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Evaluation of Energy Related Risk Acceptance
(APHA Energy Task Force)*

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ABSTRACT

Living in a technological society with large energy requirements involves a number of related activities with attendant health risks, both to the working and to the general public. Therefore, the formulation of some general principles for risk acceptance is necessary.

In addition to maximizing benefits and minimizing risk, relevant considerations must be made about the perception of risk as voluntary or involuntary, the number of persons collectively at risk at any one occasion, and the extent to which a risk is a familiar one.

With regard to a given benefit, such as a given amount of energy, comparisons of the risks of alternate modes of production may be utilized. However, cost-benefit consideration is essential to the amelioration of current or prospective risks. This is unusual, since it is based on some estimate of the monetary value per premature death averted. It is proposed that increased longevity would be a more satisfactory measure.

On a societal basis, large expenditures for additional energy-related pollution control do not appear justifiable since much larger, nonenergy related health risks, are relatively underaddressed. Knowledgeable health professionals could benefit the public by imparting authoritative information in this area.

*Research carried out at Brookhaven National Laboratory under contract with the U. S. Department of Energy.

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Introduction

All of us are at risk of injury, illness and eventual death. As an ideal, we would prefer to avoid the first two insofar as possible, and to have the latter take place from wearing out at a ripe old age. In the meantime, we seek to live in secure comfort, and to engage in interesting and pleasurable activity. As currently exemplified in the U. S. lifestyle (not all of which may be essential, since some other nations appear to live as well on a lower per capita consumption), this entails the consumption of a large amount of energy, about 3.5×10^8 BTU/capita/year. All of the energy-related activities (extraction, processing, transportation, utilization and disposal of residual wastes) carry with them some health risks, both to those occupationally involved and to the general public. Clearly, we cannot have the benefits stemming from the availability of this abundant supply of energy, without some degree of risk, however much we endeavor to minimize it. This recognition suggests the desirability of the identification of some general principles for risk acceptance.

Such an effort is fraught with many problems. Risks are difficult to identify satisfactorily, especially at low levels of exposure to potentially harmful agents. Even if identified, they may not be readily comparable. Additionally, the equity of the distribution of risks and benefits is a profound underlying consideration.

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Though we may not place identical agreement on the value of the benefits or on the undesirability of the risks, it seems obvious that as an initial general principle, we would like to maximize the benefits and to minimize the risks. A suggestion of the direct relationship between the value of the benefits and the acceptance of degree of risk is shown in Figure 1 (from reference 1). It is also apparent, as shown in Figure 1, that risk acceptance is influenced by the extent to which it is perceived as a voluntary or an involuntary risk. Much larger risks seem to be accepted when the individual feels some degree of control of them (i.e., sports or driving an automobile), than for activities which are imposed on or over which the individual feels less control (i.e., air pollution or traveling by air). The number of persons who may collectively be involved on any one occasion also influences societal risk perception (2). Comparatively little attention is paid to single fatality incidents, even though they are the cause of most accidental deaths, whereas infrequent disasters, in which more than a few people perish are widely publicized (i.e., airplane crashes) and better controlled. It is also obvious that the degree to which a risk is known and/or familiar is an important factor. For example, even though they are demonstrably greater, the health effects of fossil fuel power plants effluents appear to arouse relatively little public concern, compared to those from nuclear power plants.

Additionally, we are faced with the balancing of short and long term health effects. For example, we have on one hand a concern over the genetic legacy of the additional exposure to radiation produced by the nuclear fuel cycle, and on the other, the potential change in insolation which may be produced by the combustion of additional fossil fuels.

Each of us has an individual value system which influences the importance we attach to each of the above and other factors in risk assessment, so that it contains a strong subjective element. Nevertheless, it is to be hoped that the identification of the objective elements may be conducive to agreement.

Risk Assessment

For predictive purposes and for some aspects of existing energy technology, an objective assessment of probable risk can be arrived at statistically from the available data. For example, the probability of mining injuries, transportation accidents, etc., can be obtained in this manner. For infrequent phenomena, an assessment of probable risk can be arrived at analytically from system models and failure rates of components, when known. While it is obviously dependent on inclusiveness of the model and accuracy of input data, it appears to be the only practicable method for large systems which cannot be tested in toto at a reasonable economic cost. The Reactor Safety Study (3) is an example of this approach, which has yet to be fully accepted by some critics. Somewhat less rigorous, but still useful is the intuitive judgment of informed experts, particularly in cases where all of the relevant factors cannot readily be defined or are unknown, such as in much of medical practice. The competence and objectively on the informed experts is especially important to the acceptance in this latter case, so that professionals with a code of ethics have more credibility.

However, it is evident that for the individual, risk acceptance ultimately depends upon the perceived risk, which may not correspond very closely to the objective risk. In such instances, and in the absence of convincing evidence, opposing views tend to take on the overtones of theological conflict, over what individuals believe to be true. When such a gap (between perceived and assessed risk) arises, societal decision makers are often called upon to resolve it. Too often, in such instances, it is the wheels which squeak the loudest, irrespective of their objective merit, which prevail. As a result, large expenditures of funds and efforts are sometimes made to solve a supposed "problem" often with no clear perception of their magnitude or even that they are in fact real problems.

Those occasioned by the current thrust in the U. S. for the near-universal application of cooling towers to power generating plant condensor outlet streams seem illustrative. Parker has recently observed that U. S. industry will have to invest an additional \$8 x 10^9 to meet the requirements of "best practicable" water pollution control, whereas the cost of thermal discharge limitation will be \$9.5 x 10^9 (4). Considering the known incidence of disease from the discharge of heavy metals, carcinogens, mutagens, etc., with its known incidence from thermal discharge (zero), the relative emphasis being given to the thermal pollution abatement seems disproportional.

Risk Comparisons

As a starting point in deciding on the acceptability of energy technologies, one may simply compare the health risk of the alternatives, since in this case, the benefits (a given amount of energy) are identical. Clearly, the alternative with the lowest health cost should seem the most acceptable (unless there are some other overriding factors). For example, a summary of the enhanced risk of death per year because of alternative modes of electrical production is shown in Table 1 (from reference 5). Such comparisons offer only a relative basis for choice and are not instructive as to what minimum level of health risk, if any, seems acceptable, nor do they offer an objective basis for the amelioration of current or prospective energy-related health risks.

But this approach has a number of additional shortcomings. It is misleading insofar as it assumes an equivalence of health effects. For example, ionizing radiation can produce genetic damage that would affect generations, roof falls in coal mines can mean instant death, and air pollution from fossil fuel consumption can produce disabling lung diseases, all widely different health effects. Equivalence of fuels is not necessarily warranted. Nuclear energy is useful for generating electricity, as is coal. Neither is suitable for directly powering automobiles.

Risk comparison also assumes the existence of equivalent data bases on which to estimate projections, which is not the case. While there is circumstantial evidence linking petroleum refineries with lung cancer, precise identification of carcinogens remains to be done. On the other hand, the effects of coal mine dust in producing chest diseases has been extensively studied.

But more importantly, the risk comparison approach implies a passive stance to the control of energy technologies, as if the current level of risk is inevitable. This assumption, kin to the obsolete "assumption of risk" doctrine that predated workers compensation laws, is inadequate insofar as it assumes that little can be done about risks associated with energy technologies.

Risk-Benefit

A more objective ordering of societal priorities for such purposes may be arrived at by examining in addition to what people say, what they actually do, or in this instance what risks they actually accept. Starr has suggested that a risk of death of 1 x 10^{-6}/year, which corresponds to that of natural hazards such as tornado, earthquake and flood, seems to be a lower limit of public concern, in that such events are generally accepted as acts of God. On one hand, in a population of 200,000,000 this seems crass, in that it implies the acceptance of 200 fatalities annually. On the other, in a society of finite resources, there is some limit to the amount that can be expended per life saved.

This view implies the setting of some monetary value of human life, by means of which the cost effectiveness of alternatives for the amelioration of energy-related health risks may be evaluated and priorities for effecting them may be established. It seems obvious that as a society, we place a different (and usually greater) value on an identified life at risk, as compared to an anticipated statistical risk of life. Large sums are occasionally spent to find lost children or to rescue survivors of disasters. We appear to be generally more casual about averting statistically anticipatable loss of life, witness the resistance to the installation and mandatory use of seat belts in automobiles. Estimates for the value of a statistical life lost may be derived from various sources, including jury awards, potential future earnings for an "average" man, and hazard pay. In a 1971 survey Otway found them to be in rather good agreement, at between $50,000 and $500,000 (6). Using a flat rate of $50 per diability day and the National Safety Council equivalent of 6,000 disability days per fatality, Sagan arrived at a life value of $300,000 (7).

When compared to the cost of abatement per life saved, the above consideration offers some basis for objective assessment of the worth of abatement proposals. It has been estimated that a 4.5% decrease in U. S. mortality rate could be effected by a 50% decrease in air pollution at an economic cost of $9 billion (8). This would be at a cost of $100,000 per life "saved". Following public protest about environmental radiation from nuclear power plants, the Nuclear Regulatory Commission introduced stricter regulations, which necessitated the installation of additional effluent control features. On the basis of the criteria of $1,000 per person-rem as used by the Commission in establishing cost effectiveness, it may be calculated that they felt an expenditure of $5,000,000 per life "saved" was justifiable.

Increased longevity is perhaps a more satisfactory measure of the acceptability of alternative technologies and/or of the benefits from risk reduction measures. Calculations of the gain in expectation of life at birth which would be provided by the complete elimination of the leading causes of death are shown in Table 2 (from reference 9). If 50% of respiratory related mortality can be ascribed to energy-related air pollution, then the complete elimination of the latter would lead to a life expectancy gain of 3/4 of a year. The complete elimination of the 0.5 mrem/year general population exposure anticipated with the widespread adoption of nuclear power in the year 2,000 would lead to a statistical increase of life expectancy of 0.5 days.

Risk/benefit analysis seems intuitively appealing but contains some serious limitations. It is an improvement over simple risk comparisons insofar as it does not assume that a given level of risk is inevitable, but it is narrowly focussed on the economic aspects of risk reduction. Risk/benefit analysis examines tradeoffs between money spent to reduce risk on the one hand and actual savings of lives and health on the other. Various quantitative methods are employed to estimate how much it will cost to achieve a given level of safety. Risk/benefit analysis is appealing because it appears realistic, practical and rational, but this narrow/base is open to question. Some critics of risk/benefit analysis argue that it is impossible or immoral to put a dollar value on lives. Proponents urge that in a world of finite resources, choices must be made, with a certain cost to reach a certain level of safety. The question of the worth of a certain level of safety thus takes on a political and social dimension.

But there is a further limitation. Risk/benefit analysis makes the assumption that the risks and benefits are borne by "society" when in fact there is often a disproportion between the distribution, in which one group of people may take most of the risks, while another receives most of the benefits. The first direct payment for risk reduction is usually by management or operators, while those most exposed to the risks are usually workers, neighbors or consumers. The minimization of costs for risk reduction is a benefit to management, insofar as the "savings" can be redirected or completitiveness enhanced. Thus, safety arrived at through risk/benefit analysis may obscure political conflict.

Risk Acceptance

The basic principles underlying risk acceptance have fundamental political aspects having to do with democratic decision making and minority rights. For example, the National Academy on Sciences in a recent statement (10) said,

> "The decision making process should be as open as possible to outside participation. An equitable decision making process is one where the consideration given to the interest of potentially affected individuals is proportional to the anticipated effects of the decision on those individuals."

The anticipated effects discussed here are concerned with health and safety. These health and safety concerns appear in two broad categories: occupational and public. Their relevance arises not only from the analytical convenience, but also from the conditions under which people are exposed. That is, are people exposed (or do they expose themselves) voluntarily or involuntarily? Clearly, no sharp distinction can be made. In a society that values individual liberty as much as ours, everyone is in principle "free" to base an occupation, a neighborhood, a mode of transport, etc. However, such concepts appear naive in our technological-industrial society, in which real options and full information are limited. Thus, it appears more realistic to think of voluntary and involuntary not as fixed categories, but as opposite ends of a spectrum.

Thus, conditions may be described as more voluntary or involuntary depending on the extent of knowledge concerning risks and of control over a range of different options in deciding what to do when confronted with them.

Conclusion

A widely held view is that there is no threshold for risk acceptance, and that the best available control technology should be applied to all energy related pollutants. The annual risks of death, for a variety of diseases and accidents and other causes are shown in Table 3. By way of comparison, the annual risks of premature death directly related to the generation of electrical power appear to be in the range of 10^{-7} (nuclear and gas) to 10^{-5} (oil and coal).

On a societal basis, it seems difficult to justify large expenditures for additional energy-related pollution control unless one is convinced that all of the greater risks of the life shortening causes shown in Table 2 or all Table 3 are not amenable to efforts and expenditures for their reduction. It is also evident that knowledgeable health professionals could benefit the public, through efforts to impact authoritative information on energy related health risks, toward the evolution of a consistent acceptance of energy related health risks with societal risks in general.

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Table 1

Summary of implications of quantitative assessments of health effects in the general population associated with electricity production (all values rounded)

		Coal and Oil	Natural Gas	Nuclear
Premature deaths/year/1000-MWe plant		2-100	0	0.01-0.2
Added risk/year[a]		1 in 10,000	0	1 in 5,000,000
Age	Normal risk of death/yr	Enhanced risk of death per year because of electricity production[a]		
10	1 in 3800	1.38 in 3800[b]	1 in 3800	1.0008 in 3800
25	1 in 700	1.07 in 700[b]	1 in 700	1.0001 in 700
45	1 in 200	1.02 in 200[b]	1 in 200	1.00004 in 200
65	1 in 40	1.004 in 40	1 in 40	1.000008 in 40
All ages	1 in 100	1.01 in 100	1 in 100	1.00002 in 100
Number of premature deaths in 30 years associated with routine operation of 300 plants[c]		20,000 to 1,000,000	0	100 to 2,000
Number of deaths statistically predicted from catastrophic accidents in 30 years from 300 plants [Rasmussen estimate (39) d]		-	-	10

[a]Upper estimates.
[b]These estimates are undoubtedly quite high because premature death from fossil fuel combustion products fall almost exclusively in the older age groups.
[c]This represents the total operation for a generation of power plants that would supply about 300 million people.
[d]Based on 1 chance in 10^5 of an accident per reactor-year causing 1000 immediate and delayed casualties.

Note: From reference 5

Table 2

Gain in expectation of life at birth due to elimination of specified causes of death, by color and sex: United States, 1969-71

Cause of death	Total	White		All other	
		Male	Female	Male	Female
1. Infective and parasitic diseases.......	.17	.13	.12	.37	.32
2. Tuberculosis, all forms...............	.04	.03	.02	.14	.08
3. Malignant neoplasms..................	2.47	2.31	2.57	2.33	2.41
4. Malignant neoplasms of digestive organs	.60	.55	.62	.64	.61
5. Malignant neoplasms of respiratory system..............................	.50	.69	.22	.66	.20
6. Diabetes..............................	.24	.17	.28	.24	.55
7. Major cardiovascular-renal diseases....	11.76	10.46	11.98	10.39	15.29
8. Diseases of the heart.................	5.86	6.14	5.17	5.29	6.28
9. Rheumatic fever and rheumatic heart disease............................	.12	.10	.14	.09	.12
10. Ischemic heart disease................	5.06	5.45	4.40	4.17	4.89
11. Acute myocardial infarction...........	2.43	3.01	1.79	1.71	1.62
12. Cerebrovescular diseases..............	1.19	.86	1.36	1.36	2.16
13. Arteriosclerosis......................	.13	.09	.17	.09	.16
14. Nephritis nephrosis..................	.07	.05	.05	.15	.17
15. Diseases of the respiratory system.....	.83	.86	.61	1.22	.96
16. Influenza and pneumonia..............	.47	.41	.40	.81	.70
17. Bronchitis, emphyserna, and asthma.....	.20	.26	.10	.17	.10
18. Peptic ulcer..........................	.06	.06	.04	.07	.04
19. Cirrhosis of the liver................	.28	.30	.20	.46	.35
20. Congenital anomalies..................	.29	.30	.30	.26	.26
21. Certain disease of early infancy.......	.82	.82	.66	1.19	1.05
22. Motor vehicle accidents...............	.70	.93	.41	.97	.37
23. All other accidents...................	.63	.76	.35	1.21	.54
24. Suicide...............................	.26	.34	.18	.19	.08
25. Homicide..............................	.23	.16	.06	1.46	.35

Note: From reference 9

TABLE 3 Annual Death Risk from Leading Causes, United States*

*From Monthly Vital Statistics Report, Annual Summary for the United States, 1975, (HRA)-76-1120 24: 13 (6/30/76) except estimates of subcategory of accident from U.S. National Safety Council, Accidents Facts, 1976 edition.

Cause	Annual Risk	Cause	Annual Risk
All causes	8.96×10^{-3}	Influenza	2.70×10^{-4}
Diseases of heart	3.39×10^{-3}	Diabetes	1.68×10^{-4}
Malignant neoplasms	1.74×10^{-3}	Cirrhosis of liver	1.51×10^{-4}
Cerebrovascular disease	9.18×10^{-4}	Arteriosclerosis	1.37×10^{-4}
Accident (total)	4.81×10^{-4}	Mortality in early infancy	1.28×10^{-4}
Motor vehicle	2.09×10^{-4}	Suicide	1.26×10^{-4}
Falls	7.20×10^{-5}	Bronchitis	1.19×10^{-4}
Drowning	3.80×10^{-5}	Homicide	1.02×10^{-4}
Fire	3.00×10^{-5}	Congenital abnormalities	6.70×10^{-5}
Poisoning (solids and liquids)	1.90×10^{-5}	Nephritis and nephrosis	3.90×10^{-5}
Suffocation	1.50×10^{-5}	Peptic ulcer	3.20×10^{-5}
Firearms	2.50×10^{-5}		
Poisoning (gases)	1.60×10^{-5}		
Natural phenomenon	3.10×10^{-6}		
Electrocution	2.50×10^{-6}		

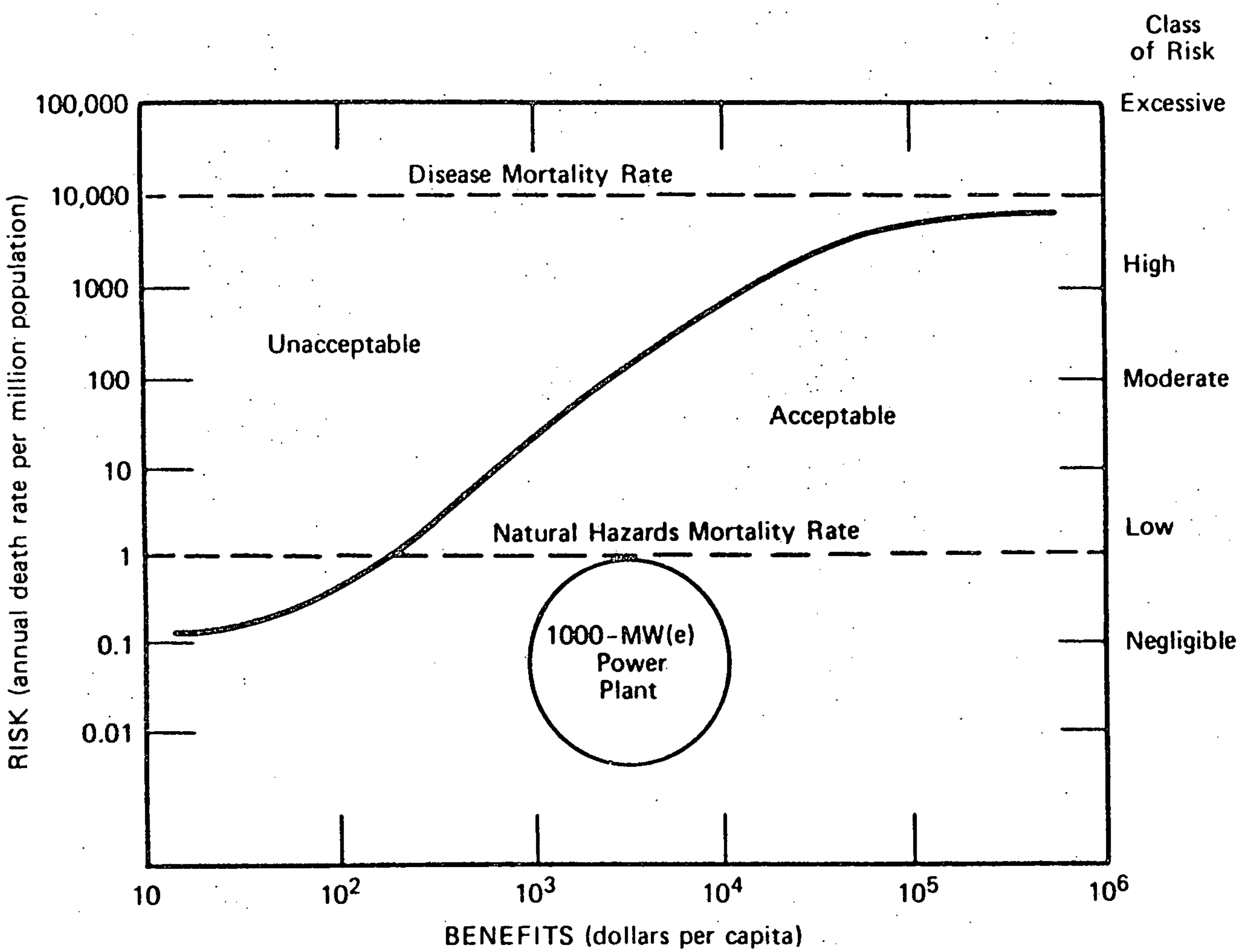

Figure 1 **Benefit–risk pattern for involuntary exposure.**

From Reference 1