Comment on Societal Risk

David Okrent

Summary. There is a need to measure societal risk more accurately; to examine and reevaluate our priorities in risk reduction; to determine the level of expenditure for risk reduction beyond which adverse economic and political effects may be overriding; and to develop a national approach to risk management.

The terms "hazard" and "risk" can be used in various ways. Their usage in this article is defined by the following simple example.

Three people crossing the Atlantic in a rowboat face a hazard of drowning. The maximum societal hazard in this case is three deaths. Three hundred people crossing the Atlantic in an ocean liner face the same hazard of drowning, but the maximum societal hazard is 300 deaths. The risk to each individual per crossing is given by the probability of the occurrence of an accident in which he or she drowns. The risk to society is given by the size of the societal hazard multiplied by the probability of the hazard. Clearly the hazard is the same for each individual, but the risk is greater for the individuals in the rowboat than in the ocean liner (*1*).

Some general observations follow:

1) Society is not risk-free and cannot be. No energy source is free of risk, either to the environment or to the public. This includes solar energy (*2*). Measures toward achieving "soft" energy, zero increase in energy consumption, and even conservation inherently carry risk.

2) There are large gaps in society's understanding of risks and the economics of risk management (*3*). Risk-benefit analysis, in the legislative process and elsewhere, is an important tool in decision-making, and should be judiciously employed. Procedures are needed to ensure proper disclosure of assumptions, uncertainties, unaggregated results, and so forth, and to ensure impartial evaluation and review of any important risk-benefit decisions.

David Okrent is professor of engineering and applied science at the University of California, Los Angeles 90024. This article is based on testimony he presented on 25 July 1979 to the Subcommittee on Science, Research, and Technology, U.S. House of Representatives.

3) The consequences of two different hazards may vary greatly with respect to their measurability. This problem (together with the possible erroneousness of the raw data), has led to a questioning of the desirability of using such information in making decisions. Furthermore, some hazards, such as the greenhouse effect or the effect of energy policies on the chance of war (*4*), introduce risks that can be difficult to quantify. Nevertheless, for many societal hazards, risk quantification, albeit imperfect and frequently containing large uncertainties, is usually possible and desirable. Decisions still have to be made, and they are likely to be better if they are made with the benefit of more complete information—keeping in mind the need for judgment as to when the inability to completely quantify may lead to unwarranted dependence on estimates. Consideration should be given to requiring risk quantification, as practical, for societal endeavors.

4) Society uses the word safe in a vague and inconsistent fashion. Efforts to reduce risk are not necessarily made in the most cost-effective way. Our priorities should be reevaluated.

5) In view of their statistically smaller contribution to societal risk, major accidents may be receiving proportionately too much emphasis compared to other sources of risk, such as chemical residues, pollutants, and wastes.

6) Society's resources are limited. When resources are lavished on a needed service, less is available for use in measures that reduce the number of injuries and premature deaths. Thus a more expensive source of electricity carries an economic penalty compared to a cheaper source. Above a particular level, expenditure of resources on additional programs to reduce risks to health and safety may be counterproductive because of adverse economic and political effects.

7) Congress should take the lead in establishing a national risk management program that is equitable and more quantitative.

The Need for Information

There are few published assessments of the many hazards and risks to which society is exposed. And there are still fewer risk assessments that (i) provide a detailed statement of the assumptions made in arriving at the conclusion, (ii) point out any uncertainties in the results, and (iii) have the benefit of a detailed evaluation by a competent independent body.

For example, it is difficult to find published quantitative estimates of the risks posed by the thousands of large dams in the United States. In fact, the safety of such dams is generally poorly known, particularly with respect to the more serious, lower probability modes of failure. The situation is the same for facilities in which large amounts of hazardous chemicals are stored.

We also know little about the risks created by emissions of substances into the atmosphere, by the disposal of liquid and solid wastes, by coal-fueled electric power stations, by residues and additives in our food, by occupational environments—and the list could go on.

Nevertheless, substantial improvement can be made in our knowledge about risks and the costs of their reduction.

Examples of Hazard and Risk Estimates

Canvey Island. An interesting and significant risk study, "Canvey: summary of an investigation of potential hazards from operations in the Canvey Island/Thurrock area" (*5*), was released in June 1978 by the Health and Safety Executive of the British government.

Canvey Island lies in the Thames River and is 9 miles long and 2.5 miles wide. It has 33,000 residents and seven large industrial complexes, including petroleum, ammonium nitrate, and liquefied natural gas facilities. The largest risk of death from an accident at one of these industrial facilities was estimated to be about 1.3×10^{-3} (1 in 800) per year for some of the nearest Canvey residents. This risk is about five times as large as the average risk of dying in an automobile accident in the United States. The

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average risk of death from an accident at these installations was estimated to be about 5×10^{-4} (1 in 2000) per year for all the island's residents. This is about twice the risk of death from an auto accident in the United States. The chance of 1500 people being killed in a single accident was given as more than 1 in 1000 per year. The chance of 18,000 being killed in a single accident was given as 1 in 12,000 per year.

It was stated that these estimates probably erred on the side of pessimism by a factor of 2 or 3, but probably not by a factor of 10. The Health and Safety Executive recommended that improvements be made that would reduce the likelihood of each of the risk estimates by a factor of 2 or 3. With these improvements, it was judged, the risks would be acceptable.

My discussions with British experts in safety assessment have given me the impression that they doubt the practicality of obtaining improvement, for every large facility in the British chemical industry, by more than a factor of 10 over the risks estimated for Canvey. However, the British are making it a matter of national law that safety assessment reports be submitted by each industrial facility utilizing or storing more than a particular quantity of a hazardous chemical. Notification is still required if some specified lesser quantity is stored. The Health and Safety Executive will have the responsibility for evaluating the risk assessment and deciding on the acceptability of the risk.

Japan is also instituting safety design requirements for chemical plants, requirements that become increasingly strict in proportion to the number of deaths that might occur if there is a serious accident.

Should not the United States be developing some systematic approach to these and other societal risks? I have little doubt that we have many chemical installations posing risks not unlike those at Canvey.

Dams in California. Limited studies of ten California dams by our group at the University of California, Los Angeles, indicated that up to 250,000 deaths could result from catastrophic failure of the largest of these dams (*6*). Historically, large dams have failed (although not necessarily suddenly and in gross fashion) at a rate of about 1 in 5000 per year. However, our crude estimates of the failure rate for some of the dams studied were as large as 1 in 100 per year.

During the San Fernando Valley earthquake in 1971, the Van Norman Dam nearly failed catastrophically due to soil liquefaction, a phenomenon recognized only after its construction. Had the reservoir been full, the dam would have failed (*7*), possibly causing 50,000 to 100,000 fatalities.

The state of California has had a dam-safety law since the 1971 earthquake. The law specifies that the safety of each state-controlled dam must be reviewed and a finding of "safe" made. However, under the law the state need not publicize the risk it is imposing when it determines that a dam is safe. And, of course, the maximum possible number of fatalities remains unchanged by any finding.

Earthquakes in California. California faces serious safety questions concerning the possibly catastrophic effect of earthquakes on its cities. This is also true in other states, but in California the problem is acute. On 17 March 1976 the U.S. Geological Survey advised Governor Brown of the relatively large likelihood that a major earthquake in Los Angeles would kill many thousands of people, primarily from collapse of seismically substandard buildings and from dam failure. A report prepared for the Federal Disaster Assistance Administration makes equally gloomy predictions (*8*). To my knowledge, seismically substandard buildings have not been posted as hazardous in Los Angeles, nor have instructions been issued on where to go in the event of dam failure. The city of Los Angeles, of course, has been grappling with the problem of seismically substandard buildings for years (*9, 10*). Seismic retrofit or building condemnation is very costly. So far as I know, the state of California has not devoted significant financial resources to this problem.

Liquefied natural gas (LNG). The LNG technology has been the object of increasingly intense safety review in the past few years. One of the few large proposed U.S. chemical installations for which a serious, detailed risk study has been published was the LNG facility for Los Angeles (*11*), Oxnard, or Point Conception, California.

The study, which was performed under a contract for the corporation requesting to build the facility, has been a subject of considerable controversy. It did not include a self-critique in which assumptions were clearly identified and uncertainties critically evaluated. And it did not establish quantitative criteria against which to judge the acceptability of the risk at each of the proposed sites.

Although other risk estimates for these proposed facilities have been issued (most project larger risks), a detailed study and evaluation by an independent group is not, to my knowledge, available.

The state of California has imposed very stringent siting requirements for LNG facilities, but California makes no systematic assessment of the hazards from large chemical installations, some of which may pose risks similar to or greater than those from the previously proposed LNG facility in Los Angeles harbor. Thus, in a state that is relatively advanced in its efforts to control risk to the public, it is difficult to find a uniform rationale for the standards, priorities, and resources used in this job.

The Flood at Big Thompson Canyon

Some may call the flood at Big Thompson Canyon, Colorado (*12*), a natural disaster. But if most of the fatalities could have been prevented by proper advance planning or emergency action, I am unwilling to shrug off the event as a natural disaster, seemingly beyond our control and not to be compared with accidents in man-made facilities.

During the evening of 31 July 1976, an intense thunderstorm stalled over a small portion of Big Thompson Canyon, dropping ten or more inches of rain in a 3-hour period. Because of the steep mountain topography, the runoff quickly formed a virtual wall of water that displaced everything in its path. Of about 4000 people in the canyon, 139 died and 4 were never found. Property damage exceeded \$41 million.

The area was totally unprepared for such an event. Efforts to evacuate were made, but they were obviously inadequate. Was the loss of life the result of a natural catastrophe that could not be avoided? It might have been avoided altogether by restrictions on building in the floodplain—a controversial matter. Accepting the de facto use of the floodplain, the loss of life could still have been minimized with the benefit of some prior analysis, a reasonably direct method of measuring and monitoring rainfall, and a suitable warning system.

I do not recall any congressional investigation of the matter. Colorado has since imposed restrictions on rebuilding in the floodplain in Big Thompson, but these restrictions are being fought. There are many similar canyons all along the Front Range of the Rockies, including one that opens onto Boulder, Colorado. What safety precautions are being taken for these canyons and for other similar "natural" hazards? Is this question being given the same priority as new LNG facilities or nuclear power plants?

Expenditures to "Save a Life"

The expenditures made by society to save a single life vary to a remarkable degree. Morlat (*13*) estimated that in France, $30,000 was being spent per life saved through road accident prevention and about $1 million per life saved through aviation accident prevention. Sinclair (*14*) estimated that in Great Britain the expenditures ranged from $10,000 for an agricultural worker to $20 million for a high-rise apartment dweller.

Comparable disparities among implicit values of life are easily found in the United States. In a report prepared by the National Academy of Sciences (NAS) for the Senate Committee on Public Works in March 1975, estimates were made of the health costs of the pollutants from coal-fired electric generating plants (*15*). A figure of $30,000 per premature death was used (*15*, p. 611) "rather than the value of $200,000 used in highway safety." The reasoning for this choice was that "most of the deaths occur among chronically ill, elderly people, and the amount by which their lives are reduced may be only a matter of days or weeks." This value of life was then used as the reference value for cost-benefit trade-offs that provided a basis for evaluating the merits of various approaches to control of emissions from coal plants, including the timing of such controls. The estimated number of premature deaths resulting from the activities of coal plants was lower in the NAS report than the highest estimate given in other publications (*16*). The actual value is quite uncertain.

On the other hand, in its "As low as reasonably achievable" (ALARA) criterion for routine releases of radioactivity from a nuclear power plant, the Nuclear Regulatory Commission (NRC) employs $1000 per man-rem as the expenditure limit for making improvements. On the basis of estimates from the BEIR report (*17*), this translates into more than $5 million per premature death deferred. Furthermore, this death would probably occur after the age of 50; hence, if one remained consistent with the philosophy promulgated in the NAS study, the $5 million derived from the NRC criterion should be compared to a value less than the $200,000 quoted in the NAS report.

The societal risk from the disposal of hazardous liquid and solid wastes is substantial. I doubt that society is using the same risk-acceptance criteria or value of life in its choice of criteria for disposal of radioactive and nonradioactive wastes. I believe that a similarly large discrepancy exists with respect to regulation of the transportation of hazardous radioactive and nonradioactive materials.

Resource Allocation

Resources for the reduction of risks to the public are not infinite. At some point, a greater improvement in health and safety is to be expected from a more stable and viable economy than from a reduction in pollution or the rate of accidents. For example, Siddal (*18*) recently showed a direct correlation between increased life expectancy and improved economic circumstances in Great Britain.

Perhaps Congress should initiate appropriate studies to enable a reasonably accurate evaluation to be made of the proper level of expenditure for risk reduction. Within such a level of expenditure, if we fail to devote our resources to those risks in which the most reduction is achieved per dollar, we are not optimizing the effect of our capital outlay (*19, 20*). Of course, one must ensure that there are no gross inequities; that no individual is knowingly left exposed to a risk significantly greater than some upper limit of acceptability.

Each individual or group that makes recommendations, or otherwise takes actions affecting national priorities, bears some responsibility for any adverse effects. Thus an individual who effects the banning of DDT in a tropical country may inadvertently cause far more deaths than he defers, since the incidence of malaria will then increase. Similarly, if coal-burning electric generating plants are found to cause far more premature deaths than nuclear power plants (in agreement with most published estimates), an individual or agency that successfully advocates the construction of coal-burning plants instead of nuclear power plants may be responsible for unnecessary deaths. If the media should present an unbalanced perspective on some aspect of risk in society, and this causes risk-reduction priorities to be set inefficiently and even wrongly, the responsible media would, in effect, be contributing to the causing of premature deaths that might otherwise have been averted.

Approaches to Risk Acceptance

Lowrance (*3*) said, "A thing is safe if its risks are judged to be acceptable."

The Van Norman Dam was presumably considered to be safe before it nearly failed in 1971. Was it safe?

The Los Angeles *Times* some years ago editorialized concerning the proposed Auburn Dam, saying, "Let's build it if it's safe." What does safe mean in the context of an Auburn Dam whose failure was estimated by an experienced engineer to be capable of killing 0.75 million people (*21*)? We cannot prove that there is zero probability of its failure. What estimated failure probability is acceptable? What level of uncertainty in this estimate is acceptable? Will it be possible to demonstrate that such a safety goal can be achieved?

The NRC licensed reactor No. 2 at Three Mile Island before the accident there. Hence it had determined that "there is reasonable assurance that the activities authorized by this operating license can be conducted without endangering the health and safety of the public." However, the NRC did not provide an estimate of the residual risk remaining after the inclusion of required safety features. And the NRC still has not qualified its definition of "reasonable assurance" with substantive numbers.

The approaches society might use in coping with "How safe is safe enough?" include (i) nonintervention (rely on the marketplace), (ii) professional standards (rely on the technical experts), (iii) procedural approaches (muddle through), (iv) comparative approaches (reveal or imply preferences), (v) cost-benefit analysis, (vi) decision analysis, and (vii) expressed preferences (rely on public perception of risk).

It is to be anticipated that any generally accepted approach would incorporate facets of most of the above, as appropriate. It is not proposed that quantitative risk-acceptance criteria can or should represent the whole approach. However, they should play an important role.

It is not easy to develop a workable, defensible set of quantitative risk-acceptance criteria that also allow for benefits, societal needs, equity, economics, political and social effects, and so forth. As a result, few specific proposals have been published. In an effort to stimulate discussion on the subject, Okrent and Whipple (*22*) described a simple quantitative approach to risk management that incorporates the following principal features:

1) Societal activities are divided into major facilities or technologies, all or part of which are categorized as essential, beneficial, or peripheral.

2) There is a decreasing level of acceptable risk to the most exposed indi-

vidual (for example, 2×10^{-4} additional risk of death per year for the essential category, 2×10^{-5} for the beneficial category, and 2×10^{-6} for the peripheral category).

3) The risk is assessed at a high level of confidence (say 90 percent), thereby providing an incentive to obtaining better data. (The expected value of risk must be smaller the larger the uncertainty.)

4) Each risk-producing entity is subjected to risk assessment in terms of both the individual and society. The assessment is performed under the auspices of the manufacturer or owner but must be reviewed and evaluated independently; the decision on acceptability is made by a regulatory group. (For practical reasons, there would be some risk threshold below which no review was required.)

5) The cost of the residual risk is internalized, generally through a tax paid to the federal government, except for risks that are fully insurable and, like drowning, readily attributable.

6) The government, in turn, redistributes the risk tax as national health insurance or reduced taxes to the individual.

7) Risk aversion to large events would be built into the internalization of the cost of risk, but with a relatively modest penalty. If a technology or installation poses a very large hazard at some very low probability (and many do), case-by-case decisions are made, with considerable emphasis on the essentiality of the venture.

8) An ALARA criterion on risk is required, although an incentive to reduce risk and associated uncertainties would already be provided by establishing a suitable level for the risk tax.

This quantitative approach to risk management is, of course, untested. It may be both too complex and too simple. It is subject to the obvious difficulty of defining what constitutes a risk-producing entity. However, there has been all too little real discussion of the question, "How safe is safe enough?" Comar (*23*) suggested a "de minimus" approach, and there are a few other proposals. But, more typically, entire symposia are held on risk management without so much as mentioning the subject of quantitative risk criteria.

In conclusion, if our priorities in managing risk are wrong, if we are spending the available resources in a way that is not cost-effective, we are, in effect, killing people whose premature deaths could be prevented. There is some optimal level of resources that should be spent on reducing societal risk, a level beyond which adverse economic and political effects may be overriding. Finally, there is need for the development of a national approach to risk management, one that Congress, the President, and the public can support.

References and Notes

1. This example is, of course, simplified with regard to the hazards faced on such a journey. Those in the rowboat face the possibility of dehydration and starvation, while those on the ocean liner are subject to fire and falling overboard. Other hazards can be imagined.
2. In 1957 I designed my own passive solar home in northern Illinois. It was very well insulated and had the tightest storm windows available. Not till 20 years later did I become aware that I had thereby been exposing my family to increased indoor air pollution. I have learned to be a skeptic about risk. I am particularly skeptical of those who advocate a particular technology as benign, or attack a technology as too risky, without presenting a detailed, quantitative risk evaluation, without making a choice among feasible alternatives, and without placing the risks in some broader societal perspective.
3. Modern risk-benefit thinking had its real birth with the classic paper by C. Starr [*Science* **165**, 1232 (1969)]. For background material, see Committee on Public Engineering Policy [*Perspectives on Benefit-Risk Decision Making* (National Academy of Engineering, Washington, D.C., 1972)]; W. W. Lowrance [*Of Acceptable Risk: Science and the Determination of Safety* (Kaufmann, Los Altos, Calif., 1976)]; W. D. Rowe [*An Anatomy of Risk* (Environmental Protection Agency, Washington, D.C., 1975)]; A. J. Van Horn and R. Wilson ("The status of risk-benefit analysis," discussion paper, Energy and Environmental Policy Center, Harvard University, Cambridge, Mass., 1976); D. Okrent, Ed. [*Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop* (UCLA-ENG-7598, University of California, Los Angeles, 1975)]; National Academy of Sciences Forum [*How Safe is Safe? The Design of Policy on Drugs and Food Additives* (National Academy of Sciences–National Research Council, Washington, D.C., 1974)]; D. Okrent [*Final Report: A General Evaluation Approach to Risk-Benefit for Large Technological Systems and Its Application to Nuclear Power* (UCLA-ENG-7777, University of California, Los Angeles, 1977)].
4. I favor a national energy approach that emphasizes conservation and the wise use of all domestically available resources. Diversity will better ensure resiliency. Too much discussion has made it appear that the United States must choose between solar and nuclear energy or between the "soft" or "hard" energy paths. We need solar and nuclear and coal energy.
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10. Earthquake disaster studies have also been prepared for Salt Lake City and the Puget Sound area. Most major U.S. cities are vulnerable to catastrophic damage from an earthquake, although the likelihood is highest in Los Angeles and San Francisco.
11. *LNG Terminal Risk Assessment Study for Los Angeles, California* (SAI-75-614-LJ, Science Applications, Inc., Los Angeles, 1975).
12. D. B. Simons *et al.*, *Flood of 31 July 1976 in Big Thompson Canyon, Colorado* (National Academy of Sciences–National Research Council, Washington, D.C., 1978).
13. G. Morlat, "Un modèle pour certaines décisions médicales," (Cahiers du Séminaire d'Économetrie, Centre Nationale de la Recherche Scientifique, Paris, 1970).
14. C. Sinclair, P. Marstrand, P. Newick, *Innovation and Human Risk: The Evaluation of Human Life and Safety in Relation to Technical Change* (Centre for the Study of Industrial Innovation, London, 1972).
15. "Air quality and stationary source emission control," prepared for the U.S. Senate Committee on Public Works by the Commission on Natural Resources, National Academy of Engineering, Washington, D.C., 1975.
16. C. L. Comar and L. A. Sagan, *Annu. Rev. Energy* **1**, 581 (1976).
17. *Report of the Advisory Committee on the Biological Effects of Ionizing Radiation* (National Academy of Sciences–National Research Council, Washington, D.C., 1977).
18. E. Siddall, *Nuclear Safety in Perspective* (Canatom, Toronto, Ontario, Canada, 1979).
19. R. C. Schwing, *Technol. Forecast. Soc. Change* **13**, 333 (1979).
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21. H. Cedergren, testimony at the hearing of the Water Projects Review Committee, Sacramento, California, 21 March 1977.
22. D. Okrent and C. Whipple, *An Approach to Societal Risk Acceptance Criteria and Risk Management* (UCLA-ENG-7746, University of California, Los Angeles, 1977).
23. C. L. Comar, *Science* **203**, 319 (1979).