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Risk vs Benefit: Solution or Dream

los alamos
scientific laboratory

of the University of California

LOS ALAMOS, NEW MEXICO 87544

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An Informal Report
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Risk vs Benefit: Solution or Dream

Harry J. Otway, Editor

A Compendium of Papers from a Symposium Sponsored by the Western Interstate
Nuclear Board with the Cooperation of the Los Alamos Scientific Laboratory at
Los Alamos, New Mexico, November 11 and 12, 1971.

Foreword

This symposium entitled "Risk vs Benefit - Solution or Dream?" grew out of a series of small meetings sponsored by the Western Interstate Nuclear Board on an isolated ranch at Breckenridge, Colorado. At these meetings, people from the nuclear industry and utilities, leading nuclear critics and representatives from the AEC laboratories were able to sit down and discuss the problems and concerns of nuclear energy in a relaxed and non-confrontive atmosphere.

The main benefit of these meetings appeared to be in the establishment of mutual respect between people who held different views about nuclear energy, and the opportunity to discuss these views face to face. Channels of communication were also opened for exchange of information which might otherwise not have happened.

Almost all the attendees at the smaller meetings felt that an effort should be made to enlarge the meeting size in the hopes of extending the benefits of open communication to a larger number of people. Each of those who attended the larger Los Alamos meeting will have to judge the success for himself. A summary of a questionnaire given to those attending is presented in Appendix II.

I would especially like to thank those attendees at the first Breckenridge meeting who formed the "Breckenridge Cabal" and without whose support and assistance the symposium would not have gotten off the ground. They are: Dean Abrahamson, Dave Engdahl, Don Geesaman, Bob Hammon, Gary Higgins, Pete Metzger, and Harry Otway.

I also appreciate the time and effort Bill Ogle put into chairing the meeting for us.

A. T. Whatley
Executive Director
Western Interstate Nuclear Board

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"THE QUANTIFICATION OF SOCIAL VALUES"

by

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Presented At A Symposium Entitled:
"Risk versus Benefit Analysis: Solution or Dream?"
November 11, 1971
At The
Los Alamos Scientific Laboratory

In the general problem of determining the societal acceptability of technological application, the subject of risk- (or cost-) benefit assessment has received ever-increasing attention. This has become, rather like the weather, something everyone talks about. In the present discussion we will confine our comments to the field of nuclear energy, the area of greatest immediate interest to most people attending this symposium; however, the principles are applicable in the broader area of technology assessment.

Many people such as Metzger⁽¹⁾, Commoner⁽²⁾, Gofman and Tamplin⁽³⁾, and others^(4, 5, 6), who have been sometimes loosely grouped as "nuclear critics", have variously suggested that the risk-benefit calculus has not been properly considered in the assessment of nuclear programs. They have, in essence, asked to see a public disclosure of and formalization of, the risk-benefit calculation. Others^(7, 8) have reached opposite conclusions based upon the same data. The risks and benefits of various activities have been considered, but in a largely subjective fashion. Every decision made is based upon an intuitive estimate of non-zero

risks balanced against benefits that were felt to outweigh these risks. Subjective risk-benefit assessment has proven unworkable as seen by this controversy surrounding the acceptance of nuclear energy programs. A number of men of apparent good will have reached opposing positions based upon subjective appraisals of the same data. Because of this, an attempt to quantify risks and benefits appears increasingly attractive as a possible way to improve the decision making process.

Now, following the U. S. Court of Appeals decision on the Calvert Cliffs nuclear power plant case⁽⁹⁾, the AEC has adopted a set of guidelines for the preparation of Environmental Statements which specifically requires risk-benefit quantification:

"... shall include a cost-benefit analysis which considers and balances the environmental effects of the facility and the alternatives available for reducing or avoiding adverse environmental effects, as well as the environmental, economic, technical and other benefits of the facility. The cost-benefit analysis shall, to the fullest extent practicable, quantify the various factors considered. To the extent that such factors cannot be quantified, they shall be discussed in qualitative terms."⁽¹⁰⁾

*Work done under the auspices of the U. S. Atomic Energy Commission Contract No. W-7405-ENG-36

This essentially means that those in the nuclear field are more or less stuck with attempting to quantify the costs, or risks, and benefits in advance of the application of technology. It has been asserted that the "debate of intangible and subjective cost/benefit ratios . . . does not make sense" and is tantamount to requiring ". . . our learned authorities symbolically to debate the number of angels that can stand on the head of a pin . . ." ⁽¹¹⁾ While this may seem true to those with backgrounds in physical sciences or engineering, such judgments seem premature before an attempt has been made to investigate the subject with the same vigor that engineering problems have been attacked.

The goal of risk-benefit quantification is not a precise computer-like formulation of decisions. Rather it is to reduce, by quantification, the number of variables involved so that better decisions can be made on a more rational basis. Further, such analyses, with a full and open discussion of the assumptions involved, might promote informed public participation in the debate surrounding complex technical issues.

In this paper we will outline the mechanics of risk-benefit quantification to provide a common reference frame and look at some historical applications of human value judgments. Finally, we will discuss encouraging aspects of research in two areas which have received much attention as being difficult to analyze: the value of life and the quantification of subjective values.

THE RISK-BENEFIT CALCULATION

In many of the routine activities of life there exists the possibility of sudden death or injury, yet we continue to participate in these activities. The reason, of course, is that the participant derives some benefit that, to him, outweighs the risk involved. A common example might be automobile travel. More than 55,000 people are killed annually in automobile accidents, more than

two million are injured, and the automobile is a major contributor to atmospheric pollution and resource consumption. Yet we continue to drive, because, as a society, we have subjectively and collectively decided that the benefits of personal transportation outweigh these well-known risks.

There are many examples of how we make, usually subconsciously, risk-benefit trade-offs in our private lives. A simple example might be that of a man living in the city who decides, partly because of the rising crime rate, that life in the city is no longer "safe". He may then decide to move his family to the suburbs where life is "safer" and then accept an additional risk of death or injury by commuting to the city. He has subjectively decided that, in balance, the risk of being harmed due to urban crime is more than the risk of being harmed due to his additional freeway exposure. Of course, there are many other, even more subjective factors, which are even harder to measure. He may personally prefer injury in an automobile accident to injury by mugging. The cleaner air in the suburbs represents a lessening in health risk as well as an aesthetic benefit. Our cultural system also would place value upon the protection of his family even at his own increased risk. However, the point is that a risk-benefit evaluation, however informal, has been made. It is also important to note that this risk-benefit judgment has been almost entirely intuitive rather than quantitative in nature. When speaking of social group decisions as opposed to individual decisions, this intuitive approach is no longer adequate. Unless the risks and benefits are quantified, so far as possible, there are no means for communicating individual opinions to the group.

Figure 1 shows a crude, and somewhat arbitrary, approximation of the procedures involved in making a risk-benefit quantification. The first step shown is that of enumerating the positive (benefits) and negative (risks) aspects of the proposed process. For a nuclear power plant the

FIGURE 1: The Risk-Benefit Process

negative aspects might include nuclear effluents, both routine and accidental, the discharge of hot water and an aesthetic or psychic detriment. Some efforts have been made to assess the risks from routine reactor effluents⁽¹²⁾ and from accidental releases, as a function of probability, from reactors.⁽¹³⁾ The primary beneficial aspect would be the power produced. The next consideration would be determining the distribution through the ecosystem in terms of space, time and biological species. Here we would also consider the distribution of the benefits in terms of population, space, and time.

Next, one must estimate the integrated effects of the risk and benefits. Risk examples here might be the radiation doses to humans and the effects of thermal effluents upon aquatic life. On the benefit side, one must consider the net effect of additional supplies of electricity, and the possibility of increased soil fertility through warm water irrigation. Increased electricity could be positive, in the case of life-lengthening in an underdeveloped

country, or perhaps negative in supplying unnecessary labor-saving devices to an already under-exercised, power-rich people. The effects upon both the local and national economies must also be considered here. Quantification of negative effects would include, for human radiological exposure, the morbidity-mortality probabilities following exposure and the perceived effect of aesthetic detriment upon those affected. The upper limit of the dose-response relationship for irradiation of humans is reasonably well known. Watson⁽¹⁴⁾ has written on estimating the carcinogenic effects of atmospheric pollutants through analogy with known carcinogens.

The final, and potentially most difficult step, is the conversion of positive and negative effects into a consistent set of units, as far as possible, so that they may be compared as one of several inputs to the decision-making process. This question of quantification and conversion of human and aesthetic values will be discussed later in this paper.

Note that as the calculational process in Figure 1 moves from left to right, there is a continuous change in the disciplines required. The design of the process is mostly a function of physical scientists while the determination of distribution and effects falls to biological scientists and economists. The estimation of aesthetic effects and, perhaps conversion of units, tends toward the behavioral sciences. A thorough analysis of a risk-benefit problem is truly an interdisciplinary effort and no one discipline can hope to cope with the whole process.

In addition to providing the input to decision making as shown in Figure 1, there is a second very important function served by the analysis. There is much discussion of involving the public in decisions affecting the environment. The National Environmental Protective Act requires an environmental analysis that is available to the public for 60 days in draft form. The idea behind this requirement is that the "public" can then make its input at hearings held specifically for the purpose. This concept is valid, however, only if the "public" can make informed input or criticism. Most, if not all, members of the public, including scientists, are not capable of understanding the consequences of, say, 1 man-rem or 10 ppm of SO_2 in the air. The benefit-risk quantification and conversion of units in the last two steps in Figure 1 should help people understand the relative magnitude of the individual risks and may even bring the perceived or "felt" risks more nearly in line with the actual risks. The importance of fear of the unknown should not be under-estimated and the benefit-risk analysis should help move some of the unknowns toward the known.

AN HISTORICAL PERSPECTIVE

The problems that have been considered most limiting in risk-benefit quantification are evaluation of human life and aesthetic values. However,

society is constantly setting monetary values for human life, both directly and indirectly. For example, when a jury recommends a financial settlement in a loss-of-life lawsuit, they are placing a value upon human life. If, after a catastrophe causing both property damage and loss of life, one comments upon the tragedy of life loss, he has unconsciously stated that the value of those lives exceeded, to him, the value of the property. This judgment made in reverse would indicate the opposite. The concept of premium pay for people engaged in hazardous occupations provides another example. The employee effectively sets a monetary value upon his own life in terms of the extra compensation he receives in return for accepting a certain increased statistical probability of death from his employment.

Perhaps one of the earliest examples of weighing human values was for use in setting standards for social behavior found in the Code of Hammurabi⁽¹⁵⁾, Babylonian King in the 18th Century B. C. The King's subjects were divided into three social classes. The higher classes were entitled to greater compensation for injuries, but were also liable to heavier punishment when they themselves committed offenses. In criminal law, the question of human values was treated on the basis of equating of risks -- i. e., the principle of "a life for a life". This extended to situations such as the execution of the son of a man who had caused the death of another man's son. For lesser offenses, monetary compensation was prescribed, but payment was to the injured rather than to the state. Imprisonment and forced labor were not used in the criminal code.

In Anglo-Saxon and Germanic laws in the early Middle-Ages, the idea of wrong to a person, or his family, still superseded the concept of wrong against the social group. This resulted in a crude attempt to place monetary value upon human life and injury. These laws predate the reign of Alfred the Great (871-899) and were found

in the laws given by Henry I in the 12th Century. The wer or wergild was the value set upon a man's life. This amount depended upon the social rank of the individual with a scale adjusted so that any injury (including death) to any individual had a price, increasing with his rank. The offending party, if unable to pay the wergild to the family of the slain, was outlawed or sold into slavery. According to Norman records, the wer of a churl, then an ordinary freeman (the word has a somewhat negative connotation in modern usage) was set at four pounds, while that of a thegn, an administrative officer of a great man (such as the king) was six times greater. The unattonable offense was killing in secret, that is, by poison or witchcraft. In such cases, the murderer was delivered to the slain man's kin for revenge. This system gradually evolved into one where capital crime was considered an offense against the social order. (16)

In the 17th Century, Sir William Petty estimated the monetary value of a member of the English population at "£80 . . . the value of each head of Man, Woman and Child . . ." (17) His method, crude by modern economic principles, considered the total earnings of the populace and the amount of capital necessary to yield this income if invested at interest. He suggested that, from his calculation, "we may learn to compute the loss we have sustained by the plague, by the slaughter of men in war, . . ." Farr (18), in 1853, made estimates for the monetary value of life based upon the present value of future earnings. He suggested a value of 191 pounds sterling at age 15 and 246 pounds sterling at age 25.

An English traveler, J. S. Buckingham (19), told of an early effort at what is now called cost-benefit analysis. He reports the attempt of an anonymous Kentucky slaveholder, in about 1840, to compare the costs of black slaves, motivated to work only by the fear of punishment, with the cost of hiring free laborers:

"He said he had not only made the calculation, but had actually tried the experiment of comparing the labour of the free white man and the Negro slave; and he found the latter always the dearer of the two. It took, for instance, 2,000 dollars to purchase a good male slave. The interest on money in Kentucky being ten per cent, here was 200 dollars a year of actual cost; but to insure his life it would require at least five per cent more, which would make 300 dollars a year. Add to this the necessary expenses of maintenance while healthy, and medical attendance while sick, with wages of white overseers to every gang of men to see that they do their duty, and other incidental charges, and he did not think that a slave could cost less, in interest, insurance, subsistence, and watching, than 500 dollars or £100 Sterling a year; yet, after all, he would not do more than half the work of a white man, who could be hired at the same sum, without the outlay of any capital, or the incumbrance of maintenance while sick, and was, therefore, by far the cheaper labourer of the two."

Unfortunately, history does not tell us if, based upon this analysis, he then freed his slaves.

All of these examples (a sampling of many) illustrating early efforts to assess human values in concrete terms are today of purely historical interest. However, they do demonstrate that man has, for a variety of reasons, had a long-standing interest in this problem.

LIFE VALUES

In the last section we noted that society has, both indirectly and directly, set monetary value on human life and continues to do so today. This concept can be important in the use of risk-benefit principles for technology assessment where, as mentioned earlier, there is often difficulty in comparing risk and benefit in a consistent set of units. For a very simple risk-benefit exercise, the risk estimate might be expressed in units of deaths statistically expected, while the estimate of benefits might appear in units of monetary value.

This comparison of results in these dissimilar units presents a rather complex study in value judgment.

We must realize though, that as a society, we place a far different value upon an identified life as opposed to a statistically expected loss of life. For example, large sums of money might be spent to find a lost child or to rescue survivors of a mining disaster, shipwreck, or airplane crash. We are far more casual about a statistically expected loss of life, such as the appropriation of funds to install a traffic light at a dangerous intersection where someone is, ultimately, sure to be killed. The same is true of many public safety measures where the future victims are anonymous. The concept of placing actuarial value on human life is valid only in the statistical sense.

When we consider a situation where risks are allocated involuntarily to the public, it is necessary that a relatively large segment of the population be affected by the proposed activity, and that the maximum risk assumed by any population group or individual not be unduly large. This is necessary so that the risk-benefit distribution may be viewed statistically when risks and benefits are assumed by different groups of people. In this way decisions may be made to maximize the net benefit to society viewed as a whole.

Several estimates have been made for the value of the statistical life, with rather good agreement among various sources. Jury awards in loss-of-life lawsuits fall mostly in the range \$50,000 to \$500,000 with a geometric mean of about \$250,000⁽²⁰⁾. The present value of future income for an average man (corrected for 1971 wages) is about \$200,000⁽²¹⁾, a fact which may not be unrelated to the magnitude of the jury awards.

Carlson⁽²²⁾ has summarized several cases where, directly or indirectly, human values have been assessed. For example, the hazardous duty pay for a typical U.S. Air Force pilot (captain, 10 years service) is about \$2,280 per year. For a man flying "average" aircraft with "typical"

exposure, the increased mortality probability results in a statistical life value of \$980,000. For pilots flying new jet fighters, with higher risk, the corresponding value of life reduces to \$135,000. This study also reports results of a Federal Aviation Agency study to compute the value of life saving in commercial air transport accidents. Both direct and indirect costs were included with a resulting estimate of \$373,000 as the life value per average fatality.

Lightowler⁽²³⁾ has discussed the treatment of children with complications of spina bifida (a congenital abnormality in which the spinal column is not completely closed). Intensive medical care is required for those children who survive. In this study the cost of medical, social services and future maintenance for the survivors was estimated at £7,250 per patient. This figure was compared to the necessarily limited future earnings of those eventually able to work and the legal value of these lives as might be determined by lawsuit in the event of accidental death. The early medical treatment of these patients was questioned in the light of limited funds for maintenance of survivors.

More specifically, in the nuclear field, several investigators have made monetary estimates of the biological damage caused by exposure to ionizing radiation or, what expenditure is justified to avoid a given radiation exposure. This approach also rather explicitly infers a monetary value for human life. Cohen⁽²⁴⁾ made an estimate of \$250 per man-rad of radiation exposure. A Swedish study⁽²⁵⁾ to determine the expenditure justified to reduce public radiation exposure by one man-rad, yielded a value of \$100 per man-rad (since revised to \$200 per man-rad⁽²⁶⁾). A similar study in England⁽²⁷⁾ resulted in a figure of "a few pounds sterling per man-rad" -- about \$10 per man-rad.

Lederberg⁽²⁸⁾ made assumptions regarding the fraction of the U. S. national health bill attributable to genetic mutations which might be caused by background radiation. Based on these

assumptions, he arrived at a value of \$100 per man-rad exposure. He made a further estimate based on attributing a highly conservative fraction of natural cancer incidence to background radiation, which resulted in an upper-limit figure of \$600 per man-rad.

The author of this paper surveyed a number of people on their recollections of catastrophic accidents. When the ratio of property damage to number of lives lost in a particular event exceeded \$200,000, all respondents remembered primarily the property damage to the exclusion of life loss. This seems to represent a subconscious assessment of life value at about \$200,000 per life.

The economic estimates of life value may be converted into units of dollars per man-rad for comparison purposes if we conservatively assume that the biological effects of irradiation are linear with dose and that there are no threshold or dose rate effects. For this conversion we have used a figure of 10^{-3} for the mortality probability per rad of radiation exposure, although use of a smaller number would probably be justified⁽²⁹⁾. These estimates are compared in Table I. These numbers, either directly or indirectly, are estimates of statistical life value. The agreement among such diverse sources is interesting.

TABLE I
VALUE OF RADIATION RISK

	\$/Man-Rad
Cohen	\$250
Hedgran and Lindell	\$200
Dunster	~\$10
Lederberg	\$100-\$600
Otway	\$200*
Jury Awards	~\$250*
Future Earnings	~\$200*
Hazard Pay	\$135-\$980*
FAA Estimate	\$373*

*Inferred from life value estimates.

To make these comparisons, we converted the estimates of monetary value of a statistical life into units of radiation risk, dollars per man-rad. This conversion could also be made in the opposite direction to convert Table I into units of dollars per statistical life. This consistency is encouraging because it indicates that, in the broader area of making risk-benefit analyses, the formulation of these difficult value judgments is within the realm of possibility. Whether it is acceptable is a different question which must be posed along with the question of alternatives.

QUANTIFYING SUBJECTIVE VALUES

An even more complex judgment, when one speaks of quantification of risks and benefits, is that of attempting to include such ethereal factors as aesthetic and emotional values. However, this is another area in which we routinely make such judgments in an informal way. For example, the auction sale of an art object. This transaction requires that a monetary value be placed upon an article whose worth is largely aesthetic -- that is, the sales price is considerably more than the cost of the materials and labor involved in creation. This is not to say that these aesthetic values do not or should not exist, merely that we often make decisions requiring the equation of monetary and aesthetic value.

Starr⁽³⁰⁾ investigated the increasing acceptance (measured by participation) of various technologies and found it to increase as the associated risk decreased. He postulated the value of the statistical risk of death from disease to be the "psychological yardstick" by which people subjectively establish the acceptability of other risks. He further found the public willing to accept voluntary risks about a factor of 1,000 higher than that found acceptable for involuntary exposures.

Experiments^(31,32) have shown that people tend to be overconfident in predicting the outcome

of events over which they can exert some control. This is analogous to the apparent readiness to accept higher voluntary risks where the degree of participation can be controlled. On the other hand, evidence indicates that people tend to be underconfident when facing uncertainties of external origin.⁽³³⁾ This verifies the apparent overestimation of vague environmental risks which must be accepted involuntarily by the public.

Another study⁽³⁴⁾ looked at the probability of accidental deaths, from various causes, for the average person in the population. It was found that people intuitively seem to be unaware of risks at a mortality risk level of 10^{-6} per person per year. A mortality risk level of 10^{-7} per person per year was postulated as an acceptable maximum risk for those living nearest to nuclear power plants.

A form of quantification of essentially subjective elements has been useful in the investigation of natural hazards. In a survey of people in 496 urban locations⁽³⁵⁾ an approximate log normal distribution was postulated to describe the perception of flood hazard. That is, locations of intermediate measured flood frequency had a higher relative perception of flood hazard than places experiencing either more frequent or infrequent flooding. Another survey⁽³⁶⁾, also concerned with natural hazards, administered a test to assess the risk avoidance response of people to situations representing physical, social, and natural hazards. For the total sample, avoidance to physical threat (automobile accident, attacked and robbed) was greatest with natural hazards in the second position above social items. Hazard avoidance was further considered in connection with the personal experience of the respondents and their personality types.

Behavioral scientists, those most familiar in dealing with subjective values, often use quantification and statistical methods to help sort out the

variables involved. For example, quantitative analysis has been useful in the classification of depressed patients^(37, 38) and in the formulation of a numerical scale for correlating the severity of depression and the seriousness of suicide attempts.⁽³⁹⁾

Another area in which subjective factors can be important is in the perception of physical illness. In 1960, Hinkle⁽⁴⁰⁾ in a survey of disabling diseases, defined the seriousness of illness as its probability of leading to the death of the patient, strictly a function of the estimated epidemiologic probability of death. This study then defined the severity of disease as the degree of disability incurred, that is, the extent to which a person is unable to carry out normal social function. The concept of severity could also be quantified by such measurements as the number of days missed from work because of an episode of illness. Neither of these definitions includes the more subjective components of illness. They are strictly a probabilistic estimate of death in one case, and the measurement of number of days disability in the other. These are useful concepts if we are interested only in a probabilistic estimate of severity or seriousness of injury or illness. However, subjective values, that is, how one perceives his illness, is not included in this concept.

In 1968, Wyler,⁽⁴¹⁾ through survey techniques, attempted to quantify the subjective aspects of illness from a gestalt point of view. For this survey, the concept of seriousness of illness included such factors as prognosis, duration, threat to life, etc.; but, more important, it also included the emotional and aesthetic factors, which influence one's perception of how serious a particular illness is. In this study, a list of 126 disease items was shown to a sample of medical out-patients. They were then asked to rate these diseases in a quantitative manner using a given illness as a modulus item. The quantitative rankings given by out-patients to various diseases were also compared

to the results of the same survey applied to a group of physicians, whose knowledge of disease might lead them to rank disease items in a different manner than the general public. The differences in ranking between the two groups, the general public out-patients and the group of physicians turned out to be very small. The Spearman rank order correlation coefficient between the two groups was a highly significant 0.947. The geometric means of the quantitative rankings of these disease items was used to form the Seriousness of Illness Rating Scale (SIRS). This survey was later tried with a second group of physicians to check reproducibility with excellent results;⁽⁴²⁾ and, as a further check, the cross-cultural consistency was estimated by testing groups in Ireland and Spain⁽⁴³⁾ again with resultant high correlation coefficients.

In asking the sample groups to rate illnesses, peptic ulcer was given an arbitrary value of 500 points. The respondents were asked to compare the seriousness of each of the remaining illnesses to that of peptic ulcer. That is, to rate the relative seriousness, using all their experience -- direct and indirect, objective and subjective -- in arriving at an answer. It is important to note that this method of ranking definitely includes the emotional, aesthetic and moral prejudices associated with various diseases. A sample of some of the diseases included in the SIRS and their mean ratings is shown in Table II.

Note that the subjective impressions of various diseases have indeed been quantified. Syphilis, for example, which has high negative moral connotations in our society, but which is seldom fatal if treated promptly, was given slightly less than half the rating given cancer. Sexual inability, with an obvious emotional loading, was rated about half as serious as heart attack -- although never fatal unless in conjunction with suicide. Such items as bad breath and dandruff may appear to be overvalued when compared to other disease items. However, if advertising is any indicator, the fear

TABLE II
SOME ITEMS FROM THE SERIOUSNESS OF
ILLNESS RATING SCALE

	MEAN SCORE
Leukemia	1080
Cancer	1020
Multiple Sclerosis	875
Heart Attack	855
Muscular Dystrophy	785
Stroke	774
Blindness	737
Chest Pain	609
Peptic Ulcer*	500*
Syphilis	474
Sexual Inability	382
Pneumonia	338
Irregular Heart Beats	302
Whooping Cough	230
Measles	159
Acne	98
Common Cold	62
Bad Breath	49
Dandruff	21

*Modulus Item

of bad breath and dandruff have generated a sizable industry in the United States. The point here is that it appears that it is indeed possible to attach some quantitative significance to the emotional, moral and aesthetic factors attached by people to various ailments.

For some time a correlation between psychic stress and physiological disease has been observed, that changes in persons' lives seem to occur in clusters prior to the onset of physical illness. Hinkle⁽⁴⁴⁾ showed that it was the individual's perception of stress which was correlated with illness. Experience with over 5,000 patients was used to tabulate some 43 life-change events which require a degree of individual social adaptation⁽⁴⁵⁾

Some of these items were objective changes such as marriage, divorce or vacation; others were far more dependent upon the individual's subjective interpretation of them, such as sexual difficulties or significant changes in work or eating habits.

This list was used to form the Social Readjustment Rating Scale (SRRS) which was administered in a questionnaire form similar to that just described for the SIRS. The personal adaptation to marriage was used as the modulus item and arbitrarily assigned a value of 500 points and respondents were instructed to compare each item to marriage and assign a numerical value to the required social readjustment. The SRRS test was given to groups of white Americans, ⁽⁴⁵⁾ Japanese, ⁽⁴⁶⁾ American minority groups, ⁽⁴⁷⁾ Western Europeans, ⁽⁴⁸⁾ and Spanish. ⁽⁴³⁾ In each case there was a high degree of reproducibility within cultural groups and also a high degree of cross-cultural correlation. Cross-cultural correlations for the SRRS were not as high as that found for the SIRS. However, this was believed due to the fact the illness and the perception of illness is rather similar in different cultures, whereas the readjustment to social change is culturally specific, depending more upon particular cultural values. A correlation has since been found between life-change magnitude, as measured by the SRRS, and the onset of serious illness, using the SIRS as a measure of relative seriousness. ⁽⁴⁹⁾ Some items from the SRRS are shown in Table III. Again, the important point to be brought out here is that elements essentially subjective in nature have been quantified in a reproducible manner.

The examples of the quantification of subjective values given here have little direct relationship to the use of risk-benefit principles for technology assessment of standard setting, but the techniques used could be applied in other fields. The problem of the quantification of aesthetic values for risk-benefit assessment does not seem an insurmountable one. The use of appropriate survey techniques

TABLE III
SOME ITEMS FROM THE SOCIAL
READJUSTMENT RATING SCALE*

	MEAN SCORE
Death of Spouse	770
Divorce	593
Marital Separation	517
Marriage**	500**
Death of Family Member	469
Fired from Work	378
Sex Difficulties	316
Pregnancy	301
Death of Close Friend	269
Trouble with In-Laws	213
Change in Residence	140
Vacation	74
Minor Law Violation	54

* Results of American Sample

**Modulus Item

could help eliminate some of the difficulty in evaluating phrases such as "people just don't seem to like it". Indeed, even a semi-quantitative ranking of the public perception of various alternatives could be most helpful in decision making.

CONCLUSION

Quantitative benefit-risk analyses have been attempted recently but no formalism has evolved and been accepted. Those first suggesting a "calculus" of benefit-risk analysis felt that quantification of such values as human life and aesthetic values would be a difficult and time-consuming process, if possible at all. A survey of the literature reveals that many of these judgments have already been made in preliminary form and techniques exist for determining others. Thus, it seems likely that, with a proper interdisciplinary effort, performance of risk-benefit analyses is

within reach. As such studies continue and more is known about the perception of subjective values, subsequent efforts will become easier.

It is clear that benefit-risk evaluations can neither be performed nor developed by "task forces of experts" because there are no experts yet and no group of "experts" can judge the values and opinions of the people to be affected by a proposed activity. The acquisition of the required information is, however, within scientific capabilities if an appropriate research effort is made.

Finally, it is to be hoped that a properly performed benefit-risk analysis, with a full discussion of associated assumptions, would help in communicating the elements of complex technical processes to the public and promote the participation of an informed public in the decision making process.

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"RISK-BENEFIT ANALYSIS IS A DREAM"
(OR IN THE SPECIAL CASE OF ATOMIC ENERGY, IT'S A NIGHTMARE)

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Presented At A Symposium Entitled:
"Risk versus Benefit Analysis: Solution or Dream?"

At The
Los Alamos Scientific Laboratory
Los Alamos, N.M., November 11, 1971

Back in Boulder writing this speech, I found that I just couldn't get a grin off my face. There I was alone up in my cabin in the mountains, writing a serious talk to be delivered to serious people about a serious subject, but the absurdity of it all kept on breaking through. I mean: bright guys, friends of mine, were actually trying to quantify arithmetically on the one hand, something as complex as human values, and on the other hand, trying to do so in the field of atomic energy which is a very bad place to invest your time and money these days.

Now we're all here at Los Alamos today to explore the possibilities of risk-benefit analysis: a new approach, using rationality, to the problems of acceptance that come up when a strange technology is presented to society.

Now, I'm going to divide my remarks into three parts. First, why the field of atomic energy is probably the dumbest place of all to begin this experiment (but I assume it started here because it's the field which most needs the assumed benefits

of risk-benefit analysis), secondly, why, for sociological and psychological reasons, it is naive to believe in the constructive application of risk-benefit analysis, and lastly, what I believe will actually happen in real life.

PART I

In the last couple of years, a new and exotic technology was introduced into my state of Colorado. The real truth about this new technology, its risks and its benefits, were kept from the people of my state. The whole truth was a secret from them, not because of some government "secret" classification, but simply because of the technical complexity of the new technology; also because the only government agency responsible for releasing information about this new technology was at the same time charged with promoting that very same technology. As a consequence, the benefits of the technological adventure were

exaggerated beyond all reason, while the risks were almost totally ignored.

Last month a man died in Colorado, and very probably he would not have died if it weren't for this new technology.

Now I'll bet you all think I'm going to say that he breathed some of that radioactive natural gas and that he died of cancer right there at the Rulison site, but that wasn't it. The man was an elk hunter from Texas, and he died in an avalanche near Silverton. The avalanche buried him and his companion last October 18, at a time when such avalanches were quite uncommon there. But it also happened shortly after the start of a cloud seeding project in the San Juan Mountains, an effort run by EG&G (sound familiar?) and financed by the Bureau of Reclamation, to "mine water out of the sky" as they say, by seeding clouds with silver iodide.

Now why have I told you this story? Imagine for a moment what would have happened if instead of an elk hunter, dead in an avalanche, it was someone else, dead of a cancer that could have just as tenuously been blamed on atomic radiation - maybe from Project Rulison. Well you can be sure that it would have stopped that atomic venture dead in its tracks. Demonstrations, lawsuits, proposed legislation outlawing atomic blasts in the state, fantastically bad press, unfavorable reports out of the Governor's Advisory Groups, all the rest, would descend like a plague, down upon the heads of the atomic promoters. One mistake in an atomic project finishes it off. Depending on the mistake - it could finish off all atomic projects for a long time.

Now why is this true? Why are atomic promoters discriminated against? Why can other new technologies kill people and get away with it while atomic technology can't enjoy those same privileges?

Why there are even more similarities between the cloud seeding promoters and the AEC? Like the benefits of atomic energy, the benefits of

cloud seeding have been similarly oversold to the public. You know, the typical calculations are made; the total value of each acre foot is integrated over the total water up there and an astonishing figure emerges, gigabucks of water are up in the sky - just for the taking. It reminds me of those Bureau of Mines calculated, and AEC advertised, 300 trillion cubic feet of natural gas in tight formations all over the country, just there for the taking. The next thing we'll see is a Bureau of Mines calculation that there is enough granite in Pikes Peak to supply the nation's tombstone needs for the next 300 years. But there is always a fly in the ointment. I don't know what will stand in the way of the Pikes Peak adventure, probably some "outside agitators", or the cremation lobby, but the flaws in other technologies are becoming realized already. It's not generally known, but in at least one long attempt, cloud seeding not only did not achieve extra rainfall, but it actually caused a net 20% reduction. That was the result of a 1969 analysis of the five-year Whitetop cloud seeding project in southern Missouri and northern Arkansas.

Furthermore, like atomic promoters, the cloud seeders give misleading and expansive assurances of the safety of their technology. Not only have they provided assurances that the locals will not be bothered by excess snow (how that's possible is still a mystery) but their response to the death of the elk hunter was to assay the nearby snow for silver iodide, when they found none, they announced to the press that their project "wasn't in any way responsible for the avalanche or heavy snows in the area" even though "the Bureau had been seeding clouds in the area." Like the atomic promoter, they didn't include in their explanation the fact that silver iodide cannot be found in detectable quantities in the snow produced by a cloud seeding operation. The way it works is that the silver iodide provides a nucleus around which a snow crystal forms. This snow crystal itself

becomes a nucleus for still more snow to form. In this way one silver iodide crystal catalyses the formation of countless snow crystals. If it didn't happen that way, you wouldn't be able to produce one inch of rain over 20 square kilometers by seeding clouds with only 100 grams of silver iodide (that's an optimum result and a breeding factor of a trillion). So there's damn little silver iodide in any given snow sample, too little to assay for, no matter what. But like the AEC, (who freely and falsely advertised that the high levels of radioactivity in the Grand Junction radon homes were due to natural background radiation there), the Bureau of Reclamation assured the public that they couldn't possibly be at fault, despite the fact that they didn't know what the hell they were talking about. So, like the AEC, the Bureau of Reclamation tells lies as well. Why can the Bureau of Reclamation get away with lying to the public and the AEC can't? It's even worse -- the AEC can't even tell the truth any more without people naturally assuming that they've lied. Credibility is like virginity, once you've lost it, you can never get it back.

Well, I say that there's something special about atomic energy that makes it so hard to sell to the public. I think most of you here will agree to that -- we'll differ only on what that something special is. I think I know what it is. But first let me tell you some of the things it isn't. Firstly, stewards of the American atomic establishment are fond of putting the blame on the professional "stirrer-uppers" as Commissioner Ramey and Representative Hollifield call us critics of the AEC. They even believe that we make our living from it. Why, Hollifield and Aiken are even on record as believing that an article in Science Magazine critical of the AEC brings the author \$10,000 (Commissioner Tappan had to straighten them out on that one). It isn't the critics that have skewered the AEC so badly; how could we have done so, considering the odds, if the AEC itself hadn't been such a help?

Another thing it isn't, but the Joint Committee's staff thinks it is, is the so-called American guilt associated with the first use of atomic energy in wartime, destroying Hiroshima and what's-its-name with only one bomb each. No, worse raids have happened in that war and we don't even remember them. Speaking of what's-its-name, Nagasaki itself is a forgotten incident. Some books that discuss Hiroshima in detail don't even mention the Nagasaki raid. The voluminous official history of the AEC gives the incident only one sentence, and at that, Nagasaki is mentioned as a passing reference, just something that happened on the same day that Russia entered the war against Japan. So war guilt as the reason is another red herring.

The real reason is that for good cause, the American people have learned first to distrust the AEC and then atomic energy in general. This is because most of the technical judgments that the Atomic Energy Commission has made and told to the public were half-truths, the rest were outright lies. The Joint Committee on Atomic Energy not only backed up those lies, but added a measure of arrogance and disdain for opinion contrary to their own which completed all the ingredients necessary for what we are seeing today and about to see more of tomorrow: a wholesale rejection of nuclear energy by the public. It will be done precipitously, irrationally, and in some aspects, unjustly, but that's what is happening and typical of their insensitivity and ineptness, it is the stewards of the AEC and the Joint Committee on Atomic Energy who, insulated from the real world by each other's opinions as they are, it is they who will be the last to know.

In case you think my statement is extreme about the lies the AEC tells, let me divert (in my own defense) from the theme of this symposium, for a moment, just to list them. I'm finishing a book on the subject, and in there, you'll find several hundred references of documentation, which should convince you, in case you're not

already. The AEC's incompetence in handling the fallout problem of the late 1950's was glossed over by a blanket of self-serving lies told at the Joint Committee Hearings in 1962. Uranium purchasing policies of the AEC sent thousands of miners underground without a word of caution from the AEC, who knew at the time that 1000 European miners had already died of lung cancer under conditions that the AEC was recreating on the Colorado Plateau. AEC licensed mills were permitted to so poison rivers that "biological deserts" were created in the streams and radium concentrations in the drinking water of 30,000 people far exceeded permissible limits. Hundreds of thousands of tons of uranium tailings were removed from those AEC licensed mills, under the eyes of monthly AEC inspections, so that today 5,000 home owners will receive letters this month in the city of Grand Junction, Colorado, alone, that their houses were made dangerously radioactive because of tailings used in their construction. Radioactive waste at every AEC waste depot is, according to the National Academy of Sciences, improperly stored. A final solution to the waste problem in a Lyons, Kansas, salt mine, was studied for 15 years by the AEC and the plan itself was dumped only six months after a rush full appropriation of the whole \$25 million required was requested by the AEC.

But here's why all of this is important: throughout every one of these blunders, the truth of the hazards involved became known only through independent and outside scientists, over the objections of an AEC that has over the years turned into a fanatically defensive protectionist clique of tenured bureaucrats, drawing job security and prestige from the miraculous achievement of the Manhattan Project, here, 25 years ago, and whose best efforts today are divided between wildly inappropriate technological adventures and the justification of their past mistakes.

A year or two ago I believed in risk-benefit analysis and said so at a symposium here (and at Livermore and NVOO as well). I believed that if men of good will sat down together in order to get to the real business of supplying the energy needs of our nation, that a plausible form for the dialogue could be risk-benefit analysis. I've seen a lot more of the AEC and particularly the Joint Committee on Atomic Energy since then, and I've changed my opinion. I don't think there are enough men in either of those two bureaucracies of good will and proper motivation to swing the balance the other way.

No, I wouldn't take a delicate new idea like risk-benefit analysis and subject it in its infancy to being tarred with the same brush that's being used today, and justly so, to tar and feather the AEC.

PART II

I said I'd tell you next why, for sociological and psychological reasons, it's naive to believe in the constructive application of risk-benefit analysis is at this early stage in its history. That is: what it is I think which will not work. By the extension of scientific logic into the field of human sociology and psychology, it attempts to quantify and thus to reduce to arithmetic parameters, human values, so that they may be arithmetically manipulated to facilitate their comparison, one with another. The values, thus compared, are adjusted to make a fair case, for or against a new technology. Whether the risk-benefiters admit it or not, they tacitly expect that the public, impressed with the logic of the deliberations, and similarly logically inclined, will accept the considered judgments in the risk-benefit analysis and everything will be just swell.

The values typically compared (although not always) are physical comfort and life shortening. It can be as simple as this: a dollar value is assigned to a human life, and a number of rem

is accepted as that amount of radiation needed to cause "one statistical death". The first figure is divided by the second and you get a dollar value for the amount of "death", a certain amount of radiation will cause. Then you apply this number: you can examine a new atomic benefit-risk producer and determine what benefit each man will receive from it in terms of kilowatts or whatever. Then you calculate his risk in rems, from which you derive his degree of "life shortening". Then, over coffee, you tell your lab mates what you've done and it's all a lot of fun.

It's the kind of game scientists like: You come up with astonishing figures (that's why scientists like it) such as: "What's all this fuss about Project Rulison anyway? Why, each man's risk had a dollar value of only 0.1". It becomes obvious to all the technical types in the cafeteria that there's something to the argument after all. Besides, it's a new way of looking at things and that's something that scientists are hypnotized by. If there's one intellectual occupational hazard of the scientist, it's his tendency to get carried away by a new idea - sometimes too far.

And that's what I think we're observing here: A clever, ingenious and intellectually stimulating dream. Risk-benefit analysis will fail, not because the men promoting it are not of good will, but because they have dropped a very important parameter from their calculus. That parameter will be very difficult to develop because it must account for the fact that all those people out there aren't similarly inclined to scientific logic.

How has it worked until now? Until today the AEC PR flak would tell the public the risk argument: That the new machine down the road will put out atomic radiation it's true, but the amount will be only a "tiny fraction" of the natural background. Would you think it foolish and dismiss it if I said that a substantial fraction of the public might feel that zero above background is the only level they'll accept?

Representative Holifield, the most powerful single man in the American atomic establishment for 10 years or more, and the man most single-handedly responsible for the public problems of atomic energy today, dismissed with scorn and disdain such protests. In 1969, he said of the "people in this country": "They are going to have their electricity and they are going to shut up about ecological conditions. They are all comfort seekers."

I wouldn't be surprised if many of you here today believed that same thing in 1969 too, but you don't today, otherwise you wouldn't be here. When an audience in a town in the San Juan Mountains of Colorado was being briefed on the weather modification programs there (the one that killed the hunter - maybe) a man stood up, (not exactly the radical type, either, he looked as if he stepped out of American Gothic) and said that he'd not stand for one extra flake of snow falling on his land that God didn't intend to fall there. And, later, after the meeting, he was heard to say that he would be up there at the silver iodide generators during the winter and dynamite them right off the ridge. So much for your "natural background" argument. And I'm not sure that he doesn't have a point, either, but I told you that, because that's the situation the risk-benefiter is walking into.

But all that happened yesterday; today we have risk-benefit analysis. Let's imagine a "real" situation: An atomic enterprise comes to town and a complete and honest risk-benefit analysis is done. Imagine a dialogue between the Risk-Benefiter and the Representative Average Man (RAM). Also imagine that each is equally intelligent and both are men of good will; they just don't think alike. Now before the Risk-Benefiter explains anything at all, he's got one big obstacle to overcome, and that's what I discussed in Part I, it's the AEC:

Risk-Benefiter: Hi, sir! I'm from the Good Will Risk-Benefit Institute and we've just prepared

this report, at our expense, (here's your own copy, sir!) which says that the new black box down the road will take atomic energy and . . .

RAM: (Interrupting) Now hold it right there pal. Did you say atomic energy - 'cause if you did I don't want any part of it. That AEC's the biggest bunch of liars in Washington - and that's going some.

Risk-Benefiter: No, sir, I'm not from the AEC. As a matter of fact, sir, this whole enterprise is out of private industry. By law the only part the AEC plays is to oversee the safety of the project.

RAM: (ignoring Risk-Benefiter's answer) Now what's a nice guy like you doing with a bunch of liars like that anyway? No thanks, pal, I'm just not buying. I guess I'll just have to wait until it's too late - till we have brown outs and black outs and energy rationing and all before I'll come around.

But suppose, since we're supposing, that the first obstacle can be overcome, the Risk-Benefiter takes: Tack 1.

Risk-Benefiter: Well, now that we've sold you on the benefits, here's your two bits (the Risk-Benefiter counts out a nickel and two dimes and offers them to RAM). Our risk-benefit analysis says that your risk amounts to one millirem of radiation, or a "life shortening" effect of just one-half hour; so here's your quarter.

RAM: Oh no you don't. I know how that works. Your black box up the road will cause one statistical death since it puts out 1000 rem. It may be that all one million of us here in Gotham City will lose one half hour of life, for which we're each paid two bits, or it may mean that our new baby will die in the first year of his life, and no one else will be affected, or since my wife and I are both 35, and have already lived half our lives, it may mean that one or both of us will die as soon as you

turn that thing on. I just can't take the chance; I reject your quarter.

Risk-Benefiter: But the odds are so great against any one person . . .

RAM: (Interrupting) That's true. But it isn't the odds - it's the stakes! And there's something more. Stroke runs in my family. When we go, we go fast - a cerebrovascular accident - just like that. Radiation exposure increases your risk of cancer. That's a slow way to go - I'd rather go quickly like my father before me. You are taking away my freedom of which way I'm going to die!

Risk-Benefiter: Oh no sir! Radiation does increase cancer, it's true, but it also decreases longevity in general. People die of all the same things, only sooner, so you can still die of your stroke if you like - only a half hour earlier. You just age a little faster.

RAM: Age a little faster do you? Well, my wife won't like that. I'll tell you what - since you say that 1000 rem will cause "one statistical death" and that's worth \$250,000, why don't you go out and find the ten men whose lives are going to be shortened by 2,500 days each and just give them \$25,000 each. That's not a bad deal: Seven years of life in trade for \$25,000 in one lump sum. I'd even buy that one.

Risk-Benefiter: Well, sir, I'm afraid our "little exercise" (as it's been called) isn't so advanced that we can predict with accuracy just who it will be.

RAM: Well - That's too bad because if you could - then you'd have a deal. But as it stands, I'd just rather pass if you don't mind.

Tack 2: Comparisons between old familiar health risks and new strange health risks.

Risk-Benefiter: Well sir, let's look at it another way: Our risk-benefit analysis indicates that by the conventional method now used, you are already suffering three times the risk that the new black box will produce, and in five years (if

you take our quarter) we'll phase out the old method so your overall risk will be cut to one third.

RAM: Look - I've been living with the old way for a long time. I feel comfortable with it. It's annoying sometimes, but it hasn't bothered me so much. Sure some days I get a sore throat or a congested feeling in my chest, but I get over it.

Risk-Benefiter: But that's just what I'm trying to tell you sir! Don't you think that those episodes take their toll after a while?

RAM: Why - it can't be much. How bad could it be? Shorten my life by a day and a half maybe? That's not so bad.

Risk-Benefiter: Good God, sir! That's precisely what I've been trying to say all along. A day and a half is three times longer than a half a day. You know sir, you're very irrational.

RAM: So what else is new?

Risk-Benefiter: All right, let's get back to those occasional sore throats and chest congestions you've had. You know that if you were debilitated with a respiratory ailment or something similar, you'd be that much worse off.

RAM: Aha! Now I've got you. You see, I don't have a respiratory ailment - I don't smoke and I keep myself fit. So I'm more immune to the conventional risk than the average Average man. Now radiation is another story - it can hit anybody no matter how fit they are. You can't protect yourself from it. Besides I like the old risk - I've lived with it all my life and I ain't dead yet.

Tack 3: Dire Predictions of Economic Risks

Risk-Benefiter: You know sir, if you don't take our quarter, there'll be an energy crunch, there'll be brown outs and black outs and power rationing. Risk-benefit analysis doesn't concern itself with these more obvious arguments but they're there anyway.

RAM: Yes, so I hear. Well let me answer that one. As an average 35 year old, those problems don't worry me too much because they're well into the future. If our country has a severe

energy crisis in 30 years, I'll be 65 and will be past caring. My mom is 65 already and she doesn't care for obvious reasons. My 15 year old son wouldn't mind seeing power rationing, right now, so those arguments simply don't impress me.

Risk-Benefiter: But it won't be 30 years from now everywhere. Some parts of the country will be experiencing brown outs much sooner.

RAM: I've heard that too. Those are the crowded places that have all of the other problems as well. All I can say is that anyone that puts up with what they put up with must like it. Another problem won't even be noticed. You won't get any sympathy from me for those people.

Risk-Benefiter: Now that's no attitude, sir! We've all got to help each other a little in this world.

RAM: Now look buddy: I know that last one didn't come out of your risk-benefit analysis handbook there; but since you mention it, I say that you're asking for behavior from me and all the other Average Men that we've never exhibited at any time in recorded history. And speaking of precedents, your whole pitch presupposes a logical, scientific, measured and above all, rational response from me and all my fellow Average Men, that likewise has never existed before in recorded history. You call yourself a scientist - you sound more like a dreamer to me.

Risk-Benefiter: Well sir, I'm sorry you feel that way! I'll just continue on down the block and hope that your neighbors are more receptive than you've been. (Risk-Benefiter turns to go).

RAM: Say, wait a minute. I've got one more thing to add: Before you came, I mistrusted atomic energy because I think the AEC is a bunch of liars and that atomic energy is strange and therefore scary. Now that you've talked to me, I'm really scared. Hell, I didn't even know about "life shortening" and "statistical death" before you came by. Now you've really given me something to worry about this time. I'm even more

against new technologies now than ever before because before you only had the feeling there was danger because the AEC said there wasn't. Now you people are admitting it. No thanks - I'm not buying it.

Risk-Benefiter: You mean that I've accomplished more harm than good by coming here?

RAM: You betcha! And that isn't all, we Average Men have suspicions about you scientists. I mean, you just can't be brought up on Frankenstein movies without suspecting that deep down all scientists have a certain Strangelovian preference for scientific experiments over the value of human life. When you come here and tell me that you calculate how many lives you're willing to spend to promote your new technology, it just confirms our suspicions. You know, if this whole thing wasn't just snake believe, we might just run you all out of town on a rail.

PART III

If risk-benefit analysis fails, what will happen? Well, what will happen is what's already happening. What risk-benefit analysis really is is non-binding arbitration! Since men all have their special interests, nobody is likely to give up anything unless he has to. Would Calvert Cliffs and the score of other reactors do what they've just been forced to do if they weren't made to do so?

Can you imagine the reception any technical critic would receive if he knocked on the promoter's door and said "Please limit your technology"? Or here in Los Alamos, at a risk-benefit symposium, he presented reams of unassailable data to support his case? Is there a single precedent in human history for a promoter voluntarily limiting his technology?

And so, after taking his case to the promoter himself, the critics take their case to the public, to the press, to the courts and to Congress and the polemic is made public - and indirect. The promoter's charges are printed in yesterday's paper and the critic's charges in today's - they seldom meet in person.

Therefore, because it requires motives and capabilities not present in our species, risk-benefit analysis, as a scientific discipline, is a dream. But getting together like this has real value. Scientific meetings are important not because of the formal presentations there, but because of the informal contact one makes with his fellows. And I assume in the end, that we're all fellows, that is, we want to see, each in our own way, the technical problems of our society solved. Certain problems concerning the acceptance of new technologies are just beginning to show themselves and promoters and critics getting together like this must turn out to be a help in solving them.

BENEFITS AND RISKS FROM CONVENTIONAL

AND NUCLEAR COPPER MINING

by

Gary H. Higgins

ABSTRACT

The benefits and risks, or costs, of conventional and nuclear explosion stimulated copper production methods are tabulated. Each of the risks has been evaluated in terms of its dollar value, and the ratio of the value of the copper to the sum of the values of the risks -- the benefit-risk ratio -- was derived. The major risks or environmental costs of conventional copper production are sulfur oxides, pits, tailings, mine dumps, and miner injury. Their value totals between \$70 and \$120 per ton of copper produced. The major risks from nuclear explosion solution mining of copper are ground shock and radioactivity. Their value totals \$5 per ton of copper for an assumed population distribution within 30 miles of the mine site. For conventional copper production the benefit-risk ratio is 9 to 14, and for nuclear production it is about 200.

I. INTRODUCTION

This paper is an attempt to perform a quantitative comparison of two methods of copper production. For the reader unfamiliar with the copper industry, brief descriptions of the method are included; however, because of their brevity much must be accepted by stipulation.

Copper is presently recovered by mining rock containing copper minerals and recovering and refining the copper from that rock in man-made plants. The alternative proposed method consists of using the earth as the reaction vessel for recovery of a copper solution, and then refining the copper in conventional plants. The mineral-bearing rock is first shattered with a nuclear explosion to allow access of chemicals to the copper minerals.

The paper is not an attempt to justify one or the other method. Rather, it is designed to show how two quite different technologies might be compared from an environmental point of view. A similar comparison of the economics of the two methods has been performed but is not included in this paper.

The greatest risk from present mining methods arises from process tailings. Lesser risks come from refining and smelting effluents (to both air and water), seismic or blast motion, and aesthetic impacts. The greatest risk which may arise from nuclear solution mining of copper is from ground shock on man-made structures and from radiation exposure to plant workers. Lesser risks come from radioactivity (air and water). Thus, there can be no direct quantitative risk comparison of the different mining-smelting methods because different kinds of risks arise from each. The value judgments necessary to compare the cracking of 100 plaster walls with the landscape degradation from a pit several cubic miles in volume are very difficult and speculative. The risks are defined in each category as quantitatively as possible, but are based on regional or national averages rather than specific operations or mines. Each mine and plant will have characteristics which will alter from the average the magnitude of various risks at that site. No attempt has been made to include the variation from the averages.

The categories of pollution, or risk categories, include chemical, thermal, radioactivity, shock, noise, population, and aesthetic. "Aesthetic" includes dust, silt, smoke, and landscape modification, and "population" pollution means crowding numbers of people into too small a space. Little consideration has been given to population, noise, or thermal pollution because the environmental impact from any of the methods for copper recovery is small relative to the impact from other industries and activities. In addition, the environmental impact from these categories is relatively much smaller than from the other categories of risk from the copper industry.

The areas of the environment upon which these categories can impact are all the parts of the biosphere. The biosphere is usually subdivided into land surface, hydrosphere, atmosphere, and the plants and animals (including man) which occupy these regions. The relationship between the residents and regions is the subject of ecology, although the word ecology is popularly confused with the word biosphere.

In this paper the word "risk" is used to describe a detrimental feature which may have hazardous effect on the biosphere, and the word "pollution" is used to describe an excessive amount of a substance in the biosphere. "Excessive" is defined by standards established in various ways. There is no case in which excessive can be defined as "presence" contrasted with "absence". The biosphere contains significant natural radioactivity which has always been a necessary factor in mountain building and other orogenic processes which keep the continents from eroding away into the seas. Silt or dust in the atmosphere and hydrosphere is a necessary part of the soil maintenance process. Trace elements are necessary in a variety of ways in all parts of the biosphere. For example, a stream of pure water would be devoid of all life, and if the atmosphere contained no CO_2 there would be no land plants and probably no aquatic plants as well. Thus, risk involves an anticipated detriment, the consequences of which are irreversible. Pollution is "too much" contrasted with "enough".

II. PRESENT COPPER MINING AND SMELTING PRACTICES

The 1969 world mine production of copper was about 4.83 million metric (100 kg) tons, and the

total refined was about 5.79 million ton/year.¹ U. S. mine production is about 1.56 million tons, and the total copper refined in the U. S. is about 1.72 million tons/year.² The average grade of copper ore now being processed in the U.S. contains about 0.65% copper.³ The average grade being mined worldwide is a little higher. The difference between copper "mined" and "refined" is copper recovered secondary to some other mined value such as molybdenum.

Commonly, present copper production involves the following steps: mining, milling, concentration, roasting-smelting, converting, anode casting, electrorefining, melting-casting. About 80% of all copper now produced is subjected to this sequence of refining steps.⁴ The remaining 20% of world copper production is from either the TORCO process or by chemical leaching of dumps or permeable underground ore deposits. The trend is toward increased recovery by leaching. The TORCO process involves high temperature formation of metallic copper with ordinary salt and charcoal as preparation for the concentration step. This process is used only for a special class of the more refractory ores and is not of general applicability. The leaching process bypasses the milling, concentration, roasting-smelting, and conversion steps by removal of copper with acid, H_2SO_4 , or $\text{Fe}_2(\text{SO}_4)_3$ directly from the rock to form a dilute copper sulfate solution. The copper in solution is then reduced to cement copper with iron metal (presently the most common practice) or concentrated by solvent extraction processes and reduced to metal by electrowinning. Solution leaching followed by solvent extraction and electrowinning is becoming more favored as a conventional recovery method because it is both economically advantageous and does not involve SO_2 production.

Mining consists of removal of rock-bearing copper minerals from the ground. This is carried out either in open pits or by shafts allowing access to more deeply buried deposits. Most production in the U.S. is from open pits. The ore is usually transported from mine to mill in the form it is removed from the mine.

Milling consists of crushing or grinding the ore to fine particles, usually much smaller than 1 mm maximum particle size.

Concentration is usually accomplished by flotation. The finely divided ore is mixed with water and a froth producing oil-like agent, the slurry is agitated, and air is blown into it to produce bubbles or foam. The mineral values are concentrated in the foam which is removed from the surface and the flotation cells. Copper content of the concentrate usually runs between 20% and 50%.

Roasting-smelting involves the conversion of copper minerals to crude metallic copper. At present, common practice is to heat the material in air (O_2) to partially convert the sulfides to oxides (roasting) and then reduce the oxides and remaining sulfides to metal in an air stream. Roasting is distinguished from smelting by temperature and oxygen abundance. It is carried out below the fusion point of the concentrate, and during roasting most of the iron sulfides are converted to oxides, but the copper is left as sulfide. Roasting is used less as a process step with higher grade concentrates. Smelting is accomplished in a series of steps each carried out in the molten concentrate and in the presence of air. First lime is added, without addition of excess air and iron and silica are removed as slag ($FeSiO_3$ and $CuSiO_3$) leaving a heavy residue of copper and iron sulfides called matte. Then, after the lighter slag is tapped off, the matte is converted to metal by injecting excess air or O_2 . During air injection any remaining iron sulfides are first converted to oxides and sand is added to form $FeSiO_3$, which is removed as a surface slag. Then some of the copper sulfide is converted to oxide which immediately reacts with the remaining copper sulfide to form copper metal and SO_2 . Finally, the impure copper is treated with reducing gases (green wood or methane) to reduce the excess copper oxide, and anodes are cast of the product, called blister copper.

The copper anodes average 98% pure copper and contain as impurities gold, silver, iron, arsenic, antimony, bismuth, and other metals. They are then electrorefined, during which the anode is dissolved and plated on a cathode with electric current. The impurities enter the sulfate cell solution or are precipitated as cell slimes. Copper cathodes are 99.7% pure copper with iron, zinc, sulfur, and oxygen as impurities. This material is then remelted and cast into shapes used in commerce.

Several of these procedures impact on the environment with some potential risk. During mining, particularly in open pits, sizable charges of high explosive are detonated to fracture or break the ore. Explosions of 50 tons aggregate are common, and occasionally as much as 200 or more tons are detonated in large bench blasts. Ground shock from these explosions can cause structural or architectural damage within a radius of several miles. The experience from these blasts and their effect on nearby structures has formed the basis of many of the standards for ground shock control.⁵ Air blast also is created during these explosions, and some risk of window breakage accompanies them. Except in unusual meteorological situations or failure in explosion behavior, the range of window breakage is less than that of architectural damage due to ground shock. A total of about 50,000 tons of explosive is detonated each year during copper mining in the U. S. There is some small risk associated with the manufacture and transport of these explosives to the mine sites. The "pollution" from these detonations is confined within a few miles from the mine site.

Chemical pollution arises almost entirely from the grinding, smelting, and refining processes. Each ton of copper produced creates one to five tons per year from this source. This, in turn, is about 10% of the total annual SO_2 discharge (26 million tons in 1966).

Through efforts to reduce atmospheric pollution, some of the SO_2 is captured and converted to H_2SO_4 at the refinery site and, as leaching processes become more common, the use of fire refining will diminish. Hence, SO_2 production will diminish. At present, however, no copper smelting-refining conforms to established standards for SO_2 emissions (generally in the order of 0.5 ppm). One plant in Montana exceeds state emission standards - by four to ten-fold - in spite of expenditure of tens of millions of dollars for plant improvements and equipment to capture SO_2 . There seems to be, thus, little prospect of conforming to the standards for several years.⁶

In addition to SO_2 pollution, predominantly atmospheric, the copper industry has problems with arsenic pollution in plant air where workers have

abnormally high incidence of respiratory disease.⁶ Arsenic is not now generally released in stack gases and is recovered as a byproduct with filters and precipitation.

The copper itself can, and does, become a chemical pollutant. Tailings dumps contain as much as 10% of the copper originally present in the ore. As these dumps are subjected to the effects of weather, the remaining copper minerals are slowly oxidized and become soluble in water. At many sites secondary dump leaching is carried on to recover this copper, but some solutions are inevitably lost. If, or when, these solutions reach streams or ground water, they can produce excessive copper concentrations. Standards for water presently require copper content of such water to be limited to 1.0 ppm.⁷ Thus, if dilution were the only control, it would take about 20 trillion gallons of water to reduce the copper concentration to acceptable levels from a modest sized (100 million ton) tailings dump during the course of all time. Water from the flotation tanks is similarly contaminated with both traces of copper and with very fine silt. The flotation concentration process consumes about 1500 gallons of water per ton of ore processed. The whole U.S. production requires about 300 billion gallons of water per year, and this water is so contaminated as to be unfit for direct disposal to streams or other uses. In areas where it is impounded for evaporation or percolation all life is destroyed. While the problem is manageable, the water thus used is not available for other uses.

Through heroic and costly efforts, the copper industry is slowly but conclusively solving the chemical risk problems, but inherent to all these conventional processes is the mining of ore. This creates two apparently unavoidable risks; the production of immense piles of tailings and the permanent aesthetic damage created by the pit or mines from which the ore is removed and the dumps on which the tailings are disposed. In the U.S. about 200 million tons of tailings are produced each year, most in the form of fine silt or sand. This is equivalent to a pile a mile square and about 200 ft high. The material is somewhat toxic to life, as noted above, and is a source of fine dust or sediment. It is devoid of plant nutrients so it cannot sustain vegetation, and if washed or eroded into

streams, chokes most plant and animal life. It has been assumed that these tailings dumps are the necessary environmental price of continuing copper availability. Another unavoidable price of mining is the risk of disability or death assumed by miners. On the average, there are about 150 serious disabilities or deaths incurred by miners in the U. S. copper industry each year. While the risk is incurred by choice, the mining phase of the copper industry is among the second most hazardous group of industries. (Only coal mining is more hazardous)

III. POTENTIAL NUCLEAR SOLUTION METHOD FOR COPPER RECOVERY

Since there is neither commercial application nor full-scale field test of this method, its evaluation must be based on calculations and on extrapolation from laboratory and pilot plant experiments. Briefly, the method consists of three steps: explosion shattering, oxygen leaching, and electrowinning. Its distinguishing and important feature is that no rock is removed from the ground (mining), thus avoiding the most costly (60 to 65%) and undesirable step in conventional copper recovery. In addition, it has the potential of making new types of copper deposits useful as ore because it is applicable to the deeper, lower grade ore not presently minable.

Since there is no mining or smelting connected with this recovery method, few chemical, particulate matter, or aesthetic risks are associated with it. Slight possible risks could arise from loss of acid solutions during pumping when contamination of near-surface water supplies could occur if there were inadequate casing precautions, and slight risks might arise to the aesthetic environment if good architectural and house-keeping practices are not followed.

Risks from radioactivity can arise during all three phases: shattering, leaching, and electrowinning. During the explosion shattering phase, there is a slight risk of prompt venting of the explosion products. Experience obtained during weapons experiments allows evaluation of the upper limit of this risk. There have been 65 weapons program tests conducted underground in the low-intermediate yield range, which includes the yield expected for copper ore shattering. None of these tests has released

prompt radioactivity, although three have seeped radioactive gases. Tests in this yield range are usually buried between 350 and 400 W^{1/3} feet deep (W = explosive yield in kilotons, 1630 to 1860 feet for 100 kilotons). For most ore shattering applications the 100 kiloton explosive would be buried about 540 W^{1/3} feet or deeper, and this burial would decrease the chance of both prompt venting and gas seepage more than five-fold, as well as reduce the amount of release in case venting should occur. Since none of the previous experiments have vented, it is not possible to calculate a venting probability, but almost certainly the chance is less than one-in-one-thousand at the proposed depth for copper ore shattering. In the worst case, radiation doses from such a one-in-one-thousand prompt venting would be less than the annual exposure guideline standards (0.17R) at all distances beyond 17 miles, and there would be no risk from iodine contamination in excess of standards for milk beyond 25 miles. The total dose would be 40 R at one mile distance, to a person spending his whole life at that location, 5 R at five miles, 0.7 R at 10 miles, and 0.090 R at 20 miles.

In a 500 million ton ore body developed entirely by this technique, that is, one in which there were about 100 detonations, there is less than one-in-ten chance that such radiation exposure would ever occur. As experience with more deeply buried explosions accumulates, this upper limit should be revised, since it is very likely to be too large by a considerable amount.

During leaching, radiation risks will arise when, during drilling, the radioactive zone is encountered near the bottom of the broken ore and when, during leaching, some of the recirculated gases are vented. In the first case, based on previous drilling experience with sampling nuclear explosion tests and the fact that the drilling will be conducted three months following the detonation, the risk will be confined entirely to the operation site and will be well within guidelines for radiation workers. During leaching the bleed-off gases will potentially contain a total of about 1500 curies of krypton-85 which might be released at the rate of 5 curies per day through a vent stack. During the first two months a comparable concentration of argon-37 should be expected. The gases might also

contain as much as 9×10^{-12} curies of tritium per cubic centimeter, and, if the ore body contains 1% CO₂ as carbonate, about 200 curies of tritium will be released as water vapor (HTO) in more than one billion cubic feet of gases, primarily CO₂, bled off during the leaching operation. These radiation levels are low enough to meet present standards for stack release, so there is but a small risk to local inhabitants. The worldwide inventory of both tritium and krypton-85 would be increased, so there is an additional burden to the whole world population.

During electrowinning, radiation risks arise from the radionuclide contamination in the copper-bearing acid solutions. This risk is borne entirely by the operating personnel of the plant and by the environment immediately adjacent to or surrounding the plant. Calculations show it is less than the radiation risks in uranium ore processing mills.⁸ Risks to the wider environment are subject entirely to the degree of containment of the process fluids which would be recirculated into the broken rock after copper recovery. Table I shows the maximum expected level of radioactive contamination in process solutions during processing.⁹⁻¹¹

TABLE I
MAXIMUM CONCENTRATION OF RADIOACTIVITY IN LIQUOR
AND SLUDGE 400 DAYS AFTER DETONATION

Isotope	Concentration in Copper Solution		Isotope	Concentration in Copper Solution	
	pCi/cm ³	MFC Av (40)		pCi/cm ³	MFC Av (40)
Cs ¹³⁷	230	(400)	Ru ¹⁵⁴	0.2	(400)
Er ⁹⁰	78	(5)	Ru ¹⁵²	0.4	(2000)
Se ¹²⁵	37	(3000)	Co ⁶⁰	0.025	(1000)
Po ¹⁴⁷	630	(6000)	Po ⁵³	77.	(20,000)
Ra ¹⁵⁵	96	(6000)	Ra ²²	0.03	(1000)
Ra ¹⁰⁶	410	(400)	Cs ¹³⁴	0.95	(300)
Cs ¹⁴⁴	1640	(300)	Na ⁵⁴	0.39	(4000)
Ra ¹²³	30	(2000)	Zn ⁶⁵	0.26	(3000)
Ta ^{127m}	83	(2000)	Ca ⁴⁵	1.1	(300)
Er ⁹³	300	(2000)	Er ³³	13.6	(2000)
Y ⁹¹	130	(800)	Se ⁴⁶	0.05	(1000)
Se ⁸⁹	75	(300)	Po ⁵⁹	0.01	(2000)
Ra ¹⁰³	460	(400,000)	Zr ⁹²	242,092	(100,000)
Ta ^{129m}	7	(1000)	Ca ¹⁴¹	10.0	(3000)

(Note: Underlined species exceed drinking water standards for 40-hour exposure of radiation workers. Concentration in sludge is 250 times the table value.)

The fine sludges carried in the solution are expected to be about 250 times more contaminated per unit weight than the circulating solution itself. Also shown in Table I are the standards for 40-hour exposure from drinking water to radiation workers.¹² The most severe contaminant (Sr^{90}) is estimated to be about 20 times the permissible level for drinking water in the plant, although the copper and acid would make the water im potable. The copper (6 mg/cm^3) will be about 6,000 times allowable in drinking water before copper processing, and perhaps 600 times allowable afterwards. Thus, the copper itself presents the greatest risk to plant workers, should they drink it. However, no one will drink such water, and the numbers are shown only to contrast the levels which are quite low.

Tritium in the form of tritiated water vapor may present an inhalation risk to plant workers in case there is poor ventilation in the process plant. With no air circulation at all, and a temperature of 21°C (70°F), tritium concentration in the plant could reach about 300 times the level permissible for a 40-hour week exposure. Good practice for minimizing solvent loss requires close capture hoods and ventilation, and with this equipment and reasonable plant ventilation little inhalation exposure is anticipated.

There will be no radioactivity in the copper product, hence no risk to the general public. Based on laboratory experimental data,⁹⁻¹³ the possibility of a trace (1 to 20 disintegrations per minute per gram of copper) of Ru^{106} cannot be eliminated. This is too small to be measurable without chemical separation or very sophisticated equipment, and even in photographic equipment it would not contribute significantly to the cosmic ray background.

At the time of copper recovery, the total radioactivity (except tritium) in the rubble column is about eight times the natural radioactivity (K^{40} , U^{238} , U^{235} , and Th^{232} , plus daughters). The gross gamma ray energy emitted will be almost the same for natural and artificial radioactivities (800 Ci) at the same time.

The nuclear explosion will create risks to existing plant facilities and neighboring structures, mines, and other manmade objects from ground shock. Based on a wide variety of experience, Table II has been prepared showing examples of the maximum range

TABLE II
GROUND SHOCK EFFECTS FROM 100-KT
BURIED 2500 FT IN HARDROCK

Effect	Range (Miles)
Definite minor damage to plant facilities or residential structures	1
One-in-one-thousand chance of damage to mine tunnels or shafts	2
Ten percent chance of damage to process plants and associated equipment	3.5
One-in-one-thousand chance of architectural damage to residential structures	15
One-in-one-million chance of minor damage to high-rise structures and stacks	40

at which various kinds of ground shock hazards are expected.¹³⁻¹⁶

The specific nature of each structure and site will determine the exact risk, and Table II should not be used to evaluate specific hazards. At specific sites, for example, a mine tunnel or shaft in poor repair and subject to imminent natural failure would not likely survive the ground shock at two miles, even though the probability of failure for the "average tunnel" is only one-in-a-thousand at that range. Similar qualifications apply to each effect category. From Table II it can be seen that the region within 10 to 50 miles of a nuclear solution copper mine is subject to ground shock risk. This risk is extremely transient and represents no long-term threat to the local environment or ecology. Structures and man-made objects are more subject to this risk than natural environmental features.

Concern has been expressed over the secondary effect of ground shock on water supplies. Detailed studies of several sites and hydrologic situations indicate there are very slight risks to the hydrologic environment, other than transient changes in the water table level (a few inches) at distances a mile or so from the detonation site.¹⁵ Nearer to the explosion site larger effects can be observed, depending on the details of the geologic and hydrologic environment.

IV. SUMMARY OF RISKS

It must be emphasized that the nuclear solution copper recovery method is not an alternative

to conventional copper mining at the same location because it requires a considerably different kind of ore body and significant overburden coverage. It is competitive only in an economic sense. Conventional mines are most profitable in shallow, dry, secondary copper deposits, while nuclear solution mines require deep, wet sites. With this caveat, Table III shows the risks for conventional mining and the proposed nuclear solution method. Minor risks are not included.

TABLE III
RISKS FROM COPPER MINING

Conventional Mining		Nuclear Solution Mining	
A. ENVIRONMENTAL		B. ENVIRONMENTAL	
1. SO₂ RELEASE		1. SO₂ RELEASE	
a) See also the rate of SO ₂ from roasting and smelting, also from leaching and tailing of copper.		a) Same thousand gallons of copper, with and without concentrated waste, per ton of copper.	
b) See various treatment systems of SO ₂ and sulfur dioxide waste from leaching, also SO ₂ from sulfur and acid manufacturing, also from leaching, per ton of copper.			
2. WATER POLLUTION		2. WATER POLLUTION	
a) See various types of water pollution from tailing and water pollution, per ton of copper.		a) Same thousand gallons of copper, with and without concentrated waste, per ton of copper.	
b) See various types of water pollution from tailing and water pollution, per ton of copper.			
3. WATER POLLUTION		3. WATER POLLUTION	
a) See various types of water pollution from tailing and water pollution, per ton of copper.		a) Same thousand gallons of copper, with and without concentrated waste, per ton of copper.	
b) See various types of water pollution from tailing and water pollution, per ton of copper.			
4. WATER POLLUTION		4. WATER POLLUTION	
a) See various types of water pollution from tailing and water pollution, per ton of copper.		a) Same thousand gallons of copper, with and without concentrated waste, per ton of copper.	
b) See various types of water pollution from tailing and water pollution, per ton of copper.			
5. WATER POLLUTION		5. WATER POLLUTION	
a) See various types of water pollution from tailing and water pollution, per ton of copper.		a) Same thousand gallons of copper, with and without concentrated waste, per ton of copper.	
b) See various types of water pollution from tailing and water pollution, per ton of copper.			

V. COST OF RISKS

It is very difficult to compare the relative importance of the various risks in Table III. However, any comparison which reduces these risks to some common set of units necessarily involves value judgments. These value judgments vary with choices exercised. In this section the risks shown in Table III will be transformed into estimated dollar costs using stated value judgments, which are solely those of the author.

The environmental cost of the release of a ton of SO₂ can be estimated from the cost of hospitalization, medication, lost time, etc., due to oxides of sulfur in the atmosphere. Recently it has been suggested that a 50% reduction in sulfur oxides level would result in a \$1 billion annual reduction

in health costs.¹⁷ This estimate, based on statistical correlation studies, appears to be somewhat generous by perhaps as much as two- to five-fold. However, atmospheric pollution causes other detriments besides poor health. For example, irritation and general inconvenience cause community loss. A value of \$1 billion is therefore chosen for this estimate with the understanding that it includes both the direct health costs and the cost of a less desirable environment. In 1966, 23 million tons of oxides of sulfur were released to the atmosphere in the United States.¹⁸ From these two numbers, the environmental cost of a ton of environmental SO₂ is seen to be about \$43. In addition to this general whole atmosphere cost, there will be specific risks at each site, depending on population and land use distribution.

The environmental cost of polluted water is very difficult to assess. If the polluted water is released without control, the assessment must include impact on the whole ecologic chain. Assuming the control of such water, the cost is the temporary loss of the water for other uses. The value of water depends on the use to which it is put. For irrigation this might be as little as \$5/acre/ft (1 acre/ft = 1.2x10⁶ liters). For domestic consumption, \$200/acre/ft is sometimes acceptable. Water used in concentrators and process in conventional mining eventually returns to the hydrologic environment through evaporation or percolates slowly into ground water. In the case of nuclear solution mining, it is assumed that deep ground water is used for processing and returned to the rubble column. It is questionable that this water would ever be considered part of the immediate hydrologic inventory. For distant future use, one hundred or more years hence, it is as available for use as before. In both cases it is assumed that the cost of water contamination is \$10/acre/ft. Thus, the cost of process water for conventional flotation-roasting recovery is \$7/ton of copper. The cost of water for conventional leaching and for nuclear solution mining of copper is about \$.70/ton of copper. Actually, because of better control, the nuclear solution method may be nearer \$0.007/ton; however, the higher number will be used.

The environmental cost of tailings, dump deposits, and open pits arises from permanent scars

to the aesthetic environment, sources of stream pollution, and sources of particulate pollution of the air. By their nature, they can be permanent or nearly permanent in the same sense that the expenditure of a depletable resource is a permanent loss. One method for assessing their environmental cost is to compute the cost of removing them. Thus, the cost of an open pit is the cost of filling it. Assuming the material can be replaced at a cost of \$0.50 per cubic meter (or \$0.25 per ton), the environmental cost of the tailings and dumps would range from \$25 to \$100 per ton of copper, depending on the grade of ore, the ore to overburden ratio, the mining method, etc. If the pit or dump is not removed, its continuing impact on the environment can be calculated as a discounted future cost. Assuming an average present value of these features as \$50/ton of copper, that the pit is left unfilled for 100 yrs, and that money inflates at the average rate of 4%/yr, the pit cost would be somewhat over \$5,000/ton of copper; however, in Table IV we show the cost as \$50/ton of copper.

TABLE IV
COSTS OF ENVIRONMENTAL RISKS FROM COPPER MINING

1. <u>Chemical</u>	2. <u>Chemical</u>
a) Oudex of sulfur = \$42/ton *	a) Water = \$0.7/ton
b) Heavy flotation = \$ 7/ton	
leaching = \$ 0.7/ton	
2. <u>Aesthetics and Particulates</u>	2. <u>Aesthetics and Particulates</u>
a) Pits, tailings, and	Negligible
dumps = \$30/ton	
3. <u>Shock and Vibration</u>	3. <u>Shock and Vibration</u>
Negligible	a) Population within 50
	miles, \$1.54/ton/1000
	people.
4. <u>Worker's Risks</u>	4. <u>Radioactivity</u>
a) Accidental death and permanent	a) Population within 15
disability = \$21.75/ton	miles, \$0.05 ton/1000
	people.
	b) Plant workers, \$2.06/ton
	c) Worldwide ^{60}Co and tritium
	\$0.44/ton
TOTAL = \$72 to \$115/ton	TOTAL = \$3.06/ton*
BENEFIT-RISK = 13.9 - 8.7	BENEFIT-RISK = 300

* depending on population density and proximity.

There are essentially no risks from ground shock and vibration in conventional mining. Such small costs as are incurred are absorbed as direct internal costs. In the case of nuclear solution mining, while the cost will probably be direct and reimbursed, it has a greater nuisance value, since it extends to greater distances. At any given nuclear solution mining site, these costs must be calculated on the basis of the actual environmental inventory. For purposes of general assessment, it is assumed that there are 1,000 people resident in the area out to a radius of 50 miles, that there are 250 structures subject to damage, and that, except for the operator's plant, there are no other high-rise buildings or sensitive commercial facilities. Each architectural damage instance is assumed to cost \$500 to repair. Damage to the in-plant facilities is assumed to cost \$50,000 to repair. On the basis of the damage frequency curve and the figures mentioned above, the cost of off-site seismic damage will be about \$11/ton of copper/1,000 people. The cost of plant damage will be about \$4/ton of copper. Low probability damage, i.e., a high-rise building or refinery smokestack at a distance of 40 miles (60 km), contributes a negligible risk per ton of copper. In the example, if we assume \$20 million for the maximum one-in-a-million damage, the cost would be about 1/20 of one cent per ton of copper. Similarly, costs for residential structures near the outer range of architectural damage, 15 to 30 miles, would be about 1% or less as large as those calculated above. These are the costs which will be internalized through seismic damage insurance or direct repair. The nuisance cost can be estimated as the value of the time lost by those exposed to the ground shock. Again, assuming 1,000 people within 50 miles and uniform distribution beyond 1 mile, the loss of one day out to 10 miles, one hour from 10 to 20 miles, and fifteen minutes from 30 to 50 miles, the total cost, at \$50/man-day, is \$17,000, or \$1.54/ton of copper.

The environmental cost of radioactivity has been the subject of a number of studies, including genetic damage and disability up to ten generations in the future. Suggested values range from \$100 to \$500/person/rad.^{19,20} The release of radioactivity to the atmosphere involves both exposure to the immediate population and to the whole world population.

In addition, persons engaged in operation of the plant facilities are exposed to the radioactive solutions, drill cuttings, and so forth. Cost of radiation of the whole world population has been estimated by assuming the gaseous radioactivities released to the atmosphere are ultimately diffused throughout the available atmosphere, that each person is exposed uniformly for a period of time necessary for the radioactivities to decay, and an environmental cost of \$250/man-rad. The release of 1 curie of tritium as HTO thus costs the environment about \$0.10, and the release of 1 curie of Kr⁸⁵ costs about \$5.26.²⁰ On the basis of values in Table III, the environmental cost of the release of tritium and krypton is about \$0.64/ton of copper.

In the intermediate range, the calculation is more complex and is specific to the environmental factors associated with each site. For purposes of calculation it has been assumed, as in the case of the seismic damage estimates, that there are 50 people living within a radius of 15 miles, and that no person lives closer than one mile. It is also assumed that there will be an emergency procedure so that in the unlikely event there is a prompt release of gross radioactivity, the residents can be protected (that is, by evacuation), and that this protective action will cost \$50/day/person for a time sufficiently long that exposure will not exceed a fraction of 1 R/man. In this case, the genetic cost and long-term cost to the population is negligible compared to the cost of protective action. Since the probability is only 10^{-3} per detonation, or 9×10^{-8} per ton of copper, the environmental cost is less than \$.06 per ton of copper per 1,000 people, or \$.003 per ton of copper in the case there are 50 people in the risk region.

Within the plant, the exposure levels can and should be kept well within the limits imposed by present guidelines. If, through bad practice or misfortune, those workers are exposed to the maximum guideline dose, 5 R/yr, the maximum external cost can be calculated from an estimate of the number of workers exposed. The total working plant force is eighteen²¹ so there are potentially 80 man-rem/year exposure. At \$250 per man-rem, this is equivalent to \$2.06 per ton of copper.

The cost of workman's risk in conventional mining is the probability of permanent disability

times \$250,000, a rough average of jury awards in such cases. This is $8.7 \times 10^{-5} \times 2.5 \times 10^5 = \21.75 per ton of copper.

It must be emphasized that the values in Table IV depend strongly on the judgment and assumptions used in deriving them. However, two other factors should also be emphasized. First, the environmental cost of the copper industry, whether by conventional mining or the proposed nuclear solution method, is small compared to the value of the copper to society. It must be assumed that the value of the benefit is comparable to the market price of copper - about \$1,000/ton. If it were not, people wouldn't buy copper since there are substitute materials for almost every copper use. The total benefit-risk ratio is shown in the last line of Table IV.

The second major conclusion one can draw from Table IV is that in the conventional mining procedure, the greatest environmental cost is from the pits, tailings, dumps, etc. In the nuclear solution method, the greatest risks arise almost equally from radiation hazard to in-plant workers and seismic architectural damage to the local population.

Finally, examination of Tables III and IV together permits one to conclude that the risks from the nuclear solution mining technique are surely no greater than from conventional copper mining, and they are probably an order of magnitude less. None of the nuclear solution method risks involve permanent alterations to the environment. The longest risk accrues from the krypton-85 which has an environmental half-life of 10 years and whose genetic effects may persist up to 10 generations of people. The unfilled open pit mine remains almost forever unless the environmental cost is internalized and the pit filled and landscaped after completion of mining.

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QUANTITATIVE DECISION MAKING

by

Marc Ross

ABSTRACT

Extreme uncertainty in the definition and/or evaluation of certain costs and benefits must be considered. Positive attempts to deal with these particular items qualitatively will be more helpful than a particular misleading number. These questions are discussed in terms of the London Airport cost-benefit analysis.

I would like to discuss an inherent limitation of simple numerical indices as aids to decision making: the difficulty of defining and accurately determining the desired quantity. Although this meeting concerns nuclear power, my example will be from a different problem - aircraft noise.

In December 1970, what was probably the most ambitious cost/benefit analysis yet made was completed by the Roskill Commission in Great Britain.¹ The Commission labored for 2½ years, spent 2½ million dollars, and had a total staff of about 60, all to recommend a site for a new London airport. This airport will be in addition to the present main airport, Heathrow, and the main backup airport, Gatwick. Their main activities were the calculation of the cost differences, both direct costs and some indirect or social costs, between different sites. An important part of this analysis was the placing of monetary values on the nuisance due to aircraft noise in the neighborhood of each projected

airport.* Their study of noise costs showed that, since the present population in the area of the proposed sites is small, the absolute cost and cost differences due to noise are small. However, their methods are subject to criticism; in addition to general reservations as to philosophy, one can state that investigations of existing noise costs at Heathrow, the quality of noise level determinations, and development in time of noise costs at any new site, were not undertaken and would have been very valuable. Presentation of comparison calculations for a familiar existing situation as at Heathrow,

* Note that this analysis carried with it no suggestion that those made to suffer should actually be paid compensation. Although near Paris' Orly Airport a group of municipalities have successfully sued for noise compensation related to the actual noise burden, in England such judgment would be explicitly ruled out by law, while in the United States it is a very unlikely possibility.

would have been an important way of educating the non-professional into the meaning of the calculations. Hypothetical examination of this question will lead to basic criticism of the economic methods employed in noise costing. The Commission's analysis was thoughtful on many detailed economical questions, but with regard to the quality of prediction of noise levels, it was disturbing to me, as a physical scientist, that no new field investigations were carried out. A noise index and contours of this index were determined from earlier data and idealized aircraft performance.

Let us examine the method of costing and discuss its hypothetical application to the noise due to present Heathrow operations. The basic measure of sound level is the power, P , the arriving sound energy per second (in appropriate units and appropriately weighted in pitch). I will quote "A Scale" weighted sound levels. The sound level is defined:

$$S = 10 \log_{10} P \text{ decibels}$$

Typical sound levels are:

80 dBA ringing alarm clock at 1 yd.

90 dBA pneumatic drill or loud vehicle at 25 ft

110 dBA submarine engine room.

The peak sound power arriving from an aircraft and the number of aircraft per day are important measures of the nuisance of aircraft noise. An attempt was made to bring these two effects together into a single "noise and number" index (NNI) in 1962.² A social survey established that, under conditions then prevalent near Heathrow, there was a rough equivalence between loudness and number of aircraft such that people felt the same annoyance, leading to the annoyance index:

$$NNI = \bar{S} - 67 + 15 \log_{10} N$$

Here $\bar{S}$ is the level associated with the average of the peak sound powers from each aircraft, in dBA, and N is the number of

aircraft in a 12 hour period.* Only aircraft louder than 67 dB (similar to the sound of normal conversation) are counted. We see, for example, that 10 aircraft a day as loud as a pneumatic drill at 25 feet would correspond to an NNI in the low 40's.

There is considerable controversy about the validity of this single index to describe the nuisance of aircraft noise.³ For example it does not describe day-night differences or day to day fluctuations. If the Roskill study had been extended to Heathrow, as a comparison site, it would have been essential to subject the NNI to experimental scrutiny, to reconsider whether a single such index is adequate.

Assuming that the difficulties associated with establishment of an index are resolved, we have to assess a cost, as it depends on the index, community by community. The Commission's method was to hire real estate agents as consultants to price comparable housing at given NNI and at low NNI.⁴ This apparently gave consistent results for suburban housing in the general area of Gatwick airport.** If we were to consider Heathrow we would

*The NNI was defined using a different weighting in pitch - "Perceived noise," rather than A scale, decibels. I have made a rough adjustment to A scale because it is fairly standard in noise studies.

**As a matter of general interest, I note that the commission found in suburban areas that medium-priced housing decreased in value about 9% for $35 < NNI < 45$ and about 17% for $45 < NNI < 55$. Extending these results to Heathrow and including other financial losses would lead to a very rough estimate of 1/2 to 1 billion dollar noise cost associated with operation of this airport (discounted at 10% per year) or roughly \$5 per passenger use at present.

encounter difficulties with this method. Heathrow noise extends over low income housing where low prices do not reflect much consideration of amenities and where other noise is also prevalent. In addition, Heathrow noise has built up over many years, so that people are somewhat accustomed to it. A study showed very little relation between NNI and housing prices under these conditions.^{4*} This presumably involves some moving away of sensitive people and moving in of insensitive people but it also involves people who have been forced to grow accustomed to the nuisance, for example people who cannot afford to move, and children.⁵ The low "market" cost of noise associated with people who are poor or have grown used to it is not a reasonable value for its social cost. Similar arguments apply to many risks and nuisances, for example possible low level radioactive pollution due to nuclear reactors. What are the monetary social costs of imposing this probably injurious burden on a group of people? It could be argued that a study based on extrapolated medical data and life insurance policies would reveal the value people associate with this risk, i.e., "every man has his price." A proper cost-benefit analysis cannot simply rely on market values in this kind of situation: Thus, even if we are fortunate enough to deal with an item for which market value may be well defined, particularly a poor man's price for accepting risk or loss of amenities, this item will often, as a matter of community interest, have a social value very different from the market price.

Thus, there is considerable uncertainty in assessing a cost such as noise and subtle value judgments are involved. There is an alternative to standard cost-benefit analysis

*Using the low local market evaluation the noise cost due to Heathrow would be very roughly 1/10 of that mentioned in the previous footnote.

ysis in the case of environmental amenities and safety. I will call it "constraint-cost" analysis. Imagine the constraint that no more than n people live in an area associated with aircraft noise about a certain index. There are several ways to help meet such a standard: Purchase of large areas of land about the airport site with use reserved for agriculture or industry, improvements of aircraft, lighter loading of aircraft, extreme flight patterns, use of sites with over-water flight paths, limitation of traffic, etc. A full set of postulated constraints and of methods used to meet them would have to be considered together to evaluate the cost. The output of such an analysis would be the direct cost, plus perhaps certain indirect costs, as it varies with variation of the constraints. The setting of constraints would be the point at which society would make its value judgments, rather than at the relatively obscure point of presetting social cost scales in standard cost-benefit analysis. If a standard cost-benefit approach were not made for certain difficult items it should still be possible to quantify many of them using constraint-cost analysis. For any major project, there would still probably remain non-quantifiable considerations in addition to the qualitative questions surrounding proper choice of constraints.

The difficulty with providing advice to the decision maker in a quantitative form is, then, that only some aspects of the project and its consequences can be satisfactorily quantified, and these may not be the most important aspects. We may gain perspective if we try to categorize various common indices. The most widely discussed quantitative measures for the value of a particular or a model project are

- Direct cost at prevailing standards
- Direct cost (constraints)
- Risk, loss of amenity (constraints)

Demand (cost)

Social benefit (cost, demand)

Social cost (risk, loss of amenity)

Here all but the first item are functions of the item in parenthesis. The direct cost and social cost and benefit⁶ are expressed in dollars. The constraints are publicly imposed standards on the activity which will take the form of limits on environmental damage through monitored standards of physical performance. Risk is measured in loss of life and injury over suitable populations and time. Amenity loss can be quantified by various indices appropriate to the effect in question, for example a biological measure of lake eutrophication and trends in game fish populations. In many cases the amenity loss could be quantified in exactly the same way as the corresponding constraint. Risk and amenity loss are not quantified in dollars.

I have attempted to order the types of measures, in order of increasing difficulty of definition and evaluation, downward. I suggest that at a certain level of difficulty in this list, the quantities are so controversial of definition and/or so difficult to determine that they are not useful. With this in mind let us go through the list: the direct cost, capital and operational, of a project of specified performance is a part of all engineering planning and design. We are aware that there are some difficulties of accuracy because of changing conditions and because we often are attempting to apply a new technology. Similar remarks can be made about projecting costs as a function of various constraints. In many cases it will be very difficult to calculate the risk⁹ remaining in the presence of a particular constraint (e.g., risk of cancer associated with a certain maximum level of radioactivity). The demand schedule, e.g., the use of electricity, and its projection into the future, as a function of the cost per kwh, are of course very difficult to determine accu-

ately. The benefit calculation - one of the principal topics of this conference - is fraught with difficulty of definition and evaluation intimately related to the problem of evaluating social cost illustrated above. The definition relative to production of a particular good must involve reference to demand schedules which show trade-offs that would be made if the good was available in greater or lesser amounts (i.e., at lower or higher price). If, in the power industry, the demand curve considering competing sources of energy were available, one could attempt a definition of benefit which might command acceptance. However it would still leave out trade-offs between consumption of energy and other activities; and it would still be simply a market place evaluation. Unfortunately the risk-benefit relationship postulated by Starr⁶ is a sensitive relation: if the benefit changes by a factor of 10, the "acceptable" risk changes by 10^3 to 10^4 . Finally the calculation of social cost in dollars associated with risk and amenity loss, the dream of some economists, is, in detail extremely controversial and difficult, as I have attempted to illustrate.

In my opinion, the quantification becomes to problematical to be valid and useful somewhere in the middle of this list. Thus, thorough research might reveal a useful set of risk vs. cost and an amenity loss vs. cost curves for a particular activity. Attempts to go too far toward obtaining an overall numerical evaluation should be resisted. The exact situation of course, depends on the size of error acceptable in the study. Usually, I imagine that there will be sharply competing needs for public investment so that, e.g., a factor of five uncertainty in an important cost item would render the number for that item useless. If this is so, the item should be handled through development of improved qualitative methods: better

public education and participation, more effective probing of expert opinion, better basic education of decision makers, diversity in types of adopted technologies, etc.

In conclusion I would repeat that the essential point about the quantitative aids to decision makers is that decision makers and the public are quite rational in suspecting that the numbers from any such study (excluding probably direct cost estimates) are not accurate enough for the purposes, because, indeed, they often will not be accurate enough.* It is relevant I think, that the heavily researched and highly respected Roskill Commission analysis of London Airport sites resulted in a site recommendation, which was, within 4 months, rejected by the British Government and a poorly recommended alternative chosen.⁸ The quantitative analysis was not sufficient.

*Indeed the particular inaccurate number positively brings forth a suspicion of bias.

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SOME COMMENTS ON THE PUBLIC PERCEPTION OF PERSONAL RISK AND BENEFIT

by

Chauncey Starr

In previous papers* addressed to the general question of "How safe is safe enough?" it has been shown that the public accepts very much greater risk from voluntary exposure than it does from involuntary exposures imposed on the public by social decisions. While this difference can be summarized by the statement "We are loathe to let others do unto us what we happily do to ourselves", the cause of such a difference of several orders of magnitude in the public acceptability of risk exposures deserves further elucidation.

In this discussion I would like to explore the possible factors which might influence such a wide discrepancy in public attitudes. It is almost immediately evident that the individual may perceive the values and risks associated with any activity in a manner quite different than that which would represent an objective overall societal evaluation of the same factors. For the purposes of this discussion, I will assume that for any given socio-technical system there exists an average risk which can be objectively evaluated in terms of frequency versus severity for accidents which expose and damage the public. Assume also that in those cases where a man-machine interaction is involved, that the average of such interactions over the total population is sufficiently consistent that such a societal evaluation is a reliable objective base. The true public risk is then the integral of the frequency

versus severity curve, and can be reasonably expressed in a simplified quantitative manner.

There is a general distinction that can be made between healthy risk-taking in the normal activities of a population, and neurotic risk-seeking or suicidal impulses. This latter may be considered a medical illness to be treated psychiatrically. For want of a better definition, I am considering individual healthy risk-taking as that type of activity which results from a benefit-risk analysis (conscious or unconscious) which indicates that the benefits are sufficiently large to justify the risks. This definition assumes that the great majority of the population has an aversion to risk. For example, the swimmer or boater doesn't expect to drown, the tennis player does not expect to have a heart attack on the court, the skier doesn't expect to break a leg, and the hunter doesn't expect to get shot. In all these cases, of course, the individual realizes there is some risk of these eventualities but assumes that they are small compared to the benefits to him of the activity.

In this discussion, I am also separating risk to physical health from the uncertainties of challenges to man's skills. Such situations can be provided by card games, chess games, jigsaw puzzles, foreign travel, hiking, and other exploratory activities both intellectual and physical. I am assuming that the exhilaration associated with meeting such challenges is part of the rewards connected with the activity and is a normal part of a healthy pleasure stimulus.

*Science, 19 September 1969, volume 165, pages 1232-1238.

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Even with the assumption that it is possible to express a risk frequency versus severity curve for our major activities, it is clear that one curve would not be applicable to describe the risk situation for each individual in a voluntary activity. For example, one might plot the frequency of automobile accidents versus their severity for the population of the United States. This curve however, would not be a proper evaluation of the risk situation for the individual driver. We know that the careful driver is less prone to have accidents than the average. We know that there are sufficient variations in driving skill that under certain circumstances an individual will evade an accident which might develop for the average.

In fact, it is evident that in almost every voluntary activity which an individual undertakes, there is a wide spread in the ability of the individual to manage the situation which produces the risk. I am therefore suggesting that the opportunity to manage risk situations is one of the basic determiners which distinguishes individual acceptance of voluntary risks, as compared with involuntary exposures. Thus, the automobile driver who feels confident that he can handle his vehicle on a wet or icy road at high speed may evaluate the risk situation quite differently from one who is incapable of handling even a mild skid. The expert skier will presume that he is less prone to have accidents on the slope because of his ability to maneuver in and out of difficult situations. Perhaps the most common example is that of the ordinary kitchen knife - an instrument which causes thousands of cuts and other injuries each year. Yet, it is an instrument which we all confidently use on the assumption that we can minimize our individual risk by our careful handling. In contrast, if someone else wields the knife on something we are holding, our increased caution due to the absence of self-management becomes evident.

We have a more revealing situation in the case of automobile safety belts. In spite of the very valid evidence that the use of safety belts will decrease the physical injuries resulting from an automobile accident, only a small fraction of the population uses these. It is evident that the individual driver must believe that his ability to manage the awkward situations which lead to driving accidents is sufficiently great that the additional safety provided by the belt does not justify the nuisance of using it.

An essential element of our individual confidence in risk management is the extent of our familiarity with the risk situation. An unfamiliar, but perceived, risk involves sufficient uncertainty that the cautious approach of the individual is to estimate its magnitude on the high side. In addition, the specific characteristics of the risk may also be unclear, leading to doubts concerning its manageability by the individual. We have many common examples in our lives - an unusual severe pain, walking in the dark in unfamiliar surroundings, driving in a dense fog, etc. The public's fear of radiation shows many of these characteristics. Thus, the mere act of living and coping adequately with a potential risk situation for an extended time provides an ingredient of familiarity which increases our confidence to manage a risk when it occurs. This attitude of the individual may have little connection with the objective probabilities and consequences of the situation.

A different type of situation is that which is illustrated by the recent studies on deaths due to heart disease. It has been estimated that in the United States 800,000 deaths annually can be attributed to arteriosclerosis, commonly known as "hardening of the arteries". The evidence is very clear that this is a situation which usually develops from lifelong eating habits associated with high fat diets. In spite of this rather significant correlation between death and a cause, it

is apparently very difficult to significantly alter the eating habits of the American public. I believe that part of the difficulty is that our daily pleasure in eating is an immediate reward. The penalty may be decades away. Thus, it is possible that in the perception of risk, the individual undertakes a present value (or future discounting) approach in his unconscious evaluation of the risk.

One might therefore hypothesize from these examples that the perception of the individual is highly influenced by his presumed ability to manage the risk-creating situation. Thus, even with knowledge of the societal average for the statistical risk associated with an activity, the individual presumes that he can "beat the game" by his own special abilities in handling the situation. Secondly, we may also hypothesize that present benefits which might result in future risks involve an unconscious discounting process which must be considered in evaluating individual behavior.

The other side of the equation—the benefits—also vary when the individual is compared with the societal average. As I pointed out in my early paper on the subject, the public perception of the benefits of an activity may often be heavily influenced by subjective factors not related directly to its primary utility. I presented in that paper an arbitrary function called "benefit awareness" which was defined as the product of the relative value of advertising spent on the activity, the square of the percentage of population involved in that same activity, and the relative usefulness or importance of the activity to the individual. As pointed out in that paper, there seems to be a very close correlation between this "benefit awareness" parameter and the public acceptability of risk levels. Of course the most startling example of the effect of advertising and large group participation is our very popular custom of cigarette smoking. Even admitting that there is a real utility for the smoker in the activity, the

public acceptance of the risk is very clearly the result of social usage and heavy advertising.

An extreme case of poor public perception of benefits is provided by those social services whose primary function is to minimize the impact on the public of the operations of large socio-technical systems. Our public health systems and other efforts we undertake to clean up our environment are generally very poorly perceived by the individual. In fact our national anti-litter campaign inherently assumes that the individual has a very low perception of the damage caused by his careless habits. It is only when the physical environment surrounding an individual becomes sufficiently oppressive that he can correlate his discomfort with the operation of a technical system, that he specifically focusses on ameliorating that condition. In this respect, the organized effort to advertise the environmental impacts and to make a social good of a clean environment is directed to developing an individual perception of the benefits to be derived from environmental controls.

Individual evaluation of risk and benefit situations are usually compounded by the fact that it is relatively rare for the benefits and risks to be focussed only on the individual participant. It is much more customary to find one factor dispersed throughout society. It is certainly clear that in such situations the normal perception of the individual of the acceptable trade-off between benefit and risk is not likely to be that of the societal perception of the same situation.

In particular, the societal costs associated with a risk situation are apt to be widely different than those perceived by the individual. For example, the young hot-rodder speeding his car down a highway may not be concerned with the major investment which society has made in supporting him through his growing and educational period. In general, the social investment in

bringing a population age-group to a productive stage is rarely a matter of concern to that group. On the risk side of the equation, we have a similar imbalance. Except for the terminal risk represented by death, most other physical damage produces a social burden of long duration of which usually only a fraction is borne by the individual. We have all seen the evidence of a societal obligation to carry for an individual a medical burden, a genetic burden, and a welfare burden, with an overall effect on reducing the general quality of life in the society.

If these hypotheses are correct -- that indeed the individual perception of risk and benefit associated with the various activities involved in our complex socio-technical society are markedly different from the perception of a national planning or policy group, then the difference between the public approach to voluntary activities as compared to involuntary would be expected. If one

considers the problem of the application of national resources to improving the quality of life of the population as a whole, it becomes important that these resources be allocated on the basis of their maximum marginal utility, objectively evaluated for society as a whole. With the individual perception being widely different from that of a societal evaluation, a key incompatibility develops.

Hopefully, continuous public education and increased public participation in the management of involuntary exposures through the political system may reduce this hurdle of public acceptance of socially desirable decisions. Pragmatically, public participation in confusingly complex national issues is usually conducted through either representatives of interest groups or by the leadership of authority figures. Our society's administrative problem is how to provide a workable mechanism for such participation in the management of public risks.

LIMITATIONS OF THE MIND OF MAN: IMPLICATIONS FOR DECISION MAKING IN THE NUCLEAR AGE¹

by

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"Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write."

--H. G. Wells

The question I wish to discuss today, from a psychological standpoint, is whether man is capable of the kind of high-level thinking and reasoning that decision making in the nuclear age will require.

Just what kind of thinking do we need when making decisions about nuclear power? Such decisions demand an understanding of the probabilistic nature of the world and they demand the ability to think in probabilistic terms. They also require the ability to make forecasts, predictions, and evaluative judgments on the basis of fallible or incomplete data. Because statistics is a formal discipline designed to help people evaluate information and make decisions in the face of uncertainty, I shall refer to this kind of thinking as "statistical thinking."

Most of the time when we make judgments and decisions, we bypass formal statistical reasoning

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and when we do this we are acting as "intuitive" statisticians. There have been a number of recent studies pertaining to the adequacy of our performance as intuitive statisticians and I think many of these studies have important implications for decisions relevant to the development of nuclear power. In general, these studies have uncovered some surprising and rather disturbing deficiencies in man's ability to think in probabilistic terms or to balance risks against benefits when making decisions.

BIASED JUDGMENTS OF PROBABILISTIC EVENTS

Because of the importance of probabilistic reasoning to decision making, a fair amount of effort has been devoted to studying how people perceive, process, and evaluate the probabilities of uncertain events. One basic conclusion from this research is that probabilistic judgments show large and consistent biases that are quite difficult to eliminate.

Understanding Random Sampling

The "law of small numbers." One example of man's inadequacy as an intuitive statistician comes from a study by Tversky and Kahneman (1971a), who analyzed the kinds of decisions psychologists make when planning their scientific experiments. Despite extensive formal training in statistics, psychologists usually rely upon their educated intuitions when they make their decisions about how large a sample of data to collect or whether they should repeat an experiment to make sure their results are reliable.

After questioning a number of psychologists about their research practices and after studying the designs of experiments reported in psychological journals, Tversky and Kahneman concluded that these scientists had seriously incorrect notions about the amount of error and unreliability inherent in small samples of data. They found that the typical psychologist gambles his research hypotheses on small samples without realizing that the odds against his obtaining accurate results are unreasonably high; second, he has undue confidence in early trends from the first few data points and in the stability of observed patterns of data. In addition he has unreasonably high expectations about the replicability of significant results. Finally, he rarely attributes a deviation of results from his expectations to sampling variability because he finds a causal explanation for any discrepancy.

Tversky and Kahneman summarized these results by asserting that people's intuitions seemed to satisfy a "law of small numbers" which means that the "law of large numbers" applies to small samples as well as to large ones. The "law of large numbers" says that very large samples will be highly representative of the population from which they are drawn. For the scientists in this study, small samples were also expected to be highly representative of the population. Since his acquaintance with logic or probability theory did not make the scientist any less susceptible to these cognitive biases, Tversky and Kahneman concluded that the only effective precaution is the use of formal statistical procedures, rather than intuition, to design experiments and evaluate data.³

In a related study, this time using Stanford University undergraduates as subjects, Kahneman and Tversky (in press) found that many of these subjects did not understand the fundamental principle of sampling, namely, the notion that the error in a sample becomes smaller as the sample size gets larger. To illustrate, consider one of the questions used in this study.

³ People are not always incautious when drawing inferences from samples of data. Under somewhat different circumstances they become quite conservative, responding as though data are much less diagnostic than they truly are (see Edwards, 1968).

"A certain town is served by two hospitals. In the larger hospital about 45 babies are born each day, and in the smaller hospital about 15 babies are born each day. As you know, about 50% of all babies are boys. The exact percentage of baby boys, however, varies from day to day. Sometimes it may be higher than 50%, sometimes lower.

"For a period of one year, each hospital recorded the days on which more than 60% of the babies born were boys. Which hospital do you think recorded more such days?

"Check one:

- a) The larger hospital _____
- b) The smaller hospital _____
- c) About the same (i.e.,
of days were within
5% of each other _____."

About 24% of the subjects chose answer a, 20% chose b, and 56% selected c. The correct answer is, of course, b. A deviation of 10% or more from the population proportion is much more likely when the sample size is small.

Kahneman and Tversky concluded that "the notion that sampling variance decreases in proportion to sample size is apparently not part of man's repertoire of intuitions. For anyone who would wish to view man as a reasonable intuitive statistician, such results are discouraging.

Judgments of Correlation and Causality

Next, let's look at another facet of statistical thinking--the perception of correlational relationships between pairs of variables. Correlation between two variables means that knowledge of one will enable you to predict the value of the other.

Chapman and Chapman (1967, 1969), studying a phenomenon they have labeled illusory correlation, have shown how one's prior expectation of a relationship between two variables can lead him to perceive correlation when it does not really exist. They found that most subjects learned to see what they expected to see even though there were no real correlations in the data they were shown. The Chapmans noted that in many decision situations an expert may be reinforced in his observations of illusory correlates by the reports of his colleagues, who themselves may be subject to the same illusions.

Such agreement among experts is, unfortunately, often mistaken as evidence for the truth of the observation.

Several studies have investigated subjects' perceptions of correlation and causality in simple situations involving just two binary variables. Consider a 2×2 table in which variable A is the antecedent or input variable and B is the consequent or output variable and the small letters are the frequencies with which the levels of these variables occur together.

	B_1	B_2
A_1	$A_1B_1 = a$	$A_1B_2 = b$
A_2	$A_2B_1 = c$	$A_2B_2 = d$

A correlation or contingency exists between A and B to the extent that the probability of B_1 given A_1 differs from the probability of B_1 given A_2 : that is, to the extent that $a/(a + b)$ differs from $c/(c + d)$. If B_1 is as likely to occur given A_2 as it is given A_1 , there is no correlation between A and B.

Research indicates that subjects' judgments of contingency are not based on a comparison of $a/(a + b)$ versus $c/(c + d)$. For example, Smedslund (1963) had students of nursing judge the relation between a symptom and the diagnosis of a disease. He found that the judgments were based mainly on the frequency of joint occurrence of symptom and disease (cell a in the matrix), without taking the other three event combinations into account. As a result, the judgments were unrelated to actual contingency. Similar results were obtained by Jenkins and Ward (1965) and Ward and Jenkins (1965). Ward and Jenkins concluded:

"In general . . . statistically naive subjects lack an abstract concept of contingency that is isomorphic with the statistical concept. Those who receive information on a trial by trial basis, as it usually occurs in the real world, generally fail to assess adequately the degree of relationship present [p. 240]."

A recent example in the newspaper illustrates several of these biases. A woman asked Abigail Van Buren the following question: "Dear Abby: Why do so many people say that marijuana is harmless? Our daughter began using it in January. She went on to mescaline in March, and was in a mental hospital in July." Abby replied that marijuana apparently can be destructive to some individuals and there is no way of knowing who can handle it and who cannot.

Thus we see that the woman who asked the question and Abby were both drawing an inference about the relationship between marijuana and later problems on the basis of a very small sample (1 case) that fell in cell a of the 2×2 table shown above.

Judgments of Probability

Availability bias. One source of distortion in probability estimates that may be quite relevant to evaluations of the risks involved in nuclear power is the notion of "availability bias." Tversky and Kahneman (1971b) found that one cue that we use when judging the probability of an event is the ease with which relevant instances of that event are imagined. Another cue is the number of such instances that are readily remembered. The availability of instances is affected by factors such as recency, saliency, and imaginability which may, but need not, bear any relation to the event's probability. For example, the letter k is three times as likely to appear as the third letter of an English word as the first letter, yet most persons judge it as more likely to be a first letter. Tversky and Kahneman hypothesize that, when subjects make this judgment, they try to think of words either beginning with k or having k as a third letter. It is easier to think of words that begin with k, and if we use that fact as a cue on which to base our intuitive probability estimates, these words will be perceived as more probable than words with k in the third position. In general, the harder it is to recall or imagine instances of an event, the lower the judged probability of that event.

The effects of availability bias are not likely to be limited to the psychological laboratory. In thinking about nuclear power plants, for example, it

is not difficult to conceive of circumstances that could make a serious accident highly available or imaginable--a recent accident or a vivid film or lecture could do the job. Such incidents could lead to considerably inflated estimates of the probability of such an accident.

Value bias. Other studies have found that the desirability of an event biases its subjective probability, although the effects are complex and differ from person to person (Slovic, 1966). Some people are overly optimistic, tending to attribute greater probability to highly-desired events than to undesired events, other factors being equal. Other persons are pessimistic. They consistently overestimate the likelihood of unpleasant events.

Compound events. One feature designed to minimize the risk of a nuclear accident is the system of multiple safeguards whereby a breakdown would occur only if each of a number of independent components failed simultaneously or in close sequence. When components are independent of one another, their joint failure is a compound event whose probability is simply the product of the probabilities that each individual component will fail. Several studies have shown that the perceived probability of compound events is more similar to the sum, rather than the product, of the component probabilities, thus the probability of the compound event is overestimated (Slovic, 1969).

Problems in Quantifying Uncertainty

One of the most interesting and important types of bias is illustrated in studies conducted by Alpert and Raiffa (1969) and Tversky and Kahneman (1971b). In both of these studies, subjects were given "almanac questions" such as the following:

"How many foreign cars were imported into the U.S. in 1968?"

- a) Make a high estimate such that you feel there is only a 1% probability the true answer would exceed your estimate.
- b) Make a low estimate such that you feel there is only a 1% probability the true answer would be below this estimate."

In essence, the subject is being asked to estimate an interval such that he believes there is a 98% chance that the true answer will fall within that interval. The spacing between his high and

low estimates is his expression of what he knows or doesn't know about the quantity in question. We cannot say that this single pair of estimates is right or wrong. However, if he were to make many such estimates or if a large number of persons were to answer this question, we should expect the band between upper and lower estimates to include the truth about 98% of the time--if the subjective probabilities were valid. What is typically found, however, by Alpert and Raiffa and by Tversky and Kahneman, is that the 98% confidence band fails to include the true value from 40% to 50% of the time, across many subjects answering many kinds of almanac questions. In other words, subjects' confidence bands are much too narrow, given their state of knowledge. Alpert and Raiffa observed that this bias persisted even when subjects were given feedback about their overly-narrow confidence bands and exhorted to widen the bands on a new set of estimation problems.

These studies indicate that people believe they have a much better picture of the truth than they really do. Why this happens is not entirely clear. Tversky and Kahneman tentatively hypothesize that people approach these problems by searching for a calculational scheme or algorithm by which to estimate the answer. For example, in answering the above question one might proceed as follows:

"I think there were about 180 million people in the U.S. in 1968; there is about one car for every three people thus there would have been about 60 million cars; the lifetime of a car is about 10 years, this suggests that there should be about 6 million new cars in a year but since the population and the number of cars is increasing let's make that 9 million for 1968; foreign cars make up about 10% of the U.S. market, thus there were probably about 900,000 foreign imports; to set my 98% confidence band, I'll add and subtract a few hundred thousand cars from my estimate of 900,000."

Tversky and Kahneman argue that people's estimates are conditional on the validity of their computational algorithms. However, there are two sources of uncertainty that plague these algorithms. First, there is uncertainty at every step in the sequential estimation process and there is uncertainty about the algorithm itself. That is, the whole calculational scheme may be incorrect. It is apparently quite difficult to carry along these several sources of uncertainty and translate them intuitively into a

98% confidence band. Once the "best guess" is arrived at (e.g., the 900,000 figure above) the token adjustments fail to do justice to the many ways in which this estimate could be in error.

The research just described implies that our estimates may be grossly in error--even when we attempt to acknowledge our uncertainty. This may have profound implications for many kinds of judgments about the risks and benefits associated with nuclear power--for example, judgments about the operating lifetime of a certain nuclear plant or the durability of a vessel storing radioactive wastes. Estimates of future costs are particularly likely to be susceptible to this kind of bias.⁴

PROBLEMS IN INTEGRATING INFORMATION FROM MULTIPLE SOURCES

Thus far, the discussion has been concerned with the assessment of risks and estimation of uncertain quantities. At this point I would like to turn to a somewhat different problem. Suppose that we have good information about both risks and benefits. How capable are we of balancing these several factors and coming up with an optimal decision? By optimal, I don't mean a decision that will, necessarily, turn out well. Some good decisions work out poorly and vice versa. I'm thinking of optimal decisions in the sense that such decisions faithfully reflect the decision maker's personal values.

As if we didn't have enough problems with our tendencies to bias probability judgments, there is some evidence to the effect that our information-processing limitations may often lead us into decisions that are inconsistent with our underlying values. One example of this within a risk-benefit

⁴For example, the cost of major weapons systems is running nearly 50% ahead of original estimates according to a recent congressional study team. In one case the original estimate for 6 submarine rescue vehicles was 18 million dollars. Later the estimate was revised to 463 million dollars! This overrun, like most of the others, was blamed on a failure to foresee development problems. There are many ways our judgments can go wrong, and it is difficult to incorporate our uncertainty about these possible sources of error into our actual judgments.

context comes from a study by Slovic and Lichtenstein (1968) in which subjects were asked to indicate how much they would like to play various gambles for which the probabilities of winning and losing and the winning and losing payoffs were stated precisely.

The experiment was straightforward. One group of subjects rated the attractiveness of playing each of a number of gambles on a ten-point scale. Another group of subjects indicated the attractiveness of these same gambles by a method in which they put a price tag on each to indicate its worth to them. That is, they stated an amount of money such that they would be indifferent between playing the gamble and receiving the stated amount. In addition, some of the subjects in both of these groups indicated their subjective weightings for the four risk dimensions of a gamble (i.e., probability of winning, probability of losing, amount to win, and amount to lose) by distributing 100 points over the set of dimensions according to their feelings about the relative importance of each dimension. When subjects rated the attractiveness of a gamble, probability of winning was found to be the most important dimension. When they put a price on a gamble, attractiveness was determined more by the gamble's payoffs. Yet subjects in both groups stated that they valued probability of winning as the most important consideration. Apparently, there was a failure to properly implement this value when making the pricing responses.

A later experiment (Lichtenstein & Slovic, 1971) replicated the response-mode effect. Consider the following pair of gambles:

Bet A: .90 to win \$ 4 and .10 to lose \$2

Bet B: .30 to win \$16 and .70 to lose \$2

Bet A has a much better probability of winning but Bet B offers a higher winning payoff. Lichtenstein and Slovic's subjects were shown many such pairs of bets. They were asked to indicate, in two ways, how much they would like to play each bet in a pair. First they made a simple choice, A or B. Later they were asked to assume they owned a ticket to play each bet, and they were to state the lowest price for which they would sell this ticket.

Presumably these selling prices and choices are both governed by the same underlying quality, the subjective attractiveness of each gamble.

Therefore, the subject should state a higher selling price for the gamble that he prefers in the choice situation. However, the results indicated that subjects often chose Gamble A, yet stated a higher selling price for Gamble B. Why should this happen? Lichtenstein and Slovic have traced it to the fact that subjects used different cognitive strategies for setting prices than for making choices. Subjects choose Bet A because of its good odds, but they set a higher price for B because of its large winning payoff.

A "compatibility" effect seemed to be operating here. Since a selling price is expressed in terms of monetary units, subjects apparently found it easier to use the monetary aspects of the gamble to produce this type of response. Such a bias did not exist with the choices since each attribute of one gamble could be directly compared with the same attribute of the other gamble. With no reason to use payoffs as a starting point, subjects were free to use any number of strategies to determine their choices. In most cases, they relied primarily on the probabilities of winning and losing. When faced with their inconsistent decisions, many subjects had a very hard time changing either of their conflicting responses. They felt that the different strategies they used for each decision were appropriate. However, strict adherence to an inconsistent pattern of prices and choices can be termed irrational, since the inconsistent subject can be led into purchasing and trading gambles in such a way that he continually loses money.

The overdependence on payoff cues when pricing a gamble suggested a general hypothesis to the effect that the compatibility or commensurability between a cue dimension and the required response effects the importance of that cue in determining the response. This hypothesis was tested in a recent experiment by Slovic and MacPhillamy (1971), who predicted that dimensions common to each alternative in a choice situation would have greater influence upon decisions than would dimensions that were unique to a particular alternative. They asked subjects to compare pairs of students with respect to potential college Grade Point Average. The subjects were given each student's score on two cue dimensions (tests) on which to base their judgments. One dimension was common to both students and the other

was unique. For example, Student A might be described in terms of his scores on Need for Achievement and English Skill, while Student B might be described by his scores on Quantitative Ability and English Skill. For this example, since English Skill was a dimension common to both students, it should be weighted heavily. That is, a comparison between two stimuli along the same dimension should be easier, cognitively, than a comparison between different dimensions, and this ease of use should lead to greater reliance on the common dimension. The data strongly confirmed this hypothesis. Common dimensions were weighted much more heavily than unique attributes. Interrogation of the subjects after the experiment indicated that most did not wish to give more weight to the common dimension and were unaware that they had done so, illustrating again a systematic deficiency in judges' ability to implement their subjective values.

The message in these experiments is that the amalgamation of different types of information and different types of values into an overall judgment or decision is a difficult cognitive process and we often resort to judgmental strategies that may do an injustice to our underlying values. In other words, even when the risks and benefits are known and made explicit, as in the gambling situation, subtle aspects of the decision we have to make, acting in combination with our intellectual limitations, may bias the balance we strike between these risks and benefits.

ARE IMPORTANT DECISIONS BIASED?

Experimental work, such as that just described, documents man's difficulties in weighing information and judging uncertainty. Do these difficulties diminish once the subject leaves the artificial confines of the laboratory and resumes the task of using familiar sources of information to make decisions that are personally important to him?

While there is little systematic evidence bearing on this question, there are some hints, at least, that man's information-processing limitations do influence decisions outside the laboratory. For example, there is extensive data indicating that the risks of natural hazards are grossly misperceived (Kates, 1962; Burton & Kates, 1964).

Slovic, Kunreuther and White (1971) discuss the close parallel between the nature of these misperceptions and the biased judgments of probabilities found in psychological experiments.

Examination of business decision making and governmental policy making suggests that, whenever possible, decision makers avoid uncertainty and the necessity of weighting and combining information or trading-off conflicting values. For example, Woods (1966; p. 95) summarizes his observations of one business firm's investment strategy as follows:

"In estimating the value to their company of a potential investment, the managers in the organizations studied are preoccupied with searching for a comparable prior investment rather than identifying the relevant variables and forecasting the underlying uncertainty. Uncertainty is avoided like the plague, while the certainty of historical information is accorded such a premium that it dominates the managers' mental processes completely."

Cyert and March (1963; p. 120) also note the avoidance of uncertainty by business firms.

"Our studies, however, lead us to the proposition that firms will devise and negotiate an environment so as to eliminate the uncertainty. Rather than treat the environment as exogenous and to be predicted, they seek ways to make it controllable.

". . . one conspicuous means of control is through the establishment of an industry-wide conventional practices.

"For example, prices are frequently set on the basis of conventional practice. With time such variables as the rate of mark-up, price lines, and standard costing procedures become customary within an industry. The net result of such activity . . . is that an uncertain environment is made quite highly predictable."

Lindblom (1964) comes to similar conclusions on the basis of his analysis of governmental policy making. He notes that administrators avoid the difficult task of taking all important factors into consideration and weighing their relative merits and drawbacks. Instead they employ what he calls "the method of successive limited comparisons." This method simplifies decisions by comparing only those policies that differ in relatively small degree from policies already in effect. Thus it is not necessary to undertake fundamental inquiry into

an alternative and its consequences: one need study only those respects in which the proposed alternative and its consequences differ from the status quo.

The decision makers studied by Cyert and March and Lindblom were also found to avoid long-range planning and forecasting. They preferred to take small steps and to monitor short-run feedback rather than to try to predict the consequences of a long-range move.

The avoidance of uncertainty, the avoidance of "weighing relative merits and drawbacks," and the avoidance of long-range forecasting are just what one would expect, given what the laboratory studies indicate about our cognitive limitations. When we can use feedback as a guide--that is, when we can afford to learn by our mistakes, such behaviors may be satisfactory approximations to optimal performance.

IMPLICATIONS FOR DECISIONS REGARDING NUCLEAR POWER

I'd like to conclude with some additional speculations about the possible implications of this research for decisions bearing upon the development of nuclear power.

First, we all acknowledge the importance of personal values and subjective probabilities in guiding our thinking about nuclear power, but how can these probabilities and values be measured? We can infer them from our overt actions or we can ask people to estimate them directly. The problem is that different estimation methods impose different modes of thought that, in turn, may produce quite inconsistent results. Knowing how response biases operate, however, may help us determine the best way to elicit an individual's opinions about risks and benefits. At present, the technology for assessing these subjective opinions is primitive and awaits development.

Second, it seems quite likely that there will continue to be very great disagreements between the forecasts and perceptions of engineers and scientists on the one hand, and the public on the other. Each group is subject to error--especially when good empirical data is lacking. The technical people may run into problems because of an inability to quantify what they don't know--as indicated by the almanac experiments described above. The public may go

astray because of availability biases, wherein very subtle factors play upon imagination and memory in a way that alters the perception of risk.

If our intuitive judgments are so poor, why do we have such great confidence in them? For one thing, our basic perceptual motor skills are remarkably good, the product of a long period of evolution, and thus we can process sensory information with remarkable ease. This may fool us into thinking that we can process conceptual information with similar facility. Anyone who has tried to catch a baseball by calculating its impact against the bat, trajectory of flight, etc., knows, however, that our analytic skills lag far behind our sensory abilities.

Man has faced decisions of great consequence, like those involving nuclear energy, only within his recent history. It might be argued that he has not had enough opportunity to evolve an intellect capable of dealing conceptually with uncertainty. He is essentially a trial-and-error learner and his early experiences with nuclear energy give little assurance that he can change his ways even when errors will be quite costly (see, for example, Schrader, 1971). How does such a creature learn by experience yet avoid catastrophe in the nuclear age? A pessimist might advise him to take very small steps--small enough so that he can recover from the inevitable miscalculations. An optimist would reply that the technology of decision making will undoubtedly advance rapidly within the next decade. Perhaps with proper educational techniques, computer simulations, and sophisticated methods of decision analysis, we will be able to minimize many of the types of judgmental biases discussed here. Then, if the balance between benefits and risks is judged favorable, the development of nuclear power could proceed at an accelerated pace. And the cynic, noting the aforementioned tendency for psychologists to overgeneralize on the basis of small samples of data, would advise us to disregard the research on biases and continue to have faith in our intuition.

Time will tell.

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GOALS OF COST-BENEFIT ANALYSIS IN ELECTRICAL POWER GENERATION

by

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I. INTRODUCTION

The convening of this symposium indicates that there is a significant degree of uncertainty about the expectations and goals of cost-benefit analysis, particularly as it relates to development of nuclear technology. It is hoped that cost-benefit analysis can be a vehicle for including technological factors in the public decision-making and policy-making processes. Recently, with the Calvert Cliffs' decision, the need for dependable, well-focused cost-benefit assessment has been sharpened considerably. This paper is an examination of a few of the realistic expectations of cost-benefit analysis. Rather than being comprehensive, these parenthetical comments should be complementary with other papers to be presented.

I think it is ironic that cost-benefit analysis, under a variety of names, is so casually accepted in the "non-scientific" fields of politics, industry, and business, but is a source of major controversy and debate among many scientists, even though they, by tradition, have preempted the field of quantitative evaluation of phenomena and interactions. I believe the problem arises from the "subjective" variables which must be included in cost-benefit analysis even though they are difficult or impossible to quantify. Yet, in many cases, if the variables to be considered are limited to those that can be accurately evaluated, the scope of the analysis will be much too limited; costs, risks and benefits can be evaluated to any desired accuracy, according to any internally consistent method, and still be irrelevant to the problems of the day. For example, the risks of carcinogenesis from both nuclear and fossil-fueled power plants should be

compared. Neither of these risks is intrinsically very high, but the degree of public concern surrounding the issues is so great, the evaluation problem itself is of exquisite importance. For this reason, an "objective" cost-benefit analysis would be virtually useless if it did not address the real, but subjective, problem areas.

Before proceeding, I would like to make a distinction between "costs" and "risks" to provide a frame of reference for comparing them. Costs are effects which vary continuously with their driving forces -- in relation to society or the individual. On the other hand, discrete phenomena, which are either manifested or not in individuals, have associated levels of risk; the value of the risk is defined as the probability of the phenomenon's occurrence.

Risks can be characterized as costs if the frame of reference is expanded from the individual to the society as a whole. In other words, the occurrence of discrete events can be approximated by a continuous function if the population is large. As an example of the "cost-valuation" society applies to such phenomena, cancer is considered to be worthy of a much greater research investment than amyotrophic lateral sclerosis, an invariably fatal -- but much rarer -- disease. Accordingly, there is ample precedent for considering costs and risks to be qualitatively equivalent if the frame of reference is larger than the individual. With this justification, a major task confronting cost-benefit analysts and decision-makers is to find an acceptable medium of exchange, or common basis for quantitative comparison, for the two.

THE "ART" OF COST-BENEFIT ANALYSIS

I have characterized the field of cost-benefit analysis as an "art" to indicate that its application will not always depend on accurate assessments of all of the variables to be considered.¹ In the art of medicine, for example, costly and/or risky treatment is characteristically prescribed on the basis of a "presumptive" diagnosis. Such a diagnosis depends upon many factors, of which only a few can be rigorously measured. To distinguish an "art" from a "science," an art is characterized as a field in which it is more important to be right than to be rigorous. This designation emphasizes some of the features shared by the practice of cost-benefit analysis and that of the art of medicine.

In medicine, a recommendation for treatment is made if it is predicted that benefits will be derived which outweigh the risks and costs. The benefit the patient can expect is the overall reduction of the risk of mortality or morbidity, but this benefit will really exist only if the diagnosis is correct; it is inevitable that for some cases, the costs and risks of the treatment will be incurred with no actual benefit at all. The art of medicine is practiced acceptably, though, despite a significant degree of uncertainty surrounding specific applications to individuals. The acceptability results from the favorable integrated benefit-cost balance it offers the society as a whole, and also from the generally recognized fact that research designed to improve this balance is continuously in progress.

In the field of cost-benefit analysis, as in the field of medicine, there are strong pressures to produce acceptable solutions for current problems. Decision-makers cannot always wait until they have all the facts. Consequently, human judgment and intuition must be used to extend the relevance and applicability of limited information and meager knowledge. Since society both provides the pressures for solutions, and establishes the levels of acceptability, this intuitive approach will be most productive if the scientific and technological institutions work together with our broad social and political bodies. Furthermore, these institutions must use trial-and-error problem-solving methods, so they cannot realistically be expected to uniformly provide perfect solutions.

RISK-ACCEPTABILITY EVALUATION

Some very small risks are extremely important simply because they are thought to be important. That phenomenon is real, even though it doesn't "seem right." The roots of society's evaluation of risk are found in the individual's ability to comprehend the meaning of risk, but it is difficult for an individual to intuitively assign a "cost-value" to a risk of any given magnitude. Even though the "real," or intrinsic value of a risk may be low, the individual may attribute a much higher extrinsic value to it. Because of the disparity between the intrinsic and extrinsic values of risks, risk evaluation and risk-acceptability evaluation are two distinct problems. Since costs are related to individual experiences, and risks are related to population experiences, it seems reasonable to look to the society as a whole for examples of "acceptable" levels of risk for activities that have some associated level of benefit. This could be called retrospective risk-acceptability evaluation.

A prospective risk-acceptability evaluation is much more difficult, obviously. This approach must be used, though, to estimate the extrinsic value which is placed on a future risk, such as that from nuclear power plants. I anticipate that society's reactions to new, and therefore untested, risks are likely to be manifested by high extrinsic values on the risks. Again, psychological characteristics of individuals are expected to determine the population response; in this case, intrinsically low-level risks that are unfamiliar are likely to be given higher extrinsic valuation than equally low level risks that are familiar. Thus, "fear of the unknown" and "familiarity breeds contempt" are reactions that must be expected.

It is hoped that benefit-risk analysis can be helpful in reconciling the differences between intrinsic and extrinsic evaluations. Reaching this goal itself, however, is an independent problem. To accomplish it, the level of familiarity for the projected risk might be increased by an abstract education process. Since intuition, a process of mental analogy-referencing, is a necessary part of risk evaluation, the public might be effectively informed by referring to risks in already familiar terms. Perhaps, for this purpose, a unit of risk

might be used that has a name such as "cig," which would be defined as the level of risk incurred by smoking a single cigarette.

COST-BENEFIT CONSIDERATIONS FOR ELECTRICAL POWER SOURCES

The predominant sources of electrical energy in the coming generation will be fossil fuel combustion and nuclear fission. Since the major benefits of electrical power generation are the same regardless of the ultimate source, comparison of cost-benefit considerations of nuclear and fossil-fueled power plants reduces to a problem of cost comparisons alone. In fact, if there were only one source of energy, cost-benefit analysis would not even be necessary, since the benefits of electrical power production so far outweigh the costs of production, including environmental costs.

Except for thermal release, which is about the same quantitatively for fossil-fueled and nuclear plants, the potential environmental effects of operation of these sources are not directly comparable. Most of the harmful effects of fossil fuel combustion are manifested as costs -- acute human health effects, and damage to materials, plants and commercial crops. On the other hand, the expected radiation-related effects of nuclear plants are risks -- these would result from long-term low-dose exposure to radionuclides. Still, there is a body of experimental evidence suggesting that combinations of air pollutants emitted from fossil fuel combustion processes, including electrical power production, are capable of producing and/or promoting cancer.²

It can be predicted that fossil-fuel pollution presents a significant risk of carcinogenesis to the general population. This qualitative prediction is based on two sets of observations; first, that benzo(a)pyrene (BaP) is one of the most potent and most abundant of the carcinogens in cigarette smoke, and second, that the ambient air of American cities contains enough BaP to provide a dose rate to individuals equivalent to that of light smokers. It is not accurately known whether the magnitude of the risk is of the same order as that from radiation-related environmental pollution due to nuclear power production. Nevertheless, the qualitative prediction carries with it a presumption that must not be

ignored when comparing the relative environmental costs of nuclear and fossil-fuel power production.

A very rough approximation of the dose-risk relation for BaP alone can be made by referring to the smoking-cancer studies, by oversimplifying in places and by ignoring co-carcinogens altogether. This value, in turn, can be used to estimate the magnitude of the risk incurred by breathing polluted air. These calculations depend on a few simplifying assumptions: (1) the lung cancer initiation rate among cigarette smokers increases linearly with the integrated BaP inhalation rate; (2) the co-carcinogens in cigarette smoke amplify the effectiveness of BaP by a factor of 40; that is, BaP alone accounts for only 1/40 the total activity of cigarette smoke; (3) the effective duration of risk in the human population is 40 years; and (4) by averaging the male and female lung cancer initiation rates for the range of 1-19 cigarettes a day, a wide range of physical smoking parameters will be included.

A "bapman" is defined as a unit of exposure of one man to one microgram of BaP in one year. The annual rate of BaP exposure from smoking 10 cigarettes a day is about 60 micrograms. Using the assumptions above, and values of the annual excess risk of lung cancer for all ages of smokers, men and women taken together,³ it can be shown that the risk associated with one bapman exposure is 5×10^{-6} . In other words, 2×10^5 bapman of exposure would result in one death. It follows that the risk associated with the bapman unit is about an order of magnitude less than that for a man-rem.

The exposure to BaP from ambient air breathed by American urban populations can be calculated in bapman units by referring to data in the literature,⁴ and by assuming a daily tidal volume of 30 cubic meters. For 10 cities, representing a total population of 17.2 million people, the exposures range from 2.6×10^7 bapman in New Orleans, to 4.9×10^8 bapman in New York. The calculated average projected death rate using the 10 city sample is about the same as for light smokers -- 48/100,000 population, on an annual basis. For a population of 100 million persons at risk, the predicted incidence of cancer resulting from BaP exposure is 48,000. Assuming that electrical power generation accounts for only 1% of the total BaP in the atmosphere, the expected number of deaths due to fossil fuel power

production is about 480/year currently, from an exposure of 3×10^6 bapman. By comparison, this risk is larger by a couple of orders of magnitude than that expected to result from the 5 to 6×10^4 man-rem due to nuclear power production by the year 2000.

SUMMARY

Cost-benefit analysis is a promising vehicle for promoting meaningful communication between the technological and the public-policy-making communities. However, the realization of this potential depends on the realistic assessment of the goals and limitations of cost-benefit analysis. Cost-benefit analysis is characterized as an "art" to indicate that it can be practiced imperfectly, but acceptably, in the absence of definitive information, while still investing in increased knowledge from research. Because of imperfect knowledge, and imperfect decision-making institutions, it is unrealistic to demand perfect answers from cost-benefit analysis. Nevertheless, in view of the pressure for acceptable solutions to current problems involving nuclear technology, it should be practiced despite the uncertainties.

Risk-acceptability evaluation is distinguished from risk evaluation, and is considered to be relevant to the overall goals of cost-benefit analysis. It is suggested that the public might over-react to proposed projects, despite small intrinsic risks, because there is no intuitive familiarity for phenomena which have not been experienced. It is proposed that the disparity between intrinsic and extrinsic risk values can be reconciled by positive

attempts to inform the public, with the goal of increasing the public's familiarity with risks.

As an example of the use of comparative risk evaluation, the risks of carcinogenesis from fossil-fueled and nuclear power generation are compared. Despite considerable uncertainty in establishing the magnitude of the risks, it is shown that current levels of pollution from fossil-fueled power plants constitutes a risk that is probably considerably higher than that from projected nuclear power plants.

ACKNOWLEDGMENT

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A CASE FOR BENEFIT-RISK ANALYSIS **

by

Jerry J. Cohen

ABSTRACT

Nuclear operations cannot be judged on a "safe or unsafe" basis, but rather on a "how safe" basis. The allowable degree of risk should be commensurate with the anticipated benefit from the operation. Benefit-risk analysis attempts to provide sound techniques for such determinations.

A phenomenon of recent times is the strong public awareness and concern with regard to the environment. Today one can hardly pick up a newspaper or hear a newscast without learning of some major ecological disaster which is about to befall us if we are not vigilant. Student and citizen groups are organizing to fight pollution and save our environment from one menace or another. I sometimes wonder how mankind could have survived to this day without the enlightenment that is currently being provided us by the plethora of latter-day environmentalists surrounding us.

Unfortunately, much of this activity has resulted in confusing the public to the point where they do not know who or what to believe, and has also managed to stimulate or stampede, depending on your point of view, various governmental agencies into taking action. To install a nuclear power reactor nowadays, it seems one must essentially provide an ironclad guarantee that no adverse consequences of any kind or degree will occur as a result.

Certainly public awareness and concern over matters of pollution can go a long way toward preventing abuses of the environment. The problem comes in determination of just what is abuse, and what is a reasonable and acceptable consequence of industrial development. It comes when emotionalism enters the picture, when those who apparently believe that no sacrifice is too great to achieve a pristine environment oppose any industrial plan which carries

with it any degree of risk, no matter how slight. In a state of emotionalism and rancor it is difficult to maintain any reasonable perspective. To resolve such problems we should first realize that no industrial operation or, indeed, any endeavor of mankind, is entirely devoid of risk. Therefore, judgement should be made not on the basis of whether or not an operation is safe or unsafe, but rather on how safe. Having determined this, one is then confronted with another question: "How safe is safe enough?"

In recent years a few articles have appeared in the literature attempting to place radiation risks in perspective. The authors who have ventured to discuss the subject include names such as Sowby, Barry, Otway, Lindell, Dunster, and Starr. Their efforts consisted, more or less, of preliminary attempts to quantify the risks of radiation exposure and other risks commonly accepted in everyday life. In general, the methods and techniques for doing this have been categorized under the heading of Benefit-Risk Analysis. Benefit-risk analysis has as its objective, to determine a rational means of evaluating the potential benefits of any given operation, program, or technology against its possible risks. To understand what benefit-risk analysis might accomplish, one may simply look at what happens if we don't use it.

For example, in evaluating the potential radiation effects of nuclear applications, an approach

which has historically been taken is the use of the so-called "worst case" or "maximum credible incident" concept. This involves a determination of the worst possible chain of events and biological consequences which might occur as a result of the particular application considered. In my opinion, this approach has been abused. It often has made little difference how bizarre or improbable the assumptions in such an analysis were, since one had only to show that some undesirable effect could occur at a probability level greater than zero. Opponents of a proposed operation could destroy it simply by exercising their imaginations to dream up a set of conditions which, although they might admittedly be extremely improbable, could lead to some undesirable result. With such attitudes prevalent, planning a given nuclear operation becomes somewhat perilous since it requires predicting the extent to which the adversaries can employ their imagination.

To those basically opposed to nuclear development, any amount of risk is apparently unjustified. Such attitudes can be considered unreasonable for the simple reason that any industrial enterprise involves some risk. One might reasonably ask why nuclear development should be singled out for special restriction. A far more rational approach might be to determine whether the risks are justified by whatever benefit is to be anticipated.

To evaluate and compare benefit versus risk, it is necessary to measure both in comparable units or to essentially determine a common denominator. In our society, money has historically been the method of barter, and people are conditioned to think in monetary terms. Certainly, the value of money is better understood by most people than anything else. For this reason we have advocated a system of evaluation of risk in monetary terms. For radiation exposure, as an example, we have estimated the value of \$250 worth of damage per man-rad of exposure. Estimates by other authors have been consistent with this value. Use of such a figure allows one to determine a measure of risk in monetary terms against which one could compare the cost for avoiding such risks.

Such an approach was stimulated by the observation that people's response to risk or potential threat of danger often bore little relationship to the magnitude of the danger. Grosser, Weschler, and

Greenblatt, in their book The Threat of Impending Disaster,* give illustrations of this point. For example, on one hand are shown examples of people ignoring hurricane warnings, despite the fact that once a warning has been issued in a given area, the probability of a hurricane striking is quite high. On the other hand, threats involving ionizing radiation such as the siting of a reactor nearby, can bring a strenuous overreaction out of all proportion to the seriousness of the threat.

People's reactions to threat of danger is often a function of their earlier conditioning. Given the knowledge that the nuclear age was begun in wartime, it is understandable that visions of Hiroshima can easily be conjured up whenever nuclear applications are considered, at least in the mind of the general public.

By placing risks and benefits on a common scale of measurements, we might hopefully guide public consideration to a more rational and objective basis of understanding.

A summary of the points I have attempted to make follows:

1. No industrial operation, be it nuclear or conventional, is devoid of risk. Indeed, no endeavor of mankind can make such a claim.
2. This being the case, one should not speak of operations in terms of "safe" or "unsafe", but rather "how safe". Quantitative evaluations of risk should be essential.
3. Acceptance of any given operation or program should be based on a quantitative comparison of these risk evaluations to benefits to be derived from their application. Should the risks outweigh the benefits, the operation should, of course, be rejected. The amount of effort expended in determining potential benefits should be commensurate with that involved in determining the risks.
4. These evaluations should be expressed in some commonly comprehensible basis. I submit that monetary values best serve as such a basis.

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Appendix I
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Appendix II

Results of Attendee Survey

In order to assess the success of this Symposium those attending were given a questionnaire asking for numerical evaluation of several factors. Respondants were asked to rate these items on a scale of zero (very negative) to five (very positive). Space was also available on the form for other comments; anonymity was provided in hopes of eliciting frank replies. On the zero to five scale, a rating of 2.5 would indicate that the meeting met the persons's expectations on a particular point. Scores below or above 2.5 would indicate that expectations were, respectively, not met or exceeded.

1. Do you feel that the time and effort you put in to attending this meeting were well spent?

<u>Score</u>	<u>Response</u>	
0	2	
1	2	
2	3	Average = 3.5
3	11	
4	11	
5	11	

2. Do you feel that a similar meeting on other subjects (radioactive waste disposal, plant siting, etc.) would be worth while?

<u>Score</u>	<u>Response</u>	
0	3	
1	0	
2	2	Average = 3.4
3	15	
4	10	
5	8	

3. Was the mix of attendees reasonable?

<u>Score</u>	<u>Response</u>	
0	1	
1	3	
2	6	Average = 3.3
3	7	
4	20	
5	4	

4. Did the format used (few talkers, open discussion) seem effective?

<u>Score</u>	<u>Response</u>	
0	1	
1	2	
2	3	Average = 3.7
3	6	
4	15	
5	12	

5. Were the speakers and topics selected worthwhile?

<u>Score</u>	<u>Response</u>	
0	0	
1	3	
2	6	Average = 3.1
3	15	
4	11	
5	4	

Some typical comments from the questionnaires follow:

"More critics needed - Power people kept so quiet it had to be a planned thing, therefore they

cannot be considered to have been participants, only wary observers. This is really remarkable when you think about it, since, nominally at least, they have the greatest immediate stake in the outcome of this symposium."

"Not enough participation from Industry representatives. Is there some way this could be changed?"

"Need emphasis on techniques -- how-to drill and then on limits, what else needs to be done."

"There was not enough discussion on the method of Risk-Benefit Analysis."

"Meeting on methods of risk benefit might be worthwhile."

"With one exception, the speakers talked about familiar material at a very rudimentary level. Many speakers took the opportunity to knock other participants' positions in a manner irrelevant to the meeting. Without an opportunity to delve further into the issues they added nothing to the meeting."

"Good start on a difficult problem -- next should be a marshalling of experts in the pertinent disciplines to kick off laying the foundations for a test study."

"Should have had more speakers from anti-energy, anti-AEC, anti-technology, to present alternatives to present programs. No real discussion of benefit cost methodology."

"The interface of multidisciplinary persons with the obvious difference of interests is the real criteria of success in this type of meeting: i.e. -- even though we may still differ in our beliefs, at least this type of face to face exchange opens the door to understanding why someone does not agree with you. Further, these meetings also provide another key necessary to successful arbitration -- introduction to the opponent."

"Stimulating, well-organized. Particularly appreciated the exposure of critical views like Metzger's."

"It was interesting, but not really helpful -- everyone went out the same door they came in ---"

"Probably future meetings need better definition of topic and educational talks at the beginning."

"Chairman did a very good job of running the show. Since he is the key, suggest you make sure any other meeting has a good man."

"Informal bull-sessions were most valuable to me. Good mix of people to talk with."

"Much benefit from informal sessions."

"Too much emphasis in the discussions on the philosophy and not enough on the specifics and the techniques that might be useful. I found the best interchanges took place outside the formal sessions."

APPENDIX III

Miscellaneous Photographs Taken During Session