# THE USE OF RISK COMPARISON TO AID THE COMMUNICATION AND INTERPRETATION OF THE RISK ANALYSES FOR REGULATORY DECISION MAKING[1]

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ABSTRACT

Risk comparisons can aid communication by providing reviewers of risk analyses with a conceptual "ruler" that helps them to understand and interpret risk analysis results. The pitfalls of using comparative risk information and suggestions for overcoming those pitfalls are presented.

KEY WORDS: Risk Communication, Comparative Risk, and Risk Analysis

## INTRODUCTION

The numerical outputs of risk analyses are often difficult for decision makers to interpret. One promising approach for improving the ability of decision makers and others to interpret the results of risk analyses is to provide them with a means for placing estimated risks in perspective. If decision makers who review risk analyses have information on the level of risk associated with other more familiar risks, they possess a conceptual "ruler" that can help them to understand and interpret risk analysis results. For this reason, comparative risk information is an important component of a comprehensive methodology for communicating the results of risk analysis.

The paper describes the results of a brief research task to develop and describe a preliminary methodology for incorporating comparative risk information into the presentation of risk analysis results. To provide background and context, the paper begins with a description of previous attempts to use comparative risk information. The principal criticisms that have been directed at such applications are then summarized. Finally, the elements of a methodology designed to minimize these limitations while retaining the potential benefits of risk comparisons are described. The methodology is illustrated using an example application involving nuclear reactor safety decision making.

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## PREVIOUS APPLICATIONS OF COMPARATIVE RISK INFORMATION

Many analysts have recognized the potential for using comparisons to promote understanding of numerical risk estimates. The risk measure receiving the most attention to risk comparisons is the low-probability event. Most individuals, including most scientists, have little intuitive feeling for probabilities that are less than $10^{-4}$. Studies have shown that people have a limited capacity to distinguish small probabilities (e.g., the different between $10^{-5}$ and $10^{-6}$) and to understand the significance of those differences (Sjoberg, 1979). Thus, it is not very helpful simply to tell someone that it has been estimated that the probability of large numbers of fatalities resulting from an accident is less than $10^{-6}$ per year.

To help convey low probabilities, analysts sometimes compare their estimates with the probabilities of various reference events. These reference events are typically natural risks or technological risks that are relatively familiar to most individuals or of interest because of the attention given to them by the media. Two approaches are available. One is to estimate the extend to which one would have to be exposed to familiar hazards to produce a level of risk equal to the risk whose clarification is desired. The second approach is to locate the estimated risk along a scale of greater and lesser risks. Reference risks serve as benchmarks in this approach.

Most comparisons based on equating risks have focused on the probability of death, one of the risk measures that might be produced by a risk analysis. Wilson (1979), for example, used toxicological and exposure data to reduce a number of familiar activities to a level that would increase an individual's annual chances of death by one chance in a million. He found, for instance, that actuarial statistics may be interpreted to suggest that smoking 1.4 cigarettes or traveling 300 miles by car both appear to increase the annual probability of dying by about once chance in a million. Some of Wilson's other comparisons are summarized in Table 1. Similarly Crouch and Wilson (1982) estimated the length of time required to accumulate an average risk of dying of one in a million from several natural causes and life-style activities. Some examples of their results are provided in Table 2.

The approach based on comparing an estimated risk with greater and lesser risks requires a set of risk benchmarks. Several authors have provided such benchmarks. Crouch and Wilson (1982), for example, estimated the average probability of death per year from several common causes, occupations, and sports. Examples of their results are presented in Table 3. Sowby (1965) provided extensive data on the risks per hour of exposure for various activities and situations. Wilson (1984) recently presented a scale of risks ranging from the clearly unacceptable to the unnoticeable. Figure 1 shows Wilson's scale. Lawless et al. (1984) provided a more refined version of such a scale, reproduced in Figure 2.

Some risk comparisons have used expected reduction in life expectancy rather than probability of death as the unit of measure. An advantage of the loss-of-life-expectancy measure is that it permits risk comparisons to account for the average ages of exposed individuals and permits a more meaningful comparison with risks for which the time lag between exposure and possible death may be long (such as exposures to carcinogens). Cohen and Lee (1979), for example, ordered many different hazards in terms of their expected reduction in life expectancy. Table 4 summarizes some of their estimates, which represent average values for U.S. inhabitants. Reissland and Harries (1979) conducted a comparison of the days of life

Table 1

Risks which Increase the Probability of Death by One Chance in a Million
Source: Adapted from Wilson (1979)

| Activity | Cause of Death |
|---|---|
| Smoking 1.4 cigarettes | Cancer, heart disease |
| Drinking 1/2 liter of wine | Cirrhosis of the liver |
| Traveling 10 miles by bicycle | Accident |
| Traveling 300 miles by car | Accident |
| Flying 1000 miles by jet | Accident |
| Flying 6000 miles by jet | Cancer caused by cosmic radiation |
| Living 2 months in average stone or brick building | Cancer caused by natural radioactivity |
| One chest x-ray taken in a good hospital | Cancer caused by radiation |
| Living 2 months with a cigarette smoker | Cancer, heart disease |
| Eating 40 tablespoons of peanut butter | Liver cancer caused by aflatoxin B |
| Eating 100 charcoal-broiled steaks | Cancer from benzopyrene |
| Drinking 30 12 oz. cans of diet soda | Cancer caused by saccharin |
| Living 5 years at site boundary of a typical nuclear power plant in the open | |
| Living 20 years near PVC plant | Cancer caused by vinyl chloride (1976 standard) |
| Living 150 years within 20 miles of a nuclear power plant | Cancer caused by radiation |
| Risk of accident by living within 5 miles of a nuclear reactor for 50 years | Cancer caused by radiation |

expectancy lost by workers in the nuclear industry with estimates derived for several other industries. Table 5 summarizes their results.

Although risk comparisons are logically distinct from judgments concerning the acceptability of a risk, most of the above-mentioned risk comparisons have been coupled with an argument that certain risks were achieving too much or too little attention. Wilson (1979) commented on his comparison of one-in-a-million risks by stating, "...these comparisons help me evaluate risks and I imagine that they may help others to do so, as well. But the most important use of these comparisons must be to help the decisions we make, as a nation, to improve our health and reduce our accident rate." Similarly, Cohen and Lee (1979) referred to their results (Table 4) by saying, "...to some approximation, the ordering (in this table) should be society's order to priorities. However, we see several very major problems that have received very little attention, whereas some

Table 2

Time to Accumulate a One-in-a-Million Risk
Source: Adapted from Crouch and Wilson (1982)

| | |
|---|---|
| **Living In the United States:** | |
| Motor vehicle accidents | 1.5 days |
| Falls | 6 days |
| Drowning | 10 days |
| Fires | 13 days |
| Firearms | 36 days |
| Electrocution | 2 months |
| Tornadoes | 20 months |
| Floods | 20 months |
| Lightning | 2 years |
| Animal bite or sting | 4 years |
| **Occupational Hazards:** | |
| <u>General</u> | |
| Mining and Quarrying | 9 hours |
| Construction | 14 hours |
| Agriculture | 15 hours |
| Transport and Public Utilities | 1 day |
| Service and Government | 3.5 days |
| Manufacturing | 4.5 days |
| Trade | 7 days |
| <u>Specific</u> | |
| Fire Fighting | 11 hours |
| Coal Mining (accidents) | 14 hours |
| Police Duty | 1.5 days |
| Railroad Employment | 1.5 days |

of the items near the bottom of the list, especially those involving radiation, receive a great deal of attention." Likewise, Sowby (1965) argued that to decide whether or not we are regulating radiation hazards properly, we need to pay more attention to "some of the other risks of life," and Lord Rothschild (1979) has added, "There is no point in getting into a panic about the risks of life until you have compared the risks which worry you with those that don't but perhaps should."

Starr (1969) formalized comparative analysis as a logic for determining risk acceptability in his revealed preference approach to defining "laws of acceptable risk." Starr's approach is based on the assumption that, by trial and error, society has arrived at a nearly optimal balance between the risks and benefits associated with any activity. If this is the case, then historical data can be used to reveal acceptable levels of risk. Starr's analysis of historical data indicated that (1) the public accepts greater risks for beneficial activities; and (2) much greater risks are accepted from risks associated with voluntary activities (e.g., skiing) than from involuntary activities (e.g., air pollution) that provide similar levels of benefit. Thus, Starr concluded,

Table 3

Average Annual Probability of Death From Common Causes, Occupations, and Sports
Source: Adapted from Crouch and Wilson (1982)

Common Causes:

| | Risk per Million Persons[a] |
|---|---|
| Motor vehicle accidents, total | 240.0 |
| Home accidents | 110.0 |
| Falls | 62.0 |
| Motor vehicle collisions with pedestrian | 42.0 |
| Drowning | 36.0 |
| Fires | 28.0 |
| Inhalation and ingestion of objects | 15.0 |
| Firearms | 10.0 |
| Electrocution | 5.3 |
| Tornadoes | 0.6 |
| Floods | 0.6 |
| Lightning | 0.5 |
| Tropical cyclones and hurricanes | 0.3 |
| Bites and stings by venomous animals and insects | 0.2 |

Occupations or Industries.

| | Risk per Million Workers[b] |
|---|---|
| Mining and Quarrying | 950.0 |
| Fire fighting | 800.0 |
| Construction | 610.0 |
| Agriculture[c] | 600.0 |
| Stone quarries and mills | 590.0 |
| Transport and Public Utilities | 370.0 |
| Farming[d] | 360.0 |
| Steel worker (accident only) | 280.0 |
| Railroad employees | 240.0 |
| Police officers, total, in line of duty | 220.0 |
| Police officers killed by felons | 130.0 |
| Service and government | 110.0 |
| Tractor fatalities per tractor | 89.0 |
| Manufacturing | 82.0 |
| Trade | 53.0 |

Sports:

| | Risk per Million Participants[e] |
|---|---|
| Professional stunting | 10,000 |
| Air show/air racing and acrobatics | 5,000 |
| Flying amateur/home-built aircraft | 3,000 |
| Sport parachuting | 2,000 |
| Thoroughbred horseracing | 1,000 |
| Lighter-than-air flying | 900 |
| Power boat racing | 800 |
| Bobsledding | 700 |
| Mountaineering | 600 |
| Scuba diving | 400 |
| Glider flying | 400 |
| Football, professional and semiprofessional | 400 |
| Ice yachting | 100 |
| Spelunking | 100 |
| Bicycle racing (registered) | 90 |
| Hang gliding | 80 |
| Boating | 50 |
| Football, college | 30 |
| Hunting | 30 |
| Swimming | 30 |
| Ski racing | 20 |
| Football, high school | 10 |
| Football, sandlot | 2 |

[a]A risk of 1.0 per million persons means a risk of one in a million (or $1.0 \times 10^{-6}$) for each individual in the population.
[b]A risk of 1.0 per million persons means a risk of one in a million (or $1.0 \times 10^{-6}$) for each individual in the exposed population. Note that some of these occupations may have less than one million workers.
[c]Includes transport accidents and all agriculture.
[d]Refers to nontransport deaths occurring on farms.
[e]Data provided in this form for easy comparison with the above estimates. Most of these sports have far less than 1 million participants.

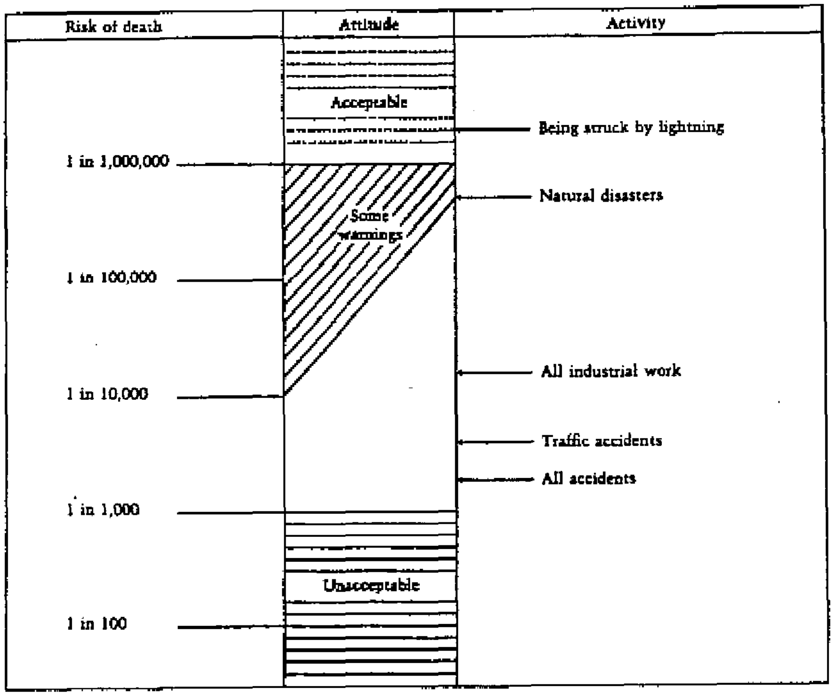


Figure 1 Regions of Acceptable/Unacceptable Risk Expressed in Terms of the Probability of Death for an Individual per Year of Exposure
Source: Wilson (1984)

acceptable risk is determined by two factors, benefit and voluntariness. The well-known graphical display to Starr's findings is reproduced in Figure 3.

Noting that risk comparisons have often been conducted by analysts motivated by a desire to create higher public acceptance for low-probability risks, Keeney and von Winterfeldt (1984) concluded that risk comparisons have generally been unsuccessful, in part "because the communicator's motives were mistrusted." Mistrust, undoubtedly, is largely responsible for the significant controversy surrounding the major studies that have attempted to compare alternative energy technologies, especially the Nuclear Regulatory Commission's Reactor Safety Study (NRC, 1975) and Inhaber's comparisons of energy product risks (Inhaber, 1979). The Reactor Safety Study compared the consequences and frequency of reactor accidents to natural disasters, such as earthquakes, dam failures, etc. Figure 4 provides an example of the comparisons. Inhaber's study was a comparative assessment of the risks of using ten different energy sources. The study considered both occupational and public health risks. A total risk was calculated for each technology and compared on the basis of calculated number of man days that would be lost per megawatt year of electricity produced. Figure 5 provides an example of Inhaber's results. Inhaber's reports and subsequent articles and books have sparked

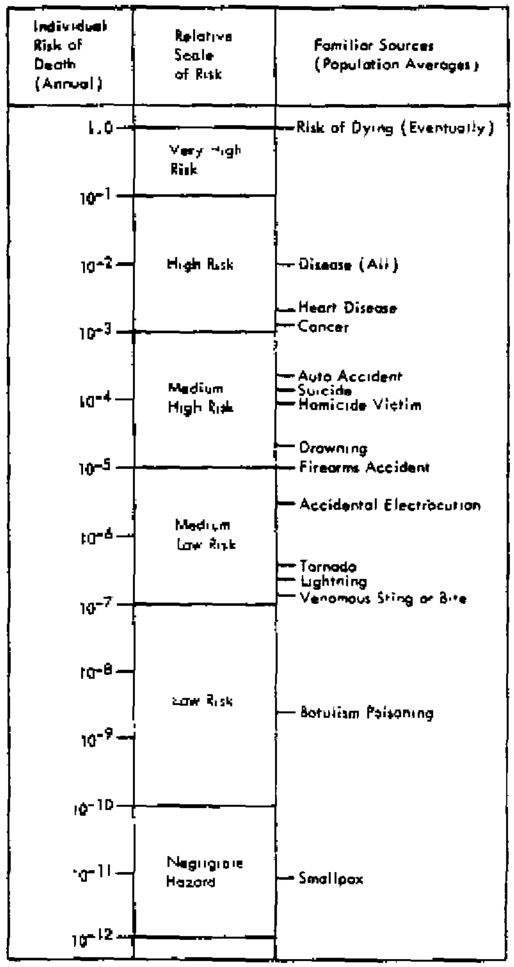


Figure 2. Comparative Scales of Individual Risks of Death from Various Causes

Source: Lawless et al. (1984)

intense interest, comment, and analysis, particularly his conclusion that nuclear power carries only slightly greater risk than natural gas and less than all other technologies considered. Criticisms applicable to the above studies' use of risk comparisons as well as the more generally directed criticisms of the use of comparative information in the communication of analytic results are presented in the following section.

Table 4

Loss of Life Expectancy Due to Various Causes
Source: Cohen and Lee (1979)

| Cause | Days |
|---|---|
| Being unmarried--male | 3500 |
| Cigarette smoking--male | 2250 |
| Heart disease | 2100 |
| Being unmarried--female | 1600 |
| Being 30% overweight | 1300 |
| Being a coal miner | 1100 |
| Cancer | 980 |
| 20% Overweight | 900 |
| <8th Grade education | 850 |
| Cigarette smoking--female | 800 |
| Low socioeconomic status | 700 |
| Stroke | 520 |
| Living in unfavorable state | 500 |
| Army in Vietnam | 400 |
| Cigar smoking | 330 |
| Dangerous job--accidents | 300 |
| Pipe smoking | 220 |
| Increasing food intake 100 cal/day | 210 |
| Motor vehicle accidents | 207 |
| Pneumonia--influenza | 141 |
| Alcohol (U.S. average) | 130 |
| Accidents in home | 95 |
| Suicide | 95 |
| Diabetes | 95 |
| Being murdered (homicide) | 90 |
| Legal drug misuse | 90 |
| Average job--accidents | 74 |
| Drowning | 41 |
| Job with radiation exposure | 40 |
| Falls | 39 |
| Accidents to pedestrians | 37 |
| Safest jobs--accidents | 30 |
| Fire--burns | 27 |
| Generation of energy | 24 |
| Illicit drugs (U.S. average) | 18 |
| Poison (solid, liquid) | 17 |
| Suffocation | 13 |
| Firearms accidents | 11 |
| Natural radiation (BEIR) | 8 |
| Medical X rays | 6 |
| Poisonous gases | 7 |
| Coffee | 6 |
| Oral contraceptives | 5 |
| Accidents to pedalcycles | 5 |
| All catastrophes combined | 3.5 |
| Diet drinks | 2 |
| Reactor accidents (UCS) | 2* |
| Reactor accidents--Rasmussen | 0.02* |
| Radiation from nuclear industry | 0.02* |
| PAP test | -4 |
| Smoke alarm in home | -10 |
| Air bags in car | -50 |
| Mobile coronary care units | -125 |
| Safety improvements 1966-76 | -110 |

*These items assume that all U.S. power is nuclear. UCS is Union of Concerned Scientists, the most prominent group of nuclear critics.

Table 5

Days of Life Expectancy Lost as a Result of Hazards in the Nuclear Industry Compared with Hazards in Other Industries
Source: Reissland and Harries (1979)

| | Age (at Beginning of Exposure) | | | | |
|---|---|---|---|---|---|
| | 20 | 30 | 40 | 50 | 60 |
| One year at risk in: | | | | | |
| Deep sea fishing | 51.4 | 41.6 | 31.9 | 22.8 | 14.9 |
| Coal mining | 5.7 | 4.6 | 3.6 | 2.5 | 1.7 |
| Coal & petroleum products | 4.1 | 3.3 | 2.6 | 1.8 | 1.2 |
| Railway employment | 3.5 | 2.9 | 2.2 | 1.6 | 1.0 |
| Construction | 3.5 | 2.8 | 2.1 | 1.5 | 1.0 |
| All manufacturing | 0.7 | 0.6 | 0.5 | 0.3 | 0.2 |
| Paper, printing & publishing | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |
| Radiation work at 50 mSv/year | 4.6 | 2.7 | 1.3 | 0.5 | 0.1 |
| Radiation work at 5 mSv/year | 0.4 | 0.3 | 0.1 | 0.1 | 0 |
| Exposed for remainder of working life to risk in: | | | | | |
| Deep sea fishing | 1393.0 | 923.0 | 551.0 | 273.0 | 80.2 |
| Coal mining | 155.0 | 103.0 | 61.3 | 30.4 | 8.9 |
| Coal & petroleum products | 111.0 | 73.8 | 44.0 | 21.8 | 6.4 |
| Railway employment | 95.5 | 63.3 | 37 8 | 18.7 | 5.5 |
| Construction | 93.5 | 62.0 | 37.0 | 18.3 | 5.4 |
| All manufacturing | 20.5 | 13.5 | 8.1 | 4.0 | 1.2 |
| Paper, printing & publishing | 12.0 | 7.9 | 4.7 | 2.4 | 0.7 |
| Radiation work at 50 mSv/year | 68.0 | 32.0 | 12.2 | 3 4 | 0.6 |
| Radiation work at 5 mSv/year | 6.8 | 3.2 | 1.2 | 0.3 | 0.1 |

CRITICISMS AND ALLEGED LIMITATIONS OF RISK COMPARISONS

Most criticisms of the use of comparative risk information attack the implication (either explicit or implicit in the comparisons) that risks that are small or comparable to risks that are already being accepted should themselves be accepted. Although intuitively appealing, this argument often breaks down because the risk comparison compares only one or two of the many dimensions of risk that are relevant to decision making. There is ample research demonstrating that people's reactions to risk depend on a wide range of factors, including not only voluntariness and benefits, as recognized by Starr, but also catastrophic potential, equity in the distribution of risks and benefits, whether the adverse consequences are immediate or delayed, the ease of reducing the risks, and so forth.

Because the acceptability of a risk depends on more than voluntariness and benefits, when Fischhoff et al. (1979) repeated Starr's analysis with a wider spectrum of risks, they found greater variability in the levels of risks that society has accepted than was suggested by Starr's analysis. As a result, they found that they could obtain results differing from Starr's depending on the reference risks considered and the measures of risks and benefits that were used. Figure 6, produced by Fischhoff and his colleagues, shows a result differing from Starr's,

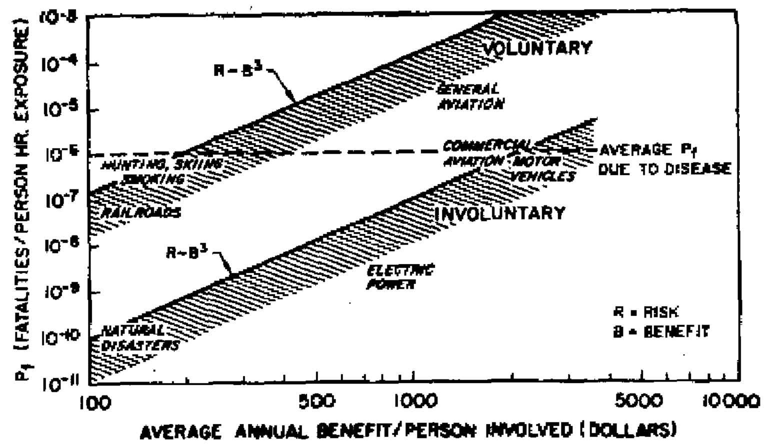


Figure 3. A Comparison of Risk and Benefit to U. S. Society from Various Sources

Source: C. Starr (1972)

obtained with another set of data and slightly different methods.[2] While Starr concluded that the acceptability of risk is roughly proportional to the third power (cube) of benefits, with risks approximately 1000 times greater being accepted for voluntary activities, Fischhoff and his colleagues arrived at the different relationship indicated in the figure (slope = 0.3, correlation = 0.55). Inspection of the data points in Figure 6 indicates the effect of factors other than voluntariness and benefits. Smoking is plotted very high in Figure 6, but it is not only a voluntary risk but also a delayed one, hence presumably more acceptable than one which is associated with swift death, such as swimming or hunting. Nuclear power is located below swimming not only because it is an involuntary risks, but also because it is perceived to be associated with catastrophic accidents, events which are far more objectionable to the public than simple personal accidents, such as drowning.

To avoid the problems associated with comparing unlike measures, the analyst must take care in selecting and comparing risks. Slovic and Fischhoff (1982), however, present a number of other criticisms that cannot be so easily countered. In criticizing Starr's analysis, these authors note that the method "assumes that past behavior is valid predictor of present preferences," which may not necessarily be valid. Thus, the method is "politically conservative in that it enshrines current economic and social arrangements." Furthermore, they say, the implication

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[2]Whereas Starr estimated risk in terms of fatality rate per hour of exposure, Fischhoff and his co-workers simply used annual fatalities. Also, while Starr measured benefit either by the average amount of money spent on an activity by a single participant or the average contribution of the activity to the participant's annual income, the Fischhoff analysis used total annual consumer expenditure as a measure of benefit.

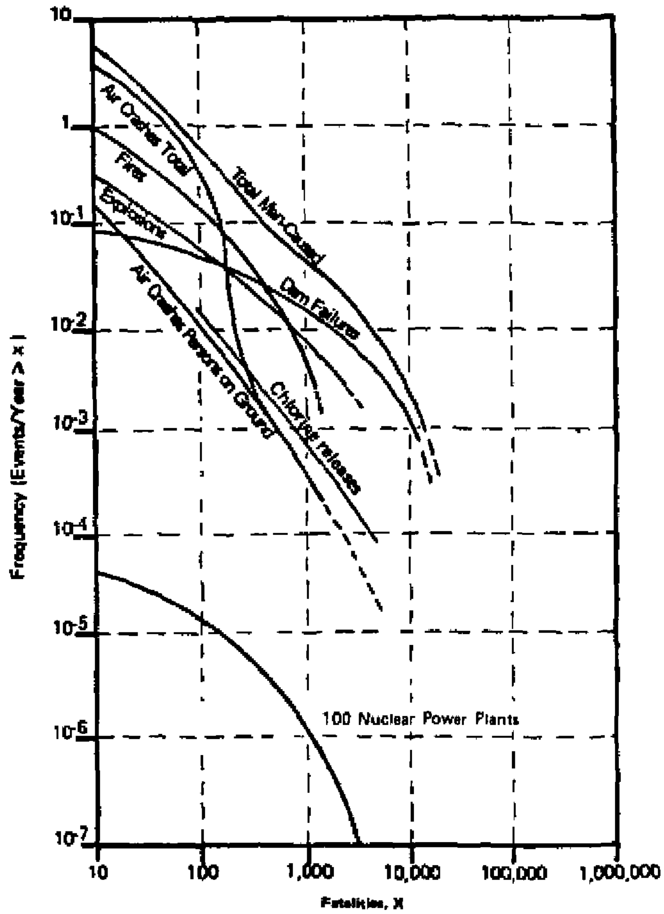


Figure 4. Frequency of Man-Caused Events Involving Multiple Fatalities
Source: Nuclear Regulatory Commission (1975)

that risks that people already accept should be used as a guideline for decisions about other risks

> ... makes strong (and not always supported) assumptions about the rationality of people's decision making in the marketplace and the freedom of choice the marketplace provides. It may underweight risks to which the market responds sluggishly such as those with a long lead time (e.g., carcinogens).

Another criticism of the use of comparative risk information relates to the influence of the risk measures selected and the format in which results are presented. To illustrate this point, Whipple (1980) cites Herman Kahn's description of the response he received to his use of two ways for expressing the estimated risks of atmospheric testing of nuclear weapons. Kahn's (1979) estimate was that a thousand cases of bone cancer or leukemia would result per thousand-megaton bomb exploded, which he also

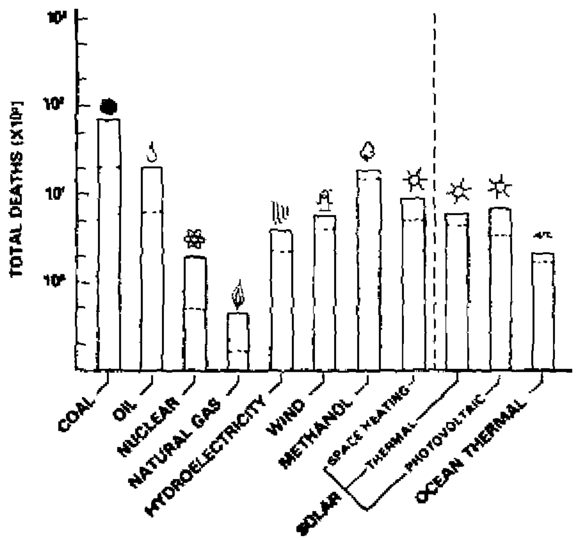


Figure 5. Total Deaths, Times 1000, per Megawatt-Year as a Function of the Energy System
Source: Inhaber (1979)

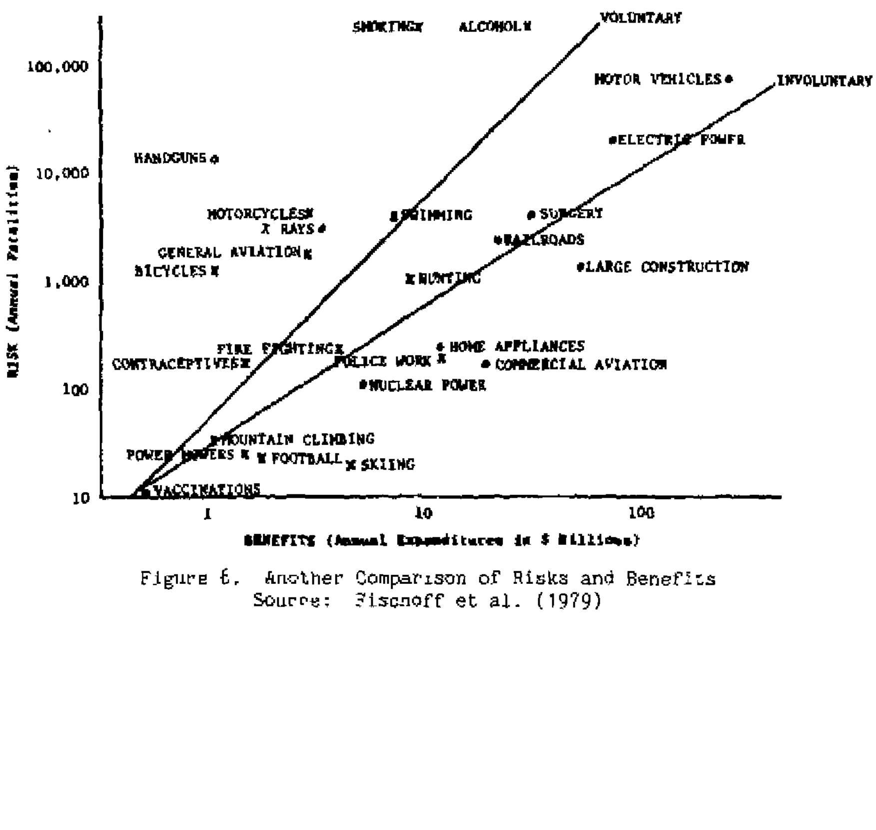


Figure 6. Another Comparison of Risks and Benefits
Source: Fischoff et al. (1979)

expressed as once chance in 3 million (assuming a world population of 3 billion). Half of Kahn's mail complained, "Why do you mention a thousand? Are you trying to scare people? There's only once chance in 3 million." The other half asked, "Why do you mention one chance in 3 million, are you trying to corrupt the thousand?"

Crouch and Wilson (1984) illustrate how the selection of risk measures can affect a risk comparison. Figures 7(a) and (b) show how two different measures of the risk of accidental death for the U.S. coal industry varied over the 20-year period from 1950 to 1970. One figure seems to suggest that the industry got substantially "safer" during this period, while the opposite conclusions may be inferred from the other. Crouch and Wilson note: "Each measure represents a different aspect of the risk of accidental death, and whether they support or deny any conclusions as to the safety of the coal industry depends, inter alia, upon a definition of 'safety' in this context."

Because of the sensitivity of risk comparisons to the measures used, it is easy to misinterpret results. In Figure 6, for example, police work is more than an order of magnitude below swimming, which might suggest to the casual observer that the latter is more dangerous. Actually, per hour of exposure, police work produces a probability of fatality that is about an order of magnitude higher than swimming, as may be inferred from Tables 2 and 3. Swimming appears higher in Figure 6 because the y-axis for this comparison is expressed in units of total fatalities rather than per unit of exposure. In general, care must be exercised in reducing risks to common units. Expressing risks in terms of expected loss of life expectancy, for example, can be confusing. As Slovic et al. (1980) note,

> ...although some people feel enlightened upon learning that a single takeoff or landing in a commercial airliner takes an average of 15 minutes off one's life expectance, others find themselves completely bewildered by such information. On landing, one will either die prematurely (almost certainly be more than 15 minutes) or will not. To many people, averages seem inadequate to capture the essence of such risks.

Another limitation of comparative risk information is the scientific uncertainty associated with the determination of reference risks. As with any other risk assessment, the estimation of risks for reference events requires the use of a model to describe the process which is being assessed and to associate a quantitative measure of risk with it. The typical approach is to propose a plausible model and then to obtain the parameters of that model by fitting it to historical data. Crouch and Wilson (1984) provide the example of the risk of death from automobile accidents. The first step in computing a reference risk for automobiles is to define a suitable risk measure, for example, the U.S. average annual death rate. Figure 8 shows the basic data for the period 1950 to 1978. The model selected by the analyst might be that this measure of risk is roughly constant over time, with random year-to-year variations. "Fitting" this simple model to the data, the analyst would conclude that the average fatality rate per year is approximately 24 per 100,000 with a year-to-year variability (two standard error confidence band) of roughly 20%. By extrapolation, therefore, the analyst would estimate that current risks (i.e., risks at the time that the comparison is being made) are roughly 24 per 100,000, plus or minus about 20%.

Crouch and Wilson point out that there are two sources of error in this estimate. The first is statistical error due to the limited data for parameter estimation. Standard methods of classical statistics are

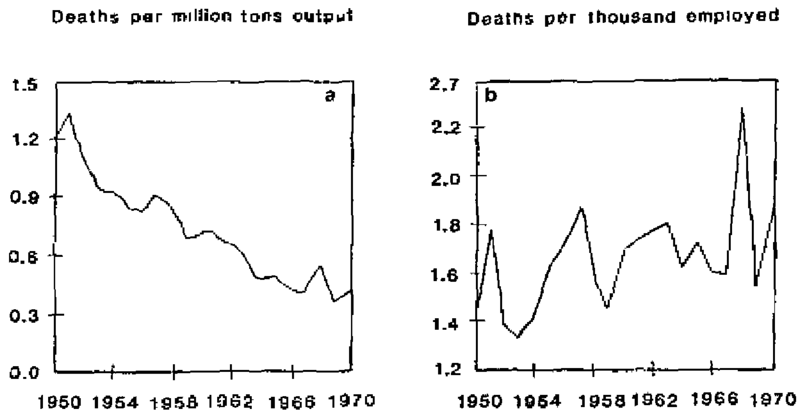


Figure 7. Different Measures Can Create Different Impressions
Source: Crouch and Wilson (1984)

available for estimating confidence bounds and other measures of statistical uncertainty due to limited data. The second source of error is the possibility that an incorrect model was chosen to calculate the risk measure. To illustrate this possibility, Figure 9 shows another risk measure for summarizing automobile fatality data--deaths per 100 million vehicle miles driven. An alternative model for estimating risk would be to multiply an estimated average number of deaths per vehicle mile traveled by an estimate of the number of vehicle miles traveled. This would obviously be a preferable model if some change (e.g., gasoline shortage) dramatically altered automobile use since the time the fatality

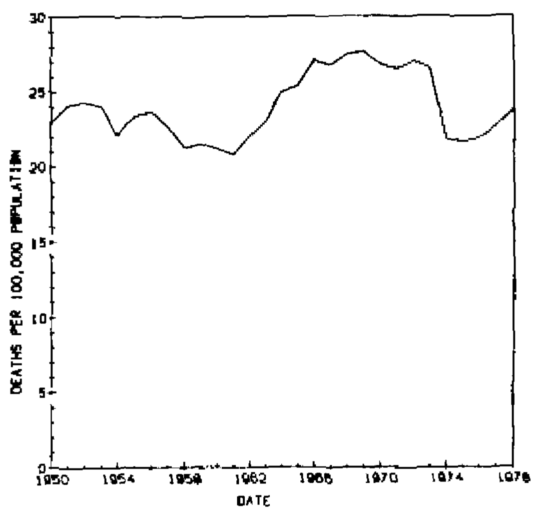


Figure 8. U. S. Motor-Vehicle Accident Deaths, 1950-1970. Deaths per 100,000 Population.
Source: Crouch and Wilson (1984)

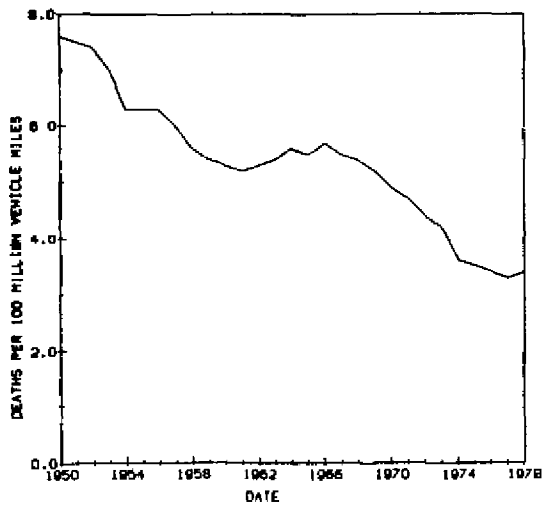


Figure 9. U. S. Motor-Vehicle Accident Deaths, 1950-1970. Deaths per 100 Million Vehicle Miles.
Source: Crouch and Wilson (1984)

data had been collected. Uncertainties due to the possible use of an incorrect model can only be guessed at by making assumptions, for example, by assuming that a certain set of models encompasses all possibilities and exploring the sensitivity of estimated risk levels to the model form selected.

Thus, because of lack of sufficient data or the use of inappropriate models, the reference risks computed for comparisons may be in error. Studies of psychological factors in risk perception suggest that if two alternatives present equal risks, costs, and benefits, but one has considerably more uncertainty surrounding the estimated level of risk, then most people would prefer the option with the more narrow band of uncertainty. Therefore, the uncertainty in estimated risk measures may be a significant factor to retain in risk comparisons

In summary, there are several significant limitations to the use of comparative risk information: risk comparisons do not provide a simple rule for risk acceptability, the measures and format selected can easily alter the impression induced, care must be taken in the conversion of risks to common units, and the reference measures themselves are subject to the same sorts of errors and inaccuracies as the risks that are compared to it. Despite these important limitations, critics and analysts alike have recognized that risk comparisons have important characteristics that make them an attractive means for aiding communication. Slovic and Fischhoff (1982), for example, state:

> Comparative analysis has several attractive features. It avoids the difficult and controversial task of converting diverse risks into a common monetary unit (like dollars per life lost or per case of sterilization or per day of suffering). It presents issues in a mode that is probably quite compatible with natural thought processes. Among other things, this mode may avoid any direct numerical reference to very small probabilities, for which people have little or no intuitive feel.

If reasonable care is taken in the design and use of comparative risk information, the method can be an important element of a communication system. The following section describes and illustrates some of the principal elements of a methodology for using comparative risk information as part of a communication package produced to summarize for a decision maker the results of a risk analysis.

## ELEMENTS OF A METHODOLOGY FOR USING COMPARATIVE RISK INFORMATION

The above consideration of the strengths and weaknesses of comparative risk information suggest that the technique has considerable potential, but that care should be taken to minimize the likelihood that such comparisons will be misinterpreted by those to whom they are presented. Furthermore, it is apparent that careful design of risk comparisons can considerably enhance the value derived. Five guidelines for effectively using comparative risk information suggest themselves. These are: (1) strive, to the extent possible, for neutral or value-free comparisons, (2) provide the decision maker with multiple comparisons using different risk measures and reference scales, (3) tailor each comparison to illuminate a particular aspect of the risk under investigation, (4) clarify for the decision maker the intent of the comparison and provide a caution against drawing unwarranted conclusions, (5) develop reference events iteratively, allowing for feedback from decision makers to ensure that the most helpful comparisons are provided, and (6) explain any assumptions or uncertainties in the reference risk estimates as necessary to prevent misinterpretation.

Table 6 summarizes these guidelines and indicates the principal objective of each. These and related considerations for the use of comparative risk information are discussed in more detail below. The reader should be cautioned that the displays presented are meant only to illustrate various considerations--the scope of this research task did not include recommending specific reference scales or risk measures for use in risk comparisons. Consequently, the comparisons presented are incomplete and no attempt has been made to optimize them for the example considered. Further research is needed to design and develop the comparative information that would be most appropriate for any given decision setting.

The example providing the context for the discussion is that addressed by Brown and Ulvila (1985a, 1985b). Brown and Ulvila (1985b) consider an analysis of the costs, risks, and benefits of a decision to install a vented containment system in a nuclear reactor. The purpose of backfitting the reactor with this system would be to reduce the probability of containment failure in the event of a core melt.[3] The intended audience for this risk/cost/benefit analysis would be senior decision makers at the Nuclear Regulatory Commission, such as Commissioners, who are assumed to be in the process of deciding whether to require such a backfit. These decision makers have limited time to study

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[3]Fitting the reactor with a vented containment system involves installing a high-volume, unfiltered vent from the reactor's suppression pool through the turbine building to the atmosphere. The vent is activated at pressures exceeding design limits, and the system would be equipped with a manual shutoff capability to protect against the release of fission products when the suppression pool is saturated and the core degraded.

Table 6

Guidelines for Comparative Risk

| Guideline | Principal Objective |
|---|---|
| Strive for neutral or value-free comparisons, make any value-laden assumptions explicit | Avoid influencing or subverting decision maker's responsibility to make value judgments |
| Use multiple comparisons based on multiple risk measures | Counter tendency of comparisons to encourage an overly simplified view of the problem |
| Tailor each comparison to illuminate a particular aspect of the risk | Increase the effectiveness of risk comparisons |
| Clarify the intent of the comparison and provide appropriate cautions | Reduce the likelihood of misinterpretation |
| Develop reference events iteratively with decision maker input | Increase the meaningfulness of risk comparisons |
| Explain all assumptions and uncertainties | Ensure that risk numbers attain a degree of influence commensurate with that which they deserve |

the extensive and highly detailed documentation that is typically produced in a cost/risk/benefit analysis. Furthermore, they are unlikely to have the technical and quantitative skills necessary to interpret rapidly and comprehend accurately the many numbers that such an analysis would produce. Thus, methods are needed to improve the communication of risk analysis information to these and similar regulatory decision makers. Providing comparative risk information may assist in this respect.

A key question for the use of comparative risk information within a system for communicating results to decision makers is the appropriate degree of simplification. As noted in previous sections, risk has multidimensional characteristics--it cannot be completely described by any single number. To distinguish various aspects of risk, analysts have proposed using multiple risk measures, including: (1) total expected fatalities, injuries, etc., per year; (2) probabilities of fatality, injury, etc., for typical or representative individuals; (3) probabilities of harm for individuals grouped by occupation, geographic location, etc. (to aid equity considerations); (4) probabilities of catastrophic losses; (5) distribution of risks over time; and (6) qualitative factors, such as voluntariness, controllability, familiarity, anxiety, etc. Some degree of aggregation across these characteristics is essential--detailed estimates for each risk measure with appropriate reference aids and caveats would overwhelm the typical decision maker. Furthermore, strict attention to the distinctions among risks would severely limit the ability of the analyst to select reference risks for comparisons that are familiar and intuitively meaningful. On the other hand, limiting or substantially simplifying analytic detail creates the danger that critical information will be lost and that the decision maker's understanding will suffer.

The use of successive risk comparisons to illuminate different aspects of the risk under investigation provides a useful approach to the problem of achieving an appropriate degree of simplification. With this approach, multiple risk comparisons would be provided, with each comparison involving an aggregation over some characteristics but not others. To help avoid misinterpretation and unwarranted conclusions, the purpose of each comparison would be explained to the decision maker. An advantage of providing multiple risk comparisons is that the inevitable weaknesses of any single scale might be overcome by relying on different scales to accomplish different things. Furthermore, the potential biases that might be introduced by a given risk comparison can be minimized by providing the decision maker with the variety of perspectives that multiple comparisons would achieve.

The first application of comparative information as part of a communication package might be to help the decision maker interpret the small probabilities produced by the analysis. For this purpose, it might be best to select reference risks whose low probabilities of occurrence can be most easily appreciated by the decision maker, without regard to whether the risks are similar along other dimensions. For example, one of the important risk measures produced by the example analysis is the estimate that backfitting the reactor with a vented containment system reduces the probability of prompt fatality due to severe accidents for individuals living within one mile of the plant from a value of $3x10^{-7}$ to a value of $1x10^{-9}$. Because the significance of such small numbers is extremely difficult to appreciate in the abstract, comparing these numbers against a reference scale, such as that shown in Figure 10, might be useful.

Figure 10 places the individual risks of death estimated as part of the analysis into perspective by comparing them with the average risks of dying from other causes. The figure indicates that the best estimate is that backfitting reduces the risk of prompt death for a typical exposed individual from a level comparable to that faced by an average U.S. citizen from lightning to a level comparable to that faced from botulism poisoning. Actual applications, of course, would use reference scales that have been tailored to the problem under study. For example, the reference scales would be composed of risks selected to be most familiar to the decision maker and the estimates would take into account any special circumstances relevant to the particular population under study. Even when the reference risks are carefully selected, however, they will differ among themselves and with the risk being evaluated along many dimensions other than the probability of individual fatality. For this reason, it may be wise to include a caution, such as that indicated in the figure, to warn the decision maker about drawing unwarranted conclusions. Information about the uncertainty in the risk estimates should also be provided.

One of the most significant characteristics of the risk associated with nuclear power in the minds of many people is the catastrophic potential--unlike many of the other risks displayed in Figure 10, which affect one or a small number of individuals at a time, a severe accident at a nuclear power plant can conceivably create a large number of fatalities, injuries, and property losses which are concentrated in time and space. To help clarify the significance of this aspect of risk, it may be helpful to provide the decision maker with a comparison along the lines of that used in the Reactor Safety Study, where the consequences and frequency of severe reactor accidents were compared to those from earthquakes, dam failures, etc., that might also produce multiple fatalities. Figure 11 illustrates one form by which such comparisons

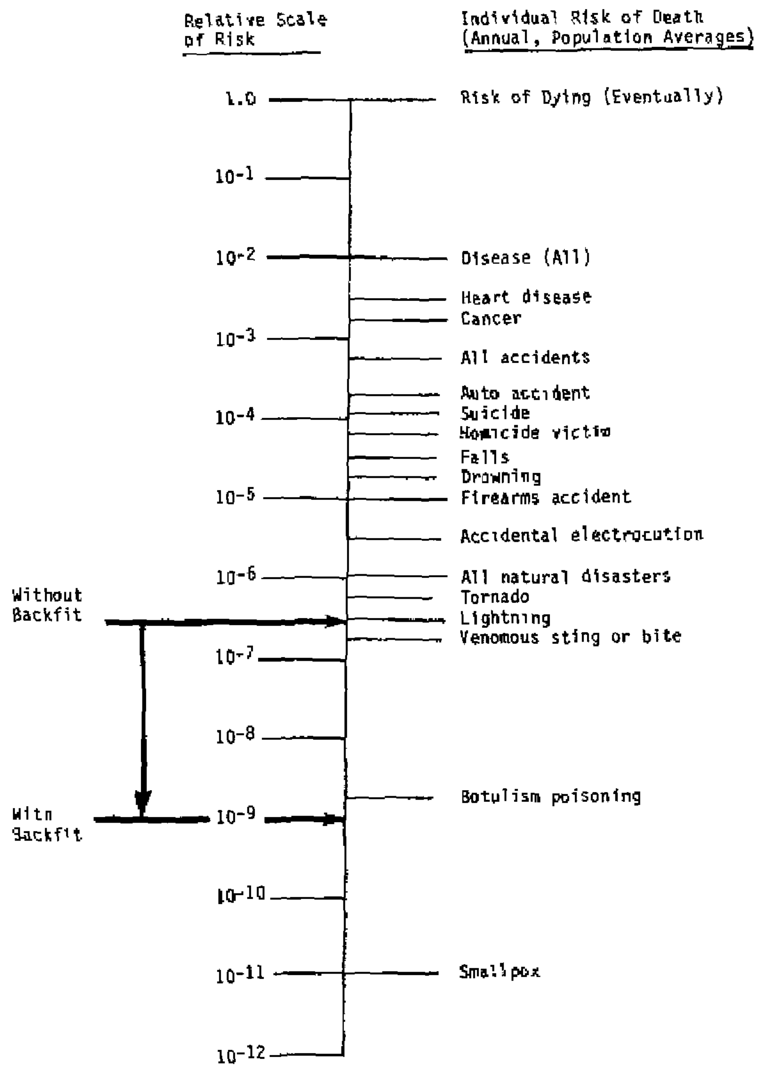


Figure 10. Using Risk Comparisons to Clarify the Reductions in the Risk of Prompt Fatality for an Individual Living within One Mile of the Plant Achieved through Backfitting with the Vented Containment System

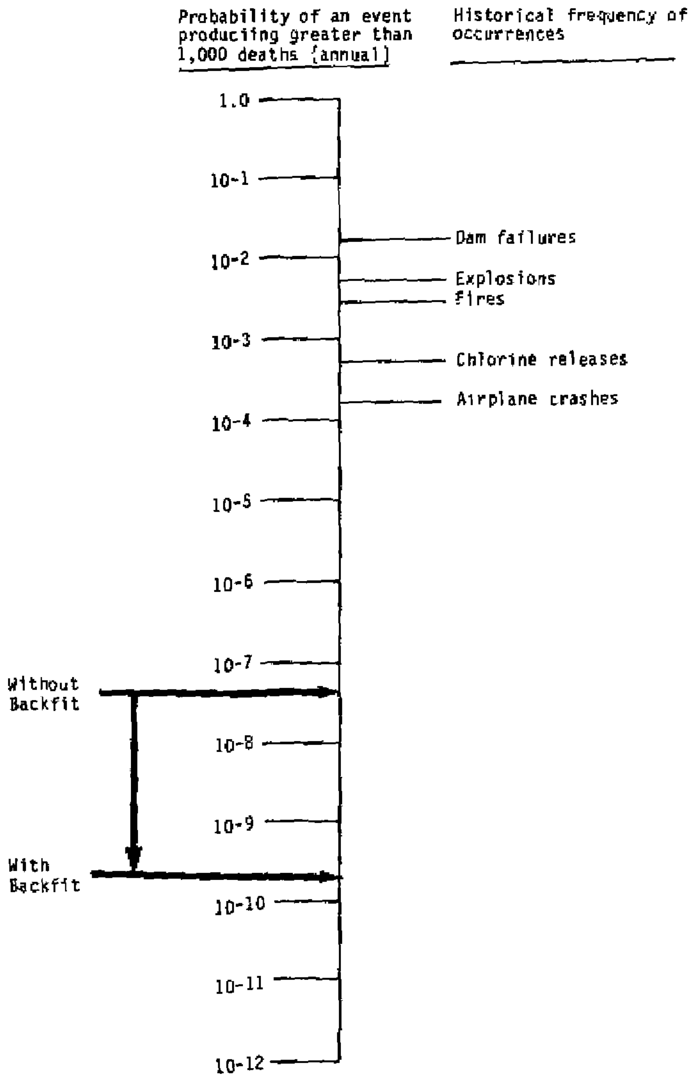


Figure 11. Using Risk Comparisons to Clarify the Reduction in the Risk of Multiple Fatalities Achieved through Backfitting with the Vented Containment System

might be made. Comparative information might also be presented in the form of risk profiles (complementary cumulative distributions). Although risk profiles (such as Figure 4) have been criticized as less understandable by a nontechnical audience (Brown and Ulvila, 1985a), they provide more information about the nature of the risk and might be justified if the decision under consideration alters the shape of the risk curve, or, if through an initial effort to become familiar with such curves, the decision maker is comfortable with their use.

In situations where the estimated risk is complicated by latency (time delay in the realization of effects), involuntariness, dread, and other complicating characteristics, developing an intuitive understanding of the significance of the risk can be extremely difficult. In the backfitting analysis, for example, it is difficult to interpret the significance of the estimate that a vented containment system would reduce the risk of latent fatality due to core melt accidents for individuals living within 50 miles of the plant from approximately $10^{-7}$ to $10^{-10}$ per year. Interpretation is difficult not only because the numbers are so small, but because the nature of a latent cancer risk is difficult to conceptualize. Understanding might be aided by decomposing this risk reduction and comparing its component parts to other risks. Part of the decrease in latent fatality risk attributed to vented containment is due to a reduction in the likelihood of core melt. According to the backfitting analysis, vented containment reduces the probability of core melt from $3 \times 10^{-5}$ to $5 \times 10^{-6}$ per year. These probabilities might be clarified for the decision maker using an appropriate scale for low probabilities similar to that in Figure 10. The other part of the decrease in latent fatality risk is due to the fact that vented containment reduces the severity of core melt accidents (by making the more serious accident sequences less likely).

To help clarify the significance of this effect, a comparison along the lines suggested by Marshall (1982) might be useful. Marshall suggests that latent fatality risks from nuclear power plant accidents can be clarified by comparing them to the risks produced from a program of compulsory smoking. The concept of a compulsory smoking program is suggested for comparison with latent fatality risks from nuclear power plant accidents because both risks involve an uncertain possibility of death from cancer. According to Marshall, the risk from a radiation dose given to an individual at any age may be simulated by supposing that the individual is obliged to smoke cigarettes regularly, starting 10 years after the incident and ending 40 years after the incident. Using Marshall's estimates the reduction in latent fatality risk from a core melt accident produced in the backfitting analysis may be expressed in terms of a complusory smoking program as follows: Without the vented containment system the probability of a core melt is $3 \times 10^{-5}$ and, if a core melt should occur, the risk of latent death for individuals within 50 miles of the plant is estimated to be comparable to that which would result if those individuals were obliged to smoke approximately 40 cigarettes (2 packs) per week. With the vented containment system, the probability of core melt would be reduced to $5 \times 10^{-6}$. If a core melt should occur, the risk of latent death is estimated to be comparable to that from a compulsory smoking program that required individuals within 50 miles of the plant to smoke approximately 1/4 cigarette per week. Figure 12 summarizes the risk reduction using this comparison. Although the comparison may be criticized for attempting to draw parallels between two very different situations, some decision makers may find that such comparisons provide a level of insight sufficient to justify their use. Again, such comparisons should be accompanied by information concerning the uncertainties in the risk estimates.

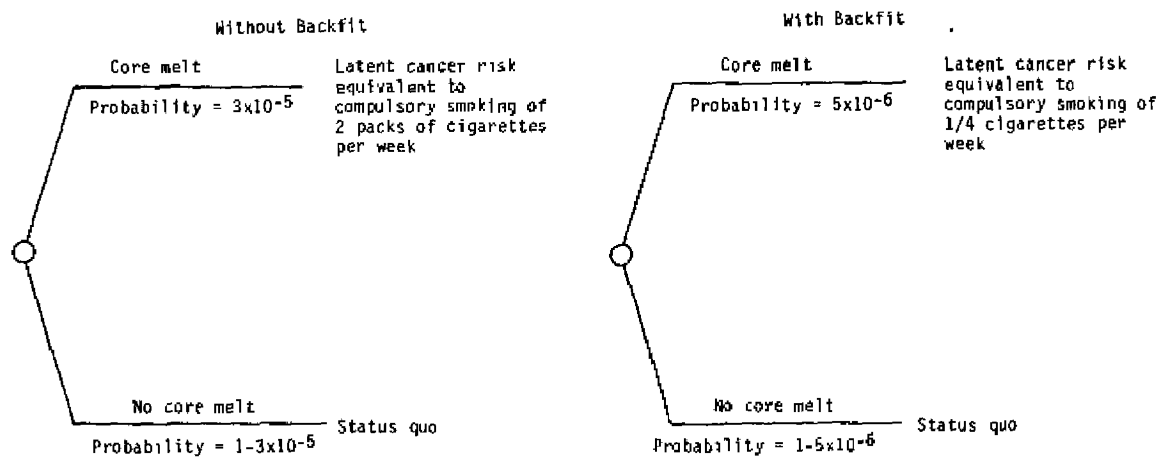


Figure 12. Risk Comparison for Clarifying the Risk of Latent Cancer Fatality Achieved through Backfitting with the Vented Containment System

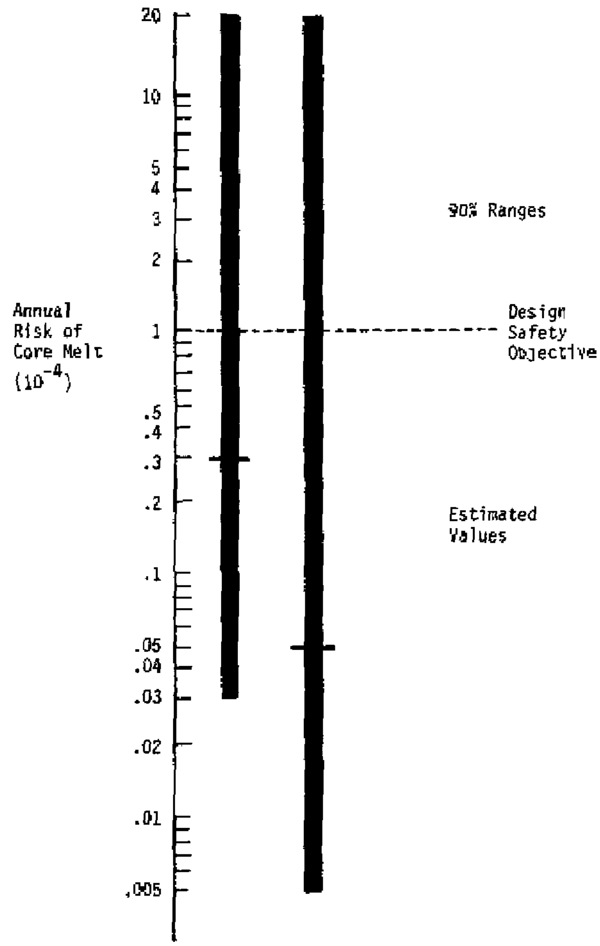


Figure 13. Risk Comparison for Clarifying Estimated Values and 90 Percent Confidence Ranges for the Annual Risk of Core Melt with and without Backfitting the Vented Containment System

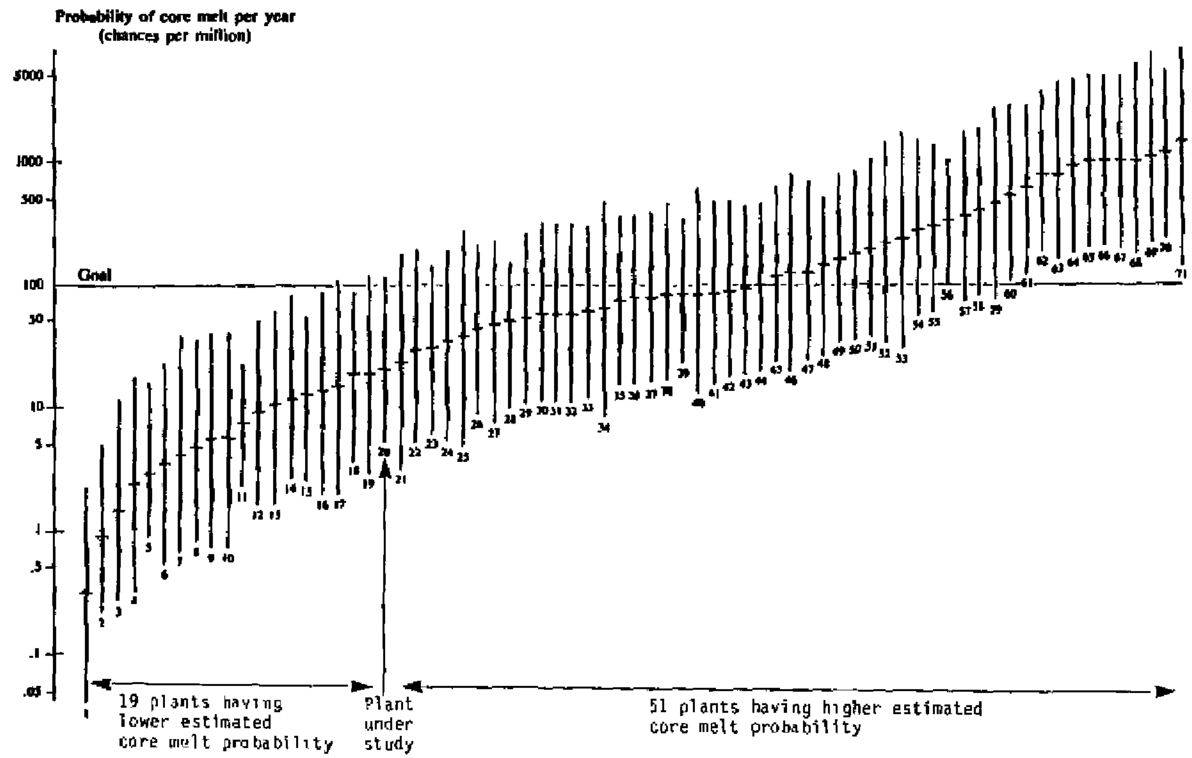


Figure 14. Core Melt Probabilites for the 71 Power Plants (Hypothetical)
(Estimate, 50%, and 90% Confidence Ranges)

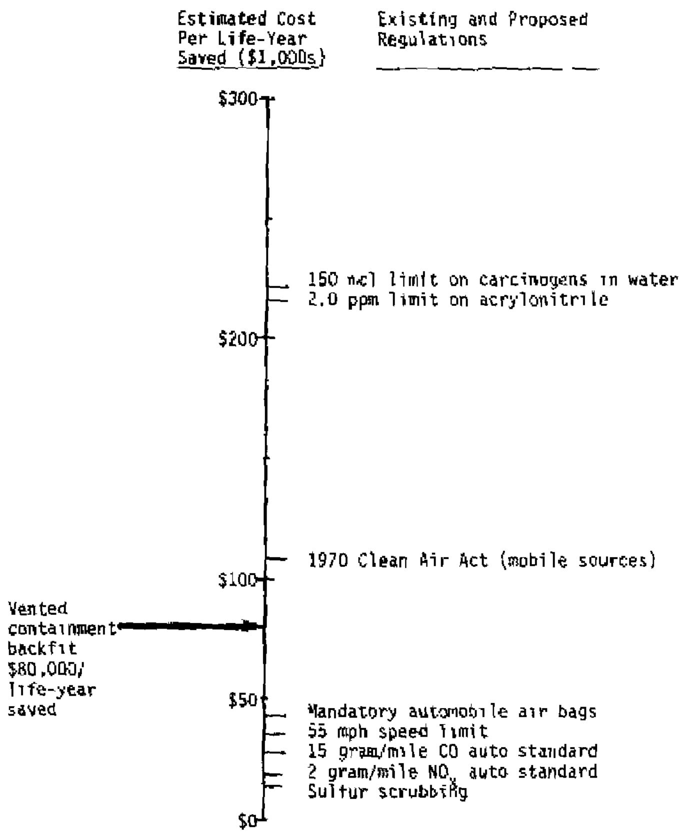


Figure 15. Risk Comparison for Clarifying Cost-Effectiveness Estimated for Backfitting with the Vented Containment System

In addition to using risk comparisons to allow the decision maker to develop a personal perspective on the significance of the numerical risk estimates, risk comparisons can also be constructed to provide an institutional perspective. Brown and Ulvila (1985a, 1985b) suggest several applications that compare risk estimates with various benchmarks that are important to the NRC. Figure 13, for example, compares estimated annual probabilities of core melt with and without vented containment to proposed design safety objectives. The figures uses range bars to indicate the uncertainty in the estimates and is similar to several plots used by Brown and Ulvila. Figure 14 compares the estimated core melt probability and range of uncertainty with similar (hypothetical) estimates for other nuclear reactors. It is also similar to a figure presented by Brown and Ulvila. As illustrated by these latter applications of comparative risk information, whenever the uncertainty in estimates is significant for the risk comparison, it should be conveyed to the decision maker. Figure 15 illustrates one final form of comparison that may help the decision maker achieve an institutional perspective. The figure compares the estimated life-saving cost-effectiveness of the vented containment system with cost-effectiveness estimates for other regulatory decisions that have and have not been taken.

## SUMMARY

There is obviously a great deal of flexibility for developing and using comparative risk information. In the absence of empirical tests for the effectiveness of alternative methods, the best strategy for using comparative risk appears to be to proceed with caution. Recognizing the danger that poorly structured risk comparisons can easily mislead, the analyst should take care to explain the limits of any comparisons and emphasize that no particular conclusion needs to be drawn. Perhaps the most important rule governing initial designs is to allow for feedback from decision makers. The reference risks, means, and formats for comparisons should be selected according to the desires and preferences of those who will use them. If initial use is monitored, the effectiveness of various methods of risk comparisons will become more apparent and initial systems will, undoubtedly, be improved upon.

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