bags were offered as optional safety equipment on several types of automobiles, but this was discontinued because not enough people were willing to buy them. They were proven to be effective and safe — an estimated 15,000 lives per year would be saved if they were installed in all cars. There is no discomfort or inconvenience connected with them. They have only one drawback — they cost money. Apparently Americans did not feel that it was worth the money to reduce their risk of being killed or injured in an automobile accident.

There is a long list of other automobile safety features. We can buy premium tires, improved lights, and antilock braking systems, to name a few. We can spend money on frequent medical examinations, we can use only the best and most experienced doctors, we can buy elaborate fire control equipment for our homes, we can fly and rent a car at our destination rather than drive on long trips, we can move to safer neighborhoods — the list is endless. Each of these also costs money. In this section we consider how much it costs to save a life by spending money in various ways. In some cases, where personal effort and time are also required, a reasonable monetary compensation for these will be added to the cost.

As an example, getting a Pap smear to test for cervical cancer requires making an appointment and going to the doctor's office; most women would be willing to do equivalent chores for a payment of $10. A Pap test costs about $20, so we add the $10 for time and effort and take the total cost to be $30. Each annual Pap test has 1 chance in 3,000 of saving a woman's life; thus for every 3000 tests, costing (3,000 x $30 =) $90,000, a
life is saved. The average cost per life saved is then $90,000. About 50% of U.S. women of susceptible age now have regular Pap tests. If you are among the other 50%, you are effectively deciding that saving your life is not worth $90,000.

This example is taken from a study completed a few years ago,\(^9\) in which all costs are given in 1975 dollars. Some other calculational details will be given in the Chapter 8 Appendix, but here we will quote some of the results of that study. Since the consumer price index has roughly doubled since 1975, we will double all costs given in the original paper.

If there were smoke alarms in every home, it is estimated that 2,000 fewer people would die each year in fires. Even with a generous allowance for costs of installation and maintenance, this works out to a life saved for every $120,000 spent, but less than half of American homes have smoke alarms.

On the other hand, a great many Americans purchase premium tires to avert the danger of blowouts. If everyone did, this would cost an aggregate of about $10 billion per year and might avert nearly all of the 1,800 fatalities per year that result from blowouts, a cost of nearly $6 million per life saved. Many Americans buy larger cars than they need in order to achieve greater safety, which costs something like $12 million per life saved.

There is clearly no logical pattern here. It is not that some people feel that their life is worth $12 million while others do not consider it to be worth even $90,000 — there are undoubtedly many women who buy larger cars for safety reasons but skip their regular Pap test. And there are millions of Americans who purchased premium tires with their new cars but did not order air bags, even though the air bags are 10 times more cost effective. The problem is that the American consumer does not calculate cost effectiveness. His or her actions are governed by advertising campaigns, salesmanship, peer group pressures, and a host of other psychological and sociological factors.

But what about the government? We pay a large share of our income to national, state, and local governments to protect us. The government can hire scientists or solicit testimony from experts to determine risks and benefits, or even to develop new methods for protecting us; they have the financial resources and legal power to execute a wide variety of health and safety measures. How consistently has the government functioned in this regard?

First let us consider cancer-screening programs. The government could implement measures to assure that much higher percentages of women get annual Pap smears; this has been done in a few cities like Louisville, Toledo, Ostfold (Norway), Aberdeen (Scotland), and Manchester (England). Ninety percent participation was achieved by such measures as sending personal letters of reminder or visits by public health nurses. Such measures would involve added costs, but tests would be cheaper when done in a large-scale program — a Mayo Clinic program did them for $3.50 in the 1960s and a British program did them for $2 apiece in 1970. Thousands of lives could be saved each year at a cost below $100,000 each.

There are several other cancer-screening programs that could be implemented. Fecal blood tests can detect cancer of the colon or rectum for as little as $20,000 per life saved. Many more of these cancers could be detected in men aged 50-65, the most susceptible age, by annual proctoscopic examinations, saving a life for every $60,000 spent, but only one in eight men of this age now get such examinations. Lung cancer can be detected by sputum cytology and by X-ray examination; the Mayo Clinic has been running such a program for heavy cigarette smokers that saves a life for every $130,000 spent, and two programs in London reported success at less than half of that cost. Nevertheless, only a small fraction of American adults are screened each year, and there has been little enthusiasm for large government-sponsored programs. Estimated costs per life saved are similar for breast cancer — the leading cause of cancer death in women — which is readily curable with early detection, but only half of all women are serviced, and again there are no large government programs.
Testing for high blood pressure has almost become a fad in this country, but the problem goes beyond detection. Treatment is quite effective, but since the condition is not immediately life threatening, many people ignore it. A well-organized treatment program would save a life for every $150,000 invested, with half of that cost compensating patients for their inconvenience, but such programs have not been developed.

An especially effective approach to saving lives with medical care is with mobile intensive care units (MICUs), well-equipped ambulances carrying trained paramedics ready to respond rapidly to a call for help. About one-third of all deaths in the United States are from heart attacks (one-third of these are in people less than 65 years old) and two-thirds of these deaths occur before the patient reaches the hospital. The MICU was originally conceived as a method for combating this problem by providing rapid, on-the-scene coronary monitoring and defibrillation services, but it has now been expanded to provide treatment for burns, trauma, and other emergency conditions. Experience in large cities has shown that MICUs save lives for an average cost of about $24,000; consequently, every large city has them. However, for smaller towns the cost goes up. When it reaches $60,000 per life saved — the cost for a town with a population of 40,000 — and MICU is often considered too expensive. In effect, it is decided that saving a life is not worth more than $60,000.

To summarize our medical examples, there are several available programs that could save large numbers of lives for costs below $100,000 each, and many more for costs up to $200,000 per life saved. These, of course, are American lives, with some chance that they may be our own.

There are numerous opportunities for highly cost-effective lifesaving in underdeveloped countries. The World Health Organization (WHO) estimates that over 5 million childhood deaths could be averted each year by immunization programs at a cost ranging from $50 per life saved from measles in Gambia and Cameroon to $210 per life saved by a combination of immunizations in Indonesia. These costs are for complete programs that provide qualified doctors and nurses, medical supplies, transportation, communication, and the like. WHO also estimates that about 3 million childhood deaths each year could be averted by oral rehydration therapy (ORT) for diarrhea. This consists of feeding a definite mixture of salt, sugar, baking soda, and "sodium-free" salt with water on a definite schedule. The cost per life saved by complete programs range from $150 in Honduras to $500 in Egypt.

Other low-cost approaches to lifesaving in the Third World include malaria control ($550/life saved), improved health care ($1930), improved water sanitation ($4030) and nutrition supplements to basic diets ($5300).

But health care is not our government's only means of spending money to save lives. Over 35,000 Americans die in automobiles each year as a result of collisions, and over a million are seriously injured, even though there are many ways in which this toll could be reduced by investing money in highway or automobile safety devices.

To some extent this has been done. A number of new safety devices in automobiles, like collapsible steering columns and soft dashboards, were mandated by law between 1965 and 1974; a study by the U.S. General Accounting Office indicated that they have saved a life for every $280,000 spent. However, this is apparently about as high as we are willing to go, and the program has ground to a halt. In 1970-1973, 16 new safety measures in automobiles were mandated, but there have been hardly any since that time. As noted previously, an air bag requirement that would cost $600,000 per life saved has not been implemented.

There are lots of highway construction measures that could save lives. For example, about 6,000 Americans die each year in collisions with guardrails, and there are guardrail construction features that could save most of those lives. But let us now get down to costs per life saved.

According to a recent report by the U.S. Department of Transportation, current programs save 79 lives per year with improved traffic signs, at a cost of $31,000 per life saved; 13 lives per year with improved lighting, for $80,000 per life saved; 119 lives per year with upgraded guardrails, for $101,000 per life saved; 28 lives per year with median barriers, for $163,000 per life saved; 11 lives per year with median strips, for $181,000 per life saved; 75 lives per year with channelled turn lanes, for $290,000 per life saved.
Presumably, these programs could be expanded, with an overall cost of something like $150,000 per life saved.

It is estimated that high school courses in driver education avert about 6,000 fatalities per year and cost $180,000 per life saved, even if we include a $100 payment to each student for his or her time and trouble. Yet there are recent indications that programs are being cut back to save on costs.

Before leaving the area of traffic safety, it should be pointed out that there are 40 serious injuries for every fatality in traffic accidents. The measures we have discussed would reduce the former as well as the latter. We have therefore erred on the high side in charging all of the costs to lifesaving; the costs per life saved are lower than those given in the above discussion.

We have seen that some of our governmental agencies are passing up opportunities for saving lives at costs below $50,000, and they are rarely willing to spend over $200,000. But this does not apply to the Environmental Protection Agency (EPA) in protecting people from pollution. In its regulation dealing with air pollution control equipment for coal-burning power plants, it frequently requires installation of sulfur scrubbers, which corresponds to spending an average of $1 million per life saved. Moreover, air pollution usually affects old people with perhaps an average of 7 years of remaining life expectancy, whereas automobile accidents generally kill young people whose life expectancy averages 40 years.

Where radiation is involved, the EPA hastens to go much further. Radium is a naturally occurring element that is found in all natural waters. This has always been so, and it always will be so. However, the EPA is now requiring that in cases where radium content is abnormally high in drinking water, special measures be taken to remove some of it. This, it estimates, corresponds to spending $5 million per life saved.

Nonetheless, the EPA is not alone in being willing to spend heavily from the public purse to reduce radiation exposure. In 1972, the Office of Management and Budget recommended that nuclear reactor safety systems be installed where they can save a life for every $8 million spent. The NRC requires a $4 million expenditure per life saved in controlling normal emission of radioactivity from nuclear power plants (see Chapter 8 Appendix). But the NRC has special rules for special substances — regulations on emissions of radioactive iodine correspond to spending $100 million per life saved.

In Chapter 12 we will see that our radioactive waste management programs are spending hundreds of millions of dollars per life saved. But probably the least cost-effective spending has been on reactor safety. In Chapter 9 we will describe how the program of the NRC for improving reactor safety has increased the cost of a nuclear power plant over and above inflation by $2 billion. This program was undertaken following release of NRC's Reactor Safety Study, which estimated that over its operating lifetime, a reactor will cause an average of 0.8 deaths. Presumably, the $2 billion was being spent to avert these 0.8 deaths, which, by NRC's own reckoning, corresponds to $2.5 billion per life saved.

From the above discussion one gets the impression that the American public is willing to go to extremes in spending money for protection against radiation. But then there is the case of radon in our homes. Government policy here is to provide information and guidance to help citizens to protect themselves from radon, utilizing the services of private industry. The cost to the citizen for implementing this protection is about $25,000 per life saved. A great deal of publicity has been given to this problem, but the public has shown little interest. Only about 2% of Americans have taken even the first step in this process of measuring the radon level in their homes, which costs about $12.

A typical attitude seems to be that we should force others to spend huge sums of money to avoid harming us, but we are not willing to spend even tiny amounts of money to protect ourselves from the same type of harm. This is an extreme manifestation of the dream of obtaining a free lunch. Somehow we haven't learned that there is no such thing, and as in other situations, we end up paying for it. The costs we inflict on utilities to provide us with super-super safety is charged back to us in our electricity bills, or in the price we pay for goods and services that require electricity for their production.
If we cut through the childish notions, we see here a truly horrible human tragedy. The $2.5 billion we spend to save a single life in making nuclear power safer could save many thousands of lives if spent on radon programs, cancer screening, or transportation safety. That means that many thousands of people are dying unnecessarily every year because we are spending this money in the wrong way.

Clearly, we have here a highly irrational situation. How did it come about? It's easy to find out. Just ask the government officials who make decisions of this type about safety requirements on nuclear plants. It turns out that at least some of these people understand the problems we are discussing. But they are powerless to follow the rational course.

The reason is that the first priority of a government official is to be responsive to public concern. That is the way a democracy operates, and that is the way we want it to operate. Anyone with a high position in government must be responsive to public concern or that person will not remain in office. Our problem, then, is not one of irrational behavior by government officials. It is rather a problem of misplaced public concern. The public has been very poorly educated on the hazards of radiation and of nuclear power.

Actually, the tragedy caused by this misplaced public concern is even deeper than we have described. The cost of the added safety measures on a nuclear plant, designed to save an average of less than one life, has made a coal-burning plant somewhat cheaper, and utilities are required to choose the cheapest alternative. They have therefore ordered coal-burning plants instead of nuclear. But, as discussed previously, a coal-burning plant causes an estimated 3,000 deaths over its operating lifetime. Every time a coal-burning power plant is built instead of a nuclear plant, about 3,000 people are condemned to an early death — all in an attempt to save one life.

In addition, there are indirect health costs. The increased price of power plants represents loss of wealth, and we have shown that wealth creates health. This lost wealth translates into additional deaths.

Many economists believe that a large part of the reason for America's economic success has been low-cost energy. Historically, energy in general and electricity in particular have been considerably cheaper here than in other countries. But, as a result of the cost increases under discussion here, that situation is changing. If we don't get our nuclear power program back on track, electricity will soon be much more expensive in the United States than in Western Europe or Japan. This could easily have serious effects on our standard of living and, more importantly, on our unemployment problems. It is surely not difficult to believe that this loss of our competitive advantage could result in a 1% increase in unemployment, which is estimated to cause 33,000 deaths per year.

The failure of the American public to understand and quantify risk must rate as one of the most serious and tragic problems for our nation. This chapter represents my attempt to contribute to its resolution.

**CHAPTER 8 APPENDIX**

For those readers who are interested, we demonstrate here how to calculate some of the results quoted in Chapter 8.

First we calculate the LLE from reactor accidents according to the Nuclear Regulatory Commission Study which estimates one meltdown per 20,000 reactor-years of operation, and an average of 400 fatalities per meltdown. All base-load U.S. electricity derived from nuclear power plants would require about 250 such plants, giving us 250 reactor-years of operation each year. We would therefore expect a meltdown every \((20,000 / 250 =)\) 80 years on an average. The average fatality rate is then \((400 / 80 =)\) 5 per year. If the United States were to maintain its present population for a long time, there would be about 3 million deaths each year, so \((5/3 \text{ million} =)\) 1.7 out of every million deaths would be due to nuclear accidents. Victims of nuclear accidents lose an average of 20 years of life expectancy (cancers from radiation usually develop 10 to 50 years after exposure), giving the average American an \(\text{LLE} = (1.7 \times 10^{-6} \times 20 =)\) 34 \(\times 10^{-6}\) years;
multiplying this by 365 days/yr x 24 hrs/day x 60 minutes/hr gives an LLE of 18 minutes, as quoted previously.

The UCS estimates are one meltdown every 2,000 reactor-years, with an average of 5,000 deaths per meltdown. Since these numbers are respectively 10 and 12.5 times higher than the NRC estimates, the LLE is larger by a factor of (10 x 12.5 =) 125. Multiplying this by 18 minutes gives 2,250 minutes, or 1.5 days. Alternatively, one could go through the entire calculation in the previous paragraph.

We next calculate the LLE from being exposed to 0.2 mrem/year, which is a lifetime exposure of (70 years x 0.2 mrem/year =) 14 mrem. In Chapter 5 we found the cancer risk to be $260 \times 10^{-9}$ per mrem. Multiplying this by 14 mrem gives a lifetime cancer risk of $3.6 \times 10^{-6}$. Since the average victim loses about 20 years of life expectancy, the LLE is $(20 \text{ years} \times 3.6 \times 10^{-6} =) 7 \times 10^{-5} \text{ years}$, or 37 minutes.

This corresponds to an LLE of 2.1 minutes per mrem (30 minutes/14 mrem). The average exposure in the Three Mile Island accident to people living in that area was 1.2 mrem, so their LLE was $(1.2 \times 2.1 =) 2.5$ minutes.

The comparisons of risks are based on the ratio of LLE. For example, if 1 pound of added weight gives an LLE of 30 days while the UCS estimate gives an LLE from reactor accidents of 1.5 days, gaining 1 pound is $(30 / 1.5 =) 20$ times more dangerous, or gaining 1/20 of a pound must be equally dangerous. Multiplying by 16 ounces per pound gives 0.8 ounces as the weight gain giving equivalent risk.

As an example of calculating the cost per life saved, consider the use of air bags. According to Allstate Insurance Company, an air bag reduces the driver's mortality rate by 1.4 deaths per hundred million miles driven. Therefore, if a car is driven 50,000 miles, its probability of saving a life is $1.4 \times (50,000/100,000,000) = 1/1,500$, or one chance in 1,500. This air bag would cost about $400, so the cost per life saved is $400 divided by 1/1,500, or $600,000. Another way of saying this is that for every 1,500 cars equipped with an air bag, an average of one life would be saved; the cost would then be $(1,500 \times $400) = $600,000 to save one life.

As another example, consider the Nuclear Regulatory Commission regulation requiring installation of any equipment in a nuclear plant that will reduce the total exposure to all members of the public by 1 mrem per dollar spent. It was shown above that we can expect one fatal cancer for every 4 million mrem; thus the regulation requires spending $4 million for each death averted.

[next chapter]