IIASA COLLABORATIVE PROCEEDINGS SERIES

CP-82-S2

RISK: A SEMINAR SERIES

IIASA COLLABORATIVE PROCEEDINGS SERIES

CP–81–S1	LARGE-SCALE LINEAR PROGRAMMING Proceedings of an IIASA Workshop, 2–6 June 1980 G.B. Dantzig, M.A.H. Dempster, and M.J. Kallio, *Editors*
CP–81–S2	THE SHINKANSEN PROGRAM: Transportation, Railway, Environmental, Regional, and National Development Issues A. Straszak, *Editor*
CP–82–S1	HUMAN SETTLEMENT SYSTEMS: Spatial Patterns and Trends Selected Papers from an IIASA Conference on the Analysis of Human Settlement Systems T. Kawashima and P. Korcelli, *Editors*
CP–82–S2	RISK: A Seminar Series H. Kunreuther, *Editor*

RISK: A SEMINAR SERIES

Howard Kunreuther, Editor

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria
1981

International Standard Book Number 3-7045-0030-5

PREFACE

This volume is a compendium of risk seminars held at IIASA from October 1980 to September 1981. Since risk is a relatively new area of research, there is considerable variety in the way different individuals approach the subject. This has the advantage of bringing a number of viewpoints into the area from which one can begin to develop a body of evidence as well as a foundation for future studies. It also presents a challenge to researchers to consolidate relevant concepts into a paradigm enabling a body of empirical research to be undertaken that will make an impact on the worlds of science and decision.

The papers in this volume present ingredients that will prove useful for future efforts in the risk field. Part I consists of papers that represent attempts to develop conceptual frameworks from several different perspectives. The papers in Part II deal with the role of risk assessment and analysis as well as the concept of acceptable risk in the context of societal decision-making. Part III contains papers that address the way laypersons as well as experts actually assess the risk associated with specific hazards. Part IV concerns methodological issues associated with estimating probabilities and values for uncertain events. The concluding section (Part V) is devoted to alternative approaches for managing risk, such as decision analysis, communicating information, resolving conflicts, inspection, and the performance of insurance markets.

The Risk Seminars represent an attempt to increase the networking role played by IIASA. A special word of appreciation goes to Craig Sinclair who jointly initiated these risk seminars and planned them with me until he left IIASA in December 1980. I am grateful to Noel Blackwell for helping to organize this volume and to Eryl Ley for her assistance in producing the manuscript. Finally, this volume would not have been possible without the support of Alec Lee, Chairman of the Management and Technology Area, Andrzej Wierzbicki, Chairman of the System and Decision Sciences Area, Roger Levien, former Director of IIASA, and C.S. Holling, Director of IIASA, who have encouraged the Risk Group in its efforts.

HOWARD KUNREUTHER
March 1982

CONTENTS

PART I

CONCEPTUAL ISSUES IN RISK

DECISION MAKING FOR LOW PROBABILITY EVENTS: A CONCEPTUAL FRAMEWORK*

Howard Kunreuther

International Institute for Applied Systems Analysis, Laxenburg, Austria

Recent empirical evidence from field surveys and controlled laboratory experiments reveal anomalies with respect to decisions by individuals to protect themselves against low probability, high loss events. In particular, behavior is frequently at odds with what would be predicted by standard models of choice which involve benefit-cost comparisons.

This paper develops a framework for analyzing decisions for low probability events and discusses their policy implications. The framework highlights the following four interrelated components:

(1) Type of information collected by individuals in making their decisions (i.e., accuracy of data on losses, probabilities and protective options);
(2) The decision process of individuals (e.g., expected utility maximization, threshold models);
(3) Implications of policies on specific groups (e.g., affected individuals, general taxpayers); and
(4) Welfare implications (e.g., equity and efficiency considerations).

Examples from studies on natural hazards, health and safety problems will be used to illustrate how this framework synthesizes descriptive models of choice with policy prescription. The paper concludes by suggesting directions for future research.

*The research reported in this paper is supported by the Bundesministerium für Forschung und Technologie, F.R.G., contract no. 321/7591/RGB 8001. While support for this work is gratefully acknowledged, the views expressed are the author's own, and are not necessarily shared by the sponsor.

I. INTRODUCTION*

Society has become increasingly concerned with developing appropriate measures for mitigating the consequences of low probability events which have potentially large losses. It should be recognized at the outset that what is a low probability event for one interested party may be viewed as a high probability event for another. Similarly, the relative magnitude of the losses is also a function of where one sits. For example, the chances of suffering a severe property loss from a natural disaster or a severe injury from an automobile accident may be viewed as very small by a single individual but treated as relatively high by a government agency concerned with national losses. Property damage from a fire may appear staggering to the affected family but seem relatively small at a more aggregate level because of the different bases used to evaluate consequences.

This paper proposes a conceptual framework for dealing with events which are perceived to have a small chance of occurrence by at least one of the interested parties. The approach emphasizes the importance of undertaking descriptive analysis as a critical input for prescriptive recommendations.

After outlining the framework (Section II), I will illustrate its applicability in Section III with several examples which have both personal significance (e.g., safety of power mowers and motor vehicles) as well as societal importance (e.g., siting of LNG facilities). The importance of understanding decision processes as

*I would like to thank Uday Apte for helping to gather material on the illustrative examples discussed in section II of the paper.

a critical input to policy is underscored by empirical data on individual decision making with respect to insurance protection against natural hazards. Section IV summarizes key results from a large-scale field survey and controlled laboratory experiments which comprised this four-year study and illustrates the possible roles that the public and private sectors can play in providing better protection against future losses. In the concluding section, a more formal model is proposed which incorporates the decision processes and the role of information as critical inputs for developing prescriptive measures.

II. DEVELOPING A GENERAL FRAMEWORK

Figure 1 depicts a conceptual framework for structuring the analysis. An appropriate starting point is Problem Formulation (Box 1). Before undertaking a detailed analysis one needs to identify and define the problem. What are the goals and objectives corresponding to the particular area of concern? Can one gain insight into the nature of the problem through an historical perspective? This initial definitional phase is critically important as it enables one to undertake a detailed descriptive or behavioral analysis which can then be linked to alternative strategies. Furthermore, it helps limit the types of policies or plans that are relevant and provides guidelines for evaluating them.[1]

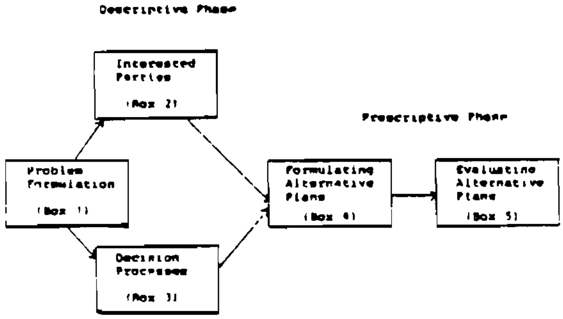


Figure 1. Conceptual framework for analysis structure.

Let us turn now to the descriptive phase. We need to define and describe explicitly *the interested parties* (Box 2) impacted by the problem. Three sectors are considered in the illustrative examples which follow: consumers (i.e., those who demand the particular products or are directly or indirectly affected by it); firms or enterprises (i.e., the organizations or business or supply the product); and government (i.e., public sector agencies or bureaus who interact with the private sector–consumers and enterprises). For each problem there are a set of legal and political constraints which determine how information currently flows between the three sectors and the groups within each sector. It is important to understand the dynamics of this interaction: *who* interacts with whom, and *when* this interaction takes place.

The other key element of the descriptive phase is the *decision processes* (Box 3) of each of the involved interested parties. By decision processes we mean the collection and processing of information relevant to the problem being analyzed. Recent empirical evidence from field and experimental studies have revealed systematic biases with respect to the processing of information and simplified rules in combining data in making decisions (Fischhoff, et al. 1980; Kunreuther, et al. 1978; and Tversky and Kahneman 1974). These findings shed considerable light on the relative importance of external events, such as past experience, as well as internal dynamics, such as discussions with others, in influencing decisions on low probability events. It is thus clear that the collection and processing of information are likely to be closely tied to the relevant constraints and the interactions between the interested parties.

Turning now to the prescriptive phase, there is a need to *formulate alternative plans* or courses of actions (Box 4) for coping with a particular problem. The generation of goals and objectives for any problem will suggest a set of plans to be considered. Two types of institutional arrangements between the interested parties circumscribe the types of plans which can be considered. One extreme is for consumers and firms to interact through a market system without any government involvement. The other extreme is for government to impose strict regulations which gives the private sector no freedom of choice. Most strategies are between these two extremes: the government sector utilizes incentives such as subsidies and taxes along with some regulations and information exchange to guide consumer and firm market interactions.

Finally, there is a need to *evaluate plans* (Box 5). How well different policies perform will be influenced by the decision processes of the interested parties. The ranking of different policies is also contingent upon the relative importance given to the interested parties. If residents in hazard-prone areas are deemed important enough to merit special treatment after a disaster, then Strategy A may be much more appealing than Strategy B. On the other hand, if disaster victims are deemed responsible for their own recovery, then Strategy B may be seen as preferable to Strategy A. In evaluating different measures one has to include the compliance costs which must be paid by the sellers as well as the enforcement costs which utilize government funds.[2]

III. ILLUSTRATIVE EXAMPLES

The framework depicted in Figure 1 can be applied to a set of problems which involve protective measures to reduce the probability of an event or mitigate its consequences. The section begins with those which involve personal safety and conclude with broader societal issues. The purpose of these illustrations is to show how the framework can structure analysis; no detailed evaluation of alternatives is undertaken.

Safer Power Mowers

Should power mowers be made safer? Each year approximately 75,000 people come in contact with moving power mower blades which can cause severe injuries. Nearly 10,000 of the blade-contact injuries involve amputations of fingers or toes (Washington Post 1979a). The problem involves a tradeoff between the costs of producing a safer mower and the reduction in injuries which presumably would result. In this case, the relevant *interested parties* are the homeowner or gardener who has or desires a power mower; the lawn mower industry; and the Consumer Products Safety Commission (CPSC), the regulatory agency with the responsibility for approving safety standards in this area.

The *decision processes* of consumers plays a critical role in evaluating any policy. If individuals are careless because they feel that nothing can happen to them when they utilize a mower, then it may be necessary to make power mowers safer. In addition, or as an alternative, warnings could be provided on the dangers of the mower (e.g., not to use it on wet grass). How well this information is actually processed by individuals determines how well such a policy works.

With respect to *alternative plans*, the CPCS has proposed mandatory safety standards in designing power mowers.[3] Industry claims that this regulation, which would increase the cost of a power mower by $35, is too strong. In *evaluating* these plans questions of product liability arise: Is the manufacturer responsible should there be an injury from a mower? A recent case awarded $6000 to a man who lost part of his foot in a lawn mower. The company claimed that the accident, which occurred because the person's foot slipped on wet grass, could have been avoided had he read the user manual which warned : "Do not use this mower on Wet Grass." In this case ignorance was considered an excuse and the claim was upheld (Business Week, February 12, 1979).

Motor Vehicle Safety

What are the appropriate safety measures for reducing deaths and injuries from motor vehicles? This question has some significance when one studies the statistics for the United States: "In 1977, motor vehicles caused 47,700 deaths, 1,900,000 disabling injuries, and approximately $12 billion in property damage" (Bick and Hohenemser 1979). At present less than 20% of the drivers or passengers in private vehicles protect themselves by wearing seat belts even though they are installed in all cars. Here, the *problem involves the tradeoffs* between personal freedom and possible adverse consequences to individuals and society when people do not voluntarily protect themselves. The relevant *interested parties* are the drivers and passengers, the automobile industry, and the National Highway Traffic Safety Administration, the regulatory agency empowered to deal with motor vehicle safety.

Echoing the same theme as above, the *decision processes* of consumers are critically important for designing prescriptive measures. Empirical evidence from laboratory studies suggests that one reason people do not voluntarily take protective action such as wearing safety belts, is because they feel that the probability of an accident is so small that they don't have to worry about it (Slovic, et al. 1978). A survey conducted by National Analysts (1971) for the Department of Transportation revealed that those most likely to wear belts are ones who have been asked by others to wear them. This raises the question of the importance of personal influence in the decision making process.

At a policy level there are several options which can be considered. Market mechanisms such as lower insurance premiums for cars equipped with passive restraints (e.g., automatic belts or air bags) could encourage people to voluntarily adopt these measures. Some countries do not pay insurance claims for injuries if it is shown that the individual has not protected himself with a safety belt, thereby providing economic incentives for individuals to use them. A stronger measure, utilized in some countries is to impose a fine for those not wearing the belt. An extreme measure would be to require that all autos be equipped with a passive restraint. Each of these measures has to be evaluated on a number of dimensions, the most important being the costs of imposing the particular approach and the potential benefits. As in all the examples in this section some parties will be helped while others will suffer depending on which alternative is chosen.

Cigarette Smoking

Should one impose restrictions on cigarettes to deter individuals from smoking and if so how should this be done? This question is stimulated by empirical data which suggests that annually 350,000 lives are lost and approximately $18 billion in hospital bills are incurred from diseases caused by smoking (Washington Post 1979b). The relevant *interested parties* are smokers, non-smokers, the tobacco industry and the Office of Smoking and Health, a regulatory agency concerned with the effects of cigarette smoking.

The *decision processes* of smokers are critical to the design of alternative policies. If individuals are aware that smoking is harmful to them but ignore these potential effects, either because they feel "nothing will happen to me," then additional information campaigns are unlikely to change behavior. There is also the question as to how sensitive the smoker is to price changes in cigarettes should additional taxes be imposed.

The spectrum of *alternative plans* range from market solutions (do nothing and let people suffer the consequences) to strict regulation (banning cigarettes). Recent proposals have involved a set of incentive systems, such as increasing taxes and using the revenue to help smokers quit (Harris 1980), or prohibiting smoking in certain public places (e.g., hospitals, theaters, and retail stores) (Washington Post 1979b). In evaluating these plans one recognizes that different importance weights on the relevant interested parties may lead to different rankings. For example, a policy of "do nothing" favors the smokers and the tobacco industry while banning cigarettes has the reverse effect. Taxation policies and fines for smoking in certain places falls somewhere between the above two extremes.

Siting of LNG Facilities

Liquefied natural gas (LNG) is a potential source of energy which requires a fairly complicated technological process that has the potential, albeit with very low probability, of creating severe losses. To import LNG the gas has to be converted to liquid form at about 1/600 the volume. It is shipped in specially constructed tankers and received at a terminal where it undergoes regasification and is then distributed. The entire system (i.e., the liquefication facility, the LNG tanker and the receiving terminal and regasification facility) can cost more than $1 billion to construct (Office of Technology Assessment 1977). The siting problem of interest is whether one should locate facilities for regasifying and shipping LNG and if so where would be the best place. The *interested parties* are the residents of areas considered as potential sites, those benefiting from this additional source of energy, the gas companies or consortium who are willing to invest in a proposed project and government agencies at the Federal, state, and local level who have responsibility for trading off the costs (including potential losses from an accident) and benefits of any decision.

Turning now to the *decision process* associated with siting, there are questions as to how each of the groups utilize information on the probability of any accident to an LNG terminal and the resulting consequences. One of the controversies emerging in the siting debate is whether one can or should specify an acceptable level of risk. Some risk assessments of a particular site focus on the chances of a catastrophic accident and conclude that it is acceptable if the probability is below some critical level. Others have utilized worst case scenarios and paid attention to the consequences without paying much attention to the chances of its occurrence.[4] There is also a need to understand how the different interested parties weigh the safety issue in relation to other concerns of a siting policy such as the economic impacts, effects on the environment and how LNG serves national energy policy.

The formulation of alternative strategies will be greatly impacted by the decision process of the different parties. One way of clarifying differences between the groups is to specify who is responsible for damages should an accident occur. If the location of an LNG facility is viewed primarily as a private venture, then some form of insurance should be offered to gas companies to protect them against catastrophic losses. If this type of coverage is not available on the private market, then government may have to provide this protection. A complementary set of plans may involve compensating residents of a proposed siting area for decreases in their real estate value and perhaps provide them with lower energy rates in return for their increased risk in the future. An alternative is to pass regulations such as the one by the Department of Energy which requires that new sites be in remote areas or in locations with relatively small population densities.

IV. INSURANCE AGAINST NATURAL HAZARDS[5]

Let us now turn to a more detailed study of homeowner decisions on whether to protect themselves against the consequences of natural hazards. The results raise a set of policy-related issues. They also shed light on the decision processes individuals are likely to use when dealing with situations such as those discussed in the previous section.

Problem Formulation

The problem of interest is the appropriate role of the public and private sectors in providing insurance protection against the consequences of natural hazards and relief in the aftermath of a disaster. An historical perspective with respect to this problem is relevant here. Annual losses from natural disasters in the United States is frequently over $1 billion dollars. Relatively few homeowners have voluntarily purchased insurance against the consequences of floods and earthquakes, even though coverage is easily available and in the case of floods highly subsidized by the federal government. In the past, the U.S government has responded to the financial plight of the uninsured victims by providing liberal relief in the form of low interest loans and grants to aid the recovery efforts.

Evidence on increased federal disaster relief is provided by comparative data on the Small Business Administration (SBA) disaster loan program. The growth of the program is easily seen in Figure 2; the increase is particularly significant in the case of home loans where both the total number and total dollar values in the 1966-76 period were more than 25 times what they were in the first 12 years of the program. It is striking that the $1.2 billion approved by the SBA for victims of Tropical Storm Agnes represented almost four times the entire amount allocated by the SBA for all disasters between fiscal years 1954 and 1965. Over $540 million of the amount approved by the SBA for victims of this disaster were in the form of forgiveness grants which did not have to be repaid.

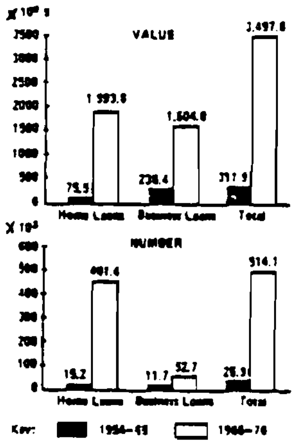


Figure 2. Small business administration disaster loans.

Interested Parties

Insurance against floods is provided by the Federal Insurance Administration with highly subsidized rates on existing property; new property is charged a premium based on estimated risk. For insurance to be offered to residents and businesses in a hazard-prone region, the community must agree to adopt land use regulations and building codes to reduce future losses from the hazard. Earthquake coverage is offered to the public by private companies. Even though coverage is not expensive ($2 per $1000 coverage on wood-frame homes in California with a 5% deductible), less than 3% of the homeowners in this earthquake-prone state have bought this insurance.

The interested parties for this problem are thus the Federal Insurance Administration (a government agency), the private insurance industry (i.e., companies and agents), the Small Business Administration, the residents in hazard-prone areas, and the general taxpayer who covers the subsidized portion of flood coverage and the subsidized portion of disaster relief.

Decision Processes

What are the factors which influence individuals to purchase insurance protection against relatively low probability events such as floods and earthquakes? To answer this question field survey questionnaires and controlled laboratory experiments were undertaken. The field survey involved face-to-face interviews with 2,055 homeowners residing in 43 areas throughout the United States subject to coastal and riverine flooding, and 1,006 homeowners living in 18 earthquake-prone areas of California. Half the respondents had purchased flood or earthquake insurance, the other half had not. The controlled laboratory experiments undertaken by Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein, at Decision Research, shed light on the causal relationships between variables entering into the insurance decision. A few of the key findings from this study which relate to individual decision processes are now summarized.

Although most uninsured homeowners interviewed were aware that flood and earthquake coverage existed, the majority were unaware that they were eligible to purchase a policy. Those who were aware had no reliable knowledge of the costs of a policy. The subsidized flood rate is between $2.50 and $3.50 per $1000 coverage depending on the proportion of coverage devoted to structure and contents. The earthquake premium on wood-frame homes in California averages $2 per $1000. Hence any homeowner estimating the respective rates between $2 and $4 for flood coverage and $1 and $3 for earthquake insurance was classified as reasonably accurate. Figure 3 shows that most of the insured homeowners were accurate in their estimate or underestimated the premium. Few uninsured individuals had accurate information and a large proportion overestimated the premium. This finding suggests that the uninsured individuals had not made any conscious effort to obtain information on rates from their insurance agent even if they knew coverage was available.

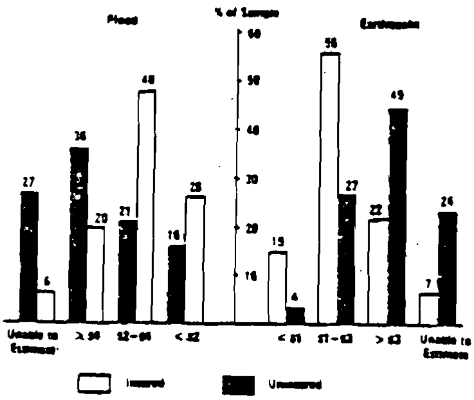


Figure 3. Subjective estimates of insurance premium.
(per $1,000 coverage)

With respect to the hazard itself, both insured and uninsured individuals had imperfect information on the probability and consequences of a severe flood or earthquake causing damage to their property and contents. When homeowners were asked to estimate the chance of a severe flood or earthquake damaging their property in the next year, 15 percent of the respondents in flood areas and 8 percent of those in earthquake areas, were unable to provide any sort of estimate. Some people thought the probability of a disaster hitting them was quite high–1 chance in 10–yet they said they had purchased no disaster insurance. Others believed the chances of a disaster affecting them was almost nil–1 in 100,000–yet they had purchased disaster insurance. It seems clear that a number of individuals participating in the field survey do not understand the concept of probability. The findings are consistent with the heuristics and biases implied by controlled laboratory experiments over the past decade (Fischhoff, et al. 1979; Tversky and Kahneman 1974).

It is tempting to attribute this casual attitude about the risks of natural hazards and protective activities to homeowners' beliefs that the federal government will bail them out in a crisis. But Figure 4 indicates that the majority of *uninsured* residents anticipate *no* aid at all from the government even when they expected to suffer large losses from a disaster. Most of these people were aware that the SBA provides aid to the victims, but they had little knowledge of the loan terms or whether they could receive forgiveness grants. On the basis of these results, one can conclude that most homeowners in hazard-prone areas have not even considered how they would recover should they suffer flood or earthquake damage. Instead they treat such events as being so unlikely that they ignore the consequences altogether.

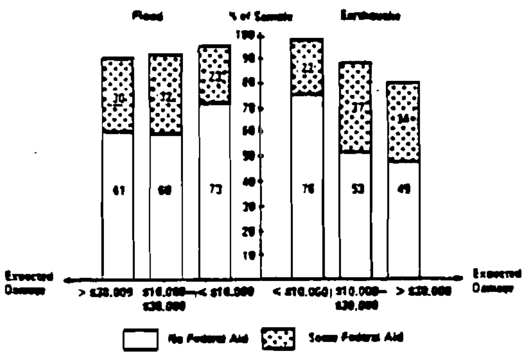


Figure 4. Impact of federal aid on uninsured homeowners.

What variables influence a person's decision to purchase insurance? A key factor is a belief that the hazard is a serious problem. This concern is found primarily among people who have had past experience with the hazard. "You ask me why I didn't have insurance before the June 1972 flood" said one homeowner in Norristown, Pennsylvania. "We had the flood in September of '71 and I had two feet of water in my basement. And I felt this I can tolerate and this is probably as high as it will ever get." To his chagrin, this man suffered severe property damage in 1972. Only then did he decide that he needed insurance. Another uninsured flood victim, said that his rationale was that "the $60 in premiums they could use for something else. But now they don't care if the figure was $600. They're going to take insurance because they've been through it twice and they've learned a lesson from it."

As shown in Figure 5, another important factor in influencing the purchase of a policy appears to be knowing someone who has purchased coverage or discussing insurance with a friend, neighbor or relative. The following example graphically illustrates this point. In a pretest of the questionnaire in San Francisco, a homeowner responded to one of the questions by saying that he did not have earthquake insurance. A friend of his who was listening to the interview commented that he had himself purchased such insurance a few years before. The respondent was dumbfounded and asked his friend about the availability of earthquake coverage and how much it cost. "I'm going to have to look into earthquake insurance myself," he added.

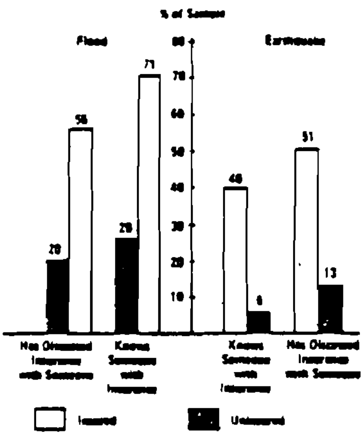


Figure 5. Interpersonal communication between insured and uninsured.

The controlled laboratory experiments on insurance undertaken at Decision Research provides further insight into these results.[6] Subjects were exposed to a variety of risks that had different losses and probabilities associated with them. By keeping the premium constant for all risks and varying the losses and probabilities in such a way that the expected loss (loss multiplied by probability) was the same, it was possible to test the importance of probability and loss on insurance purchase decisions.

One would expect that individuals should prefer to insure themselves against events having a low probability of occurrence but a high loss rather than against those having a high probability and low loss. The reverse was found to be true for a variety of experimental formats. These results suggest that if the chances of an event are sufficiently low, people do not even reflect on its consequences. In other words, people are primarily interested in buying insurance if they feel the probability of a disaster is high enough for them to stand a good chance of getting a return. They thus view insurance as an *investment* rather than as protection.

Formulating Alternative Policies

There are a set of alternative policies for dealing with the natural hazards problem outlined above. The current institutional arrangements for floods and earthquakes illustrates the role of incentives and regulations to supplement market mechanisms.[7]

In the case of the flood hazard, the federal government offers subsidized premiums as an incentive for residents to purchase coverage. They also are imposing specific land use regulations on communities who participate in the flood program. More recently banks have required homeowners to purchase flood insurance as a condition for obtaining a mortgage. Those who apply for federal relief after a disaster are also required to purchase coverage as a condition for obtaining a low interest loan. For these groups, flood insurance is mandatory rather than voluntary.

Protection against earthquake damage has been more of a private rather than public affair. No one is required to purchase insurance as a condition for a mortgage or a disaster loan. Even though coverage is available, there has been no great effort made by insurance companies or their agents to actively market policies. The insurance industry claims that it does not have enough reinsurance capacity to cover the damage from a catastrophic quake in a populated area of California if most residents and businesses were protected with insurance. Today the principal government role with respect to the hazard is through local building codes and ordnances on the design of structures and the provisions of federal aid to cover the uninsured portion of an earthquake loss.

Other programs for coping with the problem are stimulated by the following questions:

(1) What types of information would enable people to make better decisions for coping with the risk? How can either the insurance industry, government at all levels (i.e., federal, state, and local) and/or public interest groups aid in this effort?

One course of action is to make flood and earthquake coverage more attractive by presenting information through normal channels. The insurance agent may serve an important and useful function in this regard. To the extent that he has the trust of his clients, he can stimulate their awareness of the hazard by telling them the chances of a disaster occurring and the potential losses that could result. One way for the agent to increase the client's concern with the hazard may be to present information on the probability of a disaster on a different time interval than the traditional one year period. For example, in describing the chances of a 100 year flood, the agent could note that for someone living in a house for 25 years, the chances of suffering damage at least once will be .22. He can also provide details as to what coverage is available and how much it costs. Since most individuals seem to treat insurance as an investment, the agent should educate his clients that the biggest return on their policy is to have no return at all.[8]

(2) What is the balance between the use of market mechanisms for equating supply and demand, developing appropriate incentives (e.g., taxes and subsidies) as well as regulatory measures (e.g., required insurance coverage) in the design of a hazards strategy?

Financial institutions may play a key role here by requiring some type of natural hazard insurance as a condition for a mortgage on residential property. Several types of policies deserve consideration. One option would be a broader form of homeowners insurance which combines flood and earthquake. A less extreme proposal would be to add only earthquake coverage to a standard homeowners policy and maintain the current flood insurance program. A third option would be to maintain the current insurance coverage and provide disaster relief to special groups or for special situations. Distributional cost considerations may suggest that special treatment be given to low-income or elderly residents.

Evaluating Strategies

Any strategy or program impacts on the interested parties in different ways. The evaluation phase forces policy makers to come to grips with the question as to the appropriate role of the public and private sectors in hazard management. To illustrate, consider two contrasting scenarios. In scenario 1, acts of God, such as floods and earthquakes, are viewed as a public responsibility; then liberal disaster relief should be provided to all victims and/or highly subsidized insurance offered to residents in hazard-prone areas. In scenario 2, individuals are expected to assume the responsibility for protecting themselves against the hazard; then private insurance should be offered and those who decide not to purchase coverage voluntarily will be forced to suffer the consequences. Scenario 1 is equivalent to assigning a high weight to potential victims and a low weight to the general taxpayer. Scenario 2 gives increased importance to the general taxpayer. In this case, policies which require individuals faced with a risk to bear the cost of potential losses are viewed as being attractive. How this evaluation process currently takes place and should take place in the future is an important topic for discussion.

V. TOWARDS A DESCRIPTIVE MODEL OF CHOICE

The examples presented above suggest the need for an understanding of the decision processes of the interested parties before one can recommend different policies. A first step in this direction is depicted in Figure 6 where the three interested parties–consumers, firms, and government–are linked to a set of events (e.g., catastrophes, accidents) each of which has a probability and loss associated with it. To make the problem more concrete and realistic assume that there are n different consumer groups some of which have different possible losses and probabilities associated with a particular event. For example, there may be different exposures to a certain hazard so that the chances of incurring a specified loss will differ between individuals. Assume that there are m identical firms each providing the same type of protection (e.g., insurance) against the consequences of these events.

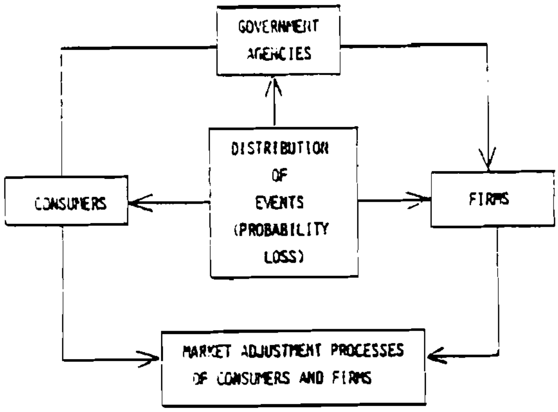


Figure 6. Descriptive component.

Performance of a Market System

Given this simplified world it should then be possible to analyze how well a market system operates under a variety of different assumptions regarding the accuracy of information by consumers and firms on the distribution of events. For example, suppose consumers and firms have perfect information on the probability and loss distribution of events. What type of insurance policies will be offered to consumer groups? How does the situation change when there is imperfect information by either or both of these parties?

A similar analysis can be undertaken if one postulates different types of decision rules used by consumers or firms. For example, suppose that each consumer evaluates the benefits and costs of purchasing insurance and chooses an amount (possibly no coverage) which maximizes expected utility. How much insurance will each consumer group purchase and what types of coverage will firms offer? Suppose, on the other hand, that consumers utilize a threshold model of choice: if the probability of the event is perceived to be below some critical level then the person ignores its consequences and does not consider any type of protection; otherwise they purchase the amount of coverage which maximizes expected utility. What impact will such a behavioral model have on the types of insurance policies offered by firms and the degree of protection adopted by consumers? In a similar vein one can investigate the impact of a model where factors such as past experience and discussions with friends and neighbors trigger search for new information and interest in protective measures such as insurance.

The impact of different assumptions regarding the accuracy of information and alternative decision rules can be investigated either at one point of time or in a dynamic context. When one looks at the situation over time then there is a need to specify the different rules that consumers and firms are likely to utilize for updating information on the probability and consequences of specific events. As shown by Arrow (1963) and Akerlof (1970) there are problems of adverse selection when firms have misinformation or imperfect information on the risks each of the n consumer groups are facing. For example, if firms cannot distinguish between high and low risk groups they may set a premium based on the average probability of a loss. If consumers have accurate information on the hazard, high risk groups will find this policy to be much more attractive than low risk groups, and will purchase a proportionately larger share of the total coverage. Over time, claims experience leads firms to set higher and higher premiums, thus making insurance less and less attractive to those in the lower risk classes. Eventually the only group who finds insurance to be attractive are those in the highest risk class.

The above example illustrating market failure is important for prescriptive purposes because it indicates that the private sector may not provide satisfactory protective solutions to potentially disastrous events, either because of misinformation and/or because of the decision processes of the interested parties. The lack of protection may then be very costly to both the disaster victims (who may not be able to get protection or are unaware of the consequences of the hazard) as well as the general taxpayer (who may have to foot the bill after a disaster occurs). The example also suggests the importance of determining what information consumers and firms have available, how accurate these data are and how they are actually utilized in the decision-making process.

Role of Government

If consumers and/or firms have misinformation, one of the important roles that the third party, government, can play is to provide better data on the hazard itself (e.g., losses, probabilities of its occurrence) as well as ways of protecting oneself (e.g., available insurance, type of coverage and its cost). It can also provide monetary incentives to encourage certain actions (i.e., subsidies) as well as disincentives (i.e., fines, taxes) to inhibit or discourage certain types of behavior. Finally, it can regulate or require certain types of actions.

The success of each of these approaches depends on the decision processes of the interested parties and the objectives of different policies. Thus, if consumers are maximizing expected utility then a subsidized insurance premium would lead to an increase in demand for coverage. This type of incentive system would have no effect for any consumer who behaved according to a threshold model and perceived the probability of a event to be below his critical level. In the latter case the only way to induce interest in insurance is to provide information on the hazard so that the probability is perceived to be above the critical level(s) or to require the person to have insurance coverage.

From a dynamic viewpoint there is a need to understand differences in *ex-ante* estimates and ex-post valuations and their effect on policy. Prior to a disaster an individual is likely to behave with one set of estimates of the probability and losses. After an event occurs he may revise his estimate considerably, partly on the basis of the new information (i.e., updating his prior estimates of probabilities and losses) but also because of the nature of this decision process (e.g., he now views the probability to be above a critical threshold level and hence is concerned with possible losses). If government policy responds to these ex post perception changes in a way that was unanticipated prior to the disaster, this process has to be understood before one designs policies. A clear example of this behavior is in the natural hazards field: government provided liberal disaster after the occurrence of a disaster because few people protected themselves prior to the event. If crises normally trigger unanticipated reactions due to political and social pressures (c.f., the Three Mile Island response), then this process must be taken into account in designing appropriate strategies for dealing with low probability-high consequence events.

Finally, there are a set of philosophical and ethical issues that have to be addressed directly when evaluating the role of government as part of any alternative plan. Given our increased understanding of the imperfect information and simplified rules that people use in making decisions, there is the open question as to "when should we protect individuals from themselves?" If policy makers have learned from experience that there is ex post regret by uninsured consumers after an event, what type of incentives or regulations, if any, should be taken ex ante? There is no easy answer to this query but it should be explicitly addressed as an issue regarding the appropriate role of government in dealing with the consequences of low probability events. It also illustrates the interaction between the descriptive and prescriptive components depicted in the conceptual framework (Figure 1) which has motivated this paper.

NOTES

1. For an excellent discussion of how one can specify goals and objectives for societal problems, see Keeney and Raiffa 1976, Chapters 1 & 2.
2. For an analysis of alternative remedies proposed by the Federal Trade Commission in the context of these and other costs, see Federal Trade Commission 1979.
3. The specific standards are that the foot cannot reach the blade of the mower and that the blade must stop within 3 seconds of release of the power switch so the hand cannot reach the turning blade.
4. These differences are clearly seen in the LNG siting debate in California. For more detail on this case, see Ahearn 1980, in press; Deutsch in press; Kunreuther 1980; and Linnerooth 1980.
5. The material in the next section summarizes the findings from a four-year study supported by funds from the National Science Foundation. Readers interested in more detail are referred to Kunreuther, et al. 1978.
6. More details on the insurance experiments can be found in Slovic, et al. 1977. The material also appears in Kunreuther, et al. 1978, Chap. 7.
7. A more detailed discussion of policy options appears in Ginsberg and Kunreuther (in press).
8. Kunreuther and Schoemaker (in press) provide a more detailed discussion of the role of the agent and the insurance industry in promoting the sale of flood coverage.

REFERENCES

Ahern, William. 1980. "California Meets the LNG Terminal." *Coastal Zone Management Journal*, 7:185,221.

Ahern, W. (in press). "The Role of Technical Analyses in California Energy Facility Siting Decisions." Proceedings of the Liquefied Energy Gases Facility Siting Task Force Meeting, IIASA, Laxenburg, Austria, September 1980.

Akerlof, G. 1970. "The Market for 'Lemons': Quality Uncertainty and the Market Mechanisms." *Quarterly Journal of Economics*, 84:488-500.

Arrow, K. 1963. "Uncertainty and the Welfare Economics of Medical Care." *American Economic Review*, 53:941-973.

Bick, T., and C. Hohenemser. 1979. "Target: Highway Risks. I. Taking Individual Aim." *Environment*, 21:7-15, 29-38.

Deutsch, R.W. (in press). "Siting an L.N.G. Facility in California: The Regulatory Framework and the Factors Involved in the Decision Making Process." Proceedings of the Liquefied Energy Gases Facility Siting Task Force Meeting, IIASA, Laxenburg, Austria, September 1980.

Federal Trade Commission. 1979. *Consumer Information Remedies*. Washington, D.C.: U.S. Government Printing Office.

Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Combs. 1978. "How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits." *Policy Sciences* 8:127-152.

Ginsberg, R., and H. Kunreuther. (in press). "Behavioral Determinants of

Market Failure: The Case of Disaster Insurance," in S. Fiddle, ed., *Uncertainty: Social and Behavioral Dimensions*. New York: Praeger.

Harris, J. 1980. "Taxing Tar and Nicotine." *American Economic Review*, 70:300-311.

Keeney, R., and H. Raiffa. 1976. *Decisions with Multiple Objectives*. New York: John Wiley.

Kunreuther, H., R. Ginsberg, L. Miller, P. Sagi, P. Slovic, B. Borkan, and N. Katz. 1978. *Disaster Insurance Protection: Public Policy Lessons*. New York: Wiley.

Kunreuther, H., and P. Schoemaker. (in press). "Decision Analysis for Complex Systems," *Knowledge*

Kunreuther, H. 1980. "Societal Decision Making for Low Probability Events: Descriptive and Prescriptive Aspects," IIASA Working Paper, WP-80-184, Laxenburg, Austria.

Linnerooth, J. 1980. "A Short History of the California LNG Terminal." IIASA Working Paper, WP-80-155, Laxenburg, Austria.

National Analysts Inc. 1971. *Motivating Factors in the Use of Restraint Systems*. Final Report, contract FH 11-7610. Philadelphia: prepared for the U.S Department of Transportation.

Office of Technology Assessment. 1977. *Transportation of Liquefied Natural Gas*. Washington, D.C.: Office of Technology Assessment.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1978. "Accident Probabilities and Seat Belt Usage: A Psychological Perspective." *Accident Analysis and Prevention*, *10*, 281-285.

Slovic, P., B. Fischhoff, S. Lichtenstein, B. Corrigan, and B. Combs. 1977. "Preference for Insuring Against Probable Small Losses: Implications for the Theory and Practice of Insurance." *Journal of Risk and Insurance*, *44*, 237-258.

Tversky, A., and D. Kahneman. 1974. "Judgment Under Uncertainty: Heuristics and Biases." *Science* 185:1124-1131.

Washington Post. 1979a. "Safety Rules Eyed for Power Mowers," January 20,

Washington Post. 1979b. "Prince George County's Smoking Ban Becomes Law," March 2.

THE CULTURAL APPROACH TO RISK: THE CASE OF POVERTY

Michael Thompson

International Institute for Applied Systems Analysis, Laxenburg, Austria

Are the poor all alike or are they different? Both, obviously. The similarities are handled by *political economy* — a long-established and familiar approach; the differences are handled by *political culture* — a newly-emerging and unfamiliar approach. Political culture looks, not at how people are differentiated by constraints — by what they *can't* do — but at how people are differentiated by capabilities — by the different things they do with what they *can* do.

If poverty has to do with the absence of the chance to choose, then non-poverty has to do with the presence of the chance to choose. This leads to the consideration of the possibility of personal strategies for resource management and for need management. There are four logically possible management strategies and one coping strategy, and the cultural hypothesis is that an individual will be led to adopt one of these strategies and to reject the others by virtue of his social context and its associated cosmology.

Fieldwork in Britain and informal guided interviews in the United States support this hypothesis and reveal that less than half of those officially classified as "poor" conform to the official image of poverty.

Political culture has implications that go beyond the arena of poverty policy. In suggesting that the economist's category "land" is not a "given" but is created and destroyed by social processes, it offers a way of identifying the cultural bias of an institution and a way of compensating for that bias. For instance, if we assume that IIASA's bias is towards caste-ism (that is, towards a personal strategy in which needs are given and only resources are manageable) then we should not be surprised to discover that those who argue from a more sectist social context (a context in which the adopted strategy is to manage needs downwards) find credible a level of energy demand two-and-a-half times lower than IIASA's minimum. This cultural approach provides us with a method for handling such disjunctions in credibility, and with a way of understanding the sorts of "perception gaps" that exist between the different parties in current debates about risk, without requiring us to play the "cosmic exile" and pronounce on who is right and who is wrong.

INTRODUCTION

"The very rich are different from you and me," said Scott Fitzgerald. "Yes," replied Hemingway, "they've got more money." Economists, by and large, side with Hemingway; anthropologists with Scott Fitzgerald. Both, in taking sides, have missed the whole point of this literary exchange which is that these two positions are not to be seen as contradictory. Scott Fitzgerald is not denying that the very rich have more money than he and Hemingway; he is insisting that, over and above that distinction of *degree*, there is some other distinction of *kind*. He is saying that, at right angles to this clearly visible *economic* axis, there is a *cultural* axis which has been overlooked. What is more, whilst the economic axis is a continuum with individuals spread out all the way along it and sliding this way and that as their fortunes wax and wane, the cultural axis involves discontinuities - individuals, far from being spread out along it, are clumped around certain points and, far from sliding smoothly back and forth, they can only shift their positions (if at all) by either headlong careers or sudden discontinuous jumps from one clump to another.

Having criticised Hemingway for missing (albeit deliberately) the whole point of the argument, let me now redress the balance a little and take Scott Fitzgerald to task for not carrying his reasoning through to its logical conclusion. Having gone to all the trouble of setting up his two axes - one a continuum, the other a discontinuum - he then goes and spoils it all by assuming that they represent dependent variables - that as you move up one you move up the other. But why should only the very rich be different from you and me? Who, come to that, is to say that you and I are the same? And why shouldn't some of the very rich be different, not just from you and me, but from others among the very rich as well? In other words, what Scott Fitzgerald has overlooked is that his two axes may represent two fully independent variables. Let me now try to rectify that omission.

The anthropologist does not disagree with the economist; he concedes that the very rich have got more money than the not-so-very rich and that, in consequence, they are able to do all sorts of things that others with less money are not able to do. What the anthropologist is saying is that, when the economist has said that, that is not all that can be said. We can go on and, slicing through social life along a very different orientation, look, not at how people are differentiated by constraints - by what they *can't* do - but at how they are differentiated by capabilities - by the different things they do with what they *can* do.

Now, of course, it is quite possible that Scott Fitzgerald, though he did not pause to consider whether his two variables might be independent of one another, was nevertheless right but the fact that the economic axis deals with problems and with continuities, whilst the cultural axis deals with capabilities and with discontinuities, suggests that this is unlikely. The mathematician will raise objections to such non-kosher dependencies and the statistician will throw up his arms in horror if asked to marry aggregations and disaggregations in this way. To these fundamental distinctions between the two axes we must add a contingent one: the economic axis is a well-trodden path that has been mapped and signposted by generations of travellers; the cultural axis is known only through the fragmentary reports of a few explorers and our attempt to traverse it will inevitably be a much more tentative and speculative business.

But at least we can make some preparations against the uncertainties that lie ahead. What might we expect to find out there? We should expect to find several, but not innumerable, distinctly different ways in which people who are all subject to the same constraints set about making the most of whatever possibilities these constraints leave open to them. Whilst it is only to be expected that these different ways of managing are likely to flourish in all their glorious variety in situations where the constraints are least severe, we should nevertheless be prepared to encounter them even when the constraints are at their most stringent. In other words, we should not be surprised to find just as many differences in kind among the very poor as among the very rich. And, if our expectations are confounded, ...if we don't find any of these differences, even among the very rich? Then, come home Ernest; all is forgiven!

A MODEL OF THE SOCIAL LANDSCAPE

Begin with the idea that individuals can be differentiated by the ways in which they are caught up in the process of social life, and further assume that these different ways of being caught up can be adequately described by just two axes - one (*group*) describing the way an individual is caught up in the processes of group formation, the other (*grid*) the way he is caught up in the processes of personal network-building (both his own network and those of other people). These assumptions give us two dimensions of *social context* and the next step is the quite reasonable one of assuming that the extent to which an individual will, in the conduct of his social life, end up by manipulating others or by being himself manipulated by others varies according to his social context.

Given these assumptions, we can represent the relationship between these three variables - the two dimensions of social context and the level of *manipulation* that they result in - by a three-dimensional graph. One such graph, which happens to be the one that underlies all that follows, looks like this (Figure 1):

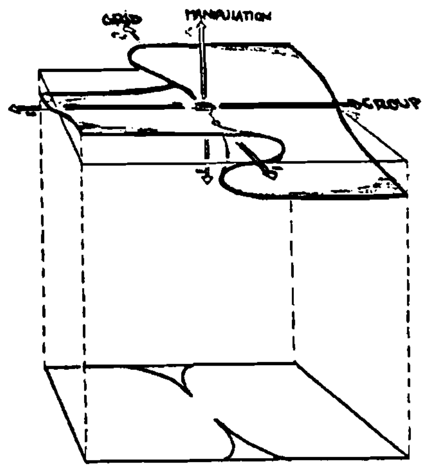


Figure 1. The Social Landscape.

I will not make any attempt here to justify this model[1] but will simply point out the way in which it satisfies the criteria implicit in Scott Fitzgerald's ideas about cultural difference.

If individuals are clumped around certain points, instead of being spread out all over the continuum, then this means that there must be some stabilizable equilibria (the clumps) separated by zones of instability (the regions where there are no clumps). In this model there are five such regions where clumps can form; they are the five flat bits - the two *hilltops* located above opposite ends of one diagonal of the social context square, the two *basins* above opposite ends of the other diagonal, and the *saddle point* that lies above the place where these two diagonals cross.

The flatness of the surface is a necessary condition for stability but it is not a sufficient condition. For an individual to come to rest at such a locality he will have to be following an appropriate *strategy*; to stabilize yourself on a hilltop you will have to follow a strategy of always moving towards higher ground, to stabilize yourself in a basin you will have always to move towards the lower ground, and to stabilize yourself on the saddlepoint you will have to make sure that you always pull back from steepening slopes. Depending on which strategy you are following (and on where you happen to be to start off with) you will eventually find yourself clumped with socially similar individuals at one of these flat bits. If, for some reason, you change your strategy then off you will slide until you eventually fetch up at an equilibrium that *is* stabilized by your new strategy.

Conversely, if you are subjected to a sufficiently large perturbation, you will be dislodged from your equilibrium *despite* your strategy. In such an eventuality you will find yourself sliding around on the slippery slopes (the regions of dis-equilibrium) that lie between those flat bits. If we introduce the further refinement that individuals always try to reach a stable equilibrium and that they may be prepared to change their strategies in order to reach one, then we obtain a not-too-un-realistic picture of social life in which the various clumps are always present yet individuals are often on the move between them. To this can be added the further realistic refinement of variations in the steepness of the slopes between these clumps. Along two sides of the square the slopes contain overhangs (cusp catastrophes) and this means that transitions between the equilibria they separate will be sudden and discontinuous; the other two slopes do not overhang and transitions here will be continuous and, perhaps, quite gradual.

An interesting feature of the overhanging sections is that they each permit two very different equilibria (a hilltop and a basin) to be stabilized at the same social context. This means that, within the overhanging regions, a change in strategy will result in a sudden switch - a conversion - from one stable equilibrium to another without any intervening region of in-stability. Another interesting property of this graph is that the volumes that it encloses above and below the social context plane are equal; manipulating and being manipulated exactly cancel one another out - power and impotence are equal, but not opposite. Power is distributed along the watershed linking the two hilltops; impotence, at right angles to this, along the troughs that run up to the saddlepoint from each of the basins.

But it is time to get back to the question of poverty. The point of the picture is simply that it will illuminate the argu-ment that follows by revealing some of the remarkable kinds of properties that a system capable of the sort of variations that Scott Fitzgerald is insisting are there will have to possess. At this stage, it is not to be taken as anything more than a light organising framework for approaching some hitherto un-explored terrain; a way of making three concepts graphically clear - stabilizable equilibria, appropriate strategies for stabilizing them, and unstable transitions (sometimes smooth, sometimes discontinuous) between them.

HOW TO DRAW THE PROFILES OF THE POOR

Why should it be that inflation, the effects of inflation upon minorities, the programmes designed to assist them, and the steps taken by their members to cope with all these, present a picture so muddled that an expensive research project entitled "Inflation and Deprivation: A Political Analysis" is needed to clarify it? We, or at any rate the economists amongst us, know what inflation *is*, so it can't be that. So the chances are that the mess has, as usual, to do with people; and my guess is that those whom the problem-solvers have assigned to the convenient pigeon-hole "deprived" (or "oppressed ethnic minorities and the permanently poor") are not, in fact, all birds of the same feather.

Oscar Wilde once said: "If only the poor had profiles there would be no difficulty in solving the problem of poverty". By this he did not mean simply that if only they were two dimensional, and so had no stomachs to fill, there would be no problem. Rather, the trouble was that "the poor" could only be perceived by the problem-solvers as an anonymous mass. If only they could discern the features of the poor - perceive them in all their individual diversity - the problem would be solved. The irritating thing about Wilde is not that he is so facetious and so witty - too clever by half - but that he is usually right as well. If he is right about the poor, then the task facing us is an anthropological one: drawing the profiles of the poor.

The task now is to devise a way of actually bringing this anthropological approach to bear on poverty in Britain. A convenient way of doing this is to look at the British definition of poverty. In fact there are (at least) three definitions - the implicit, the technical, and the practical - and the anthropological approach can be neatly slotted into the gaps between them.

1. The implicit definition of poverty: 'What really matters are the chances - or lack of them - people face; not the decisions they make, faced with these chances....In defining poverty, we should give priority to those who lack the opportunity to give themselves and their families an adequate income.'[2] So poverty is essentially *the relative absence of the chance to choose.*
2. The technical definition of poverty: Put like this, it is tempting to conclude that poverty is a consequence of inequality but the technical definition of poverty does not draw that conclusion; it simply states that poverty is *lack of command over resources relative to needs.*[3]
3. The practical definition of poverty: This involves two large assumptions: first, that *command over resources is measurable in terms of net income,* second, *that needs are expressible in terms of the current level of Supplementary Benefits.*[3]

If these two assumptions are valid then the two explicit definitions define roughly the same thing, and policy (based on the practical definition) will, give or take a few approximations, be directed squarely at the problem (identified in terms of the technical definition). But if the assumptions are not valid then policy may not have anything to do with problem; indeed, it may even be that policy is a *cause* of the problem.

The technical definition: lack of command over resources relative to needs: is a *personal* definition - it tells us when and why a particular individual is in poverty. The practical definition is an *impersonal* definition - command over resources is measured in terms of net income regardless of variations in individual resourcefulness, and the universal measure of needs in terms of the Supplementary Benefit level can take no account of the fact that some individuals are more needy than others. Within the technical definition, the poor have profiles. Within the practical definition, they have none. So how, in practice, can we draw their profiles?

Consider an individual (not necessarily a poor individual). He will have certain *wants:* a minimal daily intake of calories sufficient to sustain life, air, water, and an ambient temperature which, if his environment is harsh, may require a microclimate. In this latter eventuality, his wants will have to include such items as shelter, fuel, and clothing. And then, of course, there is security from attack and the problem of reproduction. As he makes the transfer from total isolation to involvement with others so his *wants* become submerged by his *needs*.[4] All theories of needs have run up against this obstacle: how to distinguish a 'basic need' (a *want*) from a 'derived need' (a *need*).[5] As we become social animals what we want is needs. Nevertheless there is, somewhere, a minimal, universal, biologically defined level of wants: those inputs to the individual that will sustain, not his social life, just his life.

You can increase or decrease your needs but you cannot do anything about your wants. If you practice infanticide and abandon the elderly you do not need to provide for your young family or look after your ageing grandmother. Indeed, as Swift[6] pointed out in the context of Irish poverty, you can actually satisfy your wants by divesting yourself of your needs: you can eat your children. Swift knew what absolute poverty was and he knew how to distinguish a want from a need. The current British definition of poverty does not make this distinction: both needs and wants are lumped together as wants. If we wish to draw the profiles of the poor, we have to start with Swift: you can manage your needs and you can manage your resources but you cannot manage your wants. The Lord Buddha, before he found the middle path, managed his needs in such a way that their level fell far below his wants: he chose to limit his intake to just one hemp seed per day. Since his wants were considerably above this level, he could not have sustained his physical existence indefinitely but, since a wide range of choice was open to him, he was not poor even though he was starving! The famine-stricken Irish peasants were not prepared to eat their children - they needed them. The tragedy of this situation was that their command over resources did not even meet their wants, let alone their needs.

Now, of course, the British Department of Health and Social Security[7] comes across few, if any, Buddhas in its day-to-day business nor, thank heaven, does it have to deal with potato famines. My purpose in starting with these extreme examples - Buddha's venture along the ascetic path and Swift's policy recomendations for eighteenth century Ireland - is to emphasise that people *manage* - that there can be enormous personal scope for resource management and for need management. If, in contemporary Britain, individuals do (or could) exercise some such scope, then the technical and the practical definitions of poverty define very different things. If this is the case, then an anthropological approach capable of drawing the profiles of the poor would be most useful.

How Could Anthropology Help?

There are two possible reasons for adopting the practical (no profile) definition of poverty - one justified by *equity*, the other by *efficiency*.

a) The equity argument is that it is unfair to single out individuals. The policy must be applied impartially and what better way to make sure of this than to use a theoretical framework that is *incapable* of distinguishing between individuals?

b) The efficiency argument is that it is impossible to take individual needs into account (needs and priorities are as gloriously varied as are individuals). You would have to have a separate policy for every single individual.

The anthropologist might reply, first, that if the needs of individuals vary it is not fair to treat them all the same and, second, that perhaps there exists some middle ground between the extremes of universalized and individualised needs. The needs of individuals may exhibit a diversity so vast as to be unhandleable, but the number of ways in which individuals can personally *manage* whatever their varied needs are in relation to their *management* of their varied levels of command over resources may be quite limited. There is, as they say, more than one way to skin a rabbit but, at the same time, there aren't *that* many different ways. The following logical possibilities exist:

1. You can manage neither your needs nor your resources.
2. You can manage your needs but not your resources.
3. You can manage your resources but not your needs.
4. You can manage your needs and your resources.

These four logical possibilities assume simply that, with respect to needs and to resources, you either can or cannot manage them. But, of course, these are not all-or-nothing states - you may be able to manage a little or a lot, a bit more or a bit less. The significance of these all-or-nothing states is that they map out the various extremes that it is possible for you to attain. Take, first of all, the implicit assumption that poverty is to do with the absence of the chance to choose. There are two different ways in which you may get the chance to choose: you can choose in one way if you have scope to personally manage your needs, and you can choose in another way if you have scope to personally manage your command over resources. We can represent this by drawing two axes: 'individual scope to manage needs' and 'individual scope to manage resources'. The only calibrations that we put on these axes are CAN'T at the origin and CAN at the two extremities. The four logical possibilities are depicted like this (Figure 2):

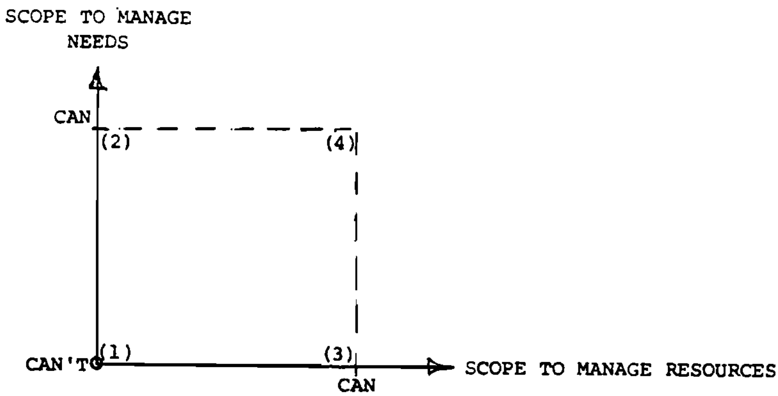


Figure 2. Two degrees of freedom

Possibility (1) has no degrees of freedom; if you are plotted there you can't manage your needs and you can't manage your resources. Possibilities (2) and (3) each have one degree of freedom and this is fully depicted on the graph. But possibility (4) has two degrees of freedom and to represent this adequately we will have to have a third axis.

If you can manage both needs and resources you can also manage the overlap between them. Depending upon how you mix simultaneously increases or decreases in needs and resources, so you can vary the size of the overlap. With possibilities (2) and (3) you cannot mix, and when you have chosen to increase or decrease your one variable you have also chosen the direction of change in the size of the overlap. At possibility (4) you have the choice of managing or not managing the direction of change in the size of the overlap according to the following simple matrix (Figure 3):

		Decrease resources	Increase resources
NEED MANAGEMENT	Increase needs	Overlap must get smaller	Overlap may get bigger or smaller
	Decrease needs	Overlap may get bigger or smaller	Overlap must get bigger

RESOURCE MANAGEMENT

Figure 3. A Third Degree of Freedom

With two combinations of mix you have scope to manage the direction of change in the size of the overlap, and with the other two possible combinations you do not have this scope. So, by virtue of this third axis - scope to manage the overlap between needs and resources - possibility (4) provides not one but two attainable extremes (Figure 4):

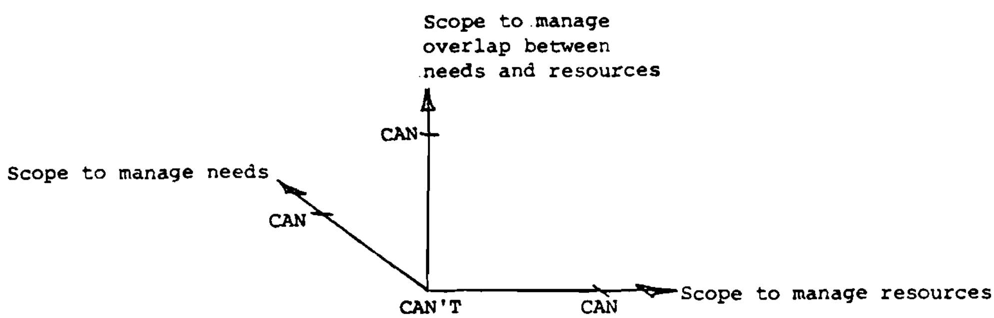


Figure 4. The Three Degrees of Freedom

As an individual moves from 'can't to 'can' in one, two or all three of these directions, so he gradually acquires more and more of one, two or all three of these freedoms. The result is a three dimensional space that defines the limit of where it is possible for him to go (Figure 5):

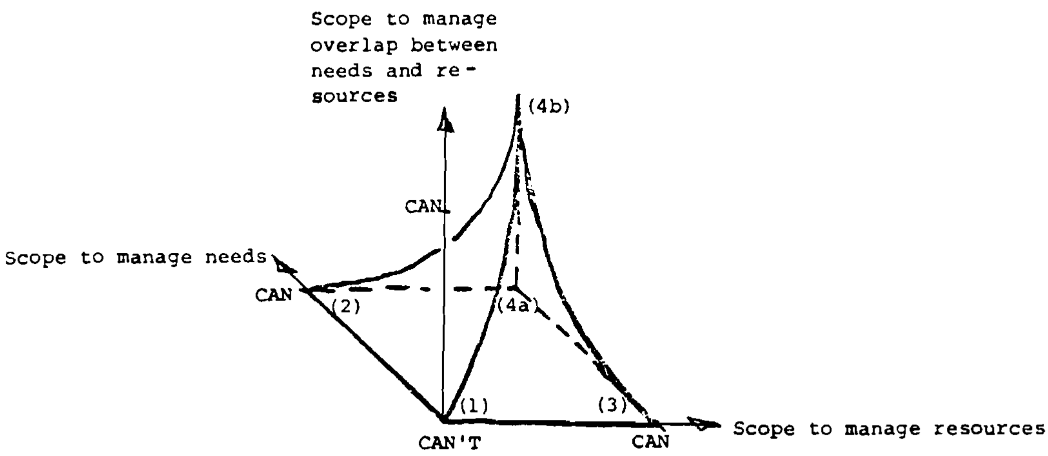


Figure 5. The Five Extremes

This picture reveals quite clearly that there are five extremes - five points or corners to this space - that it is possible for the individual to reach. If the space was spherical then any five points on its surface would be no different from any other five points on it, but this is not the case here.[8] These five points are altogether different from any other five points on the surface - they are *singularities* - and it is this special quality that gives rise to the five distinct personal strategies.

Poverty in Wonderland

It is now possible to say something about the separation between the technical and the practical definitions of poverty. First of all, neither of them has much connection with what I have called *the implicit definition of poverty* - the absence of the chance to choose. Only at possibility (1) is the chance to choose completely absent and this means that, as one moves away from any of the other four extremes and towards possibility (1), so one moves into poverty - poverty, that is, in terms of the implicit definition. But in the technical definition poverty is something else altogether - the shrinking of the overlap between resources and needs. Possibility (1) says nothing about the size of the overlap: it just says that you have no control over its size. If the overlap you have no control over happens to be narrow or, worse still, negative you will be both implicitly *and* technically poor but, if the gap happens to be large you will be implicitly poor and technically rich. At any of the other four possibilities you cannot be implicitly poor but, since you have the scope to manage your needs or your resources or both your needs and your resources, you can (if you so choose) be technically poor.

When it comes to the practical definition, things get even worse. The practical definition assumes that there is no such thing as personal scope for managing needs and resources: people just *have* needs and they just *have* resources. Of course, different sorts of people are assumed to have different sorts of needs - a single parent's needs are differently assessed from those of an elderly widow - but these needs apply to social categories not to individuals. So the practical definition puts everyone at possibility (1). By the practical definition, the whole world is poor, implicitly.

These three definitions of poverty are all social: they stress the fact that man does not live by bread alone. Indeed, they stress it to such an extent that they overlook the fact that there has to be *some* bread. If you continually manage your needs downwards, there will eventually come a point where they fall below your wants. You will then be in a fourth kind of poverty: you will be starving. But, since you are choosing to bring your needs to this level, you are not implicitly poor. Similarly, if your command over resources declined to such an extent that you could no longer satisfy your wants, then the fact that you could still manage your needs (and consequently could still increase the overlap between your needs and your resources) would enable you to die a wealthy man, technically. We must take Swift seriously and recognise that implicit poverty, technical poverty, and practical poverty are all different kinds of *socio-poverty* and that they do not always coincide with *bio-poverty*: that extreme state where either needs, or resources, or both needs and resources, fall below the level of wants.

So this anthropological approach helps us to understand what a complex business poverty is, and how contradictory our conceptions of it can be. Rather than providing us with *a* definition of poverty, it maps out the complexities and the contradictions: it reveals the vertical separations and the horizontal displacements between the four definitions (bio-poverty and the three varieties of socio-poverty) that constitute the traditional British approach to poverty. (Figure 6)

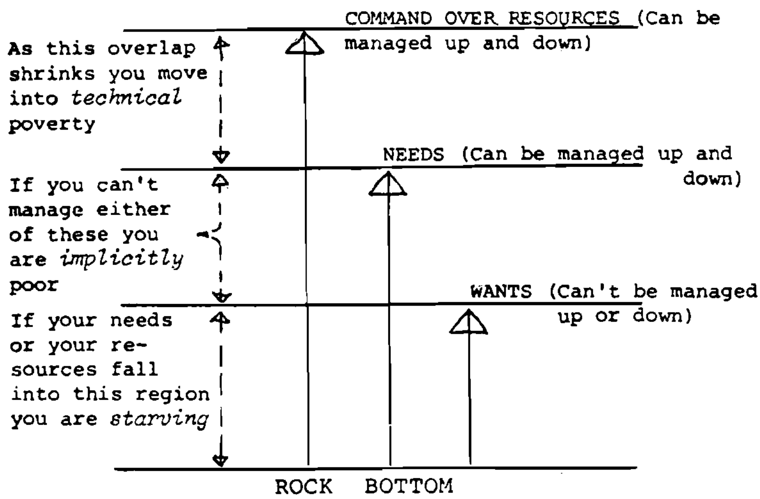


Figure 6. Complexity and Contradiction

a) If your aim is to avoid *implicit poverty* you must acquire the chance to choose. That is, you must move yourself away from possibility (1) towards one of the other four extremes.
b) If your aim is to avoid *technical poverty* you must manage your needs or your resources or both your needs and your resources so as to make the overlap between them as large as possible (or, at least, large enough).
c) If your aim is to avoid *bio-poverty* you must make sure that, in achieving these first two aims, you do not reduce your needs too much. This means that, other things being equal, it is preferable to increase your resources rather than to decrease your needs.

If you are fortunate enough to have the chance to choose, then, depending on what scopes are available to you and depending upon which of these aims you deem to be paramount, you will strive to manage your resources and your needs in such a way as to maximize certain variables and to minimize others (these variables being resources, needs, and the overlap between resources and needs). The significance of the four extreme possibilities that exist when you have the chance to choose is that they reveal that there are four, and only four, different ways of setting about these maximisings and minimisings: that there are four, and only four, *management strategies*. And, of course, there is in addition just one way of not being able to manage: not so much a strategy as a way of living with a situation over which you can have no control.[9]

Stripped to the barest essentials, these five strategies may be described as follows:

Possibility (1):	Keep your fingers crossed and hope that Lady Luck will smile on you. Survive.
Possibility (2):	Decrease needs to increase overlap.
Possibility (3):	Increase resources to increase overlap.
Possibility (4a):	Increase resources and decrease needs to increase overlap.
Possibility (4b):	Increase resources and increase needs to decrease overlap.

(For strategies (4a) and (4b) to separate we have to assume that increasing resources requires a lot of effort. With (4a) you maximise your chance to choose and minimise your effort. With (4b) you accept a high level of effort in order to maximise the satisfaction of needs.)

Two tasks remain. First, to demonstrate that these five strategies coincide with the five possible 'clumps' that are already predicted in the hypothetical model. Second, to demonstrate that all five possibilities are, in fact, taken up in contemporary Britain and in the United States and that each of the five strategies is adopted according to the social context predictions of this hypothesis.

MANAGING AND NOT MANAGING NEEDS

Most people, I suspect, will have little difficulty with the idea that you can manage your needs, upwards and downwards. What may be more difficult for them to accept is that some people are not in a position to do this. But those individuals whose lives are hedged about with all sorts of socially-imposed prescriptions will find it very difficult to do anything to their needs - they are, in one way or another, just given to them.

For instance, the young subaltern in a smart regiment will find that his time, his dress, his social relations, his recreations, even his eating, his drinking and his sleeping (and his sleeping partners) are almost totally imposed by virtue of his fairly lowly position within a complex hierarchical organisation. He has to wear a well-cut suit on an informal evening in the mess and he has to wear expensive mess dress on a dinner night. All sorts of compulsory items, ranging from donations to regimental charities to subscriptions to the Polo Loan Fund, are added to his mess bill. If he has no private income, and so no scope to increase his resources, he may be tempted to try to decrease his needs. He will find it almost impossible to do so. The additional items on his mess bill are compulsory, the dinner nights are compulsory, even the excessive drinking of champagne and the marvellously idiotic and dangerous games that go with it are compulsory. If he has a private income, he may be tempted to increase his needs - hard drinking, hard gambling, and hard riding are the traditional avenues. But, if his drinks bill, his bridge book debts, and his stable charges rise above a quite low threshold, he will be up in front of the Colonel and told to bring his mess bill down to a more acceptable level.[10]

A complex hierarchical organisation *maintains* itself by imposing equally complex and hierarchically-patterned levels of needs upon the individuals who compose it. The result is that an individual will find that, though his level of needs may be set at quite a high level, he can neither manage it up nor down. At least the young subaltern's lack of scope makes sense to him. It confirms him in his particular rank, defines the gradations between his station and those above and below him in the framework, enables those in these stations to recognise him and treat him appropriately, and impresses upon him the fact that he enjoys the privilege of holding a responsible position within a fine disciplined body of men. But what of those who, having little command over resources and a low level of needs, find themselves prevented from lowering their needs still further?

Poverty Versus Conspicuous Non-Consumption

It is well known that it is those educated and resourceful individuals with their fifteen year old Morris Minors, their cottages in Wales, and their copies of *Which* magazine who make the best peasants these days - shopping around for supermarket bargains, tending their kohl-rabi patches, knocking up nourishing stews from skirt of this and belly of that, stuffing their deep freezes with bartered allotment produce and keeping their spare cash hidden from the tax man in a stripped pine chest under their Victorian brass beds. In other words, the poor pay more.[11]

This whole area - managing or not managing a low level of needs downwards - is a political minefield and I must take care not to blow myself up. Let me just state the simple fact that, if the one who *can* manage his needs trades down and moves into a run-down house, he will probably get a letter telling him that it is now listed as a building of outstanding architectural or historical interest, and that, if the one who *can't* manage his needs moves into the house next door, he will in all likelihood get a letter informing him that it has been condemned and is no longer fit for human habitation.[12] At every turn the non-manager is hemmed in by presciptions that make little sense to him and frustrate all his attempts to manage. These prescriptions are not imposed by nature (though those who do the imposing may insist that they are). They are socially-imposed - by the setting of the Supplementary Benefit level, and by the implementation of the various policies designed to prevent individuals falling below it.

The majority of wage and salary earners in Britain have their tax deducted at source - they receive a regular weekly or monthly income, there is no problem in determining the level of tax that is due, and any small imbalances can be sorted out by the computer at the end of the tax year. Other indirect taxes are collected automatically - Mr. Average pays for his petrol and his beer and the tax component in the price is sorted out somewhere down the line between the retailer and the supplier; the same sort of thing happens when he buys a new car or sells his old one; if he has any capital it is probably tied up in his house and if he sells that at a profit it is exempt from capital gains tax.

Only nearer the top of the pile, among the company directors, the self-employed, those with investment portfolios, more than one house, property abroad, and so on... do things get more complicated. It is only here that value-added tax, capital gains tax, capital transfer tax, dollar premiums, residential statuses, currency exchange controls, exotic rates of personal taxation, and so on... begin to bite.[13] There is no doubt that this is a legislative jungle, but the person fortunate enough to enter it knows that he is entering it, wants to enter it, and what is more knows that there are plenty of guides (taxation advisers, investment consultants) who, for a tolerable fee, will be only too glad to smooth his path through it.

The astonishing thing about British poverty is that those at the very bottom of the pile find themselves in exactly the same predicament as those at the very top; except that, for them, there are no guides and they have to enter the jungle whether they want to or not.

> There is now a bewildering variety of government programmes, operating on quite different principles, which are designed to relieve poverty.... None, save expert administrators and welfare rights advisers, can understand who should get what or why.[14]

So these individuals who are caught in 'the poverty trap' - prevented from managing their needs downwards by the intervention of the state's safety net, and prevented from managing their resources upwards by the too-rapid removal of means-tested benefits - are actually forced into poverty (in terms of both the technical definition and the implicit definition) by programmes 'designed to relieve poverty' (in terms of the practical definition).

Could this counterproductive state of affairs be remedied by doing away with the safety net altogether or, less drastically, by lowering it a little and removing the means-tested benefits rather less rapidly?

Well, there is no clear-cut answer; it depends on which kind of poverty you want to relieve. It depends on how many people, once the net is removed or lowered, swim and how many of them sink; and it depends on how far you can lower the level of Supplementary Benefits before it passes below the level of wants. The dilemma is that tender paternalistic attempts to relieve technical poverty and practical poverty may just drive people into implicit poverty, whilst tough radical measures may get rid of socio-poverty by driving people into bio-poverty instead. Perhaps we should stand back from the immediate problem for a moment and, instead of asking how we can decrease poverty (in its various definitions) ask ourselves instead how we can increase wealth. In other words, how can people acquire the scope to manage their command over resources and to manage the gap between their needs and their resources? How do they gain more degrees of freedom, and does an increase in one man's scope inevitably mean a corresponding reduction in another's? Can we help them to do this, and if so, how?

MANAGING AND NOT MANAGING RESOURCES

Development experts tell us that in countries like India wealth and land are virtually synonymous. They urge that we start by recognising that this is so and they recommend development programmes that, one way or another, will increase the productive efficiency of that land. On this view India's resources are finite and fixed; when it comes to land, as Mark Twain pointed out, they don't make it any more. But could it not be that India is poor *because* the Indians insist on seeing wealth and land as synonymous? At the periphery of Indian society all sorts of people (Parsees, Sikhs, Tibetans) have become immensely wealthy thanks to their ability not to see wealth solely in terms of land.[15]

Obviously, resources do have a physical base but the Indian example suggests that it is not the resources that are actually there, but the resources that are *perceived* to be there, that matter. We are given and denied resources, not by nature, but by our *idea of nature.*

The anthropological hypothesis is that ideas of nature are socially generated - that there are only a few different kinds of ideas of nature that are socially viable, and that an individual will find one of these kinds of ideas credible (and the others incredible) by virtue of his social context. This anthropological argument is complex but it can be illustrated very simply by looking at the self-evident, yet contradictory, metaphors and catch-phrases that different people find credible images for describing the resources that are available to them.

A hundred years ago, the courageous and enterprising seeker after wealth heeded the sound advice : 'Go West, young man.' Because of this open frontier, his gain did not result in anyone else's loss (at any rate, it was not perceived as doing so). Eventually that particular frontier was closed and there are now many experts who will tell us that all frontiers are closed. On the cosmic scale, there can be no such thing as an open frontier in 'Spaceship Earth' and, on a more domestic level, we can do nothing about the size of the 'national cake' - it is already baked - all we can do is argue about how to share it out.

Culinary metaphors, it seems, are much favoured by those whose idea of nature insists that there is no scope for increasing our resources. Ecological accountants tell us that there is no such thing as a free lunch and, of course, the 'national cake' metaphor is buttressed by the compelling nursery truth that you cannot have your cake and eat it. Yet, self-evident and indisputable though these truths may seem, there are individuals who hold to other equally self-evident truths that totally contradict them. Paul Ehrlich's ecological balance sheet is contradicted by Andrew Marvell's metaphysical lunch:

> Ripe apples drop about my head;
> The luscious clusters of the vine
> Upon my mouth do crush their wine.
> The nectarine and curious peach
> Into my arms themselves do reach.[16]

Those who share such a cornucopian[17] idea of nature where, even in the desert manna falls from heaven, are declaring that it is impossible to draw up a balance sheet. For them, nature is inexhaustible.

Ideas of nature, and the self-evident truths that justify and enforce them, are profoundly moralistic. In Nancy Mitford's novel *Love in a Cold Climate* her three outrageous heroes, behaving with total hedonistic disregard for these natural laws, seem all set to receive their just desserts. To the dismay of their 'cake mentality' critics, they sail serenely on into a three-sided relationship that breaks all the social rules. Cedric, the effete aesthete whose exuberant style has opened up these triangular capabilities, triumphantly proclaims their success:

> So here we all are, my darling, having our lovely cake and eating it too, One's great aim in life.[18]

So if we look, not at nature, but at *ideas* of nature we must recognise that there are at least two contradictory versions that people can find credible and that embedded in each of them are two very different moralities.

ACCOUNTABLE NATURE	CORNUCOPIAN NATURE
<u>Metaphors of closure</u>:	<u>Metaphors of openness</u>:
'national cake' 'spaceship earth'	'Plenty more fish in the sea' 'Go West, young man'
<u>Justifications</u>:	<u>Justifications</u>:
'You can't have your cake and eat it' 'There's no such thing as a free lunch'	'You can have your cake and eat it' 'Cast thy bread upon the waters' 'Consider the lilies of the field....'

What are the consequences of all this for the personal management of resources?

With cornucopian nature there can be no obstacles to an individual managing his resources up or down. If he manages them up it does not follow that he is driving someone else's level down nor, if he manages them down, can he expect the approbation of his fellows in return for the benefits they enjoy as a consequence of his forebearance. With accountable nature the picture is very different. If an individual manages his resources up then, somewhere along the line, others are being deprived and, if he manages them down, others somewhere should feel the benefit. This is the notorious zero-sum mentality that some observers have diagnosed as the underlying cause of 'The British Disease.'[19] But this zero-sum mentality can manifest itself in very different ways, depending upon the social context in which it arises. With accountable nature the zero sum game is concerned with the control of fixed and finite resources; with cornucopian nature it is concerned with something else--control over the horn of plenty.

In a strongly individualised context the inevitability of one man's gain being another man's loss becomes one of the regrettable facts of life: an individual who manages his resources upwards will justify his behaviour with the excuse: 'if I don't do it someone else will.' Here credibility is given to the image of nature 'red in tooth and claw'. It is 'the law of the jungle' in which the strong succeed and the weak go to the wall. This inevitable process continually sorts out the weak from the strong: the former cannot manage their resources, the latter can. But the weak may still find the cornucopian idea of nature credible. It is just that the strong have gained control of the horn of plenty and it only disgorges resources in their direction. The weak, as a result, are easily attracted to millenarian movements that promise to turn the world upside down and point the horn in their direction instead.

But if, instead of this Hobbesian war of all against all, individuals are given or denied access to resources according to whether they are included or excluded from social groups, this free-for-all is stopped before it can start. Strong sanctions can be applied to individuals who put self before whole. In the French Foreign Legion the man who steals from his comrades will be pinned to the barrack-room table by bayonets through the palms of his hands, an unpopular member of a mountaineering expedition may be accused of 'secret eating,' and a non-conforming union member may be sent to Coventry[20] by his workmates. And, behind these severe sanctions, there always lies the threat of a worse one - expulsion from the group. In Britain recently, journalists who did not obey a strike call were expelled from their union. Since union and employees operate a closed shop agreement, these journalists lost not just their union cards but their jobs as well.

In such contexts the individual's scope to manage his resources is almost nil.[21] Resources are managed collectively: the small hunting band divides the day's catch (be it a buffalo or a rabbit) according to strictly observed rules, in the forced bivouac the Mars-bar is divided with surgical precision, and in the fundamentalist farming community no one works in the fields on Sunday. If access to resources is obtained by membership of just one simple egalitarian group then there is little scope for the collective management of resources: the village land or the national cake is given - all the group can do is see that it is divided fairly. But if there are several possibly overlapping groups, and if there are hierarchical divisions both within and between these groups, then a particular group can press for a larger *share* of the cake - after all its only loyalty is to its members - somebody else (the Government, the economy...God) can worry about how the cake can be cut to give each group its entitlement. It is in this way that individual members of complex groups can, by acting collectively, acquire the scope to collectively manage their resources. If such groups are fairly evenly matched and all press their claims with equal vigour such management of resources may well result in inflation.[22]

By contrast, the members of simple (small tight-knit egalitarian) groups are likely to devote much of their energy to maintaining the boundary of the group - protecting the soft vulnerable 'us' from the nasty predatory 'them'. Looking under every sheep's clothing in case it conceals a wolf, and looking under every bed in case there is a red hidden there, are time-consuming activities. Similarly, the need for scrupulous fairness will lead them to place great emphasis on precedent and tradition. These preoccupations are likely to draw attention away from the possibility of collectively increasing their resources, for to do this would require time, energy and innovation. Indeed, since innovation and personal resource management are quite possibly among the nasty activities that make those outside the boundary of the group so predatory, there is a strong chance that belief in the fixed nature of resources, and rejection of innovation, will become essential qualifications for group membership.

In the case of one group within a complex hierarchical arrangement of groups, its scope to collectively manage its resources is quite independent of the total level of resources. The group's aim is not to increase its resources by increasing the size of the cake but to increase its *share* of the cake. In such conditions the size of the cake *may* increase but the chances are that it will stay the same or even shrink. What is significant is not what is happening to the size of the cake but that no one is very interested in what is happening to it. Ideas of nature, though still accountable, will be little developed among group members. Their attitude is likely to be that nature is someone else's department. For them, nature performs a subservient role, fitting itself to the demands of the social order. Their idea of nature and of society is that they are isomorphic and clearly separate systems.[23] Le Corbusier's 'ville radieuse', in which vast complex white buildings are raised on legs above the well-ordered parkland that flows around and under them, provides a concrete expression of this idea of nature and of man's place within it.

To predict just when and where environmental concern will appear is not easy. It tends to appear in strongly group contexts but in some strongly grouped contexts (trades unions, for instance) it is remarkably absent. This is a complex problem for the anthropologist to unravel but fortunately it need not concern us too much. All we need to note here is that, thanks to the contradictory ideas of nature - cornucopian and accountable - resources, though based in nature, become subject to social control. Depending upon what sort of control is being operated, individuals will find themselves able or unable to manage their command over resources.

SOCIAL CONTEXT AND PERSONAL STRATEGY

All I need to do now is to put forward some credible and useable hypothesis showing the way the five personal management strategies relate to variations in social context.

Whether you can or cannot manage your needs depends, I have argued, on whether you are subject to socially-imposed prescriptions. So one dimension of social context can be envisaged as running from total prescription to total freedom from prescription. A second, and quite independent dimension, runs between one extreme where an individual derives all his support from group membership to the other extreme where he is excluded from all such groups. (Figure 7)

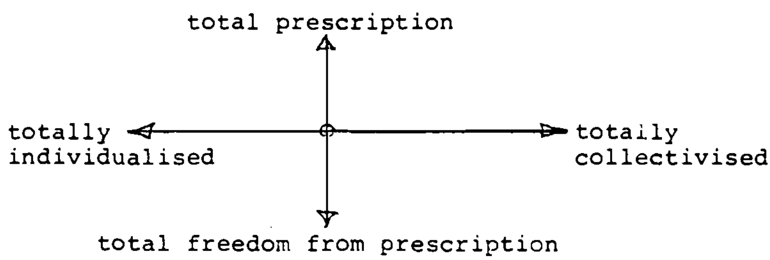


Figure 7. Social Context

The hypothesis is that the five alternative strategies generated by the ability or inability to personally manage your needs and your resources relate to your social context in the following manner. In doing this they arrange themselves in a pattern that exactly matches the five possible clumps in the initial hypothetical model.[24] (Figure 8)

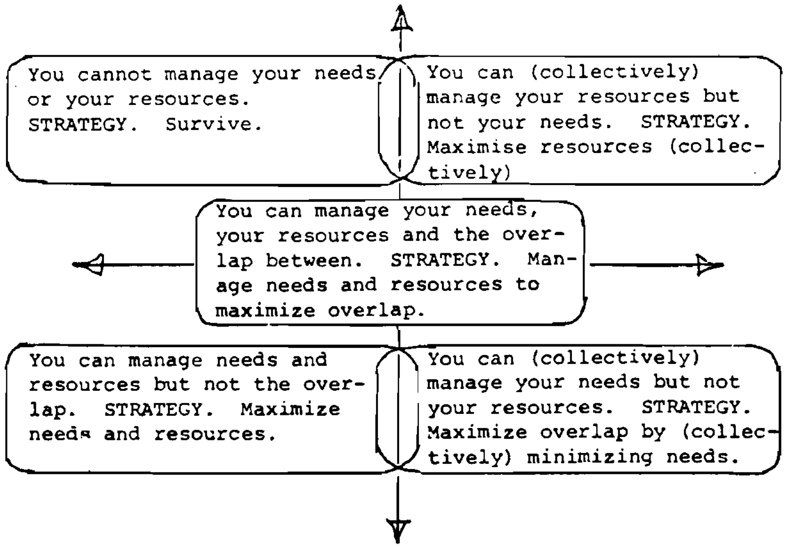


Figure 8. The Five Strategies and Social Context.

CONCLUSION

It was possible, within the constraints of this pilot project, to carry out some fieldwork (in Britain), aimed at investigating some of the social consequences of the model, and also a very small test (in the United States) of the hypotheses that this model generates.

The fieldwork was designed to explore some of the more prominent features of the social landscape revealed by the model. In particular,

a) the saddlepoint was explored by looking at a self-sufficient 'organic' farm in Norfolk, at a self-employed graphic designer in London, and at a marginal sheep farm in the Lake District;
b) the two individualized contexts, and the smooth transitions between them, were explored by looking at some individuals engaged in 'the hidden economy' - two part-time striptease artistes and a self-employed builder in London;
c) the two collectivised contexts, the smooth transition between them, and the discontinuous transition between the simple group context (positive group, negative grid)

and the entrepreneurial context (negative group, negative grid) were explored by looking at some of the Bengali immigrants in their central London ghetto in Spitalfields.

The hypothesis was then put to the test in the United States. We (Ellen Tenenbaum and myself) designed an interview format comprising nine rather general questions and then Tenenbaum carried out informal guided interviews with fifteen individuals (men and women, black and white) in Washington D.C. and in rural West Virginia. All fifteen were 'officially poor.' These interviews were designed to reveal both the individual's social context and the personal management/coping strategy that he/she was using.

In all fifteen cases the social contexts and strategies (scored independently by Tenenbaum and myself) matched in the manner predicted by the hypothesis, and it turned out that less than half of our (admittedly small) sample were poor in the way the poor are officially assumed to be poor. (Figure 9)

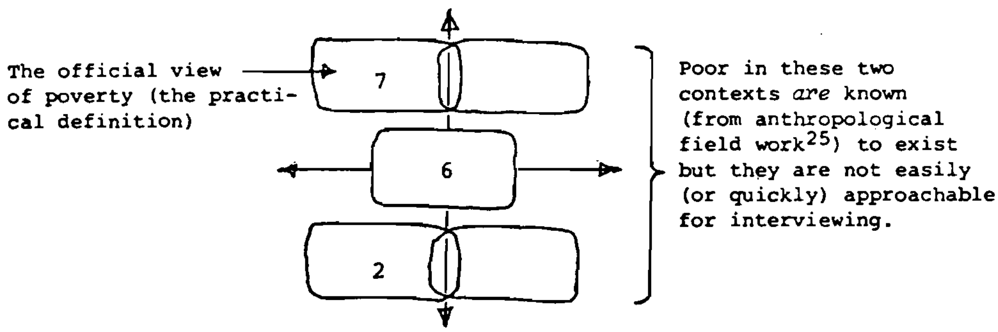


Figure 9. The Profiles of Fifteen of the American Poor.

Finally, what has all this got to do with risk? This sort of approach, by shifting our attention from a single raw nature to a small number of socially processed ideas of nature, provides the basis for a cultural theory of risk perception and of risk handling.

It suggests:

a) that there is a systematic relationship between social context and risk selection. That is, an individual will create for himself an environment of risks that upholds the idea of nature that is appropriate to the social context in which he finds himself.

b) that risk acceptance, risk aversion and risk absorption are not modes of behavior that characterize the adaptation of individuals to their objective external world but, rather, are distinctive social styles of action that emerge in response to these different risk environments that individuals, as social beings, construct for themselves.

ACKNOWLEDGMENTS

This paper is based upon the results of a pilot research project - "Inflation and Deprivation: A Political Analysis" - supported by the Rockefeller Foundation. I should also like to thank Aaron Wildavsky who supervised the project and Ellen Tenenbaum who organized, carried out and scored interviews in the United States. My debts to Mary Douglas and to Christopher Zeeman are, as usual, obvious and, equally obviously, any errors are not to be laid at their doors but at mine alone.

NOTES

1. For its justification see: THOMPSON, Michael, "A Three Dimensional Model" in DOUGLAS, Mary and OSTRANDER, David (eds.). *Essays in the Sociology of Perception.* Routledge, Kegan Paul, London, and Basic Books, New York. (To be published January 1981).

2. PIACHAUD, David. "Inequality and social policy." *New Society* Vol. 47 No. 859 March 22 1979. p. 670.

3. PIACHAUD, David. " Who are the poor, and what is the best way to help them." *New Society* Vol. 47 No. 858 March 15 1979.

4. Wants and needs may seem to be the wrong way round here. I am following the philosopher's usage: 'our basic repertoire of wants is given. We are not free to create or annihilate wants.' MIDGLEY, Mary. *Beast and Man: The Roots of Human Nature.* Harvester, 1979.

5. E.g., MALINOWSKI, MASLOW, INGLEHARDT

6. SWIFT, Jonathan. *A modest proposal for preventing the Children of Poor People from being a Burthen to their Parents or the Country, and for making them Beneficial to the Publick,* 1729.

7. The government department responsible for the implementation of poverty policy.

8. Of course, these freedoms may not unfreeze in the exponential manner depicted here - this is just *one* of the ways they may unfreeze. But, regardless of the way they unfreeze, the topological properties of this space remain the same.

9. A distinction that we make in ordinary language between 'managing' (personal scope) and 'coping' (no personal scope).

10. This vignette is drawn from six years of participant observation by the author.

11. Ref. to book of that title.

12. See THOMPSON, Michael. *Rubbish Theory: The Creation and Destruction of Value.* Oxford University Press 1979.

13. Some of these - currency exchange controls and the associated dollar premium - have now been abolished by the Conservative government of Mrs. Thatcher.

14. PIACHAUD, op. cit. 15 March. p. 603.

15. See THOMPSON, Michael. The aesthetics of risk: culture or context? in SCHWING, R., and ALBERS, W. (eds.) *Societal Risk Assessment,* Plenum New York 1980.

16. From *The Garden,* written before 1653, first published in *Miscellaneous Poems,* 1681.

17. See COTGROVE, Stephen. Catastrophe or cornucopia. *New Society* Vol. 47 No. 859 March 22, 1979.

18. The penultimate sentence of the novel, the ultimate being: 'Yes, I know,' I said, 'The Boreleys think it's simply terrible.'

19. DAHRENDORF, Ralf.

20. A form of ostracism in which all verbal communication is withdrawn.

21. The only scope he has is that he can manage his resources sharply down by choosing to leave his group.

22. A sociologist (Goldthorpe) has defined inflation as 'the monetary expression of distributional conflict' without, alas, saying anything about the *kind* of distributional conflict that produces this particular *kind* of monetary expression. This anthropological hypothesis suggests that inflation is likely in social settings where fairly evenly-matched complex groups predominate.

    An economist (Jay) has argued that the only way to get rid of inflation is to somehow arrange things so that the workers 'become infected with the entrepreneurial realities.' He, alas, does not go on to offer any suggestions as to how this massive aggregate shift of individuals towards individualised social contexts might be effected.

    GOLDTHORPE, 'The current inflation: towards a sociological account' in HIRSCH and GOLDTHORPE (eds.) *The Political Economy of Inflation.* 1976.

JAY, Peter. Employment, inflation and politics.' *Occasional Papers of the IEA,* 1976.

23. For an elaboration of this see DOUGLAS, Mary. Cultural Bias. *Occasional Papers of the Royal Anthropological Institute* 1978.

24. The way the individualised and collectivised extremes relate to *group* - the way the individual is caught up in the process of group formation - is probably fairly obvious. The way in which prescription varies in relation to *grid* - the processes of personal network building - is probably less clear. For some discussion of this see: THOMPSON, Michael. 'A Three Dimensional Model' and 'The Problem of the Centre' both in DOUGLAS, Mary and OSTRANDER, David (eds.). *Essays in the Sociology of Perception.* Routledge, Kegan Paul, London and Basic Books, New York. (To be published January 1981).

25. See, for instance: STACK, Carol B. *All Our Kin: Strategies for Survival in a Black Community.* Harper and Row, New York, 1975, and SHEEHAN, Susan. *A Welfare Mother.* Mentor, New York, 1977.

ORGANISATIONAL RESPONSES TO HAZARD

Barry A. Turner

Reader in the Sociology of Organisations,
Department of Sociology,
University of Exeter,
United Kingdom

A number of organisational and occupational responses to hazard are reviewed. Attention is first paid to the characteristics of those occupational groups within organisations which confront known danger, their cohesive and solidary qualities being stressed. Studies of organisational responses to crises are then outlined. When danger is less immediately apparent, analytical attention switches from a discussion of organisational behaviour under emergency conditions to models which stress perception of hazard and organisational intelligence gathering. Such models have formed the core of the American "disaster studies" approach to hazard responses, which starts with a notional rational model and details those factors which produce deviations from rationality.

Difficulties which have been experienced in the use of some of the models outlined to guide empirical investigations are taken as a cue to review the wider context of these kinds of models, and to question the range over which they are applicable. Particular attention is paid to a discussion of:

- *Assumptions of rational behaviour, or of minor deviations from it.* Organisational studies which commence from assumptions of minimum rather than maximum rationality are noted.
- *The interorganisational and political context.* Organisations operate in an interdependent and highly politicised environment. Responses to hazard are influenced by the competitive predatory or aggressive responses of other members of interorganisational networks, as well as by benevolent responses. Government has been recognised as a source of legislation and of possible aid, but safety matters are often subject to political lobbying, and health and safety legislation has recently been studied by political scientists as an example of "agenda control", where interorganisational lobbying and media coverage influence the content of the political agenda.
- *The cultural environment.* The models outlined embody a number of cultural assumptions: the state is assumed to be beneficient in disaster and organisations are assumed to have an "unwritten insurance contract" with the state. Anthropological studies of responses to hazard exhibited by both small, traditional societies and by segments of ex-colonial societies are ignored. The ethnocentric features of quantifiable risk as a way of responding to hazard are discussed.

In conclusion, the question of organisational response to hazard is linked to Fox's recent suggestion that industrial societies are now undergoing a fundamental public reassessment of the way in which hazard and risk and modes of dealing with them should be understood. Because of this, these problems should not be regarded as isolated technical problems the potential importance of which challenges our abilities to deal with them dispassionately.

Organisational responses to hazard are closely tied up with issues of social and technical control. Modern organisations are faced with a variety of technical hazards which intertwine with social factors and this article explores some of the ways in which these hazards are dealt with. The lack of firm and useful data in this area creates a certain amount of difficulty, but it nonetheless seems to be instructive to consider some of the models that have been developed to look at organisational responses to hazard.

One of the most influential modes of inquiry in this field is one that could perhaps be labelled the 'American disaster studies' model. At its heart is an approach to cognitive elements of decision-making under risk which has been very clearly set out by Slovic, Kunreuther and White (1974). This psychological/managerial approach to decision making has been imported into disaster studies and is linked with the work of a number of other associated researchers, notably Anderson, Haas, Hutton, Kates, Mileti and others. The essential features of this model have recently been usefully summarised by Mileti (1980).

The model is concerned, not with behaviour under direct confrontation with danger, but with the manner in which groups and organisations orient themselves to known threats, with the ways in which they try to cope with these threats, and with the characteristics of rational response in such a situation. It develops its distinctive features by starting with an exemplary pattern of rational response to risk or hazard and then modifying this pattern to take care of typical shortfalls from rationality which have been observed. The posture which, it is suggested, would rationally be adopted towards risk is one in which probabilities of damage or injury are assessed, the potential policies for adjusting to these probabilities are reviewed, the impacts of alternative policies are assessed and one or another of these responses are chosen.

However, it is recognised that this pattern is rarely adopted in practice, and in what we might call a 'modified rational model', three clusters of factors are seen as distorting a possible rational response: those factors (which seem to be assumed to be largely psychological rather than cultural or organisational) which affect the perception of risk; the social structural features of the unit concerned which affect the perceived costs and capacities of response; and the effects of incentives from other 'system units', notably those provided by directives, rewards and regulations emanating from the government.

In a brief critique of this model, Mileti notes that little is known of how one possible adjustment interacts with another, that research has concentrated upon policy adoption rather than upon policy implementation, and that the model is an aggregate one in which the variables have been drawn from different studies, rather than being observed together.

For the purposes of this paper, I would like to associate with a model which shares some emphases and also some failings with the disaster model (Identifying ref. 1). This model, based upon an analysis of public inquiries into a number of large-scale accidents in Britain between 1965 and 1975, extends or fills out Herbert Simon's (1957) view of the cognitive features of organisations, stressing their intendedly rational character and the factors which limit or bound their ability to achieve this intended rationality. This view presents organisations dealing with hazard as made up of hierarchies of overlapping decision-making groups, identified by the common clusters of assumptions which they share in their decision-making activities.

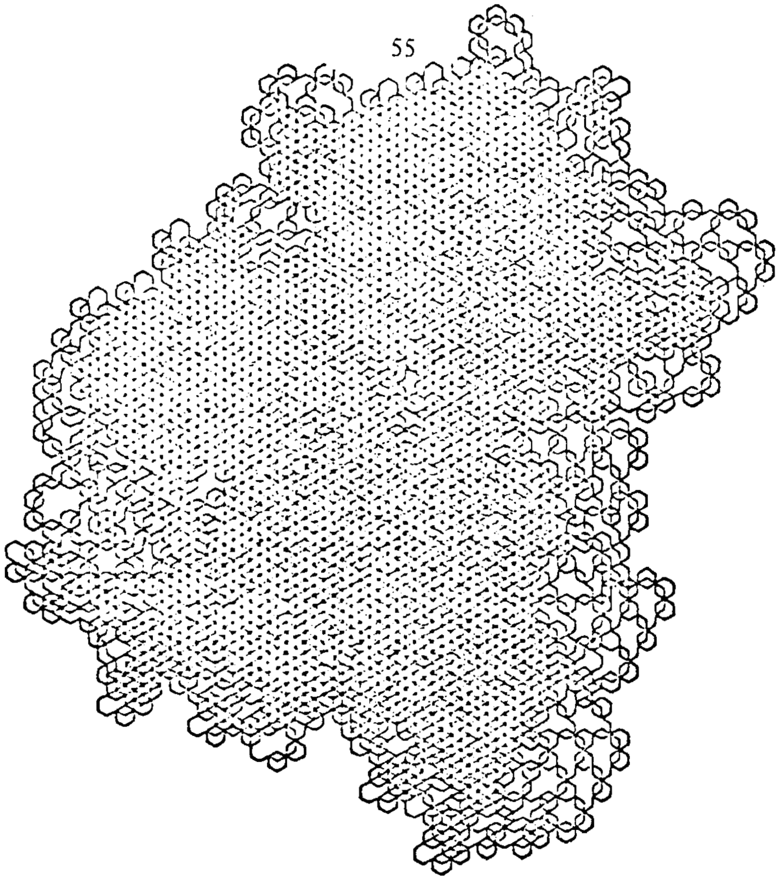
Each of these 'bounded decision zones' gathers intelligence from organisationally relevant portions of the world as best they may, and incorporates some of it into its own decision-making activities. Those zones which are powerful enough or persuasive enough transmit some of the intelligence to other zones within the organisation. This gives us a view of organisational adjustment to changes in the environment as an inevitably discontinuous process. The greater the discontinuity between the current perception of the environment and its actual state, the greater will be the need for eventual and stressful adjustment within the organisation.

This picture of organisations trying to cope with potential hazards in the environment by means of the alternation of an imperfect intelligence gathering process with discontinuous surprises of a more or less catastrophic nature is one which seems to fit well the retrospectively gathered accounts of organisational behaviour used from reports of public inquiries into large-scale accidents. It tends to divide up actions in the past into those which were routine, safe and satisfactory, dealing with known conditions whose hazards could be subdued; and those which were unanticipated, 'unseemly' (Roberts et al 1980), provoked by overlooked factors, in short, slips and errors which eventually produced the accident or disaster in question. The impact of such errors are summarised in the statement that "unintended consequences produced within organisational settings make non-random use of the rules of the organisation in their propagation". (Identifying reference 2).

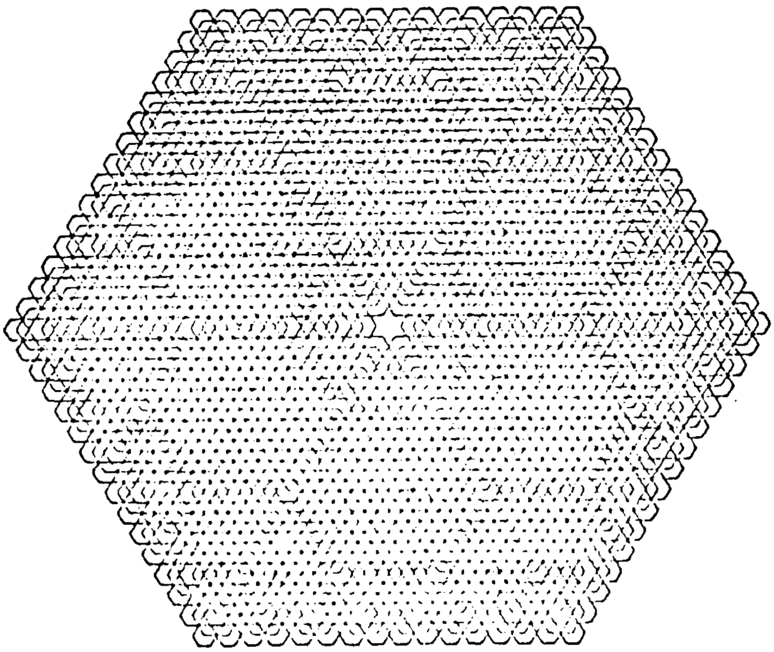
The implication is thus that, in building a castle of rationality, limited and fallible human beings cannot avoid also building into the fortifications some breaches which may eventually be used to penetrate the castle. The iconographic representation which comes to my mind in discussing this is supplied by the kinds of complex 'worm-produced patterns' shown in Figure 1, which are computer-produced by 'worms' given simple rational decision rules to apply to the choices that they meet at every node on their path in search of 'food'. The patterns produced by such rational decision-making activity look impenetrable, but they have the mathematically demonstrable property that, as a by-product of their mode of creation, there is always a clear, unused path right into the centre of the maze, by which it may be penetrated. When the 'worm' finds this path and follows it to its origin, no further 'food' exists, no further movement is possible and the programme becomes self-terminating. (Gardner, 1973; Waddington, 1977: 135-60).

The two models outlined so far have in common their stress upon cognition within and outside the organisation, their stress upon decision-making, their stress upon the intelligence function of gathering useful information from the environment and their consideration of behaviour when it is being oriented to possible future danger rather than behaviour in confronting immediate or imminent danger. In fact, it is possible to vary this last condition without varying the other properties of the model so that we can ask how an intendedly rational, risk-assessing, intelligence-gathering organisation will respond to the advent of danger, and some writers have done this. Sometimes, of course, the organisation does not respond at all, and many accident inquiries are concerned to describe precisely this condition.

Consider the case of an organisation which was discussed a few years ago in an official British government inquiry. This organisation



Cloud path generated by a gentle worm $1_a 2_{abab} 3_c 4$



The superdoily $(1_a 2_d 3_{cbab} 4_b)$

Figure 1

was described as being "safety conscious" (para. 202), as not placing pressures of production before matters of safety (para. 206) and as continually taking "conscious and positive steps" with the objective of safety in mind (para. 201). In consequence of such considerations the authors of the report entirely absolved all persons involved with the company from any suggestion that their desire to resume production in the plant which their organisation operated after a shutdown caused them knowingly to embark upon a hazardous course in disregard for the safety of those operating the plant (para. 57). (Department of Employment, 1975).

The organisation in question was Nypro Ltd., and the incident which prompted the report was the explosion at the Flixborough plant which killed 28 people, demolished much of the plant and provoked a major British government initiative to deal with industrial hazards. And yet it is not helpful to talk about this organisation 'responding' to the hazard which produced the explosion, for the awareness of such a possibility in the minds of those concerned with the plant seemed to be minimal, if, indeed, it was present at all. Allen (1977) and many others have drawn attention to features of the report such as the curious apparent incompatability between the comments from the Report of the Court of Inquiry mentioned above and the fact that the plant operated by this organisation held over 360,000 gallons of cyclohexane, naptha, toluene and gasolene on a site which was licensed to store only 8,500 gallons; the fact that there were associated 'shortcomings' in its safety procedures and uncertainties about responsibilities for safety; and the fact that a major repair to a plant processing very large quantities of cyclohexane at high temperatures and pressures was carried out with limited design, inspection and test procedures.

But this apparent incompatability hinges on the question which has been explored in a psychological context by Slovic and others, of the perception of hazard. Hazards on the scale which emerged were not being 'responded to' by Nypro, simply because they were not imagined or considered. We cannot therefore use Nypro as a case study of response to hazard, but must regard it rather as an example of the failure of organisational intelligence gathering in this crucial area (see also Stech, 1979). The Flixborough case presents in perhaps an extreme form the characteristics of intelligence failure or of the failure of foresight which is charted in most retrospective inquiries into accidents. (Identifying reference 3).

When the intelligence failure is less complete, and the organisation becomes aware of rapidly developing threats, it is possible to construct models of likely behaviour under such conditions. For example, Burgess (1976) has set out a number of speculative propositions about responses to threat which explicitly try to integrate the 'disaster studies' model with organisation theory, selecting that branch of organisation theory which treats organisations as goal-oriented, boundary-maintaining entities, seeking to sustain an equilibrium with their environment. Burgess identifies four different levels of possible organisational response to massive threatening changes in the environment: passive environmental monitoring; a defensive response to threat; opportunistic responses which try to take advantage of the organisation's situation; and an activism in which the organisation attempts to change the environment "in order to maintain the equilibrium between itself and the environment". Burgess relates these different levels of response to the flexibility, power and vulnerability of the organisations concerned and to the changes in demand for the organisations' goods or services. (See also Quarantelli, 1978).

Developments such as Burgess's may be related to another strand of literature which has proceeded more or less independently of the 'disaster studies' school: that strand concerned with the politico-organisational investigation of perception of and response to crises. This has its origins in the work of Hermann (1963, 1969, 1972), who proposed that a crisis arises when a threat to an organisational unit is combined with a limited decision time and an element of surprise. Empirical tests of Hermann's model have been only partly convincing, the element of surprise being particularly troublesome. (Hermann, 1972; Lentner, 1972; see also Identifying reference 4) . Recently, however, a cognitive model of decision-making in crisis conditions has been developed by Smart and Vertinsky (1977) which identifies the possible 'pathologies' of crisis decision-making as: narrowing of cognitive processes; information distortion; group pathologies such as Janis's 'groupthink' (Janis,1972); rigidities in programming; a lack of preparedness for decision about crisis issues and inadequate implementation of decisions.

Some tentative support for this formulation may be found in discussions of the inadequate responses of public institutions such as universities to the current climate of scarcity and retrenchment (Rubin,1979; Bozemann and Slusher, 1979), but a more pertinent development is the modification which has more recently been developed by Billings and his colleagues (Billings, Milburn and Schaalman, 1980) from Hermann's theory as a model of crisis <u>perception</u>. This model has been tested with some success against data derived from the response of organisations to the curtailment of natural gas supplies in Ohio during the winter of 1976-77. The resultant model sees a perceived crisis arising when perception of a problem is triggered, when the perceived value and likelihood of loss as a result of the problem is judged to be serious and when there is a need to respond to the problem in a limited time. The element of surprise is dropped from this model. The details of Billings, Milburn and Schaalman's model

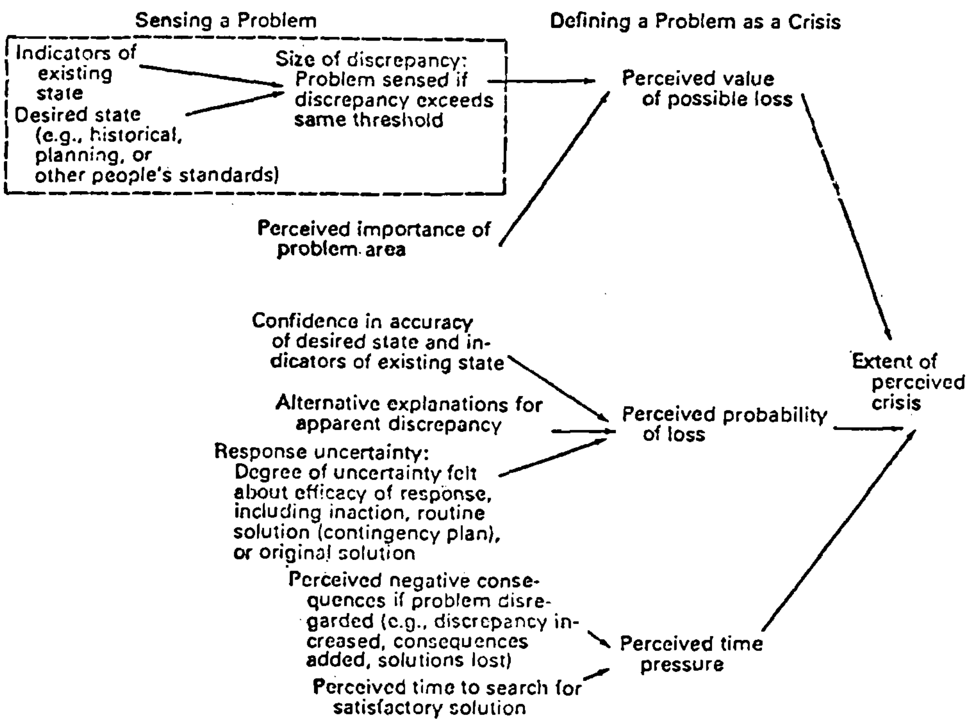
(See Figure 2) contain interesting parallels to that developed by Slovic, Kunreuther and White (1974) and it would seem to me that the two could be compared and possibly amalgamated with advantage.

What I have been outlining up to this point are a number of converging pieces of work which seem to point to a degree of agreement about the nature of organisational responses to hazard, this agreement centring upon the use of organisations as the unit of analysis, upon intelligence gathering and threat perception at the boundary between the organisation and its environment and upon subsequent intendedly rational, but ultimately imperfectly rational, internal assessments of and adjustments to the perceived risk. There is a great degree of coherence between the major elements of these models, and yet, if I might put it this way, I would not wish to guarantee my own survival in a hazardous situation using solely the kinds of guides to organisational actions in conditions of danger that I have been discussing so far.

To try to introduce the concerns that lie behind this comment, concerns about the limitations of the approaches discussed so far, my own included, let me mention another model of organisational response to hazard and disaster which has recently been produced and tested. Bardo (1978) begins with another variant of the 'American disaster model', this time one produced by Brouillette and Quarantelli (1971: See also Brouillette, 1970) which is not included in Mileti's discussion. This starting model suggests that under conditions of threat, bureaucratic organisations shift to a debureaucratised state, either with regard to the tasks which the bureaucracy is tackling, with regard to the structure of the bureaucracy, or with regard to both tasks and

Figure 2

A Model of Crisis Perception: Billings, Mulburn and Schaalman, 1980



structure. The particular form of response is seen as a function of a number of familiar factors: type of bureaucratic structure; emergency capability; internal perception of demands of the stress situation; perceived effectiveness; and external factors such as situational, ecological, interorganisational and societal contexts.

Bardo elaborates this model a little in order to take account of the response which an organisation makes when it implements a previously conceived emergency plan, and produces a typology of nine forms of response to hazard (See Figure 3). He then wishes to combine these with Barton's five processual phases of disaster: predisaster period; detection and communication of warning; immediate relatively unorganised response; organised social response; and long-run post-disaster equilibrium. (See Figure 4).

He then tries to apply this quite complex model to an actual case of an organisation responding to hazard: specifically the public works department of a middle-sized city on the East Coast of the United States to flooding caused by Hurricane Agnes in June, 1972. He encounters two difficulties which I find instructive; firstly, Barton's developmental sequence, abstracted from several earlier disasters, proved difficult to apply unambiguously, considerable problems being experienced in differentiating one phase from another, and in dealing with over-lapping phases. It was also necessary to split Barton's fourth category into two: organised response to the immediate threat; and organised short-run, post-impact response. With regard to the organisational typology in the model, what is particularly notable is that Bardo was unable to identify a <u>single</u> response of the public

Figure 3

Nine Possible Forms of Bureaucratic Responses to Disaster

(Bardo, 1978)

STRUCTURES	FUNCTIONS: Manifest	Latent	Emergent
Manifest	Type I	Type II	Type III ....
Latent	Type IV	Type V	Type VI
Emergent	Type VII	Type VIII	Type IX

Figure 4

Barton's Processual Phases of Disaster

I. Predesaster period

II. Detection and Communication of warning

III. Immediate relatively unorganised response

IV. Organised social response:

- IVa. Organised response to the immediate threat
- IVb. Organised short-run, post-impact response

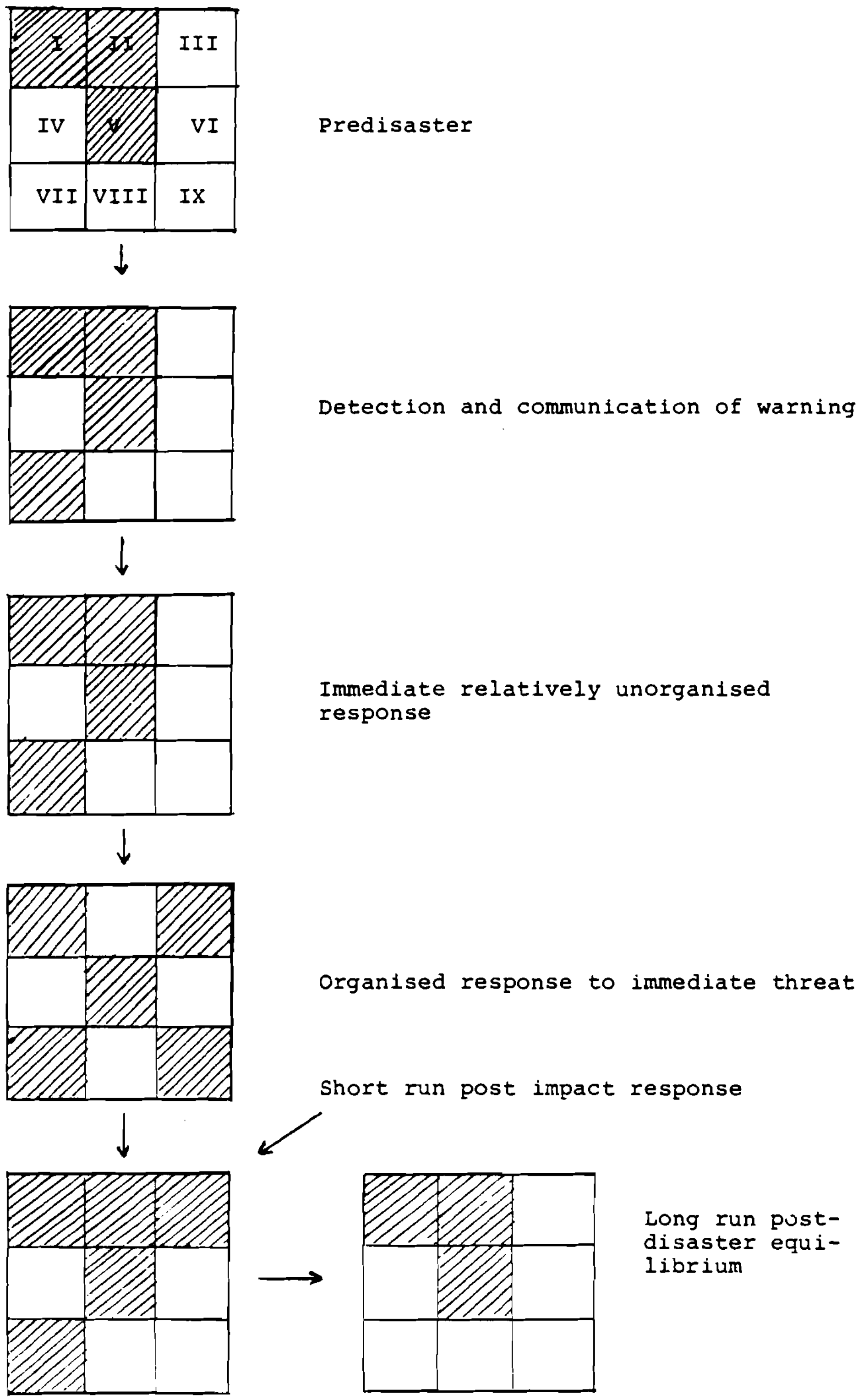
V. Long run post-disaster equilibrium

organisation in each of the phases. With the nine possible types of response, Bardo found, as can be seen from Figure 5, that even in stable periods, his organisation could be discerned to be behaving in three different ways, while in the two halves of the modified fourth phase, five different modes of response were identified.

Bardo stresses the processual nature of the events with which he was dealing, proposes modifications to the models used, and urges caution in establishing the empirical sequence of events in individual applications. What I would derive from his instructive study, however, is the conclusion that existing theoretical categories in this area of inquiry are likely to have to be elaborated ad hoc when they are matched up against the real world, that it is unlikely that organisational responses to hazard can usefully be considered as a movement from one mode of behaviour to another, but must be viewed as a multiple array of parallel responses with at least three and sometimes four or five or more different types of responses to hazard taking place simultaneously in a single, modest organisation, and that, since organisations are not unitary, they do not in any cases of significance deal with hazards singly, but in multiple ways. (See also Blanshen, 1978).

If I may move here to a more general level, I would also like to draw from Bardo's experience a more general comment which applies to all of the accounts that I have considered so far. I would like to suggest that the world is much more messy and much less systematic than these models would imply. What I would now like to do, therefore, is to suggest that these models need to be set in a broader context which limits and qualifies their usefulness, and which also draws attention to the need to consider other levels than the purely

Figure 5. Combination of Types of bureaucratic response in Different Phases of Disaster (Bardo, 1978)



organisational one. I would like to arrange my comments under three headings: first, discussion of modes of response which do not start from the assumptions of rationality; second, discussion of the interorganisational and political context of decision models; and third, discussion of the cultural context of responses to hazard.

1. Analyses which do not assume rationality

Under this first heading, I mainly wish to draw attention to the limits of a rational model of organisational behaviour, and to note other modes of response. Some organisational writers, rather than merely stressing, as I have done so far, that there is a difference between ideal notions of perfectly rational action and the actual behaviour of individuals and organisations, have pointed out that more adequate explanations are often provided by regarding events and actions as excuses for prospective and retrospective rationalisations of behaviour which serve to cloak non-rational sequences of events with an appearance of rationality. Such writers as Dalton (1959) and Weick (1969) recognised in their studies that many decisions within organisations are matters of faction, of expediency or of career advancement.

March and Olsen and their students (March and Olsen, 1976) present a picture of the organisational world as one in which such decision-making as takes place is essentially an ambiguous activity, indulged in for ambiguous motives. Here not only do choices get tied up with personal preferences and organisational modes of rhetoric, but the time and energy which individuals have to allocate among competing issues and concerns assume major importance in explaining behaviour. In this view of organisations, decisions are as often taken because of the presence of a 'solution looking for a problem' as because the outcome is a rational response to the question at issue. The 'garbage can' theory of decision-making that March and Olsen put forward suggests that committee decisions depend not necessarily upon rational processes of deliberation, but upon the interactions between the energy levels of the parties to the decision and the assorted contents of the 'garbage can' that constitutes the agenda, when it is emptied out before the committee.

It may be desirable that organisations respond to hazards in a reasonable and rational manner, but it is a commonplace that in practice they rarely behave in such a manner, and any adequate theories dealing with the socio-technical aspects of hazard have to reconcile these two opposing tendencies. We may perhaps see these tendencies particularly clearly in relation to what are often presented as the rational approaches par excellence to hazards, those of cost-benefit analysis and risk assessment. But a recent authoritative review of cost-benefit analysis in relation to hazards (Baram, 1980) noted that experts recommending this mode of analysis typically outline its shortcomings and limitations, present a tentative analysis of a particular case, but conclude by urging that, in spite of its faults, their analysis be used as a basis for decisions. I wish to discuss some aspects of risk and risk assessment later in another context: all that we need note here are that such techniques are not immune from the 'garbage can theory', and that they may well provide us with examples of 'solutions looking for problems', as Baram has suggested that they are in the American hazard legislation context. (Baram, 1980).

Another way of gaining a different perspective upon organisational responses to hazard from that provided by the 'modified rational' approach is by looking at the evidence from occupational studies about how the occupational front-line troops of hazard, those employed in dangerous occupations respond to their work situations. Studies of deep-sea fishermen (Poggie et al, 1976), miners (Fitzpatrick, 1980; Vaught and Smith, 1980), high steel erectors (Haas, 1977) and similar occupations (Aran, 1974, Corrigan et al, 1980) give us a picture of groups whose typical response to hazard is to develop a solidary cohesiveness, albeit a cohesiveness which is sometimes rather brutally achieved (Vaught and Smith, 1980).

Both the isolation and the danger which characterise such occupations promote cohesion and self-sufficiency, a sharing of danger and a suspicion of outsiders who do not share it. And all of these characteristics contribute towards the development of an occupational subculture of danger (Fitzpatrick, 1980) which is similar in some ways to the disaster subculture developed amongst those whose homes are frequently exposed to natural hazards (Hannigan and Kueneman, 1978).

The subculture provides shared perspectives which enhance the group's control over their work situation, which maximise autonomy and minimise dependance upon outsiders. Fear is often, though not always, denied within the group as a way of making the internal environment more predictable, and group norms are very important both in controlling and testing new members and in encouraging them to behave predictably in the face of danger. (Haas, 1977; Mayer and Rosenblatt, 1975). Safety may be taken seriously at one level by regarding all possible hazards as extremely dangerous (though this may not include all conditions seen as hazardous by outsiders), but these occupational groups differentiate in practice between different kinds of hazard. Miners, for example, give most instruction to newcomers about everyday dangers such as falls and slips, less about dangers of an intermediate kind such as misfired explosions, and in the face of the possibility of major hazards such as fires and large cave-ins they are more stoic and fatalistic.

Where there is a more lively perceived uncertainty in exposure to danger, some reliance is placed upon luck and providence, and, as the anthropologist Malinowski suggested decades ago (Malinowski, 1948), the tendency to engage in rituals and to maintain taboos is greater the more the individuals and groups concerned are exposed to actual danger. (Poggie et al, 1976. See also Turner, 1967; Vaught and Smith, 1980).

There are, of course, rational aspects to the kinds of group responses to danger that I have just been describing, and, indeed, it has been demonstrated that the group culture and norms can be successfully modified by the feedback of information to group members about the dangers of particular courses of action (Andriessen, 1975; Zohar et al, 1980; Zohar, 1980; Blignaut, 1979) but these responses overall cannot readily be seen as instances of decision-making in conditions of uncertainty, and can be more successfully understood as the development of what the sociologist Durkheim called 'mechanical solidarity', a group response which ties the group together by both real and symbolic threats in order to share and equalise the experience of direct exposure to danger. (Durkheim, 1964; See also Goldbart and Cooper, 1976).

We may ask the question of how far organisations of greater complexity than occupational work groups respond to hazard, and whether responses of the kind discussed here can be discerned in the larger organisations. Ouchi (1980) in a recent discussion of the limits of bureaucratic rationality, has suggested that an organisational type which he labels the 'clan', and which includes elements of mechanical solidarity, may be more appropriate for confronting certain types of uncertainty than either the market or the bureaucratic configurations (Williamson, 1975). It may be useful in the future to explore the relationship of Ouchi's model to responses to hazard.

2. Interorganisational and political context of decision-models

Turning now to the wider context of organisational response to hazard, we have seen already that the prevalent models in this field take single organisations as their unit of analysis, stressing their response to hazard as a response to a threat to the equilibrium which they seek to maintain with their environment. The environment is acknowledged to contain other organisations, but these are rather a long way off. Most of the models discussed make some reference to interorganisational relationships, but it is difficult to escape the feeling that, at present, these references have the effect more of paying lip service to current shifts in thinking about organisations rather than changing in any significant way the nature of the analyses and the assumptions that underlie them. (See also Dynes, 1978).

The prevailing view of organisations represented by these models is, as I have suggested, one which is coming increasingly into question in organisation studies (Perrow, 1980). Quite apart from the standard sociological objections to the harmony-laden, structural functional view of the world which they embody, it is coming to be much more acknowledged that the environment is not a kind of neutral soup within which the organisation floats, but that it is rather a closely inter-meshed network of relationships between other organisations, some of which are collaborative, but many of which will be competitive. A greater concentration upon interorganisational networks will lead rapidly to discussions of the political economy of the network, and to analyses in terms of resource flows and power blocs, and to discussions of the economic and social class structure of the society concerned as it relates to organisational behaviour. The interorganisational environment, that is to say, will be seen as a highly turbulent one, which is also highly politicised. Accounts of the responses of individual organisations which ignore the way in which treatments of hazard fit into this wider picture will only offer a partial analysis.

The organisational context is influenced, for example, by government legislation, and by the debate and lobbying which both precedes and follows the passage of legislation. In the face, for example, of the US figures of 14,000 deaths at work per year and an estimated 390,000 workers dying annually from occupation-related illnesses, Donnelly (1978) has noted how the strong involvement of the American business community in the law creation stage of the Occupational Health and Safety Act, 1970, and in its subsequent operation has meant that the OHSA Administration is hampered in its task by limited resources. In the United Kingdom, Carson's studies (Carson, 1972) of the Factory Inspectorate have led him to suggest the general proposition that inspectorates always become 'captured' by the organisations which they are trying to police. And in the face of the threat of proposed legislation which might seek to impose a 'zero release' concept upon industry to reduce harmful waste pollution, the American chemical industry, already facing multi-billion law suits over hazardous waste issues, is protesting that such legislation would bring industry to a halt. (Alexander, 1980. See also Hunter and Crowley, 1979).

Such interorganisational political activities have led political scientists recently to look in particular at legislation about safety and health hazards as instances of the way in which topics come to find themselves upon what they call the 'political agenda' (Brooks et al, 1976). Debates about the control of technology (Elliott and Elliott, 1976; Boyle, Elliott and Roay, 1977) or about threats to the environment, have come about partly because of individual concern with these problems, and partly because of the newsworthiness of the issues concerned. (Brookes et al, 1976). Downs (1972a, 1972b; See also Solesbury, 1976) suggests that there is an issue cycle which brings topics to the attention of the public, places them on the political agenda, but then allows them to fade, whether or not the original problem has been solved: but he also suggests that issues relating to health, hazards and the environment have a particularity, a ready media-potential and an ability to draw legitimacy from wider social values which makes it likely that they will remain on the political agenda for some time to come. The precise manner in which such issues are dealt with as they reach the political agenda varies according to the type of governmental system within which the organisations concerned are operating. Williams (1977) differentiates between what he calls the 'closed consensual' style of the United Kingdom in dealing with occupational safety dangers and environmental hazards, the Swedish 'open consensual' approach and the American 'open adversary' system. (See also Williams and Bates, 1976; Stringer and Richardson, 1980).

Governmental legislative activities provide one element in the interorganisational context, but any one organisation will be embedded in a setting which places it in a relationship with other organisations and, rather than attempting to produce a single theory or model which relates to all possible organisations, it is perhaps more appropriate, as the anthropologist Torry has suggested (1979a), to try to map variations in coping modes within a hierarchy of organisational units extending from individuals and households to nation-states. Torry himself has begun the preliminary work for such a mapping, concentrating upon studies made outside modern industrial societies.

Torry criticises homeostatically based views of the responses of small societies to hazard, arguing instead that hazard and danger are frequent, although largely unrecognised agents of irreversible social change. Such 'coping responses' as occur, therefore, are rarely maintaining the status quo, or sustaining equilibrium, but are producing forms of adaptation to hazard and disaster which may be much less satisfactory than that to those concerned. Torry (1979b) in an extensive review of the anthropological literature, lists types of such changes which include increased and sometimes forcible changes in exchange and resource transfer with neighbouring societies, the scaling down and retrenchment of societal activities and the adoption of forms of ritual regulation. But also such responses now normally take place in the context of the administrative hierarchy created by the superimposition of a modern state administration upon the smaller patterns of traditional societies, and within this context, Torry details studies which report responses to hazard and disaster affected by political considerations, by local and national rivalries, by the arousal of otherwise subdued ethnic, religious or class conflicts, and by ignorance at the centre about the needs of the periphery.

Interorganisational network responses to hazard in such contexts are characterised by Torry (1978) as giving rise to organisational cooptation as weaker organisations are dominated by the strong, to organisational predation as some organisations wilfully try to weaken or eliminate others; to organisational clutter when a variety of agencies move in, pell-mell, to try to cope with hazard, and to bureaucratic inertia when the relevant administration proves itself to be incapable of action for a number of reasons ranging from organisational rigidity to the adoption of a laisser-faire philosophy. Although Torry's reviews concentrate upon less developed countries, we should anticipate, at least until it is proved otherwise, that similar ranges of interorganisational responses may exist within more developed settings; or, at the least, we should remain aware of the possibility of cultural and societal variation in the patterns of response to hazard, and recognise that we are producing culturally specific rather than culturally universal models when we look only at our own societies.

3. The cultural context of responses to hazard

It is important because it has implications for current debates in our own societies to develop this point a little further by turning to look more explicitly at some factors which may influence cultural variation. We tend very readily to take for granted our expectation that in times of disruption and danger, community feeling will be maintained, looting and profiteering will be kept down, and that organisations will be able to take advantage of an 'unwritten insurance contract' with the state, which will supply aid when things get too bad. But these assumptions are themselves located in specific historical and cultural contexts. Jones (1977, 1978) has outlined how our present conception of the state's role in hazard management arose with the attempts of Italian city states in the late middle ages to counter the threats to both their tax revenues and their internal order provoked by disasters. The possibility of active hazard management then rested upon the economies of scale which new and larger political entities could provide in response to hazard, and upon the emergence of a consensus that disaster management was not against providence, and that attempts at management should be supported at the expense of immediate self-interest.

These last two assumptions were by no means universal, for while techniques of managing plague, famine and animal epidemics spread gradually to France, England and Austro-Hungary, these countries were unable to persuade the Ottoman Empire to adopt plague control measures, with the result that the *cordons sanitaires* originally set up around ports receiving traffic from the south-east were extended until by the eighteenth-century a thousand-mile long cordon sanitaire extended from the Adriatic to Transylvania, following the lines of the military boundary and reinforced by lookout posts within musket shot of each other. The differing cultural attitudes to hazard management which led to the creation of this barrier were evident also in the difficulties encountered by nineteenth-century, European-inspired attempts to reduce the tendency of famine in countries such as India, China and Japan to enhance existing inequities, by the introduction of hazard management.

It is not only our attitudes to hazard management which may be culturally bounded, for the very notions which we use to discuss these problems are not universal, but seem to have sprung up as part of the world view associated with the self-reinforcing pursuit of control over the material world which began with the Renaissance. The medical sociologist, Renee Fox (1980) has recently recorded her personal realisation that notions of uncertainty and risk were not part of the world view of the peoples that she was studying in Zaire, for example, for she found there that happenings were either adverse or felicitous, rarely neutral, and that they were all seen as being determinately caused by supernatural, psychological or impersonal forces, in a view of the world which left no room for the concept of probabilities. The notions of risk and uncertainty as they apply to both physical and financial hazard also sit uneasily within some other cultures, such as those based, for example, upon Islamic thought (Rodinson, 1974). And even within our own world view, when we pry into the real significance of notions like probability, randomness and risk, we find them underlain with philosophical ambiguities.

We may discern the emergence of these notions in British, Italian and French usage of the seventeenth century: the shift from the meaning at that time of the word 'risk' as a 'venturous course' to the early eighteenth-century meaning of 'the chance or hazard of commercial loss, specifically in the case of insured property or goods' would seem to parallel the movement from a society which placed a high value upon adventurism (Hamilton, 1978) and upon booty capitalism, where the risk of a death or glory expedition was not meaningfully quantifiable to one based upon rational bureaucratic capitalism calculable to a fraction of a penny by accountants.

This shift is seen, too, in the emergence of the early nineteenth-century usage of risk in the mathematical theory of probabilities, which defines it as "such a fraction of the sum to be lost or gained as expresses the chance of losing or gaining it", the financial sources of the notion being still clearly visible. We are frequently urged to make use of calculable approaches based upon notions of risk and risk assessment in orienting ourselves to hazard (Hanna, 1979) and we readily tend to assume that any rational response by organisations and their members must be couched in terms of risk and the calculation of probabilities (Strangert, 1977, Singer, 1978) but it is important not to lose sight of the fact that such ideas only make sense in a contingent, calculable view of the world, where a range of alternative future worlds, financial or physical, are readily envisaged, in which the coin may equally easily come down as heads or as tails.

But we still find difficulties in equating this view with other, humanistic strands in our cultures, difficulties which appear most regularly when we face the question of quantifying the risk of saving a human life, or try to put a financial value upon a human life. The consistent, coherent insistence of those who favour a calculable approach to these problems frequently overwhelms what seem to be more traditional opposing views, but Baram (1980) in a recent sweeping critique of the use of cost-benefit analysis in a legal context, has pointed out that many of the advocates of such approaches treat of such ethical and philosophical questions by default, and he argues for a limit to be placed upon the use of such techniques, leaving serious ethical issues to be settled by open debate. (See also Fischoff, 1977). The insistence of some contemporary workers upon guarantees of health at work rather than financial compensation for the loss of health perhaps reflects this challenge to calculability at a different level. (Boesi, 1976).

Discussion and Conclusions

The vision of a world of inexorable and continually developing technical progress which was prevalent in the nineteen-fifties, with its corollary of a continuous reduction in threats from the material world, is to some extent under challenge today. Not only are we provoking new kinds of technical dangers by our own advances, but we have become more aware of our own dependance upon restraint in socio-technical matters as we come to a greater understanding of the mechanisms by which we pollute our own environments and provoke new forms of disaster. Our dependance upon each other is closely inter-twined with our dependance upon nature: we have to control a global socio-technical environment in which we know that the worst outcome of a failure of control would lead to disaster for us all. Because of the imponderable nature of this need for control, we are emotionally involved in it as an enterprise (Elias, 1956). This involvement shows itself in increasing discussions of and legislation about health, risk and safety (The Times, 1980; Slovic, 1980) and their appearance on the political agenda, in panics where no incident has occurred, and yet one is expected (Rosengren et al 1975; New Scientist, 1980), in popular discussions of disaster (Ross, 1980); in the popularity of disaster movies where an overreaching technology is cut down to size and survival is made possible by a return to a more primitive life-style (Schecther et al, 1978). It shows itself in the incompatability of the arguments of the pro- and anti-nuclear lobbies (Eiser and van der Pligt, 1980) in the conflicting views about whether the levels of hazard we are facing are genuinely increasing, or whether our concern with safety and hazard is a luxury good, made possible by increased affluence (Slovic, 1980; Singer, 1978); and in the conflicting views about whether the hazards of advancing technology accumulate more rapidly than the benefits (Clutterbuck, 1976), whether the reverse is true (Singer, 1978), or whether this latter view is merely one of many unproven assumptions built into the debate over hazard (Williams, 1977).

If we want to study organisational responses to hazard, then we immediately get involved in some of these conflicts of views, for the level of public debate and the growing understanding of the nature of the patterns of events which make the worker, the consumer and the general public susceptible to hazard influence the manner in which hazard is perceived by members of organisations and influence the policies and the responses which are decided upon, as well as exerting their effects upon the legislative environment of the decision-maker.

Renee Fox has recently presented a most thoughtful discussion (Fox, 1980) of the changing concerns of Western and more particularly American society about medical hazards and the kinds of problems and uncertainties that surround current medical practice. Fox suggests that the degree and kinds of ferment occurring in the medical area over error, risk and hazard are indicators that we are in the midst of a process of questioning and changing some of our fundamental ways of thinking about uncertainty. (See also Rosenkrantz, 1980; Kennedy, 1980).

She argues that public concern in the medical field shows itself in a preoccupation with certain kinds of novel 'worst cases' which serve as paradigms for discussion, the recombinant DNA debate being such a paradigm in the bio-medical field. She notes that the American legal system is being used to try to cope with these new problems, and she discusses recent cases concerning organ transplants, soldiers exposed to radiation from nuclear tests, genetic counselling and arguments about medical treatments for leukemia based upon probability, all of which raise issues which are fundamental in the society and the polity, matters of birth, life, death and identity, and she points out that the legal profession is drawing back from making decisions in these most difficult areas.

It does not seem to me to be difficult to develop and extend Fox's arguments about changing concepts of health care and susceptibility, of tolerable risk and inequitable distributions of risk directly to non-medical technology, with nuclear energy and its association in the public mind with nuclear weapons, as the relevant 'worst case' paradigm.

As in the medical field, we find the same curious paradox that the public can be simultaneously indignant over the continued incapacity of specialists to satisfy the current technical needs of the population, and anxious about the arrogance of man in challenging nature with his advanced technology. Fox refers to a "boundless irresolution in the process" which is associated with the fact that "our sense of the beneficence and resilience of both nature and man-made phenomena has somehow been shaken in ways that heighten our sense of ignorance, mystery, fallibility, frailty and vulnerability to a host of hostile influences inside and around us". As in the medical field, Baram (1980) details the way in which the lawyers are drawing back from or are in dispute about the extent to which they should resolve problems of safety and technical risk for the public, or whether other public bodies should decide these questions for them.

Fox concludes that our current preoccupation with this area forms a "symbolic language through which we are communicating some of our deepest questions about the cognitive, moral and metaphysical traditions of our cultural tradition" and that through this debate we are changing our views of how we relate to society and to our planet. Whether we agree with this or not it seems to me clear that, while we cannot throw away our reliance upon systematic, rational thought, which in a sense is all that modern man has, if we are to tackle these problems of hazard within and around our organisations with a genuine and substantive rationality rather than merely a formal and superficial rationality, we need to recognise that many human responses cannot solely be considered in terms of an applied rationality, and that matters of organisational responses to hazard cannot be treated solely as isolated technical problems which arise within certain system units, and which can be resolved by techniques whose full development lies just around the corner. Organisational responses are a part of, and are interpenetrated by the interorganisational political economy of our society, and by our own cultural assumptions and attitudes towards risk and hazard and by current radical shifts in these attitudes. We need to treat these important problems with a degree of detachment if we are to handle them, but a first step towards this detachment is a recognition of the genuine complexity of the issues.

REFERENCES

Alexander, T. 1980 'The hazardous waste nightmare' Fortune 101, 21 April, 52-8.

Allen, R.L. 1977 'Some comments on the report of the Court of Inquiry into the Flixborough disaster' Appendix 3, Council for Science and Society The Acceptability of Risks London: Barry Rose/ Council for Science and Society.

Andriessen, J.H.T.H. 1975 'De verwachtingsteorie en der motavatie tot veilig werken' (The expectation theory and the motivation toward safe work behaviour) Mens en Onderneming 29(1) 3-24.

Aran, 1974 'Parachuting' American Journal of Sociology 79, 124-1.

Baram, M.S. 1980 'Cost-benefit analysis: an inadequate basis for health, safety and environmental regulatory decision making' Ecology Law Quarterly 8(3) 473-531.

Bardo, J.W. 1978 'Organisational response to disaster: a typology or adaptation and change' Mass Emergencies 3, 87-104.

Billings, R.S., T.W. Milburn and M.L. Schaalman, 1980 'A model of crisis perception: a theoretical and empirical analysis' Administrative Science Quarterly 25 (June) 300-

Blanshan, S.A. 1978 'A time model: hospital organisational response to disaster' 173-198 in E.L. Quarantelli ed. Disasters: Theory and Research London: Sage.

Blignaut, C.J.H. 1979 'The perception of hazard II: The contribution of signal detection to hazard perception' Ergonomics 22(11) 1170-1183.

Boesi, B. 1976 'Dalla monetizzazione del rischio alla gestione della salute' Centro Sociale 23, 130-2, July/ Dec. 97-116.

Boyle, G., D. Elliott and R. Roy, eds., 1977 The Politics of Technology London: Longman/ Open University Press.

Bozeman, B. and E.A. Slusher, 1979 'Scarcity and environmental stress in public organisations' Administration and Society 11(3) 335-355.

Brooks, S.K., A.G. Jordan, R.H. Kimber and J. Richardson, 1976 'The growth of the environment as a political issue in Britain' British Journal of Political Science 6(2) 245-55.

Brouillette, J.R. 1970 'The Department of Public Works' American Behavioural Scientist 13(3) 369-

Brouillette, J.R. and E.L. Quarantelli, 1971 'Types of patterned variation in bureaucratic adaptations to organisational stress' Sociological Inquiry 41: 39-46.

Burgess, H.A. 1976 'Organisational-environmental processes in relation to threat' Mass Emergencies 1(4) 291-302.

Corrigan, R.S., D. Lester and T. Loftus, 1980 'Perception of danger by police officers' Perceptual and Motor Skills 50(1) 284.

Carson, W.G. 1972 'White Collar crime in the enforcement of the Factory Legislation' British Journal of Criminology 383-398.

Clutterbuck, C. 1976 'Death in the plastics industry' Radical Science Journal 4. 61-80.

Dalton, M. 1959 Men Who Manage New York: Wiley.

Department of Employment, 1975 The Flixborough Disaster: Report of the Court of Enquiry London H.M.S.O.

Donnelly, P.G. 1978 'A sociological analysis of occupational health and safety legislation' Paper presented to the Conference of the Society for the Solution of Social Problems, 1978.

Downs, A. 1972a 'The political economy of improving our environment' in Downs, Kneese, Ogden and Perloff eds., The Political Economy of Environmental Control Berkeley, California: Institute of Business and Econ. Research.

Downs, A. 1972b 'Up and down with ecology: the issue-attention cycle' Public Interest Summer 1972 38-50.

Dynes, R.R. 1978 'Interorganisational relation in communities under stress' 49-64 in Quarantelli ed. op. cit.

Durkheim, E. 1964 The Division of Labour in Society London: Collier Macmillan.

Eiser, J.R. and J. van der Pligt, 1980 'Beliefs and values in the nuclear debate' Journal of Applied Social Psychology (in press)

Elias, N. 1956 'Problems of involvement and detachment' British Journal of Sociology 7, 226-252.

Elliott, D. and E. Elliott, 1976 The Control of Technology, London: Wykeham Press.

Fischoff, B. 1977 'Cost benefit analysis and the art of motor-cycle maintenance' Policy Sciences 8(2) 177-202.

Fitzpatrick, J.S. 1980 'Adapting to danger: a participant observation study of an underground mine' Sociology of Work and Occupations 7(2) 131-158.

Fox, R. 1980 'The evolution of medical uncertainty' Milbank Memorial Fund Quarterly 58(1) 1-49.

Gardner, M. 1973 'Mathematical games: futuristic patterns traced by programmed worms' Scientific American 229. November 116-123.

Goldbart, S. and L. Cooper, 1976 'Safety in groups: an existential analysis' Small Group Behavior 7(2) May 237-256.

Haas, J. 1977 'Learning real feelings: a study of high steel iron workers relations to fear' Sociology of Work and Occupations 4(2) 1977: 147-70.

Hamilton, G.G. 'The structural sources of adventurism: the case of the California gold rush' American Journal of Sociology 83(6) 1460-90.

Hanna, R.C. 1979 'Apply decision theory to hazard evaluation' Hydrocarbon processing 59(12) 133-150.

Hannigan, J.A. and R.M. Kueneman, 1978 'Anticipating flood emergencies: a case study of a Canadian disaster subculture' 129-146 in E.L. Quarantelli ed. op. cit.

Hermann, C.F. 1963 'Some consequences of crisis which limit the viability of organisations' Administrative Science Quarterly 8: 61-82.

Hermann, C.F. ed. 1972 International Crises: Insights from Behavioural Research New York: Free Press.

Hunter, W.G. and J.J. Crowley, 1979 'Hazardous substances, the environment and public health: a statistical overview' Environmental Health Perspectives 32 (October) 241-254.

Jones, E.L. 1977 'Societal adaptation to disasters: Disaster Management in European economic history' Paper presented to British Council of Social Biology Annual Conference, January 1977.

Jones, E.L. 1978 'Disaster management and resource saving in Europe: 1400-1800' Paper presented to Seventh International Economic History Congress, Edinburgh, August 1978.

Janis, I.L. 1972 Victims of Groupthink Boston, Houghton Mifflin.

Kennedy, I. 1980 'Unmasking Medicine' 1980 BBC Reith Lectures The Listener November 1980-December 1980.

Lentner, H.H. 1972 'The concept of crisis as viewed by the United States Department of State' 112-135 in Hermann ed. op. cit.

Malinowski, B. 1948 Magic, Science and Religion New York: Doubleday.

Mayer, J.E. and A. Rosenblatt, 1975
'Encounters with danger: social workers in the ghetto' Sociology of Work and Occupations 2(3) 227-245.

Mileti, D. 1980 'Human adjustment to the risk of environmental extremes' Sociology and Social Research 64(3) 327-347.

New Scientist 1980 'Nuclear hitches still plague Americans' 88 (1226) 6 November p.351.

Ouchi, W.G. 1980 'Markets, bureaucracies and clans' Administrative Science Quarterly 25(1) 129-141.

Perrow, C. 1980 Organisation Theory in a Society of Organisations Colorado: Red Feather Institute.

Phillips, J.J. 1979 'The unreasonably dangerous product' Trial 15(11) 22-3, 76.

Poggie, J.J., R. Pollnac and C. Gersuny, 1976
'Risk as a basis for taboos among fishermen in Southern New England' Journal for the Scientific Study of Religion, 1976, 15(3) 257-62.

Quarantelli, E.L. ed., 1978
Disasters: Theory and Research London: Sage

Roberts, John M., T.V. Goldner and G. Echick, 1980
'Judgement, oversight and skill: a cultural analysis of P-3 pilot error' Human Organisation 39(1) 5-21.

Rodinson, M. 1974 Islam and Capitalism Harmondsworth: Penguin

Rosengren, K.E., P. Arvidson and D. Sturesson, 1975
'The Barsebäck panic: a radio programme as a negative summary event' Acta Sociologica 18(4) 303-321.

Rosenkrantz, B.G. 1979 'Damaged goods: dilemmas of responsibility for risk' Milburn Memorial Fund Quarterly 57(1) 1-37.

Ross, M. 1980 'The deadly warnings of disaster prophets' *Now!* July 25-31, No. 46. 57-63.

Rubin, I.S. 1979 'Some notes on public institutions and universities under conditions of scarcity' *Sociology of Education* 52(Oct) 211-222.

Schechter, H. and C. Moleson, 1978
'"It's not nice to fool mother nature": the disaster movie and technological growth' *Journal of American Culture* 1(1) 44-50.

Simon, H. 1957 *Administrative Behavior* (Second Edit.) New York: Free Press.

Singer, M. 1978 'How to reduce risks rationally' *The Public Interest* 51 (Spring) 93-112.

Slovic, P., H. Kunreuther and G. White
'Decision processes, rationality and adjustment to natural hazards' 187-205 in G. White, ed., *Natural Hazards: Local, National Global* New York: Oxford University Press.

Slovic, P., B. Fischoff & S. Lichtenstein, 1980
'Facts vs. Fears: Understanding perceived risk' Paper presented to 1980 Meeting of The Royal Society, London, 12 November.

Smart, C., and I. Vertinsky, 1977
'Designs for crisis decision units' *Administrative Science Quarterly* 22 (Dec) 640-57.

Solesbury, W. 1976 'The environmental agenda: an illustration of how situations may become political issues and issues may demand responses: or how they may not' *Public Administration* 45(4) 379-397.

Stech, F.J. 1979 'Political and military intention estimation' Report for Office of Naval Research: Mathtech, Bethesda, Maryland.

Strangert, P. 1977 'Adaptive planning and uncertainty resolution' *Futures* 9(1) 32-44.

Stringer, J.K. and J.J. Richardson, 1980
'Managing the political agenda: problem definition and policy-making in Britain' *Parliamentary Affairs* XXXIII (1) 23-39.

The Times 1980 'Royal Society debates gap between lay and expert views on nuclear risk' 13 Nov. 1980.

Torry, W. 1978 'Disasters, societal risks and interorganisational stresses' Mimeo, Department of Anthropology, University of California, Berkeley.

Torry, W. 1979a 'Hazards, hazes and holes: a critique of The Environment as Hazard and general reflections on disaster research' Canadian Geographer 23(4).

Torry, W. 1979b 'Anthropological studies in hazardous environments: past trends and new horizons' Current Anthropology 20(3) 517-40.

Turner, R. 1967 'Types of solidarity and the reconstitution of groups' Pacific Sociological Review 10 (Fall) 60-8.

Vaught, C. and D. Smith, 1980 'Incorporation and mechanical solidarity in an underground coal mine' Sociology of Work and Occupations 7(2) 159-187.

Waddington, C.H. 1977 Tools for Thought London: Cape.

Weick, K. 1969 The Social Psychology of Organising Reading, Mass: Addison Wesley.

Williams, R. 1977 'Governmental response to man-made hazards' Government and Opposition 12(1) 3-19.

Williams, R. and D.V. Bates, 1976 'Technical decisions and public accountability' Canadian Public Administration 19: 603-632.

Williamson, O.E. 1975 Markets and Hierarchies: Analysis and Antitrust Implications New York: Free Press.

Zohar, D. 1980 'Safety climate in industrial organisations: theoretical and applied implications', Journal of Applied Psychology 65(1) 96-102.

Zohar, D., A. Cohen and N. Azar, 1980 'Promoting increased use of ear-protectors in noise through increased information feedback' Human Factors 22(1) 69-79.

IDENTIFYING REFERENCES

1. Turner, B.A. 1978: 160-188 : Man-Made Disasters London, Wykeham

2. Turner, B.A. 1978: 180 : Man-Made Disasters London, Wykeham

3. Turner, B.A. 1978 : Man-Made Disasters London, Wykeham

4. Turner, B.A. 1979 : 'Surprise' Paper presented to the fourth EGOS Colloquium on Organisational Studies, Noordvijk aan Zee, Holland, June 1979.

SOCIETY AND PROBLEM-ORIENTED RESEARCH: ON THE SOCIO-POLITICAL FUNCTIONS OF RISK ASSESSMENT

J. Conrad

Battelle e. V.,
Frankfurt-am-Main, FRG

This paper critiques the usefulness of decision analysis as a conceptual framework for managing societal risk problems. This type of scientific approach, although very useful in structuring specific problems, does not take into account the political aspects of the process. A conceptual frame of reference is proposed which views risk assessment in a somewhat broader societal context than that implied by decision analysis. The paper concludes by examining the sociopolitical functions of risk assessment in recent debates on new technological developments.

"Rather than being something that is inherent in the external world, risk and its absence are qualities that are conferred upon it by social processes. These social processes, as they set down others that have no counterpart in physical reality, create a fluctuating pool of risks somewhere between us and the universe. Since any debate about risk must take place within a social setting, it will inevitably be a debate about the properties of this fluid pool. Anyone who claims that it is not - that it is about the concrete expanse that lies somewhere beyond this pool - is falsely claiming to be a 'cosmic exile'" and
"Risk, though it has some roots in nature, is inevitably subject to social processes. Since we (being members of society) are at one end of these processes, we can never gain access to the raw unprocessed reality. Whether we like it or not, the risks to which we have access are processed risks." (Thompson 1980: 18).

So risks do not constitute independent objective facts but are moulded and defined in processes of social communication; risks are neither "right" nor "wrong", "small" or "large", but depend in their qualifications upon the consensus of those concerned, which usually prevents the development of a common standard for risk comparison. The acceptance or non-acceptance of risks change in the course of time; this may lead to accepted daily routines of the management of risks previously perceived as extraordinarily dangerous just as to an increased sensitivity to risks people were formerly unaware of. (cf. Bechmann/Frederichs 1980a).

Thompson goes on: "If only we concede that this is so, and stop pretending that we can get at the risks before they have been processed, then we can begin to understand something about them - we can begin to understand the processes of which they are the endproducts. And the first thing that we must understand is that these processes have very little to do with the individual as an isolated entity; they demand very little of his innate sensory apparatus but a great deal of his socially-acquired referential apparatus. They are pre-eminently social processes."(Thompson 1980:18)

This is not to deny the value of formal sciences and approaches. (Mathematics would soon teach anyone better). However, it points to the relevance of social context and societal substance which in the end determine the applicability and utilisation of, e.g., decision analysis.

2 Problems of a decision-theoretical perspective: a concrete example

In his paper, Lathrop describes the decision process around the attempt to site an LNG facility on the Californian coast, where different institutions involved performed or organized their own risk analyses, and where no site has been approved yet, after a negotiation and regulation phase of nearly a decade.

Lathrop's conclusions which are important in this context are the following:
"Beyond differences in how risks are evaluated, political organisations cope with the uncertainties inherent in risk management in ways very different from that assumed in typical risk assessments." (Lathrop 1980: 8)
"These political decision making processes do not take the probabilistic perspective of the risk analyst, are not ready to incorporate uncertainty into risk evaluation in any way resembling the expected utility approach, and refuse to explicitly trade off risk to life and limb against any other dimension." (Lathrop 1980: 9)
From the viewpoint of systems theory, which in principle is still a formal theory about society, this appears quite natural and unavoidable. Every output of one subsystem processed for utilisation in another one inevitably undergoes a transformation. So even if technical analysis is taken into account in the economic or political or family decision-making process, it loses its purity and receives an economic, political, religious, etc. 'mark' and meaning. That is, scientific advice will be transformed and used according to non-scientific criteria of other social systems. To hope to avoid or to counteract this transformation process is politically naive. And to have the technical analysis done in one's own subsystem, e.g. the politico-administrative system - let's assume this possibility - overlooks and denies the advantages and consequences of processes of societal differentiation. Not all scientific research can be done in the political

system, for instance. At least, de-differentiation has its price. (Certainly, another possibility is the rejection of systems theory as an adequate concept of features of (modern) society. But the results of Lathrops's case study - and many other examples as well, to be sure - seem to indicate the contrary.) Lathrop goes on:

"The most serious problem in the use of a decision analytic siting evaluation model, such as the one proposed by Keeney (1980c), is that the decision structure assumed by the model does not match the institutional structure making the siting decision." (Lathrop 1980: 10)

In view of all the agencies with different objectives involved, "it becomes very hard to identify any single self-aware decision-making process where all the trade-offs were made. To be sure, the overall process results in some decision, which can be analysed as being consistent with particular implicit trade-offs, but any similarity between trade-offs consciously made and those inferred is likely to be simply fortuitous. It is not clear where a decision analytic evaluation model would fit into such a process, whose trade-offs should be used to set the parameters, or even to whom the analysis should be delivered."(Lathrop 1980: 11)

Also, "no analysis was used in turn to aggregate this range of analyses into summary measures to guide the setting of the remote siting constraint. The drafting of the legislation was a matter of examining the range of analyses, then making direct intuitive judgements as to the most appropriate constraint. In this case, then, analyses were used in the drafting of legislation, but only for very low-level inputs that were not very directly related to the costs and benefits involved in the actual decision." (Lathrop 1980: 11)

Again, the old problem of decision theory is encountered which means that there is no single decision-making or consistent decision-making body and that it is hopeless to develop any kind of "algorithm" to aggregate different - maybe "rational" - analyses in an analytical way. Consequently, there is no way of achieving an all-embracing risk-benefit decision algorithm in politics, at least as long as the limiting conditions of complete consensus or of total manipulation in a society do not exist. In other words, the subjective rationality of action and system rationality never coincide. (Naschold 1971)

"The actual outcomes of environmental policies are influenced more by the institutional arrangements, and by people's attempts to manipulate them in their own interests, than by the technical characteristics of the instrument used." (von Winterfeldt et al. 1978: 8).

Now, what are the (research) recommendations of Lathrop? "Extend the scope of risk evaluation measures to account as much as possible for societal concerns." And, more specifically, "Future research should seek to close that gap by developing hybrid risk evaluation aids that are sensitive to societal concerns, yet provide clear risk management decision aids."

"Develop risk management decision aids that are compatible with the essentially non-probabilistic orientation of the political decision maker."

"Examine analytic techniques for aggregating the results of several different analyses, and select and adapt the most promising ones for use in the political process." (Lathrop 1980: 13)

Such a research direction, from my point of view, does not take really into account the basic problem involved, both as a methodological and a sociological one, which has often been discussed (cf. Naschold 1971, Conrad 1978). The dependence on the <u>specific</u> context of risk judgements implies that "every human action or inaction involves some risk, but also that the risk form any given action will tend to ramify, more or less strongly, through all other areas of human experience. Therefore, the hope that one can give a taxonomy, evaluation and finally technical fix to the problems of risks, is in substance as ambitious as the programme of putting all of human experience and value on to a scale of measurement, for mathematical or political manipulation." (Ravetz 1980: 6)

So, sarcastically speaking, the rationality underlying these suggestions is one which allows for continuous and endless research.

I certainly admit the usefulness of the tools of decision analysis or of simulation models. My main concern is to put them into perspective. I agree that the ways and means of bridging the gap between science and politics and administration can be improved, including the use of formal skills and instruments. And I believe in the possibility of theoretical reconstructions of political processes which in turn can guide political decision-making.

I doubt, however, that scientific analysis can essentially replace politics, that the focus on one aspect, on one problem dimension, such as risk - I assume that one does not intend to bring in all other aspects through the backdoor again, as indicated in the citation from Ravetz - will give technical analysis and formal methods of aggregation real weight, and that formal models and methods, like decision analysis do have a great chance to play a major role in political practise. Even if we assume that we are able to take into account all important aspects and process dynamics, the necessary complexity of such a model and its requirements for decomposition in the specific case are usually always inferior to the concrete experience, intuition and aptitude of the practitioner, given the time constraints in politics. (An analogous example is the minor practical relevance of formal methods in research management and the setting of research priorities.)

"It is impossible to model uncertainties and trade-offs in detail and at the same time consider a highly dynamic and interactive decision process." (von Winterfeldt et al. 1978: 68). So, the conceptual frame offered by decision theory and other approaches is more important than their case-specific utilisation in every detail for the decision maker.

"Such models can never substitute for good judgment and decision making, but they can clarify and provide a basis for communication." (von Winterfeldt et al. 1978: 70).

It should be added that my treatment of Lathrop's paper could not do justice to it, as I just took out these points to have a straw man to illustrate my criticisms.

3 Conceptual frame of the polity

Perceiving risk assessment, at least as far as we are concerned with this subject here, mainly within the scope of the interaction processes of science and politics. I'm now going to sketch those structures and processes of which risks are the end-products or outputs, as cited above.

Let me say first some words about my conceptual framework for policy analysis originating from politico-economic and systems-theoretical approaches of political theory - which clearly has to be understood only as an analytical model.

Problems of politics are generated in society and are transferred in the field of politics to be worked up and treated there. Thus, the polity does not define its socially relevant problems itself but essentially reacts to problems of system and social integration and their mediation (see Lookwood 1964 for an explanation of these terms). In western industrial societies, these problems are strongly determined by the structures and the dynamics of capitalist forms of socialisation (Vergesellschaftung in German). "Politics" as organised processes of decision-making can not be reduced to coercive relationships, to integration of social norms and values, or be interpreted according to a market and exchange model. Instead policy implies thematising, organising and treating problems of social and system integration abstracting from objectives and aims and without an inherent logic in the sense of a principle opportunism (prinzipienfester Opportunismus in German, Luhmann 1970), what puts any substantiated policy concept, which is based on rational-scientific principles of organisation, into question. The particular achievement of politics is precisely to treat ends as well as means as contingent. Moreover the actors follow their interests according to opportunities and the situational context without accepting any commitment to specific rules, norms or tasks. Neglects, omissious, injuries which rise inevitably under these circumstances are periodically "removed" via political crises. Themes for the treatment of which the political agencies and bodies could not organise time, means and consensus reach the practically relevant sphere of political attention because of their greater actuality of conflict and crisis. Therefore, the problem of politics is mainly to keep up the flexibility of its mechanisms of selection.

In order to be able to deal with and to manage social problems and conflicts the political system needs a certain autonomy in the social, substantial and time dimension. The political system needs (a limited amount of) time to establish its own information and conversion processes; it has to be reasonably acknowledged and accepted by its societal environment and it has to produce outputs fairly continuously which have their customers and clients; it must not be opposed to only one closed power in its environment but needs dependencies from different relevant environments which can be selectively called on, used and outbalanced against one another.

The state in capitalism, separated from economy but determined by it in many respects is not the central decision-making system of society but one of several primary social subsystems.

"The following determinants of political decision-making in general, i.e. of all policies, have to be stressed in particular:

1) The political system is by no means autonomous in choosing its tasks and ends. It is more reactive in character than active.
2) There are not only general (human), but also specific informational limits affecting political decision-making, which mainly result from the decentralised structure of capitalist economy to which policy-making refers and is bound.
3) The political system is basically dependent on fiscal resources to be extracted from the production process

('growth dividend'). This extractability is not unlimited, and this fact results in various determinations of political decision-making.

4) Another limitation of political decision-making stems from the ever precarious power base of the political system. It has to execute its decision and although the system is also producing legitimation (cf. Luhmann 1969), social compliance cannot be regarded as unlimited." (Ronge 1980: 221).

"From a methodological point of view, the state's determination is far more one of structure - i.e. it is 'built-in': we speak of withinputs, non-decisions, and inherent selectivity or bias - than one of intentions and activities. And it is exactly this fact which makes all decision theory approaches to politics so inadequate. To state it with a little overstress: policy-making is more than, and different from, political decision-making". (Ronge 1980: 222).

In the various phases of a policy cycle - problem perception, problem definition, policy and program formulation, decision, implementation, feedback and evaluation - the political bodies can use cognitive, normative and coercive/repressive as well as reflexive strategies, i.e. non-policies and metapolicies, using their two essential media: money and law - financial and juridical instruments.

So far a rough sketch of my conceptual framework for policy analysis which will be applied later to the case of risk assessment. I don't think real world politicians behave exclusively in accordance with this concept, just because they never are only politicians. I assume, however, that the concept reflects the more basic generalisable characteristics of politics in a bourgeois society.

From such a point of view it becomes immediately clear that task-oriented systematic decision aids like risk analysis and evaluation can achieve only a minor political status, as

reported by Lathrop for the LNG-facility-siting-decision process. Similarly Winterfeldt et al. (1978: 67) state:
"While policy analysis can provide a broad picture of the standard setting problem, the decision and game theoretic models developed are meant to aid regulators in finding good solutions once a specific subproblem for standard setting is identified. Specific here means that pre-decisions have been made about regulation alternatives, objectives, and possibly information sources to be used in the standard setting task."

On the other hand, it is questionable how much further a more general formalised (decision) model could proceed which would take into account my qualitative description of the political process, since it would be a very abstract one with little help for practical purposes where the specific situational circumstances matter.

4 Structures of problem-oriented research

In comparison to normal disciplinary science, problem-oriented research usually does not have the strong internal cognitive guidelines, characteristic of the former one. Problem-oriented research centres on externally defined problems.
"The communication relationship of the ... scientists organised about a common problem field is a particular form of scientific public. For all its participants it creates additional reference persons outside the academic cultures of their own disciplines (or, for that matter, their companies or authorities). This stabilises the problem orientation of their work. It also ensures reputation for their research, even by criteria of social relevance. In a certain sense, this community manages the interdisciplinary character of problem treatment.
This leads to a 'forum at which conflicts can be made visible about the relevance of specific targets and strategies for underlying common problem' (op. cit., p. 246). Apparently, such problem communities are indicative of 'a new social organisation of science in which research is neither tied to the rules of a disciplinary matrix nor fixed to specific political or industrial projects, but can deal with the implications of a given problem in relative independence' (op. cit., p. 248)."(Frederichs 1980: 125 f; innercitation: Böhme et al. 1978).
Certainly, there is always a tendency towards a certain degree of autonomy in scientific communities in problem definition, analysis and theoretical integration at the cognitive level, as well as in the recruitment of scientists, the judgment of scientific work and the distribution of reputation at the social level as can be derived from the principles of functional differentiation of society, as indicated elsewhere (Luhmann 1977; 1981). Problem communities are able to reject their instrumentalisation for special purposes by orienting their research towards theoretical conceptualisations of the problem. This requires, however, a common paradigm of the research community. When this is not the case and "an immature field takes on the task of expanding its research effort for

the solution of some urgent practical problem, there will be a tendency for the outcome of its labours to be a weighty argument establishing the conclusions that its sponsors and its public wanted all along." (Ravetz 1971: 399)

Problem-oriented science has to take into consideration the criteria of selection, the problem horizon, the level of abstraction, the possibilities of action and the goal system of the user in order to be potentially useful for practice, and has to reconstruct accordingly the features of the practical problem by using existing scientific knowledge and theories. Applicability is not only a question of selection of themes but also one of the methodical and conceptual integrability of problem structures, of the chosen mode of generalisation and its level of concretisation. The adequacy of these depends critically on the purpose and context of utilisation which shows the normative content of analyses oriented towards application.

On the other hand, the transfer and acceptance of scientific knowledge requires its science-analogous application and the capability for a change in sense by context alteration (Luhmann) by the user. The first point implies a certain rationalisation of practice, since "rationalisation of practise and its adequate scientific reconstruction are mutual conditions." (Kaufmann 1977: 60). The second point means, that "adequate output of scientific research for the political system, for example, requires not only scientific competence but also political competence to be able to use the results of scientific research for political purposes. If this is not the case, scientists will often have no other option but to use the contract as an opportunity to gain access to funds and research fields." (Conrad 1980: 243)

5 Risk assessment as problem-oriented research

I'm now going to describe briefly risk assessment as a problem-oriented research field with a policy consulting function on the basis of the considerations in the two previous sections. "Risk research may be regarded as an attempt to counter, by scientific means, the uneasiness about technological risks now frequently felt in society. The scientific system reacts to this challenge by differentiating a 'problem community' ... However, the basic problem of risk research, namely the problem of creating tolerable risks, has not so far resulted in a clearly defined research program. The heterogeneity of the topics of risks research can be explained in part by its reacting to changes in the risk problems brought about by societal definition processes. Although this sensitivity to societal problem definitions does not favour consistency in the field of research, it is important if advising politicians is regarded as one of the functions of risk research." (Frederichs 1980: 123)

Johnston (1980: 107) has argued "that the form of risk assessment research, its progress or lack thereof, its fragmentation and its political contextuality can be explained by three major characteristics of the field:

1) its goal direction
2) its lack of maturity
3) its reliance on inappropriate models."

Hence, it cannot be said that risk assessment has really created its own specific methods or - in spite of numerous risk conferences and seminars - organised its own scientific community since the publication of Starr's somewhat paradigmatic article more than ten years ago.

On the contrary, an elaborate institutional framework is still lacking. Scientists treat problems of risk and acceptance mainly from the perspective of their own discipline and specialty, e.g. probability theory, decision theory, cost-benefit analysis, utility theory, game theory, system analysis, psychometrics, psychology of perception, operations research, policy sciences, research into participation or survey research. The methods applied are those used in the areas of technology assessment, cost-benefit analysis and decision analysis, which form the analytical frame for risk assessment (Slovic et al. 1977). No genuine theoretical approach, such as is necessary for an independent but finalised field of science is discernible, and heuristics predominate. Therefore, it seems that risk assessment as an area dealing mainly with hazardous outcomes of technologies and their consequences, i.e. with problems defined by society, has no real prospect of forming a finalised specialty and a problem community as long as there exists no common cognitive, action-guiding paradigm integrating the different aspects of practical risk problems. The formal concept of risk is not really able to cover psychological and social dimensions. Thus, the view is more appropriate that "risk research is partly a reaction to the societal actualisation of the risk problems involved in large-scale technology, but its development also appears to be influenced by the course of those societal definition processes which shape the risk problem. The interest of risk research in the phenomena of individual or societal risk acceptance, which has been added to the scientific goal of developing objective risk criteria, may be taken as an indication of the reaction capability of research to societal problem definitions." (Frederichs 1980: 128)

In this perspective, risk assessment is <u>first</u> the outcome of some general societal development trends such as the increasing importance of safety/security as a social value due to societal processes of functional differentiation (Kaufmann 1973) and the spread of large-scale technologies.

<u>Second</u>, perhaps, the results and not only the (diffuse) desire to obtain useful results contribute to be establishment of risk assessment research.

Depending on the perspective it is possible to interpret the present situation - and we may again take the example of the LNG-facility-siting in California - either by inferring that the current political decision making processes are not (yet) rationalised enough to really enjoy the fruits of risk assessment studies or that risk research has not (yet) reached the maturity and relative autonomy and independence of a productive problem-oriented research field to supply socially useful results.

According to my concept of politics, it is clear that I prefer the latter viewpoint. However, this does not mean that risk assessment can not provide useful information. Yet if accepted (standards of) risks are the outcome of complex social system processes following other criteria, risk assessment cannot do more than provide data and information which may or may not be used in the context of (political) decision-making processes, including insights into the treatment and management of risks in these processes themselves. Owing to the immaturity of risk research, these data and information can easily be put into question, depending on the interest of those involved.

Certainly, in specific technical contexts, risk analysis may well guide decisions about safety measures, etc., such as airplane construction and development, chemical plant, nuclear installations. These are contexts where the usefulness of risk assessments has already been proven and can be assumed, although some doubts can be raised also in this case (cf. Mazur 1980). But in the wider political context the value of risk assessment will probably remain rather limited, especially as long as there is no sufficient consensus among the scientists and experts in this field. Only if experts in risk assessment succeed in gaining social acceptance in science as well as by their clients, they may play a mediating role between the science system producing specialised knowledge and the administrative planning and decision-making bodies in society, as can be seen in the institutionalisation of intellectual techniques and novel professions in the areas of planning and consulting. In view of the social features of risk indicated in the beginning, however, the probability of such a development should not be overestimated.

6 Sociopolitical functions of risk debates

If the policy-guiding (technical) role and the analytical importance of risk assessment are rather limited, one may wonder if there are other reasons which can explain the prominent role of risk in public and administrative debates in recent times.

One possibility is, of course, not to search for other functions of risk assessment, but simply to explain the fact genetically. Historical analysis and reconstruction obviously can trace back the origin and development of the risk subject quite well (cf. Mazur 1980, Conrad/Krebsbach-Gnath 1980a, Bechmann/Frederichs 1980b). However, every historical reconstruction uses theoretical concepts which first permit the selection of events, the construction of paths of development, the formation of consistent images, the explanation of the exclusion of alternative historical developments, etc. Thus it is worthwhile to look explicitly for possible functional relationships which help us understand the role of risk assessment on a structural level.

The first point I want to mention is well-known: the rise of risk assessment research is strongly connected with the nuclear energy controversy. Since the substantive contributions of risk analysis to the safety of nuclear installations are not sufficient to explain the prominence of the risk issue in the debate, another function, which is not covered by the actual approach resulting from a decision analysis viewpoint, appears to be more significant.

Risk represented for a long time the topical focus from which the controversy gained its momentum. Owing to the characteristics and richness of the risk problem in technical and cognitive terms, in the focus of technological controversies is frequently the question of risk. Risk is the common element on which every public discussion is centred but without necessarily covering all the dimensions at the bottom of the controversary. "A subject of this kind does not cristallise by chance but depends on the degree to which it enables opposing views to be articulated and can be used as an instrument to define one's own standpoint." (Frederichs/Loeben, 1979: 9). From this it follows that it is neither meaningful to try to reach agreement on the subject of risk nor is such agreement to be expected as long as the more general context in which risks arose and the background of conflicts in the field of technology policy remain valid. In this context the discussion of risk assumes first and foremost the function of a ritual:

- it serves as a means of coming to terms in symbolical terms with the potential dangers of the technology in question which cannot be eliminated in reality;
- in many cases it conceals other, more central dimensions of the conflict surrounding large-scale technologies;
- it allows conflicts to be carried out in an increasingly ritualised form (e.g. in law suits).

Another function of risk assessment can be derived from its explicit role of scientific policy consulting. Operationalised for the purposes of safety research and technology, such a risk concept shifts the debate into a field which requires specific competences. The necessary skills to understand or even to perform these formalised and often sophisticated approaches of risk assessment priviledge the expert and - to a certain degree - the bureaucrat. As a result, besided the substance of the argument in risk debates, the formalised and scientific (scientifically dressed) character of the debate already introduces a bias into it. The lay public can either trust the results of the experts' calculation and reasoning or has to look for counter experts in order to raise critical points. In any case it is dependent on the expert. This situation is not unique in the area of risk assessment, but only confirms a more general trend of development. The backing by technical expertise is expected to also provide the necessary legitimation for administrative decisions via the aureola of scientific justification and objectivity. In the nuclear controversy, in particular, risk figures and comparisons show nuclear power in a very favourable light. However, it turned out that scientific expertise does hardly fulfill any longer this legitimatory function in technological controversies and is reduced to just one more weapon in a political arsenal (Nelkin 1979, Nowotny 1979, Conrad 1981). On the contrary, the prestige of science itself is suffering in this process. The development of the whole Inhaber story - i.e. not only the Inhaber report itself but the disputes and tactical moves afterwards - is a real good example for demonstrating all these socio-political functions of risk assessment. It also shows how the respective social context determines the function of risk assessment studies.

One final function should be indicated: with the diminishing significance of the risk issue as a symbol and ritual in the (nuclear) energy debate, it appears to bear a growing transfer function: other technologies are caught up into the whirlpool which contributes to the continuity and spread of risk debates.

7 Conclusions

These reflections on probable social functions of (public) risk debates hopefully have illustrated somewhat why it can be politically short-sighted and even dangerous to focus (exclusively) on the analysis and improvement of risk assessment in a methodological or technical sense, if aimed at its utilisation and implementation in political decision-making. The neglect of power, of structural withinputs and selective filtering mechanisms in the political process, the disregard of implications and restrictions of the established differentiation of science and politics lead either to an overestimation of the possibilities of systematic (hierarchical) problem solutions for realisation, justified neither methodologically nor theoretically nor empirically by social practice, or to a theoretical helplessness which could also be a conclusion from Lathrop's description of decision processes about facility siting.

From the point of view of politics the substantial results of risk assessment studies may be of (some) importance, certainly; the political utilisation of these studies, however, inevitably provides them with a political "stigmatisation", which changes their character just because of the other context, and other functions of risk assessment often will play a more important role.

References

Bechmann, G., Frederichs, G., Vom Risikobegriff zur Akzeptanzproblematik der Kontroverse um die Kernenergie, Ms. Karlsruhe, (1980a)

Bechmann, G., Frederichs, G., Orientierungsprobleme der Risikoforschung im Konfliktfeld von Wissenschaft und Öffentlichkeit, Ms. Karlsruhe (1980b)

Böhme, G., van den Daele, W., Hohlfeld, R., Finalisierung revisited, in: Böhme, G. et al (eds.) Die gesellschaftliche Orientierung des wissenschaftlichen Fortschritts, Frankfurt a.M. (1978)

Conrad, J. Zum Stand der Risikoforschung, Battelle, Frankfurt a.M. (1978)

Conrad, J., Society and Risk Assessment: An attempt at interpretation, in: Conrad, J. (ed.) Society, Technology and Risk Assessment, London, (1980)

Conrad, J., On the Structure and Function of Scientific Expertise in Technological Controversies: The Cases of Nuclear Power and Genetic Engineering, Ms. (1981)

Conrad, J., Krebsbach-Gnath, C., Zum gesellschaftlichen Umgang mit technologischen Risiken, Zeitschrift für Umweltpolitik 3: 821 (1980a)

Conrad, J., Krebsbach-Gnath, C., Technologische Risiken und gesellschaftliche Konflikte. Politische Risikostrategien im Bereich der Kernenergie, Battelle, Frankfurt a.M. (1980b)

Frederichs, G., Risk Research - A "Problem Community" and its Role in Society, in: Conrad, J. (ed.) Society, Technology and Risk Assessment, London (1980)

Frederichs, G., Loeben, M., Die Akzeptanzproblematik der Kernenergie, Kernforschungszentrum Karlsruhe, (1979)

Johnston, R., The Characteristics of Risk Assessment Research, in: Conrad, J. (ed.) Society, Technology and Risk Assessment, London (1980)

Kaufmann, F.X., Sicherheit als soziologisches und sozialpolitisches Problem, Stuttgart, (1973)

Kaufmann, F.X., Sozialpolitisches Erkenntnisinteresse und Soziologie, in: von Ferber, Ch., Kaufmann, F. X. (eds.), Soziologie und Sozialpolitik, KZfSS Sonderheft 19, (1977)

Keeney, R.L., Siting Energy Facilities, New York/London, (1981) Lathrop, J.W., The Role of Risk Assessment and Facility Siting: An Example from California, IIASA-WP-80-150, Laxenburg (1980)

Lockwood, D., Social Integration and System Integration, in: Zolschan, G.K., Hirsh, W., (eds.) Explanations in Social Change, London, (1964)

Luhmann, N., Legitimation durch Verfahren, Neuwied/Berlin (1969)

Luhmann, N., Soziologie des politischen Systems, in: ders., Soziologische Aufklärung, Opladen (1970)

Luhmann, N., Theoretische und praktische Probleme der anwendungsbezogenen Sozialwissenschaften, in: Wissenschaftszentrum Berlin (ed.), Interaktion von Wissenschaft und Politik, Frankfurt a.M. (1977)

Luhmann, N., Die Ausdifferenzierung von Erkenntnisgewinn: Zur Genese von Wissenschaft, in: Stehr, N., Meja, V. (eds.) Wissenssoziologie, KZfSS, Sonderheft 22 (1981)

Mazur, A., Societal and Scientific Causes of the Historical Development of Risk Assessment, in: Conrad, J., (ed.) Society, Technology and Risk Assessment, London (1980)

Naschold, F., Systemsteuerung, Stuttgart, (1971)

Nelkin, D. (ed.) Controversy. Politics of Technical Decisions, Beverly Hills/London, (1979)

Nowotny, H., Kernenergie: Gefahr oder Notwendigkeit, Frankfurt a.M. (1979)

O'Riordan, T., Environmental Impact Assessment and Risk Assessment in a Management Prospective, in: Goodman, G., Rowe, W.D., (eds.) Energy Risk Management, London (1979)

Ravetz, J.R., Scientific Knowledge and its Social Problems, Harmondsworth, (1971)

Ravetz, J.R., Public Perception of Acceptable Risks, in: Dierkes, M. et al.(eds.) Technological Risk: It Perception and Handling in the European Community, Cambridge/Mass. (1980)

Ronge, V., Theoretical Concepts of Political Decision-Making Processes, in: Conrad, J., (ed.) Society, Technology and Risk Assessment, London (1980)

Slovic, P., Fischhoff, B., Lichtenstein, S., Risk Assessment: Basic Issues, in: Kates, R.W. (ed.) Managing Technological Hazard: Research Needs and Opportunities, Boulder (1977)

Thompson, M., An Outline of the Cultural Theory of Risk, IIASA-WP-80-177, Laxenburg (1980)

von Winterfeldt, D., et al, Procedures for the Establishment of Standards. Final Report Volume I, Laxenburg (1978)

PART II

RISK ANALYSIS ISSUES

REFLECTIONS ON RISK ASSESSMENT*

Alvin M. Weinberg

Institute for Energy Analysis,
Oak Ridge Associated Universities,
Oak Ridge, TN 37830

Even perfect knowledge of the dose-response at low levels of exposure (and therefore risk) does not resolve the problems of setting standards. This paper discusses that in any case de minimus (or threshold levels) ought to be the guiding principle for setting standards to the extent that the costs of hazards can be internalized. The role of the market mechanism in establishing the de minimus standard ought to be acknowledged.

*Reprinted with permission from *Risk Analysis*, Volume 1(1), 1981, pp. 5–7.

More than 10 years have passed since Chauncey Starr published his famous paper in *Science* in which he proposed that the assessment of risk posed by technology might be amenable to quantitative analysis.[1] Many papers and books have since appeared that have analyzed and reanalyzed the assessment of risk from the points of view of the technologist, the systems analyst, the decision analyst, the psychologist, and the philosopher. Though I do not claim intimate acquaintance with this literature, I have read enough of it to convince me of the usefulness both of careful analysis of the way in which risks are actually assessed, as well as more abstract study of underlying methodologies. I therefore welcome the new journal, *Risk Analysis*, where practitioners of the art of risk assessment can exchange their views and results.

I use the word "art" intentionally: I can hardly conceive of large parts of risk assessment becoming a science. This is not to say that careful analysis of underlying assumptions that go into risk assessment is fruitless; or that careful observation of damage caused by large insults is not a part of science. But there are, and will always be, strong trans-scientific elements in risk assessment. We should be prepared to recognize these, and accept them.

William W. Lowrance in his paper, "The Nature of Risk," identifies six classes of hazards: (1) infectious and degenerative diseases; (2) natural catastrophes; (3) failure of large technological systems; (4) discrete, small-scale hazards; (5) low-level, delayed-effect hazards; and (6) sociopolitical disruptions.[2] Most of risk assessment today is focused on (3), failure of large technological systems, and on (5), low-level delayed-effect hazards. Both of these I would classify as "rare events" because in neither instance is it practical to build enough nuclear reactors or DC-10's to observe the failure rate, or to conduct experiments on a sufficiently large scale to actually see a response at very low dose. To be sure, in the case of DC-10's and reactors, event-tree analysis can yield estimates of overall failure rates; but these rates are extremely small. Thus the most powerful method of science—experimental observation—is inapplicable to the estimation of overall risk in exactly those instances where public policy most demands assessment of risk. This intrinsic uncertainty is reflected in the bitter controversy that rages over the safety of nuclear reactors, or over the use of the strict linear hypothesis in setting standards for low-level exposure to carcinogens and mutagens.

Much of *Risk Analysis* will be devoted to refining and quantifying our estimates of risk in situations where exposures are large and quantification is possible—where risk analysis is indeed part of science. But if one concedes that in the more important cases of small exposures or rare events there are essentially unknowable elements in risk assessment, we are still left with the practical problem of setting standards of acceptable risk. How do we decide what is an acceptable risk in circumstances where the assessment of risk is beyond the proficiency of science, that is, is trans-scientific?

Arbitrary elements obviously must creep into standard-setting when the risks themselves are so hard to assess. But, if we are honest, we must admit that even when the risks *can* be quantified, the setting of standards is intrinsically a political act—that is, the standards themselves must in final analysis be arbitrary, or must invoke some principle that goes beyond mere quantification of the risk. Thus we now believe that the 55-mph speed limit saves several thousand lives per year. Why not reduce the speed limit further since even more traffic fatalities would thereby be avoided? We chose 55, rather than 50 or 60 mph, not by applying an elaborate cost-benefit calculus, but by a political process.

No manipulation of cost-benefit calculus can obscure this essential arbitrariness in setting standards of acceptable risk, even when the risk itself is accurately known. Would it not be more straightforward, then, to invoke some strategy other than cost-benefit analysis upon which to base standards, especially in those situations where the risks are unquantifiable?

One such possibility is the invocation of a *de minimis* principle: Below a certain level of exposure or insult, we shall simply accept whatever residual risk is incurred; we only assure ourselves that the risk is "small." The arbitrariness lies then in deciding what is a *de minimis* exposure, whether to radiation, or chemicals, or other insult, that results in a "small" risk.

Where the insult is a manmade addition to an existing background, as is the case for radiation, an exposure "small" compared to the natural background seems to me to be a sensible standard, much more sensible than a standard based on futile attempts to compute the number of casualties caused by the existing and ineradicable background and then striking an arbitrary balance between cost and benefit.

The issue hangs around the definition of "small" compared to natural background. Here I am taken by H. Adler's suggestion that "small" be defined as the standard deviation of the natural background.[3] For low LET radiation, in the continental United States, this amounts to about 20 mr/yr: This is close to the 25 mr/yr limit set by the Environmental Protection Agency for allowable exposure to effluents from the nuclear-fuel cycle.

The essence of this approach to setting an acceptable *de minimis* level is comparison of risks—in this case the risk of manmade radiation compared to background radiation. We make the implicit assumption that background radiation poses an acceptable risk, whatever that risk may be (and which we do not try to quantify). An exposure that is small compared to this is *a fortiori* acceptable. Can this principle be extended to risks for which there is no natural background? A possibility that deserves consideration is first to evaluate the risk, say of a chemical for which a standard is required, against the risk of radiation at sufficiently high levels of exposures that the risks of each can be unequivocally determined. One could then invoke a principle of consistency: The allowable exposure to the chemical in question should cause no more damage than that caused by the *de minimis* level previously set for radiation. The damage caused by the *de minimis* level for radiation and for the chemical in question is determined by the linear hypothesis. To be sure, this scheme invokes the linear hypothesis against which I have often inveighed: but it invokes it in "weak" form—not as an estimator of damage, but as a means of comparing two, essentially unknowable, risks.

Though I find the previous proposals attractive in principle, and I sense that *de minimis* is being talked about in the standard-setting community, I am left with an uneasy feeling that such proposals leave out an essential reality: that standards must always be set in a social matrix. Where the standard setter finally comes out is inevitably influenced by the social milieux in which he operates. Can the social structure in which standards must be set actually be exploited to arrive at more sensible standards? The Soviet Union and the United States represent the two extreme social structures: a centrally planned system and a market system. On the whole, standards set in the Soviet Union for, say, radiation exposure, resemble those in the United States; the glaring exception is microwave exposure levels which, in the Soviet Union, are considerably lower than in the United States. On the other hand, U.S. nuclear reactors have been enclosed in containment vessels since the beginning; Soviet reactors until recently have had no containment domes. Thus it would not be easy to attribute to the one system or the other a greater concern for the public's safety.

This flies in the face of some currently fashionable doctrine: Socialist systems, not concerned with profit, are supposedly more likely to err on the side of safety than are capitalist societies. That this is not manifestly the case may suggest that an important, and insufficiently recognized sanction exists within our market society to ensure a balance between risks and benefits, between costs and safety.

The risk-benefit balance is really a 2×2 risk-benefit matrix with four elements: public risk, public benefit, private risk, private benefit (Fig. 1). For each technology a risk-benefit matrix can be constructed. For example, in the case of nuclear reactors, the public risks are radiation hazard and proliferation; the public benefit is abundant energy. The private risk is the financial loss, even failure, of the organization responsible for the reactor. (The survival of

	Risks	Benefits
Private	Financial Loss, Company Survival	Profit, Growth of Company
Public	Radiation Hazard, Proliferation	Abundant Energy

Fig. 1. Risk-benefit matrix for reactors.

the Metropolitan Edison Company was placed in jeopardy by the events at Three Mile Island.) The private benefit is profit.

The risk-benefit philosopher (if I can use this description) or those who claim to speak in the public interest, are concerned with the public risks and public benefits. For them a decision as to when a nuclear reactor is safe enough amounts to weighing the risk of excess radiation against the benefit of abundant energy—say reduction in import of oil. The whole theory and philosophy of regulation of risks is, I believe, based on the assumption that only these public risks and benefits are germane to answering the question, "What is safe enough?"

This conventional view neglects the very real, and powerful, sanctions imposed on a manufacturer by the private risks he incurs if his products fail. The heaviest loser at Three Mile Island was the utility and the manufacturer responsible for the reactor. One can expect reactors to be built and operated more safely in the future because, as a result of Three Mile Island, every actor in the nuclear enterprise realizes that unless he operates safely, he can be put out of business. This is powerful medicine indeed: The balance between safety and cost (which is the underlying balance in all setting of standards) will surely be moved toward safety as a result of the accident at Three Mile Island.

Can the market system by itself, without government intervention, be counted upon to strike a proper balance, to maintain public risk at an acceptable level? The simple answer is no—government, that is, nonmarket interventions—will always be needed. But if the *costs* of inadequate safety could be sufficiently internalized—i.e., if designers and managers of enterprises that create and market products or devices that pose risk, could be made sufficiently aware of the private risks they incur if they draw the *private* risk-benefit line incorrectly, I should think we would rather automatically achieve a pragmatic balance between risk and benefit that would be an important adjunct to the balance we now achieve by direct intervention. I do not want to minimize the difficulties that lie in the way of internalizing the costs of inadequate safety. Clearly an informed and concerned citizenry is required if the private sector is to receive signals that are strong enough to affect the balance sheet significantly.

The issue I raise is not part of science, yet it seems to me to be very relevant, if not to the analysis of risk, then to the more practical, related question of how to set standards of acceptable risk. I hope that *Risk Analysis* continues to make room in its pages for dialogue on risk policy. Perhaps more important, I hope those who work on the scientific side of risk analysis will interest themselves in the formulation of policy that flows from their scientific findings.

REFERENCES

1. C. Starr, Social benefit versus technological risk, *Science* **165**, 1232–1238 (1969).
2. W. W. Lowrance, "The nature of risk," in *Societal Risk Assessment: How Safe is Safe Enough?* Richard C. Schwing and Walter A. Albers, Jr., eds. (Plenum Press, New York and London, 1980), pp. 5–17.
3. H. I. Adler and A. M. Weinberg, An approach to setting radiation standards, *Health Physics* **34**, 719–720 (1978).

RISKS OF RISK DECISIONS*

Chauncey Starr and Chris Whipple

Electric Power Research Institute,
Palo Alto, California

The analytical approaches utilized for evaluating the acceptability of technological risk originate from analogies to financial cost-benefit risk analysis. These analogies appear generally valid for viewing risk from a societal basis, but are not applicable to individual risk assessments. Conflicts arising from these different views of risk assessment provide insights to the origins of individual, intuitive evaluations. Societal risk decisions made under conflict represent political compromises, and the resulting decision process creates substantial conflict costs. The pragmatic use of quantitative risk criteria (safety targets) may be useful in reducing these costs.

*Reprinted with permission from *Science*, Vol. 208, 1980, pp. 1114–1119.

Technology creates many risks. Determining which risks are acceptable is an important national issue. It pervades major sectors of our economy: In food production we face decisions about pesticides and preservatives; transportation risks are increasingly regulated; and a central issue in energy policy is the controversy over the risks from power plants. Regardless of whether the seriousness of technological risk is only now being recognized, or, alternatively, that the preoccupation with risk and regulations is an overreaction, it is clear that the cost to society of the conflict over accepting technological risks is great. These costs stem from the anxiety suffered by those who are dismayed by the conflicting information about these risks, and from the litigation, misplaced investment, retrofits, and costly delays that result from industry's inability to predict the acceptance of risk by the public.

Risk assessment is growing in importance as a system design tool. The final configuration of all technical systems is the outcome of a common design sequence. The first task of a system designer is the development of a workable basic concept. The second task is reducing the vulnerability of the system to failures of component parts, including human participants. The final task is balancing the benefits and risks of the new system, starting with the internalized economic costs. The external effects have rarely been analyzed, and it is only in recent decades that we have become deeply concerned with this difficult but important part of the design process.

Risks created by technical systems arise either from routine external effects considered acceptable at the time of design, or from abnormal conditions that are not part of the basic design concept and its normal operation. Most abnormal events usually impair or stop the operation of the technical system, and may threaten the operators. The usual external effect is the loss of operational benefits to the users of the output. The major internal consequences of failures are borne by the operating institution. The timely diffusion within the institution of information about such failures usually stimulates rapid modifications to reduce the ratio of failure costs to benefits. Less frequently, a failure results in effects outside the institutional boundary, creating a public risk—and a potential cost to the public. These external costs are usually difficult to evaluate, and here the informational mechanism for system modification is usually cumbersome and slow. In recent years such modifications have been made because of an increasing public concern over the inherent risks and costs arising from previously acceptable external effects, both occasional and routine. For these reasons, the importance of risk as a design criterion is increasing.

The basic truisms about risk are readily recognized. First, everyone knows that risk taking is an accepted part of life. Living can be fun, but it is also dangerous (just how dangerous can be difficult to measure). Second, everyone reacts differently to risks taken voluntarily and to risks that are imposed by some outside group. Third, decisions imposing risks on us are being made all the time. This results in the fourth truism: a conflict is inherent when a group imposes a risk on others. Historically, such conflicts have been resolved by compromise, but rarely to everyone's satisfaction.

It is, therefore, characteristic of the functioning of an organized society that conflicts arise from the balancing of public benefits and involuntary risks to the individual. Because such conflict is unavoidable, our problem is how to manage and minimize it.

How should group decision processes operate to minimize social costs and maximize social benefits? Group processes range from anarchy to dictatorship. In most of the industrial world, we enjoy a medium between these, but the processes for decision-making have themselves become contentious issues.

Social costs include intangibles, and the question immediately evident is what costs are included and how are they weighted. It is obvious that if we have a decision process, and if we know how to determine costs to the individual, we still have a problem with the full disclosure of all the social costs. What is full disclosure? Do we include the options for societal risk management as part of full disclosure: that is, the cost of the alternatives for managing the risk? Does it include all present events, future events, the people who get the benefits, and the people who bear the costs? We have geographic distributions, time distributions, demographic distributions—all of these are included by the term full disclosure. Where do we draw the boundaries?

Decisions are not made by institutions; the decision process involves people. The government typically works through agencies and committees, so that, in fact, it is a few people in the agencies and a few people on the committees who really decide what happens. How do we allocate the responsibility and the costs of bad decisions? How do we functionally connect authority, responsibility for outcomes, and costs?

After we establish the social costs, how do we set out priorities? How do we determine the relative merits of various outcomes? That is a subject for a separate study, because, of course, value systems depend on culture, background, economic status, and all kinds of psychological factors.

Part of the problem in risk assessment comes from confusions that arise during discussions of the subject—confusions about reality, analysis, and individual perceptions. Reality is what has happened or what will happen. Analysis is a process based on collected data, anecdotal cases, and statistics, any of which may or may not be correct; and, based on these, we invent simplified models to predict an outcome. The result, of course, is a large uncertainty in the predictions.

What is the intuitive perception of the individuals involved? Involuntary risks are perceived differently by individuals. Their perceptions may be far from reality. So, in discussing public acceptance of risk, we have to distinguish between the uncertain reality of what may occur, the uncertain analysis of predicting it, and the variable perception of its potential. Similar confusions exist, incidentally, over social costs and social benefits, which are also involved. As an illustration, who in the year 1900 could have predicted the social costs and benefits of the automobile?

Finally, people's perceptions of probabilities are frequently in gross error. The accident at Three Mile Island proved very little about probabilities of such events. The inadequacy of such single events for providing probability numbers can be explained analytically, but the political response and the public perceptions are often based on single events. So even if a professional group develops analytic answers, it has difficulty persuading the public to accept them.

Recognizing all these difficulties, it is nevertheless important to explore the subject of risk management in order to improve the quality of decision-making.

Analytic and Judgmental Approaches

A question implicit in the term acceptable risk is "acceptable to whom?" Certainly congressional approval of any method for making risk-benefit decisions establishes its legitimacy, but a public consensus is needed to sustain its use. Defining this consensus is difficult because there are technologies that are favored by a majority, or at least by a plurality, but are opposed by extremely motivated individuals and groups (for example, those who fight water fluoridation and nuclear power). Because of our experience with other political issues in which similar divisions of public opinion occur (abortion, gun control), we know that we should not be optimistic over the prospects that a regulatory approach can neutralize these controversies. Problems such as these raise issues, such as the definition of majority versus minority

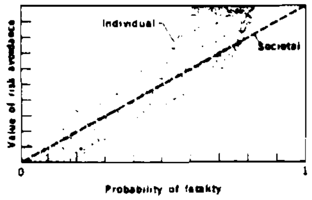


Fig. 1. Value systems for risk.

rights and the scope and limit of due process, that are well beyond those normally associated with risk management.

Congress has not defined "acceptable" risk levels, except for the few cases in which a zero risk approach was mandated. Far more frequently (*1*), Congress delegates responsibility for judging risk acceptability to regulatory agencies with the criteria that protection be provided against "unreasonable" risks. The methods by which these agencies interpret "reasonableness" range from a formal analysis of risk, benefits, and alternatives to purely subjective evaluations.

Analytic Approaches

The attraction of analytic methods (cost-benefit analysis, decision analysis) is their capacity to make explicit the assumptions, value judgments, and criteria used for making a decision. The analytic approaches are considered logically sound and sufficiently flexible to accept any value system. Given a specific set of values and criteria, a cost-benefit analysis could ideally indicate the decisions that would best balance technological risk and benefit (assuming that both tangible and intangible costs and benefits are included). But in reality it is difficult to measure group values, and at best the analytic methods can only be used to reach a rough approximation of the social cost and benefits that characterize a decision.

The debate over the relative merits of these approaches generally focuses on the effects of incomplete information (omitted and uncertain risks, benefits, and values), neglect of distributional effects, and other errors of simplification. It is not our intent to review the merits of these methods as commonly practiced; that has been done elsewhere (*2*-*6*).

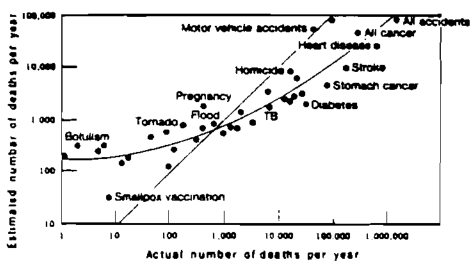
Physical Versus Financial Risk

Because of our use of the term risk as the probability of either financial or physical damage, we may tend to uncritically allow the use of premises about the acceptance of the risk to "life and limb" (*7*) to be based on an analogy to financial risk taking.

From the societal viewpoint, the presumption that risk equals cost may be valid in most cases. For example, the cost of the risk of death is sometimes calculated as being equal to the discounted net earnings of those killed. This method, now out of favor, operates as if the loss of lives were equivalent to the breakdown of productive machines.

Similarly, the value assigned to resilience (*8*) leads to a desire to avoid catastrophic accidents that parallels the strategy in which investments are diversified in order to limit losses under adverse conditions. Perhaps recognizing the differences between these two types of risk, Zeckhauser (*9*) argued that, on a per fatality basis, the social cost of multiple-fatality accidents is lower than that of a single fatality because fewer survivors are affected. For example, the social cost of the loss of a city or a family is less than that of an equivalent number of independent, dispersed fatalities. Although the basis for this argument is apparent, it is also incomplete. For example, it ignores the value placed on the continuation of a family line; the importance of this value is evident in the draft deferment that was given to sole surviving sons. Similarly, Wilson (*10*) noted,

Fig. 2. Comparison of perceived risk with actual risk. [Courtesy of the American Psychological Association]



Small accidents throughout the world kill about 2 million people each year, or 4 billion people in 2000 years. This is "acceptable" in the sense that society will continue to exist, since births continually replace the deaths. But if a single accident were to kill 4 billion people, that is, the population of the whole world, society could not recover. This would be unacceptable even if it only happened once in 2000 years.

Another example in which the ability to generalize from financial cost-benefit analysis has been questioned is when physical risks are distributed across time. Arrow (*11*) argued that these risks should be treated as other costs, and discounted accordingly; other analysts of the issue have questioned the validity of this approach, and looked for alternative methods for guidance on how to judge equity in intergenerational risk trade-offs (*12*).

Application of Expected Value to Individual Risk Assessment

Although the above analogy may be valid for the collective view of the cost of risk, it may not apply to the intuitive evaluation of risk. As Fig. 1 illustrates, the individual and societal evaluations of risk are quite different (*8*). In the societal view, the presumption of a linear relation between risk and the cost of that risk may be quite valid. But as Howard (*13*) pointed out, the individual evaluation of that cost is necessarily nonlinear, and becomes infinite as the probability approaches unity.

The use of an expected value or expected utility model is based on the premise that expected cost is simply the product of the probability of an outcome and the evaluation of that outcome. But in the individual's view of the risk of death, this is not valid, for this product is very large or infinite.

It is often presumed that the individual evaluation of the cost of risk is linear over a probability range of interest (*9, 13*), but there is little firm evidence to support any hypothesis about the shape of this curve, as far as we know. Under the common conventions of risk analysis, the slope of the curves in Fig. 1 is referred to as the value of life. The politicians' old saw that life is of infinite value can be reconciled if this refers to the individual evaluation of one's own life. This viewpoint is not inconsistent with the assignment of finite costs to risks: it is the application of an expected value model that is inappropriate for this evaluation.

A second drawback with the application of expected value to individual risk evaluation stems from the tendency

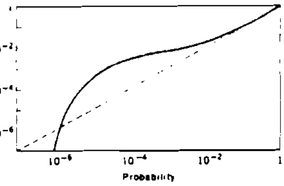


Fig. 3. Perception of probability.

by analysts to seek to accommodate differences of opinion entirely within the assignment of utility (*14*). This is because in most decision or cost-benefit analyses, the probability estimates are considered roughly valid because they are based on available data, engineering models (such as fault trees), and expert opinion. But in a study of public attitudes about nuclear power, the bulk of the disagreement was found to be due to different beliefs about accident probability (*15*). Although it may be perfectly valid to base public policy on expert estimates and data, the attempt to reconcile differences in the assignment of costs and values is misdirected if, in fact, the controversy over technological risk is due to divergent beliefs about probability.

Intuitive Versus Analytical Risk Assessment

We now consider the implications of the premise that risk acceptance is ultimately inseparable from the psychology of risk perception and evaluation. A corollary to this premise is the assumption that when the results of intuitive risk assessments differ significantly from those of the analytical methods, conflict follows.

It seems clear that intuitive and quantitative risk-benefit assessments can produce quite different results, even given the capacity of the analytical approaches to accommodate complex values relating to different risk attributes. The differences of opinion over probability assignments are not limited to those risks for which data are not available; many people intuitively fear travel by airplane more than by automobile, yet aviation is safer. Explanations of this effect focus on the degree of individual control over risk (*16*), the conditional probability of survival given an accident, and the catastrophic nature of airplane accidents (*17*).

The difficulty that arises from these differences in assessment stems from the dual meaning of acceptable risk. The analytical methods help regulators set standards that implicitly define acceptable risk. But the intuitive individual assessments of acceptability can overrule these decisions through the political process. The repeal of the seat belt interlock regulation and recent congressional action to prevent a ban on saccharin are cases in which public opinion resulted in a policy change.

Intuitive Risk-Benefit Analysis

Given the role of individual judgments of (physical) risk and benefit in determining the political acceptability of specific technologies, it seems particularly valuable to try to understand intuitive risk-benefit analysis. Efforts to develop this understanding were made by Starr (*8, 18, 19*), whose approach was based on a study of historically accepted risk (revealed preferences) and by Fischhoff *et al.* (*17*) and Slovic *et al.* (*20*), whose approach was usually based on risk-taking behavior as determined by questionnaire (expressed preferences). An additional source of information is the study by Lawless (*21*) of many controversies over technology. If we assume that many of these controversies arose because of intuitive estimates of unreasonably high risk (not true in all the cases described; some cases, such as the thalidomide tragedy, were due to late identification of a risk), then the common characteristics of risk and benefit in these controversies may indicate important factors in the intuitive risk process. Lawless did this, and his findings confirm those of other studies in identifying catastrophic potential and lack of individual control over risk as "factors that influence the impact of the threat."

Understanding the Intuitive Process

There is an attraction to try to develop an understanding of intuitive risk-benefit decisions by constructing parallels to the analytical methods. This approach leads to a model of intuitive decision-making in which subjective judgments of the probability and consequence of undesirable outcomes are somehow combined to produce a perceived risk; parallel judgments provide a perceived benefit; the two are then compared to provide intuitive judgment of acceptability.

This model is quite broad; it does not specify the intuitive procedures for arriving at either perceived risk or benefit, or for their comparison. Even so, the available evidence suggests that this model may be incorrect. First, studies of intuitive decision-making in general (not limited or applicable to physical risks alone), have identified numerous decision-making rules that do not follow the model described above (*22*). Second, there is evidence to indicate that benefits are not intuitively evaluated independently from risks.

In the survey of subjective risk and benefit by Fischhoff *et al.* (*17*), perceived risk and perceived benefit were negatively correlated, due principally to the subjective evaluation of a number of things as high in risk and low in benefit (handguns, cigarettes, motorcycles, alcoholic beverages, nuclear power). When subjects were asked to judge "the socially acceptable level of risk," those who first took the benefits into consideration consistently reported higher levels of acceptability than did subjects who first evaluated risk, which reinforces the view that risks and benefits are not evaluated independently.

Despite the limitations of the perceived risk–perceived benefit view of deciding risk acceptability, we know of no better way to attempt to understand the intuitive processes for risk decisions. Support for this approach stems from the fact that the acceptability of a risk has been found to increase with increasing benefit both by Starr (*18*) and Fischhoff *et al.* (*17*).

Benefits

Little work has been done to characterize the perceived benefits of technological activities. Starr (*18*) found a correlation between risk and "benefit awareness," which he described as a crude measure of public awareness of social benefits. This measure was based on the relative level of advertising, the percentage of the population involved in the activity, and a subjective judgment of the usefulness of the activity. The survey by Fischhoff *et al.* (*17*) included a subjective ranking of benefits, but no attempts were made to relate perceived benefit with any characteristics of that benefit.

Probability Perception

By far the most studied and best understood component of intuitive risk-benefit analysis is risk perception and evaluation. There is excellent literature on the subjective estimation of probability (*23*).

One aspect of the interpretation of probability that has been noted repeatedly is the intuitive handling of very low probabilities. As Mishan (*7*) noted: "One chance in 50,000 of winning a lottery, or of having one's house burned down, seems a better chance, or greater risk, than it actually is." The same observation was made by Selvidge (*24*). Lichtenstein *et al.* (*25*) found similar results (Fig. 2) when they asked people to estimate the number of fatalities from specific causes annually in the United States: "The full range of perceived risk is only about 10,000 while the corresponding actual range is closer to 1,000,000." Similar results were found in another survey in which risk was ranked subjectively (*17*).

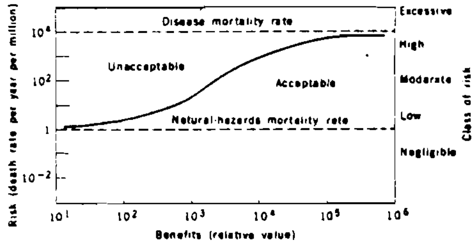


Fig. 4. Risk-benefit pattern for involuntary exposure.

The influence of this perception is important when we recall that the expected value or expected utility model calculates that a change in event probability by a factor of 1000 produces a change in expected value or utility by a like amount. If the probability is perceived as having changed by a much smaller amount, then it would not be surprising to find that an intuitive evaluation of risk is less sensitive to probability changes. This can be extremely important for low-probability, high-consequence risks, because probabilities lying below an intuitively understandable range may be overestimated.

We postulate that this is only true to a point (see Fig. 3). Although we selected these scales judgmentally, their chief purpose is to illustrate that, at some low level of probability, the intuitive interpretation goes from "low" or "unlikely" to "negligible" or "impossible." This hypothesis can be used to explain behavior regarding seat belt use and perhaps smoking. In a study of seat belt use, Slovic *et al.* (*26*) noted that if the decision to wear seat belts is approached on a per trip basis, "we might expect that many motorists would find it irrational to bear the costs (however slight) of buckling up in return for partial protection against an overwhelmingly unlikely accident." They observed that "change of perspective, towards consideration of risks faced during a lifetime of driving, may increase the perceived probabilities of injury and death and, therefore, induce more people to wear seat belts. . . . Such differing perspectives may trigger much of the conflict and mutual frustration between public officials and motorists, each believing (with some justice) that their analysis of the situation is correct." Similarly, Jacobson (*27*) referred to carcinogenic "chemicals which pose minuscule hazards to individuals, but significant hazards to the population as a whole." This last point supports our premise that much conflict over technological risk is due to differences between intuitive and analytical risk-benefit analyses. If the hypothesis that perceived probability is effectively zero for some risks is valid, then the perceived risk of a short automobile trip without seat belts or of one cigarette may be zero.

This nonlinearity in probability perception indicates that even something apparently as basic as the unit of exposure used to evaluate risk can be influential. In his analysis, Starr (*18*) commented, "The hour-of-exposure unit was chosen because it was deemed more closely related to an individual's intuitive process in choosing an activity than a year of exposure would be."

Accepting, at least tentatively, the relation between perceived and actual probability (Fig. 3), we can see a basis for the controversy over catastrophic risks. As mentioned above, high-consequence, low-probability risks are of particular concern if their probabilities are overestimated subjectively. But when part of the public believes the probability is low, and another part believes it to be negligible, these beliefs lead to radically different evaluations. This may be the case with nuclear power and other risks of this type, and may be a key reason for the controversies over these risks.

Risks Distributed over Time

Given the apparent nonlinearities in risk evaluation depending on the unit of measurement, it seems reasonable to look for other perceptual factors related to the units in which risks are expressed.

A number of distinctions can be considered: risks can be immediate or delayed, cumulative or ephemeral, and can affect future generations or our own or both. There is little evidence to indicate how these factors are handled. Fuchs (*28*) cited evidence that individual discount rates for financial and physical risk are positively correlated. But the fact remains that benefits and risk may be discounted at different rates. For decisions with very long-term implications, the use of a variable discount rate, declining with time, may more accurately reflect the value given to future risks and benefits than a constant discount rate (*29*). This is an area that seems particularly worthy of attention, for many risk controversies are about risks that are persistent or cumulative, such as carcinogens.

Predicting Risk Controversies

Because of the work to define the factors influencing perceived risk, it is now possible to anticipate the kinds of risk likely to generate controversy. Catastrophic potential and lack of individual control, particularly once an accident occurs or a risk is identified, are apparently the most important risk characteristics. When the uncertainty associated with risks is great, data concerning the uncertainty not forthcoming, and expert opinion apparently divided, apprehension by the public is understandable. Haefele (*30*) termed these risks hypothetical, and described nuclear power as the "pathfinder" for these risks. Certainly there are many risks with the characteristics described above (for example, toxic chemicals and recombinant DNA research). Whether decisions can be made about these risks without the high degree of controversy and the resulting high social cost associated with the nuclear debate remains to be seen.

Quantitative Criteria for Risk Acceptance

In May 1979, the Advisory Committee on Reactor Safeguards (ACRS) recommended "that consideration be given by the Nuclear Regulatory Commission [NRC] to the establishment of quantitative safety goals for overall safety of nuclear power reactors" (*31*). The ACRS further recommended that "Congress be asked to express its views on the suitability of such goals and criteria in relation to other relevant aspects of our technological society. . . ." A similar suggestion, accompanied by proposed criteria, was made by Farmer (*32*) in 1967; the criteria were expressed by a curve relating acceptable accident frequency with accident magnitude. Subsequent proposed criteria for acceptable risks, not necessarily limited to nuclear power, have been made by Starr (*18*), Bowen (*33*), Rowe (*34*), Okrent and Whipple (*35*), Wilson (*36*), and Comar (*37*). Currently efforts are under way within the NRC, the ACRS, and elsewhere to develop quantitative criteria for risk acceptance and to consider the many issues raised by this approach.

Incentives to Develop Quantitative Criteria for Acceptable Risks

The dissatisfaction with current regulatory systems for risk management provides impetus to develop new methods. Theoretically, quantitative criteria for acceptability would resolve many specific criticisms. One criticism stems from the fact that in several cases, a zero-risk goal has been established. This denies the concept of a trade-off between risk and benefit, and ignores the difficulty or impossibility of reaching zero risk. Further, improvements in technology have permitted identification and estimation of risk at levels far below those that were possible when specific zero-risk laws were passed; risks we might consider negligible are not treated in the regulatory process differently from much higher risks. As Hutt (*38*) argued,

> Until quite recently, a no-risk food safety policy was widely thought to be an achievable goal. . . . It is now clear that it is literally impossible to eliminate all carcinogens from our food. Moreover, many of the substances which pose a potential risk are part of long-accepted components of food, and any attempt to prohibit their use would raise the most serious questions both of practicality in implementation and of individual free choice in the marketplace.

A suggested way of handling this problem would be to set a level below which risks would be ignored, provided some benefit were associated with the risk. This low level would serve as a quantitative standard for acceptability of the risk.

A second criticism of regulatory approaches is that decisions are often made arbitrarily. Such a charge is not surprising considering that several regulatory agencies have a mandate to protect the public from "unreasonable" risk, without congressional guidance on how to judge reasonableness. The objections are enhanced when regulators are believed to be overly accommodating or hostile to the regulated industry. Certainly, one way to reduce the influence of bias and arbitrariness is to institute a numerical definition of "reasonable." Perhaps the time required for risk decisions would also be reduced by the availability of clear, relatively simple criteria.

Often, regulatory authorities specify the technology for meeting risk targets, rather than the targets themselves. The drawback of this approach is that there are no incentives to develop more efficient methods of controlling risk. The establishment of risk targets alone could stimulate the development of a variety of creative methods for risk control.

Finally, another criticism of current risk management is that the effort required to control risk (as measured by the cost per life saved) varies considerably from one risk to another; this wastes both lives and money (9). Assuming that the total funds allocated for risk reduction could be transferred freely between different risk reduction opportunities (which is certainly not always possible), the maximum number of lives that could be saved nationally is found when the marginal cost of saving a life is uniform among the opportunities. Thus the comparative marginal cost-effectiveness of each opportunity for saving lives would become the guiding principle in the allocation of resources, and the value of life would be implicit in the total national allocation of funds. There would, of course, need to be a national allocation of resources to such "life-saving" endeavors, but as with military budgets, a common-sense consensus judgment is likely to be as reliable as any analytic formula.

Applications for Risk Criteria

One of the pitfalls in trying to develop regulatory approaches for managing risk is the desire to use the same method to tackle a number of different risks. There are different types of risk decisions, and no single regulatory method seems applicable to all of them.

The use of cost-effectiveness criteria serves as an example. This issue arises when, a priori, the technology is found acceptable but the specific operating point is left to be decided. An example of this type of decision is the determination of allowable levels of a pollutant in automobile exhaust. In this case the issue involved is not the relative risk and benefit of transportation, nor the selection of a transportation technology (automobile versus mass transit). For this simplified type of decision the only issue is the marginal trade-off between the social cost of the risk and the cost of controlling it. For these cases, two kinds of quantitative criteria can be considered; the first is the standard for judging cost-effectiveness described above. There is nothing new in this approach; it is simply cost-benefit analysis in which the metric for judging the social cost of risk has been specified. The second quantitative criterion is more pragmatic: it is a lower risk limit below which no regulatory action would be taken. This could be useful in allocating a regulator's time and would help prevent the highly visible cases in which the nuisance aspects of regulation are intuitively greater than the benefits of that regulation.

The next level of difficulty in risk decisions is the choice of the best method for obtaining a specific benefit. In these cases the benefits need not be analyzed, it is presumed that the benefits are sufficiently great to justify any of several alternatives. For example, in the often heated debates over the selection of energy production technologies, it is generally assumed that, under any proposed policy, energy services will be provided (such services include conservation). For this decision, the dominant issues are the costs and risks associated with each alternative. The difficulty in making these choices is often due to the qualitatively dissimilar character of the risks (for example, air pollution risks from coal mining and burning versus nuclear reactor accident risks). It is difficult to see a role for quantitative criteria in making comparisons of the type needed. One could establish a maximum permissible risk level that would serve to screen out excessively risky alternatives, but the selection of a technology generally depends on some aggregation, either explicitly or implicitly, of the components of the social cost of each alternative. Presumably, after one alternative is selected, the decision is reduced to the determination of the preferred operating point discussed above.

A complete risk-benefit decision requires that the relative social cost of the risk be compared with the associated benefit. A pragmatic application of quantitative criteria for these cases was suggested by Starr (*19*) and by Starr *et al.* (*8*), and is illustrated in Fig. 4. This risk-benefit curve reveals the commonly proposed characteristics for risk criteria: a lower limit for concern about risk (in this case, the natural-hazards mortality rate), an upper limit for acceptability (set by the average disease rate), and provision for risk-benefit trade-off between these limits.

We should not overestimate the capacity of simple criteria, such as those illustrated in Fig. 4, to reduce risk conflict costs. Many, if not most, risk estimates include significant judgmental inputs. There are often substantial disagreements over risk estimates, the methods used to arrive at risk estimates, and the competency, integrity, and motivation of the experts providing subjective risk estimates. What is needed for the application of quantitative criteria for risk acceptance is a standard of proof for determining whether the criteria have been met. Although many different approaches to this issue have been recommended (including peer review, scientific courts, and quantitative methods for resolving differences between experts), the ultimate responsibility for judging the competency of risk analysis still resides with the regulatory agency responsible for managing the specific risk.

Conclusion

Analytical approaches to decide risk-benefit issues ideally come closer to maximizing net social benefits than any other approach. The usefulness of these methods in making assumptions and values explicit justifies their application. But a necessary condition for applying their results to specific decisions is a social consensus on the relative benefits and costs of the proposed actions. For specific types of risk, in which intuitive evaluations of risk and benefit contradict analytical evaluations, the necessary consensus may not develop, but rather a conflict requiring political resolution is likely to result.

When the conflict arises from a disagreement over the level of risk rather than the value assigned to that risk, efforts to reduce the cost of conflict by incorporating values into an expected utility approach will be unsuccessful. Quantitative risk criteria appear quite attractive in this respect, because the key to the acceptability of a technology under the proposed method is the level of risk. Assuming that the estimated risk became the central point in the debate, the public might have more confidence in the regulatory systems if their concern were directly addressed.

We see significant value in trying to understand the intuitive risk-benefit process. The evaluation of its outcome could reduce anxiety and cost if used as a tool in the design of technical systems. This is already the case, as when we use more stringent criteria for nuclear power and commercial aviation than for a more commonplace risk (*39, 40*). The balance between individual and group risk-benefit decision methods is fundamental to the development of national policies on risk acceptance. It is customarily achieved through the political process, and is not amenable to quantitative analysis.

References and Notes

1. W. W. Lowrance, *Of Acceptable Risk* (Kaufmann, Los Altos, Calif., 1976).
2. *Symposium/Workshop on Nuclear and Non-Nuclear Energy Systems: Risk Assessment and Governmental Decision Making* (Mitre Corp., Bedford, Mass., 1979).
3. L. Lave, in (*2*), p. 181.
4. S. Jellinek, in (*2*), p. 59.
5. M. Green, "The faked case against regulation," Washington *Post*, 21 January 1979, p. C-5.
6. P. H. Schuck, "On the chicken little school of regulation," Washington *Post*, 28 January 1979, p. C-8.
7. E. J. Mishan, *Cost-Benefit Analysis* (Praeger, New York, 1976).
8. C. Starr, R. Rudman, C. Whipple, *Annu. Rev. Energy* 1, 629 (1976).
9. R. Zeckhauser, *Public Policy* 23 (No. 4), 419 (1975).
10. R. Wilson and W. J. Jones, *Energy, Ecology, and the Environment* (Academic Press, New York, 1974).
11. K. Arrow, in *Energy and the Environment: A Risk-Benefit Approach*, H. Ashley *et al.*, Eds. (Pergamon, Elmsford, N.Y., 1976), p. 113.
12. National Planning Associates, *Social Decision-Making for High Consequence, Low Probability Occurrences* (PB-292735, National Technical Information Service, Springfield, Va., 1978).
13. R. Howard, in *Societal Risk Assessment: How Safe is Safe Enough?*, R. C. Schwing and W. A. Albers, Eds. (Plenum, New York, in press).
14. W. Haefele, in (*11*), p. 141.
15. H. Otway, *J. Br. Nucl. Energy Soc.* 16, 327 (1977).
16. S. Montague and E. Beardsworth, unpublished manuscript.
17. B. Fischhoff, P. Slovic, S. Lichtenstein, S. Read, B. Combs, *Policy Sci.* 9, 127 (1978).
18. C. Starr, *Science* 165, 1232 (1969).
19. ______, in *Perspectives on Benefit-Risk Decision Making* (National Academy of Engineering, Washington, D.C., 1972), p. 17.
20. P. Slovic, B. Fischhoff, S. Lichtenstein, in *Societal Risk Assessment: How Safe is Safe Enough?*, R. C. Schwing and W. A. Albers, Eds. (Plenum, New York, in press).
21. E. W. Lawless, *Technology and Social Shock* (Rutgers Univ. Press, New Brunswick, N.J., 1977).
22. I. Janis and L. Mann, *Decision Making* (Free Press, New York, 1977).
23. See, for example, A. Tversky and D. Kahneman, *Science* 185, 1124 (1974).
24. J. Selvidge, thesis, Harvard University (1972).
25. S. Lichtenstein, P. Slovic, B. Fischhoff, M. Layman, B. Combs, *J. Exp. Psychol. Hum. Learn. Mem.* 4, 551 (1978).
26. P. Slovic, B. Fischhoff, S. Lichtenstein, *Accid. Anal. Prev.* 10, 281 (1978).
27. M. F. Jacobson, *Science* 207, 258 (1980).
28. V. Fuchs, "The economics of health in a post-industrial society," *Public Interest No.* 56 (1979), p. 3.
29. J. M. English, in *Trends in Financial Decision Making*, C. van Dam, Ed. (Nijhoff, The Hague, Holland, 1978), pp. 229-247.
30. W. Haefele, *Minerva* 10, 302 (1974).
31. M. W. Carbon, letter to J. M. Hendrie, 16 May 1979.
32. F. R. Farmer, *Nucl. Saf.* 8, 539 (1967).
33. J. Bowen, in *Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975 Asilomar California*, D. Okrent, Ed. (Rep. PB-261920, School of Engineering and Applied Science, University of California, Los Angeles, 1975), pp. 581-590.
34. W. D. Rowe, *An Anatomy of Risk* (Wiley, New York, 1977).
35. D. Okrent and C. Whipple, *An Approach to Societal Risk Acceptance Criteria and Risk Management* (Rep. UCLA/ENG-7746, School of Engineering and Applied Science, University of California, Los Angeles, 1977).
36. R. Wilson, testimony before Occupational Safety and Health Administration hearings, Washington, D.C., February 1978, OSHA docket H-090).
37. C. L. Comar, *Science* 203, 319 (1979).
38. P. B. Hutt, *Food Drug Cosmet. Law J.* 33, 558 (1978).
39. C. Sinclair, P. Marstrand, P. Newick, *Innovation and Human Risk* (Centre for the Study of Industrial Innovation, London, 1972).
40. R. Schwing, *Gen. Mot. Res. Lab. Rep. GMR-2353* (1977).

RISK MANAGEMENT AND ACCEPTABLE RISK CRITERIA

Harry J. Otway
Technology Assessment Sector,
Joint Research Centre of the Commission of the European Communities,
Ispra, Italy

Detlof von Winterfeldt
Social Science Research Institute,
University of Southern California, Los Angeles

Social opposition to technologies is not new. In recent years we have seen many examples, which include rural electrification, water fluoridation, supersonic air transport, contraceptive devices, nuclear weapons and nuclear power. Although opposition itself is not new, the reasons for it have differed from case to case, reflecting a complex mixture of concerns related to morals, religion, political ideologies, power, economics, physical safety and psychological well-being. Yet, oddly enough, today's debates about the acceptability of technologies are frequently treated as if they were based upon a single issue — that of risks to public health and safety and to the environment. In fact, risk has moved so much into the forefront that the complex problem of social acceptability is too often reduced to a mathematical-numerical problem of defining "acceptable risk". In this paradigm theoretical estimates which predict *risk* levels less than those specified by acceptable risk criteria would be considered to have met both necessary and sufficient conditions for the acceptability of the *technology*. This paper traces the emergence of the "acceptable risk" problem and reviews critically some of the technical and social science approaches that have been put forward to "solve" it.

The Emergence of the "Acceptable Risk" Formulation

Policy makers in regulatory agencies stand in the centre of the bargaining process in which acceptable risks are (usually implicitly) defined. Originally, regulators negotiated primarily with the regulated industry to correct deficiencies in self-regulation. Standards, the most common regulatory tool, were products of a consensus-forming process between government and industry experts; they tended to assume a more "scientific" character through iterations with increasing experience of the new technology.

The balance of this comfortable and functioning two-way power relationship has been disturbed in the past decade by the intervention of new actors from public groups, such as environmental organisations, trade associations, and labour unions. This intervention was, in part, triggered by the emergence of new risks with unprecedented consequences, the scale and complexity of which severely limited the traditional engineering trial-and-error approach to socially responsible design; in addition, enhanced access to news media coverage of disasters, especially the dramatic visual impact of television, served to increase risk awareness and to provoke concerns about the effectiveness of regulations based upon expert consensus. One result of these concerns was that public interest groups began to educate themselves and to seek out independent expert advice. As a consequence, people were able to witness the public display of conflicting expert opinions, further undermining confidence in expert knowledge.

As the public discourse now appeared to be focusing on risk, some of the technical community began to develop methods to make quantitative, probabilistic estimates of public risk. These technical estimates were reassuring to technical people because they tended to show that physical risks were low in comparison to the risks of ordinary life; however, this sense of reassurance was not shared by representatives of many public groups who by then were well aware of their own stakes in technological decisions. Their continued intervention in political and regulatory processes demonstrated that they were using their own, sometimes not clearly articulated values and beliefs to judge the acceptability of technologies - values and beliefs which differed considerably from those of technical people in government and industry.

Puzzled by these confusingly different values and beliefs, and their perseverence in the face of "rational technical argument", demands were put forward by industry and others for pre-determined criteria by which the acceptability of risks could be judged. Since technical experts are prone to have a mathematical mentality and possess analytical skills, it is perhaps not surprising that they began to search for quantitative risk acceptance criteria[1]. An implicit assumption here is that social preferences can be expressed in engineering terms and used in the regulatory process to reduce uncertainty, ambiguity and delay - in essence an attempt to model social and political behaviours with the technical tools and the philosophy of the natural sciences. In the event, many technologies that numerical acceptable risk approaches indicated should be acceptable, have encountered serious and continuing public opposition, suggesting that this modelling approach has been inadequate.

Descriptive, Prescriptive, and Normative Models

Models of human behaviour can be descriptive or prescriptive. Descriptive models are concerned with people's actual behaviour, and with the empirical relationships between their behaviour, beliefs, and values, as, for example, in Fishbein's attitude model[2]. Prescriptive models, in contrast, deal with the behaviours that should be displayed in order to conform with axioms of rationality postulated by the modeller. Some prescriptive models contain descriptive elements, in the form of empirically observed or expressed values and beliefs, and then prescribe behaviours on the basis of consistency requirements; the implications of the latter models are naturally most relevant for those who share the values and beliefs which have been assumed. Multiattribute utility models[3,4] are examples of the mixed descriptive-prescriptive (or "conditionally prescriptive") type.

The most radical prescriptive models have no descriptive inputs, instead combining what the model builder believes to be "rational" values and beliefs with axioms of "rational" behaviour. These models substitute "facts", or "objective probabilities", for people's beliefs, make assumptions about values, and then apply maximization principles to derive optimal solutions. Implicit in these models is the assumption that the same kind of rationality should hold for all people. To distinguish them from the conditionally prescriptive models we will call them normative; most models of acceptable risk are normative.

In a typical normative model of risk acceptance, consequences of technological risks are characterized by quantitative summary measures (e.g. deaths, illnesses, injuries) and probability distributions over consequences are constructed through estimation and simulation. Having arrived at a quantitative estimate of risk, some analysts then compare it with statistics reflecting society's experience of more familiar risks of technological or natural origin, assuming that physical risk, as accepted in the past, provides sufficient information to judge the acceptability of a new technology today. These comparisons are offered as a basis for judging the social acceptability of the new risk by placing it "in perspective" as a preliminary to "'embedding' the problem into the normal conditions of life ..."[5]. A recent proponent of the embedding method is Rothschild[6] who suggested that an "index of risks" be established so that an informed public could find "... guidance as to when to flap and when not." He proposed that the "flap" threshold might be taken as the current average annual chance of being killed in a road accident in the U.K., about 1 in 7500.

There are also some more sophisticated approaches to embedding. For example, Starr[7,8] suggested that new risks should be embedded, as a function of the benefit provided, between the relatively low average risk of death from natural hazards and the upper limit represented by the average individual risk of death from diseases. Okrent[9], noting that "entire symposia are held on risk management without so much as mentioning the subject of quantitative risk criteria..", advocated a "national approach" to risk management, suggesting that activities be categorised as "essential, beneficial, or peripheral" with successively lower numerical levels of acceptable risk. He went on to propose that taxes be paid on the remaining "residual risk" (if uninsurable) and the revenue redistributed in the form of health insurance or reduced taxes.

Observing that people generally do not behave in accordance with such normative models technical experts sometimes attribute these differences to simple misperceptions, biases, or even just plain deviousness on the part of non-scientific interest groups. But it is just as easy for non-experts to argue the reverse, namely that normative models merely reflect the biased perceptions and interests of the model builders. Normative approaches to acceptable risk have not contributed materially to understanding or resolving the continuing debates about technologies; in fact, they may have served to increase tensions as technical people accuse the public of fact-neglecting irrationality while the countercharge is made that the technical community is trying to conceal selfish interests with esoteric and frivolous calculations. By denying differences, and by claiming a universal rationality, normative models of risk acceptability ignore the value and belief issues which lie at the very heart of the debate.

Descriptive models, and some prescriptive models, can offer approaches to understanding the beliefs and values which underlie judgments of acceptability (or non-acceptability); in these models the attributes which people perceive as characterising the acceptability judgment are elicited so that judgments are defined in terms of the variables that people find relevant to their own concerns. Note that these are models of rational behaviour since most of us do behave rationally most of the time in the sense of acting in accordance with our own beliefs and values to achieve our own goals. The next two sections will discuss the nature of beliefs and values.

Facts, Probabilities, and Beliefs

Scientists like to stress the factual basis of their knowledge but, increasingly, scientific statements must be expressed in probabilistic terms as suggested by Weinberg's[10] idea of "trans-science". From the standpoint of the subjectivist school of probability[11, 12, 13] the expression of expert judgments in probabilistic terms is not distressing because probability is held to be a degree of belief in an event or proposition whose truth has not yet been ascertained, i.e., there is no "correct" probability that resides somewhere "in reality". Thus, probabilities expressed by experts are not fundamentally different from the beliefs held by non-experts. Sometimes, it is possible to verify the truth or falsity of a proposition to which a probability was once attached, such as yesterday's forecast of today's weather, but confirmation of probabilistic statements necessary to judge the risks of technologies is often impossible[5].

These ideas of subjective probability and belief allow us to conceptualise today's engineering "facts", and even some scientific laws, as being strongly held beliefs shared by expert groups. Polanyi[14] gives several examples of once-accepted items of conventional scientific wisdom which since have been discarded or, expressed in probabilistic terms, the subjective probability of these propositions being true has changed dramatically. Although lay people's beliefs may be at variance with the presently available scientific evidence, it does not necessarily lessen the strength of their convictions or make their beliefs appear any less "factual" to them. Future historians, looking at some of today's scientific controversies, may find expert and lay beliefs to be more similar than dissimilar.

A number of experimental studies have explored the differences between experts and lay people in judging the probabilities of rare events. In one of them[15,16], experts and lay people were asked to rate the risks of thirty technologies or activities for which the actual annual frequency of death could be identified through data or probabilistic estimation techniques. Expert judgments of technological risks were closely associated with the best technical estimates of annual average or expected fatality rates, indicating that experts equate risk and fatality rates, and, perhaps more important, that they remembered these rates well - as would be expected of risk experts.

In contrast, lay people's risk judgments were only loosely associated with technical risk estimates. This finding might, at first, suggest that lay people are ill-informed or biased when making risk judgments; however, they were reasonably accurate when asked to make direct judgments of annual average or expected fatality rates. For example, the same group that judged nuclear power to be the riskiest technology, assigned it the lowest fatality estimate in an average year. Why do people's risk judgments differ from expert judgments and from technical estimates of expected fatality rates? One possibility is that people <u>know</u> the statistics, but that risk <u>means</u> something more to them than just fatalities, and that this meaning may even change from one technology to the next.

Several attitude studies[e.g. 17,18,19] lend support to this, having shown that there are risk attributes of psychological relevance, as well as technology-related social and political attributes, that help account for differences in attitudes, i.e. differences in attitudes about risks or technologies are more than mere numerical disagreements about risk magnitude. For example, differences were found in the beliefs of groups for and against nuclear technology as to whether the technology leads to a reliance on technical experts; whether it will increase economic growth; whether it will lead to large centralised systems; and whether it will increase the power of big business. These beliefs all concern social and economic matters which are quite separate from risk in the narrow numerical sense.

Values and Preferences

The normative, embedding model of acceptable risk assumes that numerical representations of physical risks alone should be sufficient to judge the acceptability of technologies; however, the descriptive research just summarised suggests that beliefs about other attributes of a technology can strongly influence acceptance. It is not enough, though, to know what people believe these attributes to be, it is also necessary to know if they value them positively or negatively. The attributes listed below have been found by researchers[17-30] to influence perceptions of technologies and risks; they are negatively valued by most people, therefore the stronger the belief that the technology is characterised by these attributes, the less likely people will be to accept it:

- involuntary exposure to the risk, as opposed to risks taken at one's own choice such as automobile travel, skiing, etc.;
- lack of personal control over the outcome of the risk exposure, i.e., once in the risk situation, do your own skills or actions have any influence over the risk exposure, or are you at the mercy of chance or the skill of others (no control for an airplane passenger, considerable for a skier);
- uncertainty about the probabilities or consequences of exposure (do you know what to expect, do the experts agree?);

- lack of personal experience with the risk (fear of the unknown and perhaps even unknowable);
- difficulty in conceptualising or imagining the risk exposure (e.g., radiation cannot be perceived by the senses and originates from processes which are mysterious to the lay-person);
- delayed somatic effects of present risk exposure (after appearing to escape unscathed, is there still a possibility of later damage, e.g., exposure to carcinogens);
- genetic effects of present risk exposure (threatens future generations);
- infrequent, but catastrophic accidents (the image of 1000 disaster victims is more vivid than the abstraction of a 1 in 10 million probability);
- the benefits are not highly visible (so why take the risk?);
- the benefits go to others, but the risk to us (unfair to the risk bearers);
- accidents caused by human failure rather than natural causes (a feature of modern technological catastrophe as opposed to natural disasters).

But people's judgments of technologies are not determined only by these negatively-valued, risk-related attributes. The studies cited above have also identified a number of potential economic, social and political attributes of technologies that enter into evaluations of acceptability. If the attributes listed below are believed to characterise the technology they could contribute either positively or negatively to attitude, depending upon how they are valued by the individual — often a question of personal and political philosophy:

- provide a benefit corresponding to perceived needs;
- increase the standard of living;

- create new jobs;
- facilitate economic growth;
- enhance national prestige and independence from foreign suppliers;
- cause dependence upon small groups of technical elites;
- require strict physical security measures or special police powers;
- increase the power of big business;
- lead to centralisation of political and economic systems.

The attributes on the foregoing lists are only typical and not intended to be a complete and generalisable set; in fact, they *cannot* be complete because the attributes that are relevant to judgments of technology can be *anything* that people have "learned" to associate with the technology. Items similar to those above, plus some related to other aspects of growth and centralisation, formed the basis of a national survey of the USA[31], which found substantial differences in how various social groups evaluate these attributes.

Summary and Conclusion

We have argued that the risk concept, although perhaps useful for treating pure safety issues, is too narrow to help understand the social acceptability of technologies and, in particular, that "acceptable risk" as a generalisable number or mathematical relationship cannot exist. Of course some personal judgments may be based mostly on the acceptability of risk (e.g., Is the water safe to drink?) but, even then, the judgment will be influenced by other factors such as benefits (How thirsty are you?); voluntariness (Did you forget to bring water on an outing or did the risk situation arise because industrial activities have contaminated your home water supply?); consequences (Is it a risk of getting sick or of dying?); delay (Does the water contain a poison or a carcinogen?); uncertainty (Do you know what the risk is? Do the experts know?); and so on. Judgments of acceptable risk seldom have meaning when treated as a numerical exercise remote from the decision context; it would actually seem rather odd to be able to consider risks independent of source and context - why should people be indifferent as to how they die?

Even an apparently straightforward decision to reduce or eliminate an existing risk that has been discovered to be "too high" is context-dependent. As an extreme example, an occupational risk that might be unacceptable in peacetime might be found quite acceptable in a wartime defense industry; the same qualitative differences can be observed between high and low phases of national economic cycles. This kind of decision can be complicated by other non-technical factors; there may be consumer groups quite willing to accept the risk that a regulator finds high (e.g., the artificial sweetener debate) and the prospect of unemployment resulting from the regulation could trigger political interventions. Quite aside from this, the regulated group (and their risk experts) might disagree with the regulator about the risk magnitude and the methodologies used to estimate it[(33)].

At the low risk end of the regulatory problem a quantitative threshold risk level has been visualised[(e.g. 8, 9)] below which regulatory action or review would not be required; however, it is not at all clear that satisfaction of this criterion would be sufficient to ensure social acceptability. A threshold criterion would suffice only for an imaginary technology which possessed just two characteristics: provision of a necessary benefit at the cost of a low physical risk. Because a number of quite independent cognitive dimensions can underlie judgments of acceptability, physical risks could in principle be essentially zero but the technology still be judged unacceptable (and subject to opposition) for other perfectly valid social reasons.

In spite of our assertion that "acceptable risk", as such, cannot exist, psychologists have succeeded in measuring it in the context of pencil and paper surveys. How can this apparent discrepancy be explained?

The two main lines of psychometric research on risk have been to measure attitudes toward the acceptability of risky technologies as a function of the underlying beliefs and values[e.g. 17-21], or to scale perceived or acceptable risk directly[e.g. 15, 16, 24, 32], by asking respondents to rate the risks of various technologies or activities and, if applicable, the factor by which they would have to be reduced in order to be acceptable. Using the technical community's definition of the problem, i.e. what levels of risk are people willing to accept, the direct scaling research has found replicable relationships amongst acceptability and perceptions of risk, fatalities and benefits, given similar respondent groups. Subjects asked to perform these tasks obviously try to maintain some order and structure in their responses; however, even if they have expressed a clear and replicable preference, say, for risk reduction we must remember that they have not been asked about the changes they would require with respect to other characteristics of the technology in order to make it acceptable, e.g. its implications for the change or entrenchment of social institutions. Further, the risk scaling approach necessarily ignores some vitally important real-world phenomena of social organisations such as the acquisition and use of power and questions of institutional legitimacy. Thus we have reservations as to how individual perceptions of mortality risks can be generalised to real-world definitions of the acceptability of technology policies which, in practice, emerge from complicated negotiations between special interest groups in a highly political environment.

At both the individual and societal levels risk embedding practitioners have reported finding behavioural "irrationalities" and "inconsistencies", as evidenced by the wide variation in risk levels accepted (or rejected) in connection with different activities. This does not seem so strange in view of the multi-dimensionality of risk and the simple fact that the levels of risk accepted or rejected in each activity result from separate and dissimilar choice situations: e. g., transportation risks are just part of the consequences of decisions about transportation alternatives which have considered a number of salient attributes (e. g., availability, cost, speed, comfort, convenience, safety); occupational risks are accepted as a result of decisions in which alternate job opportunities have been compared over a number of characteristics (e. g., pay, location, intrinsic interest, future, safety). In addition, each activity is regulated by a different agency with its own regulatory style and organisational objectives so that each risk is also shaped by a different political bargaining process. Thus there is no reason to expect that the risks of all societal activities (or technologies) should be more or less the same - nor is there any rational reason to try to change how people think, behave and govern themselves in order to make it so.

But sometimes opposition to technologies may be caused by factors which go not only beyond risk, but also beyond the other characteristics of the technology[34]. Positions pro and con some technologies have taken on the character of ideological commitments. For example, those pro seem to be experiencing visions of a future shaped by expert knowledge; on the other hand, demands by opposition groups for increased citizen participation in decision making[35,36] seem to reflect more than a challenge to the "experts myth" or isolated instances of ailing institutions but, it has been suggested, are a symptom of a deeper social disturbance - a growing disenchantment with the way representative democracy is functioning[37,38].

The acceptance of risks is implicitly determined by the acceptance of technologies which, in turn, depends upon the information people have been exposed to, what information they have chosen to believe, the values they hold, the social experiences to which they have had access, the dynamics of stakeholder groups, the vagaries of the political process and the historical moment in which it is all happening. We completely agree that the risks of technology are real and must be efficiently managed to provide public protection; but this is not sufficient - the resolution of conflicts about technologies requires that they no longer be treated as simple technical disagreements centering on the single issue of acceptable risk. It is necessary to admit the relevancy of other, "softer" kind of information where the expertise is held by the people whose lives are affected.

The acceptable risk formulation has provided increasingly elaborate and precise answers to the wrong question(39); future research on the acceptability of technologies must be linked to the critical questions of institutions, participation and policy implementation, for until sources of conflict have been addressed the decisions taken, no matter how technically rational, may ultimately be only empty prescriptions lacking arrangements for their realisation(40).

<u>References and Notes</u>

1. A well-known physician, accounting for the predilection of surgeons to operate in preference to more conservatice procedures, said: "If you have a hammer in your hand, everything looks like a nail." One might speculate as to how the acceptable risk criteria problem might have been conceptualised by non-technical professional groups, e.g., lawyers, clergymen, artists.

2. M. Fishbein and L. Ajzen, Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research (Addison-Wesley, Reading, Mass., 1975).

3. W. Edwards, IEEE - SMC 7, 326 (1977).

4. R. L. Keeney and H. Raiffa, Decisions with Multiple Objectives: Preferences and Value Trade-offs (Wiley, New York, 1976).

5. W. Häfele, IIASA-RR-73-14, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1973).

6. Lord Rothschild, British Broadcasting Corporation, London, 1978.

7. C. Starr, Science 165, 1232 (1969).

8. C. Starr and C. Whipple, Science 208, 1114 (1980).

9. D. Okrent, Science 208, 372 (1980).

10. A. Weinberg, Minerva 10, 209 (1972).

11. B. De Finetti, Annales de l'Institut Henri Poincaré 7, 1 (1937)

12. L. J. Savage, The Foundations of Statistics, (Wiley, New York, 1954).

13. W. Edwards, J. Lindman, and L. J. Savage, Psychological Review 70, 193 (1968).

14. M. Polanyi, Personal Knowledge (University of Chicago Press, Chicago, 1958).

15. P. Slovic, B. Fischhoff, and S. Lichtenstein, Environment 21, 14 (1979).

16. B. Fischhoff, P. Slovic, and S. Lichtenstein, Environment 21, 32 (1979).

17. H. J. Otway, D. Maurer, and K. Thomas, Futures 10, 109 (1978).

18. K. Thomas, E. Swaton, M. Fishbein, and H. J. Otway, IIASA-RR-80-18, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1980). Also in Behavioral Science 25, 332 (1980).

19. K. Thomas, and H. J. Otway, in Progress in Resource Management and Environmental Planning 2, T. O'Riordan and R. K. Turner, Eds. (Wiley, Chicester, 1980), p. 109.

20. H. J. Otway and M. Fishbein, IIASA-RM-76-80, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1976).

21. H. J. Otway and M. Fishbein, IIASA-RM-77-54, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1977).

22. R. J. Lifton, Death in Life: Survivors of Hiroshima (Random House, New York, 1968).

23. H. Nowotny, IIASA-RM-76-33, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1976).

24. B. Fischhoff, P. Slovic, S. Lichtenstein, S. Read, and B. Combs, Policy Sciences 9, 1278 (1978)

25. P. Pahner, IIASA-RM-76-67, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1976).

26. H. J. Otway and P. Pahner, Futures 8, 122 (1976).

27. R. Maderthaner, G. Guttman, and H. J. Otway, Journal of Applied Psychology 3, 380 (1978).

28. E. R. Swaton, R. Maderthaner, P. Pahner, G. Guttmann, and H. J. Otway, IIASA-RM-76-74, International Institute for Applied Systems Analysis (Laxenburg, Austria, 1976).

29. B. Wynne. In Society, Technology, and Risk Assessment. J. Conrad, Ed. (Academic Press, London, 1980), p. 173.

30. H. J. Otway. In Technological Risk: Its Perception and Handling in the European Community. M. Dierkes, S. Edwards and R. Coppock, Eds. (Oelgeschlager, Gunn and Hain, Boston, 1980), p. 35.

31. E. J. Hyman, Center for Social Research (Berkeley, California, 1979).

32. C. Vlek and J. P. Stallen, Organizational Behavior and Human Performance, in press (1980).

33. The "unacceptably high" risk criterion has even been turned on its head with the argument that the risks associated with not having the benefits of a proposed technology would be too high, thus the technology in question (and its risks) must be accepted.

34. This sequence reflects the observation that there has been a steady evolution in which problems are initially defined as scientific and technical, then as economic, and still later as intrinsically social and political (O. D. Duncan, Social Forces 57, 1, 1978; R. E. Goodin, Ethics 90, 417, 1980). For a case study demonstrating this progression see Helga Nowotny's account of the Austrian referendum on nuclear energy, H. Nowotny, Kernenergie: Gefahr oder Notwendigkeit (Suhrkamp, Frankfurt, 1979).

35. Citizen participation is a complex and emotive topic having quite different meanings to different people; S. R. Arnstein (AIP Journal, XXXV, 216, 1969) has classified participation into six categories ranging from the "tokenism" of public information/relations exercises to the true power of citizen control.

36. These demands have ranged from requests for greater accountability and freer information to, at the extreme, extra-legal attempts to "participate" in decisions through forcible frustration of their implementation.

37. J.J. Salomon, Adhésion ou Résistance au Changement Technique? (CNAM, Paris, 1981).

38. K. G. Nichols, Technology on Trial (OECD, Paris, 1979).

39. The importance of problem formation in shaping (i.e., "pre-selecting") results has been discussed by many authors, see, e.g., J. Ravetz, Scientific Knowledge and its Social Problems (Clarendon Press, Oxford, 1971) and G. Majone and E.S. Quade (Eds.), Pitfalls of Analysis (Wiley, Chicester, 1980).

40. Paper written in the framework of a collaboration with the FAST Programme (Forecasting and Assessment in the Field of Science and Technology) of the Commission of the European Communities. We wish to thank Donald Bain, Ward Edwards, Howard Kunreuther, John Lathrop, Riccardo Petrella and Jerry Ravetz for their comments. Any opinions expressed or values revealed are solely those of the authors.

VALUE STRUCTURES UNDERLYING RISK ASSESSMENTS

Patrick Humphreys

Decision Analysis Unit,
Brunel University,
Uxbridge, England

The paper deals with the psychological end of the "risk" field, looking not so much at uncertainty about potentially calamitous states of the world (and problems with the associated probability judgments), but rather at people's uncertainty about how to characterize the perceived disutility (or more precisely and also more generally, the regret associated with the downside) of risky consequences. It starts at the individual level and moves towards implications for political decision making where the views of groups with conflicting interpretations of risks must be taken into consideration.

EVALUATION OF RISKS

Keeney (1981), in examining the cases for the evaluation of mortality risks from an organisational perspective states:

> "In the literature one finds that the undesirability of various risks as perceived by the public seems to be dependent on many factors. Such factors include whether the risks are voluntary or involuntary, whether they are associated with catastrophic accidents or not, and whether the risks result in immediate or slowly caused fatalities. To the extent that these factors matter, the evaluation of risks needs to take them into account. However, it seems that if one is willing to utilize an individual's relative values for evaluating risks to themselves, the problem might be simplified."

In this paper I would like to discuss some of the issues involved in such a 'simplification' of the problem. In doing so, I will have little to say about the main concern of those approaching risk estimation from a "technical approach" (as reviewed by Lathrop, 1980): finding an appropriate distribution over fatalities, for specific 'causes' of risk. Keeney (1981) suggests that the negative quality of death itself is, for most people, independent of the cause. However, experience of risk is a property of the living not of the dead (and it can also be argued that people, not physical processes, 'cause' risk). Linnerooth (1979) has illustrated the difficulties in using loss of value (as indexed through productive capacity, etc.) consequent on premature death as an index of the value of a life, and so discussion of risks involving fatalities will be focussed here on the <u>expectancies</u> (and fears) induced in living beings through a consideration of the possibilities of such fatalities and, more important, all that leads up to them, and goes with them in the person's mind. It is the nature of such expectancies and fears which, in the final analysis, will determine the acceptability of risk.

PHLOGISTON THEORY OF RISK

From this standpoint, one must immediately dispense with what Watson (1981) has called "the phlogiston theory of risk", where risk is seen as a single substance given off at a rate to be determined by risk assessment studies as a by-product of a physical or biological process. The phlogiston theory of risk goes with the 'technical approach' to risk, whereby risk management consists of (i) determining an acceptable level, (ii) measuring the amount of substance for an activity, and (iii) rejecting an activity of too much substance. The theory is convenient because it anchors, and constrains, risk assessment to analysis of physical or biological properties of causes. This results in the specification of a level of risk as some probability function (depending upon one's definition of risk) over outcomes or side effects of the process.

There is, however, no way one can determine the nature of this function without making value tradeoffs (Keeney, 1979, 1980) and it also has nothing to say about the experience of risk in those people who do not become fatalities. Note also that the problem cannot be solved by attempting a subjective-objective mapping of probabilities, such as that attempted in a formal way by Kahneman & Tversky (1979), or in a descriptive way by Slovic, Fischhoff & Lichtenstein (1979), showing that people underestimate certain low probability events (when compared with frequencies in actuarial tables, rather than frequencies of reporting in the information providing media serving as the data base for their judgements). If risk cannot be defined by reference to a probability function, it equally cannot be defined by reference to any transformation of that function.

RISK AS UNCERTAINTY ABOUT STRUCTURE

How, then should we define risk? This is a perennial question in the literature, and there have been a plethora of answers (Vlek & Stallen, 1980, have counted over 30 different ones). Most have tried to find a formula using some mixture of any or all of probability, value and utility (probability of loss, size of credible loss, expected loss, (semi-)variance of probability distribution over consequence, function of expected value and variance of consequences, and so on). All of these definitions hold in some experimental situations but none do in all (Coombs & Bowen, 1971).

At the risk of adding yet another definition to the list, I would like to suggest that the difficulty with all these descriptions is that they express the subject's translation of the consequences of his or her experience of risks into preferences and measured within predefined, bounded and coherent problem structures. In doing this they fail to capture the experience of risk itself, which is represented at another level.

Experience of risk can best be represented, in my opinion, at the level where we examine the nature of the structure within which probabilities and utilities are represented (what Toda, 1976, called a person's Decision Making System, or DMS). At this level, 'degree' of risk can be defined in terms of a person's uncertainty about the bounds of this structure.

One might think that in the standard laboratory betting experiment investigating 'risk', there is no uncertainty about the bounds of the structure within which risk is to be perceived. All possible links between the subject's immediate acts (i.e., to choose an option, to place a bet) and ensuing outcomes are defined in terms of links with probabilities placed on them, and monetary values are assigned to all outcomes as payoffs. The subject's exploration of problem structure is usually assumed to be bounded by the defined set of outcomes which serve to define exhaustively for him or her the possible consequences of the immediate acts which may be taken.

However, such an assumption ignores the fact that the utility of consequences stems not simply from monetary payoff, but what comes after: the pleasure which can be obtained from the purposes to which gains are put or the anxiety and embarrassment in front of a bank manager, or approbation from a spouse, which may be associated with trying to raise funds to pay off a debt.

From this it follows that utilities are not fixed transformations of change in value from the status quo, even for any particular individual. The degree of utility associated with a consequence of an act under consideration depends on the chains of signification explored in long-term memory (Pitz, 1981; Humphreys, Wooler & Phillips, 1980) in concpetualizing that consequence. For most non-pathological monetary gambling situations in which people find themselves (whether in the psychological laboratory or in real life), there may be idiosyncracy, but little uncertainty. One 'knows' how one would raise a debt, that is, the influence diagram mapping the impact of future events on consequences (Howard & Matheson, 1980) is bounded.

When faced with such situations habituees tend to deny that they "are taking much of a risk", typically retorting that "I know what I am doing". The experience of risk is suddenly magnified in cases where a person says "I just don't know what I would do if (outcome A) occurs". Here the fear associated with the risk taken in following a course of action which includes outcome A with non-zero probability has to do with what Bruner, Goodnow & Austin (1956) called "terror in the face of the uncanny". Negative utilities within defined DMS situations are bounded by complete 'worst case' scenarios, but when a person exploring the structure finds a 'gap' then the negative utilities are unbounded, and considerable fear can result.

BACKGROUND OF SAFETY

This result is well known to clinicians. Sandler & Sandler (1978) discussing the development of objective relations and affects, say:

> "... we have to add something extremely important. The individual is constantly obtaining a special form of gratification through his interaction with his environment and with his own self, constantly providing himself with a sort of nutriment or aliment, something which in the object relationship we can refer to as "affirmation". Through his interaction with different aspects of his world, in particular his objects, he gains a variety of reassuring feelings. We put forward the thesis that the need for this 'nourishment' for affirmation and reassurance, has to be satisfied constantly in order to yield a background of safety."

Here, I think, is the clue to why a 'familiar' technology such as coal mining is seen by many people (excluding those actually involved in the process) as less unsafe than nuclear power, even though its risk profile, expressed as any probability function over fatalities (except one heavily biased against extreme catastrophe occurrence) is much worse. The 'safety' which is being talked about here is, in part at least, Sandler's 'background of safety', Coal mining disasters are not simply 'familiar', they are conceptualized within bounded structures. There is uncertainty about where the next one will occur, and who will be affected by it, but the rescue measures and so forth explored when thinking about "what would happen" given the occurrence of this type of disaster tend to be familiar, rather than uncanny.

Moreover, explorations of consequences of coal mining disasters (or of preparations for their prevention) do not usually lead people into imagining associated social changes where consequences are not represented in the individual's DMS. The situation is 'under control', in that consequences can be explored in a bounded way. 'Gratification' in Sandler's sense can be gained from exploring worst case scenarios; this removes the possible of "terror in the face of the uncanny" as after such an exploration one can believe that one "knows the worst that can happen".

When public enquiries on siting decisions for high technology plants, etc., limit the scope of attributes on which evidence may be addressed to physical risk probabilities, the positions of pro and anti functions typically remain intransigent and poles apart in the face of evidence from risk studies. This suggests not so much a failure to integrate information according to Bayes' theorem, but rather that the dispute is really on a different level (Edwards, 1981). For instance, Anna Gyorgy

(1979), an activist in several anti-nuclear groups, writing in her own book, "No Nukes", and thus free of restrictions concerning the attributes on which nuclear power may be conceptualized, wondered:

> "What kind of society do we want to live in? Nuclear power is such a dangerous technology that it requires special methods of social control. All aspects of the fuel cycle must be monitored and guarded, including the guards themselves. No security precaution is too great. Since the dangers of nuclear power go on and on - given plutonium's half life of 24,000 years - the security needed for a safe nuclear powered economy must be guaranteed for years to come. But how can a stable future be guaranteed - forever? The prospect seems made to order for an authoritarian system, depending for its survival on what Dr. Alvin Weinberg, former head of the Oak Ridge National Laboratories has called a 'military priesthood'." (p.222)

In this account, the main threat to safety is not due to ionizing radiation but due to the loss of freedom to control the way one structures (and lives) one's own life due to measures taken to ensure that such radiation exists at a 'safe' level. The issues involved in the experience of risk here have not to do with physical processes but, as pointed out by Otway, Maurer & Thomas (1978), with concerns which go beyond technologies to the social and political institutions they imply "including the centralization of scarce and vital resources, their control by over-large and impersonal bureaucracies, and the growing dependence on the specialized knowledge of technocratic elites".

Note that while within a multiattribute utility analysis of the value of risk this represents the need to include a greater number of attribute dimensions characterizing these issues, the analysis does not end there. There are more fundamental problems. Here I will consider just a few, Lathrop and Linnerooth (1982) consider many more.

PROBLEMS IN PROVIDING STRUCTURE

Jungermann (1980) described the main value of decision aids at the personal level as lying in their ability at "classifying, expanding and structuring the clients' perspectives to help them cope with, and maybe change reality rather than in finding the best decision". However, decision aids like MAUD4 (Humphreys & Wisudha, 1981) designed to help people formulate the structure they need to use in choosing between options where the choice is multiattributed are of only limited use in aiding the exploration of value structures underlying risk assessments.

Such aids can help to reduce uncertainty through reduction of goal confusion (Humphreys & McFadden, 1980), and provide better definition of key attributes within that part of the problem which can be structured within the individual's DMS. Nevertheless, Kafkaesque fantasies stemming from the belief about loss of control of one's modus vivendi to bureaucracies or security forces, essentially tell the message of the impossibility of defining what lies along the signifying chains behind the negative poles of the types of attributes Gyorgy and Otway et al stress. Hence the extent of the negativity of their meaning cannot be fixed, and so no relative scaling (and therefore no tradeoffs) is possible within a MAUT structure developed to capture the experience of "riskiness" associated with the situations and processes to which the fantasies relate.

One way out of this impasse is to realize that the fear associated with 'worst case' scenarios in many people faced with new technological innovations which result in wide-ranging change in lifestyle through societal side effects may, in fact, be due to the lack of definition of consequences of these side effects and hence the removal of their background of safety. Attempts to restrict discussions of the structure of consequences of implementing a new technology to non-societal (i.e., physical) dimensions makes matters worse. Otway, Maurer and Thomas (1978) state, "To expect people's attitudes toward a new technology to be primarily determined by statistical estimates of physical safety is a highly simplified, and incorrect model of human thought processes - it implies a degree of rationality as to be itself 'irrational'." The imposition of such 'rationality' on public denate seems to throw the structuring of consequences on other dimensions into the realm of the unknown - studied by anthropologists under the rubrics of 'taboo' and 'occult', wherein pehnomena excluded from public debate, rather than being neutralized, are experienced as having special agency and potentcy (c.f., Leach, 1962; Douglas, 1966).

EXPLORING SCENARIOS

It follows that exploration of scenarios on a wide canvas is an essential first step. The notion of 'risk perception' ignores the distinction between the fear which comes from awareness of lack of safety associated with the fact that consequences are not structured, and the negative affect associated with the (bounded) disutility of structured consequences. Moreover, such scenario investigation is likely to help only if it reveals possibilities of structuring consequences, through finding ways in which control can be restored to the individual. Including, for example, compensation payments for people living near a location chosen for siting a Liquified Energy Gas (LEG) plant in the scenario restores a notion of control in one aspect: with a compensation payment, either one uses the money to move away from the site, or one stays put, knowing that one has decided to, so one can gain by spending the money in pursuit of some other desire. In this way, the influence of LEG technology on one's personal life style can now be perceived as being under one's own control.

However, compensation payments are not sufficient in allaying fears of those who see the loss of control in terms of social freedom (e.g., "increased security leads to a police state"), rather than loss of individual enjoyment of life. For them, such payments are simply "an attempt to buy off the opposition".

"BACKGROUND OF SAFETY" HAS DIFFERENT CONCOMMITANTS FOR DIFFERENT GROUPS

The idea of risk as a threat to the background of safety can apply equally, but differently, to both sides in cases where there is a conflict in the introduction of new technology. Von Winterfeldt & Rios (1980) state:

> "Opinion polls and social surveys indicate that deeply rooted social conflicts may underlie these differences [between the two sides in the nuclear power debate]. Anti-nuclear groups and environmentalists often object to a growth philosphy and further the idea that "small is beautiful". Some anti-nuclear groups also favour political decentralization and socialistic views. Nuclear advocates and advocates of industrial development, on

the other hand, often favour growth, centralization and the basic principles of capitalism."[1]

One might add that the latter group also structure implications of consequences (including their version of worst case scenarios) around the continuation of such principles. "Centralized bureaucracies" and the like hold no fear for those who identify with, or exercise their power within them. Instead we find here what Sjoberg (1980) called "Knowledge Elitism" which

> "builds upon the idea that the actual knowledge in risk questions can be found only within a small group of experts, mostly experts in technology and the natural sciences. Objectivity and impartiality in their viewpoint is seldom or never in doubt. One considers oneself to be 'rational' but the idea about rationality is typically very superficial. Resistance is seen as emotional or irrational, as politically or commercially opportunistic. Resistance should be countered by trying to create a feeling of safety, or if that is not possible, by trying to isolate opponents from more uncertain or indifferent groups by pointing out, among other things, their 'complex' social and political viewpoints. The typical element of this elitist extreme attitude involved thus 'forgetting that risk judgements are in fact difficult to make, and the probabilities that are produced in risk analysis should not be taken too literally."

More than 'forgetting', according to the analysis outlined in this synopsis, this is the perspective of those who cannot afford to explore

---

1 It is interesting to note that the same distinction does not hold true in socialist countries. Nuclear power is not simply "part of the capalist armoury", but an issue taken up in playing out conflicts concerning an even more fundamental conception of risks: those associated with maintaining one's understanding of possibilities for one's life.

the implications of the contention that what should be taken literally is something other than risk analysis, as this would open up areas of their DMS which are not structured, and so threaten their own background of safety The risks of risk analysis are thus very different for the two sides whose conflict of views first led to the desire for risk analysis.

A LIMITED ROLE FOR MULTIATTRIBUTE UTILITY ANALYSIS

Nevertheless let's assume, optimistically, that one has been able to work with groups concerned in a risks debate and has explored their concern within scenarios which have been found to be bounded. Also, that one has identified (possibly with the help of a decision aid like MAUD4) those attribute dimensions which, within each group, can serve to characterize the decomposition of their attitude towards the risks (reduced to dis-utilities) and benefits involved in considering alternative options inclusive of consequences and side-effects. It may still be quite inappropriate in modelling the decision process (or in the more hazardous ploy of attempting to prescribe the 'optimal' solution) to use a composition rule (like MAU) derived from the axioms of individual rational choice.

In our own studies of group decision making where there were conflicts of interests among group members (Humphreys, 1978; Humphreys & McFadden, 1980), we found that those protagonists who were also skilled political negotiators had no wish to assess tradeoff ratios between attributes within the multi-attributed decompositions of the option-choice problems we had elected from them in order to apply a MAU composition rule. For these people, saliences (value-wise importances) of attribute dimensions were not something to be elicited or negotiated within the groups under considerations of equity. Rather, their principal activity in group debate was to try to manipulate value-wise importances of attribute dimensions. This usually involved arguing for an increased weight for a particular attribute dimension (on which the project they wished to promote scored highly) as group policy in assessing all proposed alternatives. In subsequent group decision making, this provided the rationale for the choice of one's own project, since it scored so highly on so important a dimension. Of course, this left the protagonist with the problem of justifying the expertise that gave him or her the licence to dictate the structure of the decision making problem in the first place.

This is why some index devised from a probability distribution over fatalities is liable to be promoted as the sole salient attribute dimension by adherents to the 'technical approach' to risk estimation. It may well be that such adherence stems not from a naive belief in scientism, but rather from the desire to promote a particular technology which has a good record on fatalities, but which is less attractive on other attributes of potential interest to other stakeholders (e.g., degree of centralized control, long term hazards from waste products of the process). Justifying one's expertise is less of a problem given the general acceptance of the "technical approach"; one simply cites evidence provided by "technical experts". stressing its "scientific" basis (ie., not open to question by lay people).

Edwards (1981) has criticized the trend in psychological research to develop experiments designed to produce evidence of 'bias' and inconsistency in lay people's reasoning (e.g., Dawes, 1976) as providing fuel for such justificatory activity, but this does not mean that without such experiments there would be no attempts at manipulation and justification, particularly under the assumption made here that such justification is in the service of providing a background of safety.

However, if the 'background of safety' could be provided for protagonists in risk evaluation debates by exploring scenarios and finding their bounds, so that the need to manipulate saliences loses its importance, it might then be possible to employ hierarchical multi-attribute utility procedures. These could structure a set of attributes encompassing all those given salience by any parties to the debate, with differences in parties being characterized by different attribute weighting schemes.

This is not a new suggestion, the technique has been used, for example, by Campbell and Seaver (1979) in water resource planning and by von Winterfeldt and Rios (1980) for conflicts about nuclear safety. In each of these applications,though, MAUT decompositions were used to display differences between protagonist groups for the benefit of planners. Campbell and Seaver conducted interviews with members of eight "constituencies", expressing their differences in terms of the weights assigned to a common set of criteria in a single stage (non-hierarchical) decomposition of their preferences over alternative projects for water resource management. They report that "the planners who received this preliminary decision analysis found the general model relevant to their needs and thought it would probably be useful in future water decisions, if it were used with adequately accurate data". Here the model was used to provide support for the decision making of just one of the stakeholders.

Von Winterfeldt and Rios used hierarchical multiattribute utility procedures, modelling separately each stakeholder group's evaluation criteria and each group's best estimates of the performance of the options under consideration (alternative energy generation strategies). They note that such analysis can be used "to identify areas of agreement and disagreement .... to determine additional information needs where conflict is about data and expertise; to discuss disagreements about measurement definitions (e.g., "fatality risks") and attempt to resolve them; to determine if incremental change in supply alternatives (e.g., remote siting) can produce more acceptable solutions".

Such activities do not necessarily guarantee consensus over actions to be taken, or their interpretation. When, as in von Winterfeldt and Rios' situation one stakeholder has the sole executive power to make the decision, other stakeholders will interpret that decision within their own value structures. In doing so, they may invent new scenarios which, if unbounded at any point, could threaten their background of safety afresh ("I just don't know why they chose that option: there must be something sinister about this..."). In this way, fears associated with new risks can be introduced into the situation.

In consultancy work carried out by the Decision Analysis Unit at Brunel involving groups with conflicting interests we have used, with some success, an alternative MAUT-based procedure aimed at preserving the background of safety for all protagonists in moving towards and interpreting a particular choice of option. Our procedure is similar to that of von Winterfeldt and Rios in the decomposition phase: first, scenarios are explored among the various stakeholders. Criteria and concerns identified during the explorations are then modelled within a hierarchical MAUT-based structure constructed in direct interaction with representatives of all groups of stakeholders working together[1]. Ideally, the resulting structure should be ordered in such a way that major differences between stakeholders are explicitly modelled at higher levels within the hierarchy.

Usually, in applications in MAUT , modelling stakeholder's conflicting objectives within a single structure, differences between objectives are modelled by obtaining a separate set of importance weights over all criteria in the structure for each stakeholder group, and then either (i) performing separate evaluations for each group using the appropriate set of weights, or (ii) averaging the weights across groups according to some arbitary scheme[2].

Our approach differed from both of these in that, starting at the lowest level nodes in the hierarchy, stakeholders are invited to negotiate a single set of importance weights to be assigned to the branches meeting at each node. In the arguments advanced in such negotiations, stakeholders explore their own and other's scenarios (as a stakeholder who differs with you has to explain why he or she wishes to discount your concerns, rather than just ignore them, and you, in arguing for their relative importance have to explain why it is unsafe to discount them). We have found that once protagonists have discovered that it is possible to negotiate relative weights at the lower nodes of the structure, they are prepared to continue negotiating the more controversial relative weights at the higher nodes

---

1 We have found that this can be achieved without moving into an adversary situation providing that stakeholders feel that all the concerns that they wish to be addressed are included in the structure (understanding that other stakeholders may wish to put different weights on these concerns, or even discount them entirely). The important point is that all stakeholders acknowledge the existence of each other's concerns.

2 Campbell and Seaver discuss what these schemes might be. There is no way of chosing a scheme on the basis of its optimality, equitability or rationality in any absolute sense.

in the tree[1].

The result is a complete "compromise" set of weights that may be used by consensus in chosing between alternative options. It does not mean that any option so chosen will be preferred by all (or even a majority) of stakeholders, since the "compromise" structure will not replicate any of the value structures which would guide individual stakeholder's idealized choices. What it does ensure is that (i) the basis for the decision is understood by all stakeholders before it is taken, and (ii) structuring of consequences on any area of concern is not confined to the realm of the occult. Hence any background of safety established at the outset of the analysis can be preserved.

However, this achievement also emphasizes the procedure's limitation to successful applications where parties to the decision do not have uncertainties about ares of the DMS which threaten their background of safety. In other cases the use of any overall composition rule is inappropriate, although partial compositions may be achieved in 'non-threatening' areas of the hierarchy. Ability to explore the properties of the decomposed, or semi-decomposed, structure then becomes the first priority for a decision aid.

A less serious limitation, but one which is very important to recognize, stems from the fact that the ability to 'fix the meaning' of poles of an attribute dimension, so that scaling of options may be

---

1 For details of a practical application of this procedure, see Humphreys, Larichev & Vari, 1982.

accomplished, rests on the ability to set bounds on the chains of signification which serve to define the meaning of the poles for the assessor. While this is quite a reasonable task for an individual (providing he is clear about his goal), the resulting characterization of the 'fixed' meaning of an attribute dimension will depend on what it signifies to the individual within the bounds set (Berkeley, 1981).

Much of the differences in salience accorded to dimensions by different parties within a risk debate may be due to different patterns of signification being linked to poles defined within the decision analysis by the same name for all groups' ratings (e.g., 'promotes centralization of resources'). The linguistic representation is shared across groups, the meaning is not.

Acknowledging these limitations should be a starting point not a recipe for retreat since while, as Kunreuther (1980) points out, in most debates on new technology stakeholders have unequal power and so decisions can be forced by the stakeholder with the greatest power in the short run, the long-term consequence of this is likely to be counterproductive since

> "politically, exclusion may breed anger as well as ignorance. Citizens in a democratic society will eventually interfere with decisions in which they do not feel represented. When lay people do force their way into hazard decisions, the vehemence and technical naivete of their response may leave the paid professionals agash, reinforcing suspicions about the 'stupidity of the public'. By avoiding these conflicts, early public involvement may lead to decisions that take longer to make, but are more likely to stick." (Fischhoff et al, 1981)

This has been the motivation behind my attempt in this paper to examine what is involved at an experiential level in such public involvement, and how it might be explored under the goal of reaching decisions which are more likely to stick.

REFERENCES

Berkeley, D. The meaning of rationality when conceptualizing decision problems. Unpublished dissertation. Department of Social Psychology, London School of Economics and Political Science, 1981.

Bruner, J.S., Goodnow, J.J. & Austin, G.A. A study of thinking, New York: Wiley, 1956.

Campbell, V.N. & Seaver, D. Decision analysis in water resource planning: The Shasta case. Technical report 79-1, Falls Church, Va.: Decision Science Consortium, Inc., 1979.

Coombs, C.H. & Bowen, J.N. A test of VE theories of risk and the effect of the central limit theorem, Acta Psychologica, 1971, 35, 15-28.

Dawes, R.M. Shallow Psychology, In J.S. Carroll & S.W. Payne (Eds.) Cognition and Social Behaviour, Hillsdale, N.J.: Lawrence Erlbaum Associates, 1976.

Douglas, M. Purity and Danger, London: Routledge & Kegan Paul, 1966.

Edwards, W. Human Cognitive Capabilities, representativeness and ground rules for research, Contribution to symposium on Heuristics and Biases, Eighth Research conference on Subjective Probability, Utility and Decision Making, Budapest, 1981.

Fischhoff, B., Lichtenstein, S., Slovic, P., Darley, S. & Keeney, R.L. Acceptable Risk, New York: Cambridge University Press, 1981.

Gyorgy, A. & Friends. No Nukes: Everyone's guide to nuclear power, Boston, Mass: South End Press, 1979.

Howard, R.A. & Matheson, J.E. Influence Diagrams, Menlo Park, California: S.R.I. International, 1980.

Humphreys, P.C. Multiattribute utility analysis of group decision making in real situations, Final Report HR 3982/2, Social Science Research Council, 1978.

Humphreys, P.C., Larichev, O. and Vari, A. Utilization of decision support systems in R & D decisions: 3-nation comparative case studies, Paper to be presented at the IFIP/IIASA Working Conference on Processes and Tools for Decision Support, Laxenburg, July 1982.

Humphreys, P.C. & McFadden, W. Experiences with MAUD: Aiding decision structuring versus bootstrapping the decision maker, Acta Psychologica, 1980, 45, 51-70.

Humphreys, P.C. & Wisudha, A. MAUD4, Technical Report 81-5, Uxbridge, Middlesex: Decision Analysis Unit, Brunel University, 1981.

Humphreys, P.C., Wooler, S. & Phillips, L.D. Structuring decisions: The role of structuring heuristics, Technical Report 80-1, Uxbridge, Middlesex: Decision Analysis Unit, Brunel University, 1980.

Jungermann, H. Speculations about decision-theoretic aids for personal decision making, Acta Psychologica, 1980, 45, 7-34.

Kahneman, D. & Tversky, A. Prospect theory: An analysis of decision under risk, Econometrika, 1979, 47, 263-291.

Keeney, R.L. Equity and Public Risk, San Francisco, California: Woodward Clyde Consultants, 1978.

Keeney, R.L. Utility Functions for Equity and Public Risk, San Francisco, California: Woodward Clyde Consultants, 1979.

Keeney, R.L. Evaluation of mortality risks from an organizational perspective. Major Paper, Eighth Research Conference on Subjective Probability, Utility and Decision Making, Budapest, 1981.

Kunreuther, H. Societal decision making for low probability events: Descriptive and prescriptive aspects, Working Paper WP-80-164, Laxenburg, Austria: International Institute for Applied Systems Analysis, 1980.

Lathrop, J. The role of risk assessment in facility siting: An example from California, Working paper WP-80-150, Laxenburg, Austria: International Institute for Applied Systems Analysis, 1980.

Lathrop, J. & Linnerooth, J. The role of risk assessment in a political decision process, In P.C. Humphreys and A. Vari (Eds.) Analysing and Aiding Decision Processes, Amsterdam: North Holland, in press.

Leach, E.R. Anthropological Aspects of Language: Animal categories and verbal abuse, In E.H. Lenneberg (Ed.) New Directions in the study of language, Cambridge, Mass.: M.I.T. Press, 1964.

Linnerooth, J. The value of human life: A review of the models, Economic Inquiry, 1979, 17, 52-74.

Otway, H.J., Maurer, M. & Thomas, K. Nuclear power: The question of public acceptance, Futures, April 1978, 109-118.

Phillips, L.D. The evaluation of risk estimates: Limitations to human judgement? Tutorial paper 79-2, Uxbridge, Middlesex: Decision Analysis Unit, Brunel University, 1979.

Pitz, G.F. Human engineering and decision aids, Major paper, Eighth Research Conference on Subjective Probability, Utility and Decision Making, Budapest, 1981.

Sandler, J. & Sandler, A.M. On the development of object relations and affects, International Journal of Psychoanalysis, 1978, 59, 285-296.

Sjoberg, L. The risks of risk analysis, Acta Psychologica, 1980, 45, 301-321.

Slovic, P., Fischhoff, B. & Lichtenstein, S. Rating the risks, Environment, 1979, 21, 14-20, 36-39.

Toda, M. The decision process: On perspective, International Journal of General Systems, 1976, 3, 79-88.

Tversky, A. & Kahneman, D. Judgement under uncertainty: Heuristics and biases, Science, 1974, 185, 1124-1131.

Vlek, C. & Stallen, P.J. Rational and personal aspects of risk. Acta Psychologica, 1980, 273-300.

Watson, S.R. On risks and acceptability, Journal of the Society of Radiological Protection, 1981, 1, No. 4.

von Winterfeldt, D. & Rios, M. Conflicts about Nuclear Safety: A decision theoretic approach, Social Science Research Institute, Los Angeles: University of Southern California, 1980.

PART III

MEASURING RISK

"THE PUBLIC" VS. "THE EXPERTS": PERCEIVED VS. ACTUAL DISAGREEMENTS ABOUT RISKS*

Baruch Fischhoff, Paul Slovic, and Sarah Lichtenstein

Decision Research, A Branch of Perceptronics,
1201 Oak Street, Eugene, Oregon 97401, USA

It is obvious that some members of the public and some members of the community of technical experts disagree about the risks of nuclear power. It is less obvious why they disagree. Since the source of a disagreement has important implications for how a democratic society might bring about its resolution, there may be a strong temptation to fall back on politically convenient explanations (e.g., the public is stupid; the experts have tunnel vision). The paper attempts to characterize the full range of possible and probable sources of disagreement, finding them to be rather more diverse and complicated than is often acknowledged. On the basis of this analysis, it offers some suggestions for how conflict resolution may be accomplished and where it is superfluous.

*Paper prepared for a session on "The Analysis of Perceived vs. Actual Risks: Nuclear Power Plants — a U.S. Perspective", First Annual Meeting of the Society for Risk Analysis, at National Academy of Sciences, Washington, D.C., June 1–3, 1981.

A recent public opinion survey (Harris, 1980) reported the following three results:

a. Among four "leadership groups" (top corporate executives, investors/lenders, Congressional representatives and federal regulators), 94-98% of all respondents agreed with the statement "even in areas in which the actual level of risk may have decreased in the past 20 years, our society is significantly more aware of risk."

b. Between 87% and 91% of those four leadership groups felt that "the mood of the country regarding risk" will have a substantial or moderate impact "on investment decisions—that is, the allocation of capital in our society in the decade ahead." (The remainder believed that it would have a minimal impact, no impact at all, or were not sure.)

c. No such consensus was found, however, when these groups were asked about the appropriateness of this concern about risk. A majority of the top corporate executives and a plurality of lenders believed that "American society is overly sensitive to risk," whereas a large majority of Congressional representatives and federal regulators believed that "we are becoming more aware of risk and taking realistic precautions." A sample of the public endorsed the latter statement over the former by 78% - 15%.

In summary, there is great agreement that risk decisions will have a major role in shaping our society's futures and that those decisions will, in turn, be shaped by public perceptions of risk. There is, however, much disagreement about the appropriateness of those perceptions. Some believe the public to be wise; others do not. These contrary beliefs imply rather different roles for public involvement in risk management. As a result, the way in which this disagreement is resolved will affect not only the fate of particular technologies, but also the fate of our society and its social organization.

The views about risk perceptions given by the respondents to this poll, like those offered by other commentators on the contemporary scene, are, at best, based on intense, but unsystematic observation. At worst, they represent attempts to bias the political process by promulgating self-serving beliefs. Such happens, for example, when one claims that people are so poorly informed (and uneducable) that they require paternalistic institutions to defend them or that they would be better off surrendering some of their political rights to technical experts. It also happens, at the other extreme, when one claims that people are so well informed (and offered such freedom of choice) that they can fend for themselves in the marketplace and need no governmental protection.

Like speculations about chemical reactions, speculations about human nature need to be disciplined by fact. To that end, various investigators have been studying how and how well people think about risks. Although the results of that research are not definitive as yet, they do clearly indicate that a careful diagnosis is needed whenever "the public" and "the experts" appear to disagree. It is seldom adequate to attribute all such discrepancies as reflecting public misperceptions. From a factual perspective, that assumption is often wrong; from a societal perspective, it is generally corrosive by encouraging disrespect between the parties involved. When the available research data do not allow one to make a confident diagnosis, a sounder assumption is that there is some method in anyone's apparent madness. The present essay suggests some ways to find that method. Specifically, it offers six reasons why disagreements between the public and the experts need not be interpreted as clashes between actual and perceived risks.[1]

Reason 1: The Distinction Between "Actual" and "Perceived" risks Is Misconceived

Although there are actual risks, nobody knows what they are. All that anyone does know about risks can be classified as perceptions. Those assertions that are typically called "actual risks" (or "facts" or "objective information") inevitably contain some element of judgment on the part of the scientists who produce them.[2] That element is most minimal when judgment is needed only to assess the competence of a particular study conducted within an established paradigm. It grows as one needs to integrate results from diverse studies or to extrapolate results from a domain in which they are readily obtainable to another domain in which they are really needed (e.g., from animal studies to human effects). Judgment becomes all when there are no (credible) available data, yet a policy decision requires that some assessment of a particular fact be made.

The expert opinions that comprise the scientific literature are typically considered to be "objective" in two senses, neither of which can ever be achieved absolutely and neither of which is the exclusive province of technical experts. One meaning of objectivity is reproducibility: one expert should be able to repeat another's study, review another's protocol, reanalyze another's data, or recap another's literature summary and reach the same conclusions about the size of an effect. Clearly, as the role of judgment increases in any of these operations, the results become increasingly subjective. Typically, one would expect reproducibility to decrease (and subjectivity to increase) to the extent that a problem attracts scientists with diverse training or to the extent that the field entrusted with a problem has yet to reach a consensus on basic issues of methodology.

The second sense of "objectivity" means immunity to any influence by value considerations. One's interpretations of data should not be biased by one's political views or pecuniary interests. Applied sciences naturally have developed great sensitivity to such problems and are able to invoke some penalties for detected violations. There is, however, little possibility of "regulating" the ways in which values influence other acts, such as one's choice of topics to study or ignore. Some of these choices might be socially sanctioned, in the sense that one's values are widely shared (e.g., deciding to study cancer because it is an important problem); other choices might be more personal (e.g., not studying an issue because one's employer does not wish to have a troublesome data base created on that topic). Although a commitment to separating issues of fact from issues of value is a fundamental aspect of intellectual hygiene, a complete separation is never possible (Bazelon, 1979; Fischhoff et al., in press; Sjöberg, 1979).

At times, this separation is not even desired—that happens when experts are asked for (or volunteer) their views on how risks should be managed. Because they mix questions of fact and value, such views might be better thought of as the opinions of experts rather than as expert opinions, a term that should be reserved for expressions of substantive expertise. Often the reasons for eliciting such opinions are obscure. It would seem as though members of the public are the experts when it comes to striking the appropriate tradeoffs between costs, risks, and benefits. That expertise is best tapped by surveys, hearings, and political campaigns (Hammond & Adelman, 1976: Mazur, 1981).

Of course, there is no all-purpose public any more than there are all-purpose experts. The ideal expert on a matter of fact has studied that particular issue and is capable of rendering a properly qualified opinion in a form useful to decision makers. Using the same criteria for selecting value experts might lead one to philosophers, politicians, psychologists, sociologists, clergy, intervenors, pundits, shareholders, or bystanders, depending upon how those criteria were interpreted. Thus, one must ask, "in what sense," whenever someone says, "expert" or "public" (Schnaiburg, 1980; Thompson, 1980). We will use "expert" in the restrictive sense and "public" or "laypeople" to refer to every one else, including scientists in their private lives.

Reason 2: Laypeople and Experts
Are Talking Different Languages

Explicit risk analyses are a fairly new addition to the repertoire of intellectual enterprises. As a result, the risk experts are only beginning to reach consensus on terminology and methodology. Their communications to the public are only beginning to express some coherent perspective and to help the public sort out the variety of meanings that "risk" could have (Crouch & Wilson, 1981). Experimental studies (Slovic, Fischhoff, and Lichtenstein, 1979; 1980) have indicated that when expert risk assessors are asked to assess the "risk" of a technology on an undefined scale, they tend to respond with numbers that approximate the number of recorded or estimated fatalities in a typical year. When asked to estimate "average year fatalities," laypeople produce fairly similar numbers. When asked to assess "risk," however, laypeople produce quite different responses. These estimates seem to be an amalgam of their average year fatality judgments, along with their appraisal of other features, such as a technology's catastrophic potential or the equity with which its risks are distributed. These catastrophic potential judgments match those of the experts in some cases, but differ in others (e.g., nuclear power).

On semantic grounds, words can mean whatever a population group wants them to mean, as long as that usage is consistent and does not obscure important substantive differences. On policy grounds, the choice of a definition is a political question regarding what a society should be concerned about when dealing with "risk." Whether we attach special importance to potential catastrophic losses of life or convert such losses to expected annual fatalities (i.e., by multiplying the potential loss by its annual probability of occurrence) and add them to the routine toll is a value question—as would be a decision to weight those routine losses equally rather than giving added weight to losses among the young (or among the non-beneficiaries from a technology).

For other concepts that recur in risk discussions, the question of what they do or should mean is considerably murkier. It is often argued, for example, that different standards of stringency should apply to voluntarily and involuntarily incurred risks (e.g., Starr, 1969). Hence, for example, skiing could (or should) legitimately be a more hazardous enterprise than living below a major dam. Although there is general agreement among experts and laypeople about the voluntariness of food preservatives and skiing, other technologies are more problematic (Fischhoff et al., 1978; Slovic et al., 1980). We have found considerable disagreement within expert and lay groups in their ratings of the voluntariness of technologies such as prescription antibiotics, commercial aviation, hand guns and home appliances. These disagreements may reflect differences in the reference groups considered; for example, use of commercial aviation may be voluntary for vacationers, but involuntary for certain business people and scientists. Or they may reflect disagreements about the nature of society or the meaning of the term. For example, each decision to ride in a car may be voluntarily undertaken and may, in principle, be foregone (i.e., by not traveling or by using an alternative mode of transportation); but in a modern industrial society, these alternatives may be somewhat fictitious. Indeed, in some social and professional sets, the decision to ski may have an involuntary aspect. Even if one makes a clearly volitional decision, some of the risks that one assumes voluntarily may be indirectly and involuntarily imposed on one's family or the society that must pick up the pieces (e.g., pay for hospitalization due to skiing accidents).

Such definitional problems are not restricted to subjective terms such as voluntary. Even a technical term such as "exposure" may be consensually defined for some hazards (e.g., medical x rays) but not for others (e.g., handguns). In such cases, the disagreements within expert and lay groups may be as large as those between them. For debate to proceed, one needs some generally accepted definition for each important term—or at least a good translating dictionary. For debate to be useful, one needs an explicit analysis of whether each concept, so defined, makes a sensible basis for policy. Once they have been repeated often enough, ideas such as the importance of voluntariness or catastrophic potential tend to assume a life of their own. It does not go without saying that society should set a double standard on the basis of voluntariness or catastrophic potential, however they are defined.

Reason 3: Laypeople and Experts Are Solving Different Problems

Many debates turn on whether the risk associated with a particular configuration of a technology is acceptable. Research (Slovic, Fischhoff, & Lichtenstein, 1981) has found substantial disagreements not only between people belonging to different population groups, but also within groups when the question is posed in different ways. Although these disagreements may be interpreted as reflecting conflicted social values or confused individual values, closer examination suggests that the acceptable-risk question itself may be poorly formulated.

To be precise, one does not accept risks. One accepts options that entail some level of risk among their consequences. Whenever the decision-making process has considered benefits or other (non-risk) costs, the most acceptable option need not be the one with the least risk. Indeed, one might choose (or accept) the option with the highest risk if it had enough compensating benefits. The attractiveness of an option depends upon its full set of relevant positive and negative consequences (Fischhoff et al., in press).

In this light, the term "acceptable risk" is ill-defined, without specifying the options and consequences to be considered. Once options and consequences are specified, "acceptable risk" might be used to denote the risk associated with the most acceptable alternative. When using that designation, it may be quite difficult to remember how context dependent it is. That is, people may disagree about the "acceptability of risks" not only because they disagree on how to evaluate the consequences (i.e., they have different values), but also because they disagree about what consequences and options are to be considered.

A number of well-known policy debates might be speculatively attributed, at least in part, to differing conceptions of what the set of possible options is. For example, the risks (or possible risks) of saccharin may look unacceptable when compared with the risks of (the option of) life without sweeteners. They may, however, seem more palatable when the only alternative option considered is another sweetener that appears to be more costly and more risky. Or, nuclear power may seem acceptable when compared with alternative sources of generating electricity (with their risks and costs), but not so acceptable when aggressive conservation is added to the option set. Technical people from the nuclear industry seem to prefer the narrower definitions of the problem, perhaps because they like the light it casts on their energy source, perhaps because they prefer to concentrate on the kinds of solutions most within their domain of expertise. Citizens involved in energy debates may feel themselves less narrowly bound; they may also be more comfortable with solutions such as conservation that require their kind of expertise (Bickerstaffe & Pearce, 1980).

People who agree about the facts and share common values may still disagree about the acceptability of risks because they have different notions about which of those values are relevant to a particular decision problem. All parties may think that equity is a good thing in general without also agreeing that energy policy is the proper arena for resolving inequities. For example, some may feel that both those new inequities caused by a technology and those old ones endemic to a society are best handled separately (e.g., through the courts or with incomes policies).

Thus, when laypeople and experts disagree about the acceptability of a risk, one must always consider the possibility that they are addressing different problems, with different sets of alternatives or a different set of relevant consequences. Assuming that each group has a full understanding of the implications of its favored problem definition, the choice between definitions is a political question. When the public's definition is adopted in whole or in part, then this aspect of public perceptions has been accommodated in the decision-making process without any specific component of that process being labeled as such (Stallen, 1980).

Reason 4: Debates over Substance May Disguise Battles over Form—and Vice Versa

In most political arenas, the conclusion of one battle often sets some of the initial conditions of its successor. Insofar as risk management decisions are shaping the economic and political future of a country, they are too important to be left to risk managers (Wynne, 1980). When people from outside the risk community enter into risk battles, they may try to master the technical details, or they may concentrate on monitoring and shaping the risk management process itself. The latter strategy may exploit their political expertise and keep them from being outclassed (or mislead) on technical issues. As a result, their concern about the magnitude of a risk may emerge in the form of carping about the way it is studied. They may be quick to criticize any risk assessment that does not have such features as eager peer review, ready acknowledgement of uncertainty, or easily accessible documentation. Even if those features are consonant with good research, scientists may resent being told by laypeople how to conduct their business even more than they resent being told by novices what various risks really are.

Lay activists' critiques of the risk assessment process may be no less irritating, but somewhat less readily ignored, when they focus on the way in which scientists' agendas are set. As veteran protagonists in hazard management struggles know, without scientific information, it may be hard to arouse and sustain concern about an issue, to allay inappropriate fears, or to achieve enough certainty to justify any action. However, information is, by and large, created only if someone has a (professional, political, or economic) use for it. Thus, we may know something only if someone in a position to decide feels that it is worth knowing.

Doern (1978) proposed that lack of interest in the fate of workers is responsible for the lack of research on the risks of uranium mining; Neyman (1979) wondered whether the special concern over radiation hazards has restricted the study of chemical carcinogens; Commoner (1979) accused oil interests of preventing the research that could establish solar power as a viable energy option. In some situations, knowledge is so specialized that all relevant experts may be in the employ of a technology's promoters, leaving no one competent to discover troublesome facts (Gamble, 1978). Whether the cause is fads or finances, failure to study particular topics can thwart particular parties and may lead them to impugn the scientific process.

At the other extreme, debates about political processes may underlie disputes that are ostensibly about scientific facts. As mentioned earlier, the definition of an acceptable-risk problem circumscribes the set of relevant facts, consequences and options. This agenda setting is often so powerful that a decision has effectively been made once the definition is set. Indeed, the official definition of a problem may preclude one from advancing one's point of view in a balanced fashion. Consider, for example, an individual who is opposed to increased energy consumption but is only asked about which energy source to adopt. The answers to these narrow questions provide a _de facto_ answer to the broader question of growth. Such an individual may have little choice but to fight dirty, engaging in unconstructive criticism, poking holes in analyses supporting other positions, or ridiculing opponents who adhere to the more narrow definition. This apparently irrational behavior can be attributed to the rational pursuit of officially unreasonable objectives.

Another source of deliberately unreasonable behavior arises when participants in technology debates are in it for the fight. Many approaches to determining acceptable-risk levels (e.g., cost-benefit analyses) make the political-ideological assumption that our society is sufficiently cohesive and common-goaled that its problems can be resolved by reason and without stuggle. Although such a "get on with business" orientation will be pleasing to many, it will not satisfy all. For those who do not believe that society is in a fine-tuning stage, a technique that fails to mobilize public consciousness and involvement has little to recommend it. Their strategy may involve a calculated attack on what they interpret as narrowly defined rationality.

A variant on this theme occurs when participants will accept any process as long as it does not lead to a decision. Delay, per se, may be the goal of those who wish to preserve some status quo. These may include environmentalists who do not want a project to be begun or industrialists who do not want it to be regulated. An effective way of thwarting practical decisions is to insist on the highest standards of scientific rigor.

Reason 5: Laypeople and Experts
Disagree about What Is Feasible

Laypeople are often berated for misdirecting their efforts when they choose risk issues on which to focus their energies. However, a more careful diagnosis can often suggest a number of defensible strategies for setting priorities. For example, Zentner (1979) criticizes the public because its rate of concern about cancer (as measured by newspaper coverage) is increasing faster than the cancer rate. One reasonable explanation for this pattern is that people may believe that too little concern has been given to cancer in the past (e.g., our concern for acute hazards like traffic safety and infectious disease allowed cancer to creep up on us). A second is that people may realize that some forms of cancer are the only major causes of death whose rates are increasing.

Systematic observation and questioning are, of course, needed to tell whether these speculations are accurate (and whether the assumption of rationality holds in this particular case). False positives in divining people's underlying rationality can be as deleterious as false negatives. Erroneously assuming that they understand an issue may deny them a needed education; erroneously assuming that they do not understand may deny them a needed hearing. Pending systematic studies, these error rates are likely to be determined largely by the rationalist or emotionalist cast of one's view of human nature.

In lieu of data about specific cases, perhaps the most reasonable general assumption is that people's investment in problems is determined by their feelings of personal efficacy. That is, they do not get involved unless they feel that they can make a difference, personally or collectively. In this light, their decision-making process is dominated by a concern that is known to dominate other psychological processes: perceived feelings of control (Seligman, 1975). As a result, people will deliberately ignore major problems if they see no possibility of effective action; some reasons why they might reject a change of "misplaced priorities" when they neglect a hazard that poses a large risk:

(a) The hazard is needed and has no substitutes;

(b) The hazard is needed and has only riskier substitutes;

(c) No feasible scientific study can yield a sufficiently clear and incontrovertible signal to legitimate action;

(d) The hazard is distributed naturally, hence cannot be controlled;

(e) No one else is worried about the risk in question, hence, no one will heed messages of danger or be relieved by evidence of safety;

(f) No one is empowered to or able to act on the basis of evidence about risk.

Thus, the problems that actively concern people need not be those whose resolution they feel should rank highest on society's priorities. For example, one may acknowledge that the expected deaths from automobile accidents over the next century are far greater than those expected from nuclear power, yet still be active only in fighting nuclear power out of the conviction that "Here, I can make a difference. This industry is on the ropes now. It's important to move in for the kill before it becomes as indispensible to American society as automobile transportation."

Where the priorities of experts and laypeople differ, it may not reflect disagreements about the size of risks, but differing opinions on what can be done about them. At times, the technical knowledge or can-do perspective of the experts may lead them to see a broader range of feasible actions. At other times, laypeople may feel that they can exercise the political clout needed to make some options happen, whereas the experts feel constrained to doing what they are paid for. In still other cases, both groups may be silent about very large problems because they see no options. That might be the most charitable explanation of the relative silence of scientists and citizens regarding the threat of nuclear war.

Reason 6: Laypeople and Experts See the Facts Differently

There are, of course, situations in which disputes between laypeople and experts cannot be traced to disagreements about objectivity, terminology, problem definitions, process or feasibility. Having eliminated those possibilities, one may assume the two groups really do see the facts of the matter differently. Given that laypeople and experts are talking about the same thing, it may be useful to distinguish between two situations: those in which laypeople have no source of information other than the experts, and those in which they do have such sources. The reasonableness of disagreements and the attendant policy implications look quite different in each case.

How might laypeople have no source of information other than the experts, yet come to see the facts differently? One way is for the experts' message not to get through intact, perhaps because: (a) the experts are unconcerned about disseminating their knowledge or hesitant to do so because of its tentative nature; (b) only a biased portion of the experts' information gets out, particularly when the selection has been influenced by those interested in creating a particular impression; (c) the message gets garbled in transmission, perhaps due to ill-informed or sensationalist journalists; (d) the message gets garbled upon reception, either because it was poorly explicated or because the recipients lacked the technical basis for understanding it (Friedman, 1981; Hanley, 1980; Nelkin, 1977).[3]

A second way of going astray is to misinterpret not the substance, but the process of science. For example, unless an observer has reason to believe otherwise, it might seem sensible to assume that the amount of scientific attention paid to a risk is a good measure of its importance. Science can, however, be more complicated than that, with researchers going where the contracts, limelight, blue ribbon panels, or juicy controversies are. In that light (and in hindsight), science may have done a disservice to public understanding by the excessive attention it paid to saccharin. A second aspect of the scientific process that may cause confusion is its frequently disputatious nature. It may be all too easy for observers to feel that "if the experts can't agree, my guess may be as good as theirs" (Handler, 1980). Or, they may feel justified in picking the expert of their choice, perhaps on spurious grounds, such as assertiveness, eloquence, or political views. Indeed, we suspect that it is seldom the case that the distribution of lay opinions on an issue does not overlap at least a portion of the distribution of expert opinions. At the other extreme, laypeople may be baffled by the veil of qualifications that scientists often cast over their work. All too often, audiences may be swayed more by two-fisted debators (eager to make definitive statements) than by two-handed scientists (saying "on the one hand X, but on the other hand Y," in an effort to achieve balance).

In each of these cases, the misunderstanding is excusable, in the sense that it need not reflect poorly on the intelligence of the public or on its ability to govern itself. It, however, would seem hard to justify using the public's view of the facts instead of or in addition to the experts' view. A more reasonable strategy would seem to be attempts at education. These attempts would be distinguished from attempts at propaganda by allowing for two-way communication, that is, by being open to the possibility that even when laypeople appear misinformed, they may still have some defensible reason for seeing things differently than do the experts.

For laypeople to disagree reasonably, they would have to have some independent source of knowledge. What might that be? One possibility is that they have a better overview on scientific debates than do the active participants. Laypeople may see the full range of expert opinions and hesitations, immune to the temptations or pressures that actual debators might feel to fall into one camp and to discredit skeptics' opinions. In addition, laypeople may not feel bound by the generally accepted assumptions about the nature of the world and the validity of methodologies that every discipline adopts in order to go about its business. They may have been around long enough to note that many of the confident scientific beliefs of yesterday are confidently rejected today (Frankel, 1974). Such lay skepticism would suggest expanding the confidence intervals around the experts' best guess at the size of the risks.

Finally, there are situations in which the public, as a result of its life experiences, is privy to information that has escaped the experts (Brokensha, Warren, & Werner, 1980). To take three examples: (1) The MacKenzie Valey Pipeline (or Berger) Inquiry discovered that natives of the far north knew things about the risks created by ice-pack movement and sea-bed scouring that were unknown to the pipeline's planners (Gamble, 1978). (2) Post-accident analyses often reveal that the operators of machines were aware of problems that the designers of those machines had missed (Sheridan, 1980). (3) Scientists may shy away from studying behavioral or psychological effects (e.g., dizzyness, tension) that are hard to measure, yet still are quite apparent to the individuals who suffer from them. In such cases, lay perceptions of risk should influence the experts' risk estimates.

Conclusion

There are many reasons for laypeople and experts to disagree. These include misunderstanding, miscommunication, and misinformation. Discerning the causes underlying a particular disagreement requires a combination of (a) careful thought, to clarify just what is being talked about and whether agreement is possible given the disputants' differing frames of reference, and (b) careful research,to clarify just what it is that the various parties know and believe. Once the situation has been clarified, the underlying problem can be diagnosed as calling for a scientific, educational, semantic, or political solution.

The most difficult situations will be those in which the participants cannot agree on what the problem is (and have no recourse to an institution that will resolve the question by arbitration or by fiat), and those in which education is called for, yet fails (after some reasonable, diligent effort). Policy makers then face the hard choice either of going against their own better judgment by using the public's assessment of risk (in which they do not believe) or of going against the public's feelings by imposing policies that will be disliked. Such policies may seem overly cautious (e.g., motorcycle helmet laws--to some people) or insufficiently cautious (e.g., nuclear power--to some people). When fears are ignored, the result can be stress or psychosomatic effects, which can be as real in their impact as they are illusory in their source. When strong public opinions are ignored, the result can be hostility, mistrust, and alienation. Since a society does more than manage risks, the policy maker must consider whether the social benefits to be gained by optimizing the allocation of resources in a particular decision is greater than the social costs of overriding a concerned public. A pessimistic view on "going with the public" might argue that "it only encourages the forces of irrationality (indirectly giving credence to astrology, superstition, and the like)." An optimistic view might be that risk questions are going to be with us for a long time. For a society to deal with them wisely, it must learn about their subtleties, including how appearances can be deceiving. One way of learning is by trial and error. Often, the experts will be able to say "we told you so. It would have been better to listen to us." In other cases, they may be surprised. Learning is possible as long as some basic respect remains between teacher and pupil. That respect may be one of a society's greatest assets.

References

Bazelon, D. L. Risk and responsibility. Science, 1979, 205, 277-280.

Bickerstaff, J. & Pearce, D. Can there be a consensus on nuclear power? Social Studies of Science, 1980, 10, 309-344.

Brokensha, D. W., Warren, D. M., & Werner, O. Indigenous knowledge: Systems and development. University Press of America, 1980.

Commoner, B. The politics of energy. New York: Knopf, 1979.

Crouch, E. A. C & Wilson, R. Risk analysis. Cambridge, Mass.: Ballinger, 1981.

Doern, G. B. Science and technology in the nuclear regulatory process: The case of Canadian uranium miners. Canadian Public Administration, 1978, 21, 51-82.

Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S., & Keeney, R. Acceptable risk. New York: Cambridge University Press, in press.

Fischhoff, B., Slovic, P., & Lichtenstein, S. Knowing what you want: Measuring labile values. In T. Wallsten (Ed.), Cognitive processes in choice and decision behavior. Hillsdale, N.J.: Erlbaum, 1980.

Fischhoff, B., Slovic, P., & Lichtenstein, S. Lay foibles and expert fables in judgments about risk. In T. O'Riordan & R. K. Turner (Eds.), Progress in Resource Management and Environmental Planning, Vol. 3. Chichester: Wiley, in press.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. Policy Sciences, 1978, 8, 127-152.

Frankel, C. The rights of nature. In C. Schelling, J. Voss, & L. Tribe (Eds.). When values conflict. Cambridge, Mass.: Ballinger, 1974.

Friedman, S. M. Blueprint for breakdown: Three Mile Island and the media before the accident. Journal of Communication, 1981, 31, 116-129.

Gamble, D. J. The Berger inquiry: An impact assessment process. Science, 1978, 199, 946-951.

Green, C. H. Risk: Attitudes and beliefs. In D. V. Canter (Ed.), Behavior in fires. Chichester: Wiley, in press.

Hammond, K. R. & Adelman, L. Science, values and human judgment. Science, 1976, 194, 389-396.

Handler, P. Public doubts about science. Science, 1980, 208, 1093.

Hanley, J. The silence of scientists. Chemical and Engineering News, 1980, 58(12), 5.

Harris, L. Risk in a complex society. Public opinion survey conducted for Marsh & McLennan Companies, Inc., 1980.

Mazur, A. The dynamics of technical controversy. Washington, D. C.: Communications Press, 1981.

Nelkin, D. Technological decisions and democracy. Beverly Hills, Calif.: Sage, 1977.

Rothschild, N. M. Rothschild: An antidote to panic. Nature, 1978, 276, 555.

Schnaiburg, A. The environment: From surplus to scarcity.

Seligman, M. E. P. Helplessness. San Francisco: Freeman, 1975.

Sheridan, T. B. Human error in nuclear power plants. Technology Review, 1980, 82(4), 23-33.

Sjöberg, L. Strength of belief and risk. Policy Sciences, 1979, 11, 539-573.

Slovic, P., Fischhoff, B., & Lichtenstein, S. Rating the risks. Environment, 1979, 21(3), 14-20, 36-39.

Slovic, P., Fischhoff, B., & Lichtenstein, S. Facts vs. fears: Understanding perceived risk. In R. Schwing & W. A. Albers Jr., (Eds.), Societal risk assessment: How safe is safe enough? New York: Plenum, 1980.

Slovic, P., Fischhoff, B., & Lichtenstein, S. Response mode, framing, and information processing effects in risk assessment. In R. M. Hogarth (Ed.), New directions for methodology of social and behavioral science: The framing of questions and the consistency of response. San Francisco: Jossey-Bass, in press.

Slovic, P., Lichtenstein, S., & Fischhoff, B. Characterizing perceived risk. In R. W. Kates & C. Hohenemser (Eds.), Technological hazard management. Cambridge, Mass.: Oelgeschlager, Gunn & Hain, in press.

Stallen, P. J. Risk of science or science of risk? In J. Conrad (Ed.), Society, Technology and Risk Assessment. London: Academic Press, 1980.

Starr, C. Societal benefit versus technological risk. Science, 1969, 165, 1232-1238.

Thompson, M. Aesthetics of risk: Culture or context. In R. C. Schwing & W. A. Albers, Jr. (Eds.), Societal Risk Assessment. New York: Plenum, 1980.

Vlek, C. & Stallen, P. J. Rational and personal aspects of risk. Acta Psychologica, 1980, 45, 273-300.

Warner, F. & Slater, D. H. The assessment and perception of risk. London: The Royal Society, 1981.

Wynne, B. Technology, risk and participation. In J. Conrad (Ed.), Society, Technology and Risk Assessment. London: Academic Press, 1980.

Zentner, R. D. Hazards in the chemical industry. Chemical and Engineering News, 1979, 57(45), 25-27, 30-34.

Footnotes

This research was supported by the Nuclear Regulatory Commission under Subcontract 7656 from Union Carbide Corporation, Nuclear Division, Inc. to Perceptronics, Inc.

Correspondence may be addressed to either Baruch Fischhoff at Medical Research Council, 15 Chaucer Road, Cambridge UK, CB2 2EF or Paul Slovic, at Decision Research, 1201 Oak St., Eugene, Oregon 97401.

[1]Fuller expositions of the research upon which this summary is based may be found in sources such as Fischhoff, Slovic, & Lichtenstein (1980; 1981), Green (1981), Slovic, Fischhoff, & Lichtenstein (1980), Vlek & Stallen (1980), and Warner & Slater (1981).

[2]From this perspective, the title of this conference, "The Analysis of Actual vs. Perceived Risk," is a misnomer. A more accurate, and more clumsy title, would be "The Analysis of Risks as Perceived by Ranking Scientists within Their Field of Expertise vs. as Perceived by Anybody Else."

[3]For example, Lord Rothschild (1978) has noted that the BBC does not like to trouble its listeners with the confidence intervals surrounding technical estimates.

PSYCHOLOGICAL ASPECTS OF RISK: THE ASSESSMENT OF THREAT AND CONTROL*

P.J.M. Stallen
TNO-Apeldoorn, The Netherlands

A. Tomas
University of Nijmegen, The Netherlands

From a psychological point of view the assessment of risks associated with technologies is often a complex process. This paper discusses two models for studying how individuals judge the risk associated with being exposed to particular hazards. The following questions are specifically addressed by these approaches: How do individuals represent the risk activity? Are there systematic biases involved? The analysis of data shows that individuals are not so much concerned with estimating uncertainty parameters of a physical or material system as they are with estimating the uncertainty involved in their exposure to the threat and in opportunities to influence or control this exposure.

*Paper prepared for the International School of Technological Risk Assessment, Erice-Sicily, 20–31 May 1981. Reprinted by permission of the copyright holders: Sijthoff & Noordhoff Publishers, Alphen aan den Rijn, The Netherlands. This paper reports major parts of the theoretical foundation of an ongoing extensive in-depth study of people's reaction to technological threat. This study is sponsored by the Dutch Ministry of Health and Environmental Hygiene, Ministry of Social Affairs, TNO and the Openbaar Lichaam Rijnmond. We benefited greatly by discussing our ideas with Roel Meertens, Peter Stringer, Pieter Defares and Charles Vlek, who all made extensive comments on an earlier draft.

1. INTRODUCTION

"Technological hazards are big business", Harriss, Hohenemser & Kates (1978) conclude. Compared to such major sectors of national efforts as social welfare programs, transportation and national defense, technological hazards and their management require increasingly large amounts of money. Tuller (1978) estimated the total control and damage costs due to technological hazards to be 98,0 - 180,0 billions of $ in US fiscal year 1974. Harriss et al. (1978) convincingly argue that the hazards of technology have in industrial nations replaced natural hazards of floods, pestilence and disease (see Table 1).

If for no other reasons, the expenditures and losses due to technology are deserving the attention they are receiving. Especially from the side of government and industry there is an urgent need for a better scientific understanding of safety problems of complex technological systems.
Let us assume that such a scientific interest
offers the most appropriate approach to model - and so control - technological uncertainty. Our interest in risk assessment then concerns two different levels of decision making about technology: social choice and personal choice.

	PRINCIPAL CAUSAL AGENT[a]			
	NATURAL[b]		TECHNOLOGICAL[c]	
	Social cost[d] (% of GNP)	Mortality (% of total)	Social cost[d] (% of GNP)	Mortality (% of total)
United States	2-4	3-5	5-15	15-25
Developing countries	15-40[e]	10-25	n.a.[f]	n.a.[f]

a. Nature and technology are both implicated in most hazards. The division that is made here is made by the principal causal agent, which, particularly for natural hazards, can usually be identified unambiguously.
b. Consists of geophysical events (floods, drought, tropical cyclones, earthquakes and soil erosion); organisms that attack crops, forests, livestock; and bacteria and viruses which infect humans. In the U.S. the social cost of each of these sources is roughly equal.
c. Based on a broad definition of technological causation, as discussed in the text.
d. Social costs include property damage, losses of productivity from illness or death, and the costs of control adjustments for preventing damage, mitigating consequences, or sharing losses.
e. Excludes estimates of productivity loss by illness, disablement, or death.
f. No systematic study of technological hazards in developing countries is known to us, but we expect them to approach or exceed U.S. levels in heavily urbanized areas.

Table 1. Comparative hazard sources in U.S. and developing countries. (Source: Harriss et al. 1978).

As psychologist, we feel more competent in dealing with the latter and leave the area of collective decision making about technology to other disciplines like policy science, sociology, and welfare economy[1]. However, in as far as politicians and experts too are individual decision makers, our paper may well contain relevant data to their way of expressing preferences and handling technological risks. As Slovic, Fischhoff & Lichtenstein (1976) noted, policy makers when asked to "weigh the benefits against the risks"

> "often have highly sophisticated methods at their disposal for gathering information about problems or constructing technological solutions. When it comes to making decisions, however, they typically fall back upon the technique which has been relied upon since antiquity-intuition.

1) It appears to us that this area of essentially social choice processes is much in need of systematic investigation. For one thing, it would be important to study how qualitative descriptions (e.g. Wynne, 1980) could benefit from formal mathematical analysis of social choice mechanisms. One central conclusion that both approaches seem to reach in common is that social choice processes should essentially be about alternative options. In their remarkable effort to critically review existing social choice mechanisms concerning the question "how safe is safe enough" (like revealed preference, cost benefit analysis), Fischhoff et al. (1980) conclude: "Acceptable risk problems are decision problems, that is, they require a choice between alternatives" (ii). Bezembinder & Van Acker (1979) from their point of view suggest that "the evaluation underlying intransitive choice and the alleged interpersonal incomparability of utility come together in calling for a notion of preference in which the basic object of evaluation is a pair of alternatives rather than a single alternative", (emphasis ours).

The quality of their intuitions sets an upper limit on the quality of the entire decision-making process and, perhaps, the quality of our lives. There is an urgent need to link the study of man's judgmental and decisionmaking capabilities to the making of decisions that affect the health and safety of the public".

In summary, in this paper we will concentrate on how individual persons evaluate technological risks. To us, this means studying how they judge an attribute (i.e., risk) of an activity (i.e., exposure to hazard). The important questions are: How does their representation of the risky activity look like? Or, how have they constructed an image of technological risk? Are there systematic biases involved? In the next section we will discuss two models that have recently been proposed to facilitate an answer to such questions.

1.1. MODELS OF "RISK PERCEPTION"

Vlek & Stallen (1980) have attempted to develop an ordering of aspects of risk which is meaningful from a decision-theoretic point of view. Figure 1 shows how they have decomposed the concept of acceptable risk and how its analytical components relate.

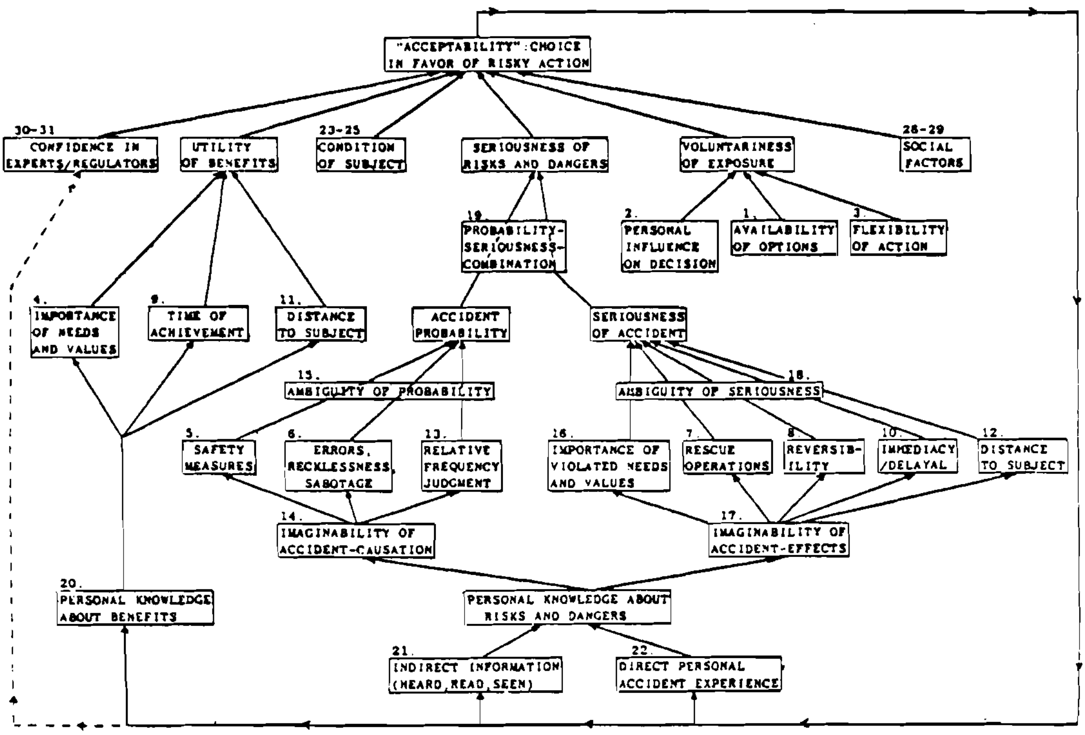


Figure 1. Rational ordering of the various aspects of risk. (Source: Vlek & Stallen, 1980).

These authors argue that patterns of personal risk experience (see bottom figure 1) may be systematically related to fundamental characteristics of risky decision situations, such as one's relative freedom of choice of exposure to hazard, the controllability of decision consequences and the type of need that is either fulfilled or frustrated by the possible consequences of the exposure. Most aspects of risk that have been discussed in the recent literature on personal risk assessment can be subsumed under one of their conceptual categories. For example, Rowe's "four most significant factors" (1977, p. 119): a. voluntariness, b. controllability, c. discounting in time, and d. discounting in space, are regarded as composed of elements 1-4, 5-8, 9-10 and 11-12 respectively (see figure 1).

Figure 1 is clearly based on the assumption of man as a rational decision maker who weighs all the risks and benefits, integrates them, compares alternatives and chooses the one with the maximum net benefit. The fact that most decisions bear upon illdefined problems, however, has led Vlek & Stallen to propose a rational structure with less global, less abstract and less formal variables. Their conceptual model has the advantage of providing a framework for ordering many studies on personal risk assessment. Moreover, it may function as a conceptual bridge between, on the one hand, the quantitative approach of most risk analysts who combine probabilities with losses in calculating levels of risks, and, on the other hand, psychologists who want to show that people necessarily use various heuristics in estimating how much risk is involved in some activity.

For studying the dynamics of such latter decision making Tomas & Stallen (1981) have proposed to use a model that gives more credit to the functional relationship between various psychological processes that mediate between the uncertain (technological) environment and behavior. Figure 2 shows the basic structure of their process-model. It are the internal processes of appraisal and coping that determine how a person will react to threatening technological uncertainty. This reaction is not necessarily a passive response, it may often as well be seen as an active process of structuring ones environment so as to make it more compatible with ones needs.

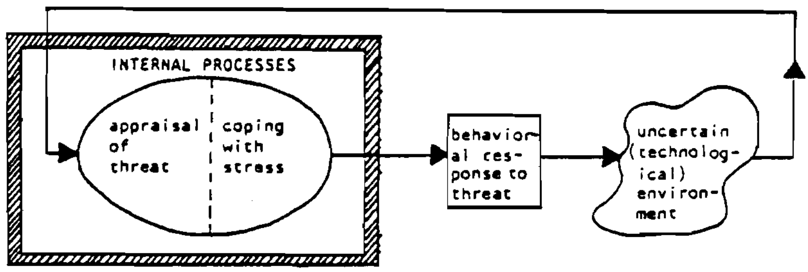


Figure 2: General model of person/environment relationship.

This more explicit emphasis on the often need-based or motivational character of peoples evaluation of threat (and their behavioral response), may be seen as a second characteristic of their model. In his analysis of environments as perceptual targets, Ittelson (1973) has asserted that "the first response to the environment is affective. The direct emotional impact of the situation, perhaps largely a global response to the ambiance, very generally governs the directions taken by subsequent relations, with the environment. It sets the motivational tone and delimits the kinds of experiences one expects and seeks" (p. 16). Most contemporary psychological

studies of personal risk assessment underestimate this role of affective or emotional processes in assessing the risk of exposure to the hazardous environment[2]. This is somewhat surprising, because most peoples response to technological risks seems to be more in terms (!) of "feelings of (in)-security" than in terms of "(in)sufficiently elaborated cognitive representations". From the first point of view one major area of psychological theory which seems to be very relevant to such feelings is the literature of stress and coping. The following elaboration of our general model may both serve as a short introduction to one dominant approach within this area and show its relevance for studying how people react to (technological) threat.
In this latter respect it primarily has a heuristic function, like the aforementioned conceptual model of Vlek & Stallen.

1.2. THREAT, STRESS AND BEHAVIOR

One of the most influential programs of psychological stress research is the work done by Richard Lazarus and his associates (Lazarus, 1966; 1976; 1980). Typical of Lazarus' approach is his view on stress as an intermediary variable between the stressor and behavior. In 1966 he defines stress as "a psychological condition involving the anticipation on the part of the organism of his inability to cope with some future stimulus". In his more recent work he stressed the interactive character of it: "Stress occurs when there are demands on the person which tax on (...) his adjustive resources" (Lazarus, 1976, p. 47).

---

2) Many people fear the possible consequences of complex modern technologies. Those who support the technological status quo often call this response too emotional and - therefore - irrational. Stallen (1980; see also Wynne, 1980), has argued that such a derogation of opposition can be seen as based upon an ideological generalization of the applicability of the dominant scientific notion of rationality to all kinds of human decisions. This, of course, is not what we mean by emotional: it is affect, value but not as opposed to fact.

Thus, both the emphasis on the ready availability of coping resources and some (future) stimulus are characteristic conditions for stress to occur:

a. the individual is called upon to respond under circumstances in which he has no adequate response available, and

b. the consequences of not responding are important to the individual.

A final characteristic of Lazarus' view on stress as well as on coping is his cognitive orientation.

With respect to this latter emphasis on cognition, we take a slightly different position. Lazarus' views stress as transactional between the person and environment (see Kanner, Coyne, Schaefer & Lazarus, in press), and not - at least not clearly - as transactional between internal cognitive and emotional states. This may foreclose seeing stress as possibly aroused by changes in the person's emotions or his motivational system. His "demands" indeed can easily be interpreted as exclusively cognitive demands. Aside from this difference in point of view, however, Lazarus' model sufficiently suits the problems that we must address ourselves to. To a large extent, the threatening stimuli in technological assessment are likely to be future expected effects of present technological developments. Often it is a rather distant future (like in the case of delayed environmental effects). It is hard to see how such stimuli could generate stress without a subject who believes them to take place. This focus on stress as related to in some sense ordinary every day exposure and often chronic threat, is also close to Lazarus' current research interests (see Kanner et al., in press; Folkman & Lazarus, in press). Far too little attention has been given to the ways most people cope with stressful events in their day to day lives, i.e. when not subject to extreme circumstances like tornadoes, parachute jumping, doctoral examinations or spinal surgeries. In our opinion, technological threat has increasingly become a "normal" condition of our life.

In theory the processes that mediate between the threatening environment and the response can be differentiated into two classes: appraisal and coping (see figure 2). These two kinds of internal processes can be distinguished in most models within the stress literature. However, in a temporal sense (with appraisal preceding the coping) a sharp distinction is often hard to make, particularly when the individual is facing acute threat (cf. e.g., Krohne, 1978). In general, the processes that will be described below will operate at degenerate levels in cases where threat is acute as compared to chronic and the individual is hypervigilant instead of vigilant (cf. Janis & Mann, 1977).

APPRAISAL

Folkman & Lazarus (in press) define appraisal as "the cognitive process through which an event is evaluated with respect to what is at stake (primary appraisal) and coping resources and options (secondary appraisal)". The primary appraisal process is seen as based on the assessment of two elements:

1. the threatening event;
2. the possible state of not having reached pursued goals, and of having lost one's stakes at the same time.

Because of its embeddedness in the subject's entire motivational and goal structure, the evaluation of this latter state already entails an implicit anticipation of future coping opportunities. The more important the goals or the larger the stakes, the more difficult it will be to substitute them for other goals and, consequently, the more the subject will feel forced to look for alternative ways of fullfilling his needs. Thus, the questions that always lurk behind the assessment of threat are: is there anything I should do to reduce the threat? And: do I feel that I have opportunities to control the threat? The answer to these questions is the result of the secondary appraisal.

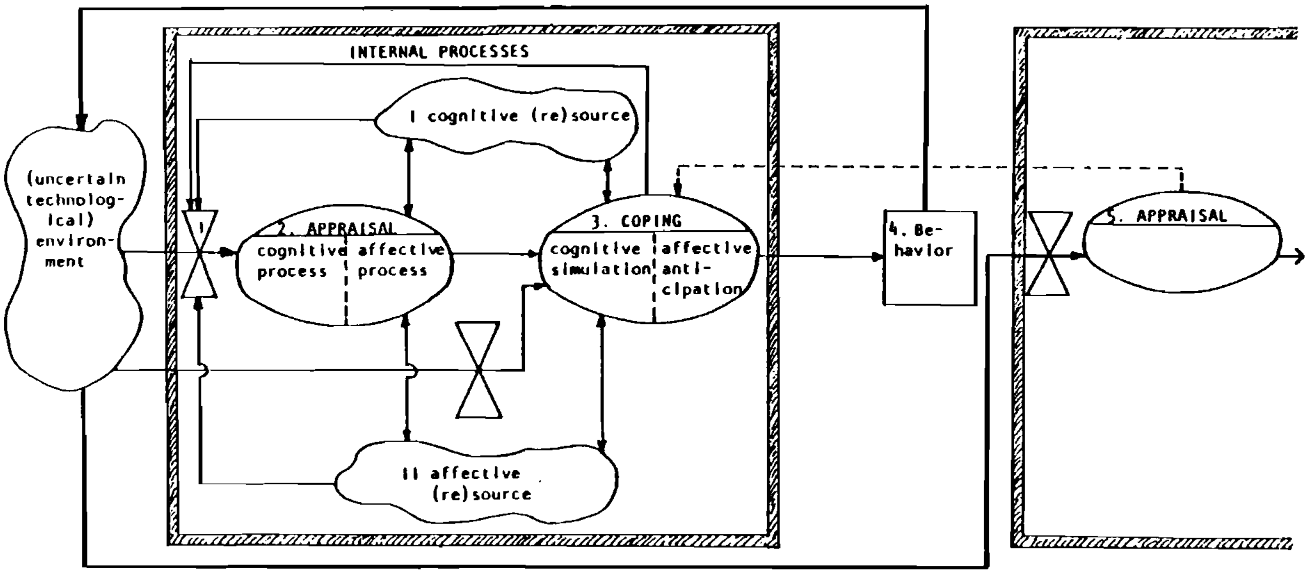


Figure 3: Schematic representation of the various psychological processes involved in dealing with a threatening uncertain environment.

In figure 3 we have shown how the various aspects of the appraisal and coping processess can be represented[3)]. Some consequence of the exposure of the person to a given technological environment called the external stimulus, is selectively perceived (box 1) as a threat[4)]. This selection mechanism is dependent upon the general psychological state of the person. For example, prejudices (source I) or fear (source II) may bias the perception. The cognitive resource primarily contains all knowledge that the person has ready at hand or can retrieve from memory. It is both factual knowledge like base rates and subjective knowing like scenarios or scripts. This all can be geared to the assessment of the threatening event. Examples are specific inferences that can be made about what to expect from the threat, or attributions about what caused or who is responsible for the event. Under affective processes we subsume the emotional involvement in the threatened situation, commitment to past behavior and the like. The relevant evaluations or affects are drawn from the affective resource. This we consider to be the value base for directing behavior. Motivational constructs like level of self-esteem and conformity are to be represented in this resource. Although affective reactions can occur without extensive cognitive encoding, and it even can be argued that affect and cognition are under the control of separate and partially independent systems (Zajonc, 1980), particularly when the threatening event is cognitively complex and affectively ambigious (as is likely with most technological threat), the interaction of cognitive and affective processes will gain fundamental importance.

---

3) The symbols of this figure are taken from system dynamics in an attempt to stimulate our thinking about the dynamics of personal risk assessment. They usually symbolize rates (⧖), levels (□), infinitively large (re)sources (☁), auxiliary variables (○) and information or energy flows (→).

4) We do not distinguish between attention and perception because it is no longer as clear as it once was (see Keele & Trammell-Neill, 1978).

STRESS

In line with Lazarus' definition we define stress as follows: it is the psychological state of an individual who experiences threat in his environment in such a way that the demand on him that follow from the threat are in conflict. Feelings of insecurity with respect to technological or industrial developments are so regarded as one specific form of stress. The notion of demand in this definition of stress, or the notions of something "at stake" and of "options" in the definition of appraisal by Folkman and Lazarus, all refer to the fact that stress arises in the context of goal directed and motivation-based behavior. It is the very relevance of the threatening event to the possibility of not attaining one's goals and not satisfying one's needs that makes the event threatening. Thus, at the same time, any threatening event does generate two hypothetical future states: one with and one without the activity. In figure 4 we have graphically represented this argument.

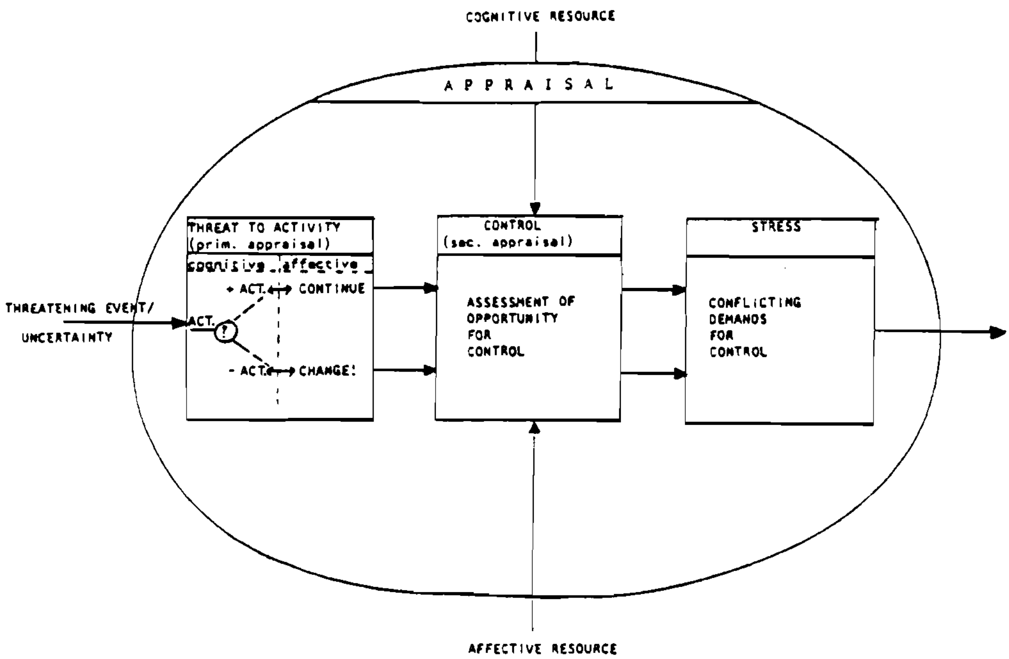


Figure 4: Structure of the appraisal process leading to stress.

In cognitive terms, the threat is represented by way of possible future consequences of the threatened activity: the activity will (+ ACT.) or will not (- ACT.) have led to the intended outcomes. As the activity has been directed to specific goals, and (quite a lot of) personal energy has been invested in it, one will generally be motivated to continue the activity. On the other hand, the threatening event calls for a change or modification of the activity. So the individual faces two mutually exclusive demands for future behavior.

As such it are demands for control of behavioral outcomes. Whether the option "change" can be realized or not will, of course, depend on available opportunities to do so. On the one hand, this is a matter of (re)sources that can be used to undertake a new or safeguarded activity.

On the other hand it requires a sufficiently well defined threat to know exactly how the activity should be changed. From a rational decision theoretic point of view one would like the person to have information about the relevant levels of all the variables of Vlek & Stallen's model (see figure 1). Both types of information - concerning the nature of the threat and the nature of the available resources - together define whether the two mutually exclusive demands make for a psychological conflict. This conflict we call stress.

There are at least three conditions that may oppose an easy change, and which will foster stress or aggrevate the conflict[5].

1. The threat could apply to other (substitute) activities. In that case it is hard to respond to the threat by changing the activity, assuming that one does not alter one's goals. Again a conflict exists.
2. It could be that the threatened activity is directed at or closely linked to central values. These it will be difficult to forgo, so a conflict arises.
3. One may (feel) having too limited capacities for choosing between the two claims to future behavior.

Examples of the latter condition are when stressors like noise impose extra demands on the attentional capacity of the subject. Hereby, reserve capacity will be occupied that otherwise could have been used to help resolving the conflict between the two claims for future action. The stressfullness of the

---

5) Note the similarities of these conditions with the first three conditions for a decision problem to occur: "A decision problem occurs when a decision maker (a) notices a discrepancy between an existing state and a desired state, (b) has the motivation, as well as (c) the potential to reduce this descrepancy, whereby (d) there is more than one possible course of action which may not be immediately available, (e) the implementation of a course of action demands an irreversible allocation of his resources, and (f) the utilities (of the consequences) associated with each choice-alternative are partly or entirely uncertain", (Vlek & Wagenaar, 1979), p. 257).

second condition, for example, is evident from research indicating the need for enduring social support in overcoming family crises. The knowledge that most food has artificial additives or the fear that at many other alternative places for settlement the soil will be polluted by chemical waste, will penetrate feelings of insecurity with respect to one's living condition. As such it exemplifies the first of the afore mentioned three conditions.

COPING

With continuously high levels of stress one will get psychologically or physically injured. One therefore has to cope with the stress. Folkman & Lazarus (in press) define coping as "the cognitive and behavioral efforts to master, tolerate or reduce external and internal demands and conflicts between them"[6]. They continue: "Such coping efforts serve two main functions: the management or alteration of the person-environment relationship that is the source of stress (...) and the regulation of stressful emotions (...)". The first type of coping they call problem focused coping, the second emotion focused coping. In most circumstances of no-acute threat this distinction can only be gradual. There are practically no social phenomena that do not implicate affect in some important way and probably very few perceptions and cognitions in everyday life are not "hot". Consequently problem focused coping will most often have a significant emotional or affective component as well. However, as Zajonc (1980) notes, "Affect is always a companion to thought whereas the converse is not true" (p. 154). Particularly when threat is acute it is likely that the problem focused coping is

---

6) Sometimes the entire internal process is labelled as coping, sometimes only the positive, healthful way of responding to stress is called coping.
For reasons of distinction, we use two separate terms, coping and acting, where others, e.g. Folkman & Lazarus (in press), use one, i.e. coping.

entirely dominated by emotion focused coping.
Since in our terms coping essentially involves the reappraisal of the threatening person-environment relationship, it has the same components as the appraisal process. Because of its orientation to future options, the components are labelled: cognitive simulation and affective anticipation (see figure 3).

In coping with stress one could seek to reduce the stress by

1. exploring one's opportunities for altering the threatening environment,
2. looking for ways to move away from the situation,
3. reappraising the threat.

As figure 3 shows, the person will generally search for new or additional information in his environment before he decides what to do. Essential is the ordering of the issues and accompanying choices, i.e. the strategy of the coping process. Janis & Mann (1977) have argued that certain questions do not come up at all before certain others are addressed.
The person generally will first explore the possibility to continue the present activity in a slightly modified (protected) way. In this way the person tries to achieve the same goals with essentially the same means. When there is no acceptable way to continue the present activity with precaution, he is forced to search for alternavites. He will do so only when he feels confident in finding an acceptable solution. If the person also cannot imagine a realistic and acceptable option (considering one's own and other available resources), and it is also not possible to forget about the activity itself, there will be a tendency to deny the necessity of making a decision. This may happen through a variety of defense mechanisms. There are three main defensive strategies:
Type A: procrastination.
Type B: shifting of responsibility.
Type C: bolstering of the least aversive alternative.

A postponement of the decision (type A) is possible when one thinks that the risks of doing so are not too serious. This will typically be accompanied by a (temporary) lack of interest in the issue.
Type B means a denial of one's own responsibility and laying the decision into someone else's hands. As an example of this one might think of the generally observed tendency within the public to belief that the authorities should act to mitigate the consequences of a natural disaster. As we will show later, this type of defense sometimes goes toghether with a shift in locus of causality. Finally, one might bolster the intention to continue the threatened activity by exaggerating its positive consequences and/or minimizing the negative (Type C)[7]. This may be facilitated by a selective attention to the threatening environment. Figure 3 shows this mechanism by the arrow from the coping back to the attention rate.

All three forms of defensive avoidance are attempts to escape from the decisional conflict which is typical of a condition of (high) stress: one cannot afford to change and one cannot afford not to change. However, these kinds of conflict resolutions are characterized by a high level of vulnerability to unanticipated challenges. Only when there is enough time to work out all options and enough confidence to find an acceptable solution one engages in what we call rational searching behavior. It is only to this kind of searching processes that one could apply Janis & Mann's procedural criteria for a high quality decision (Janis & Mann, 1977), or the 9 stages for the resolution of a poorly structured decision problem (Vlek & Wagenaar, 1979).

---

7) This divergence of consequences is a general effect with all prospective choices that have important consequences (and, thus, are more or less stressful in itself). Only when evaluations of alternative options involve public commitment to the final choice, evaluations converge (see Brownstein, Ostrove & Mills, 1979).

Finally, any action means a change in the environment. One normally would like to know whether the action has resulted in a subjectively safe(r) situation. In Figure 3 this opportunity to learn from one's own behavior is represented by connecting the appraisal of the threat in the new situation (post choice) (box 5) to the reappraisal of the threat which one - prior to choice - had expected (box 3).

2. PSYCHOLOGICAL STUDIES OF TECHNOLOGICAL RISK ASSESSMENT

To what extent do the results of empirical studies that deal with natural and/or technological hazards support the foregoing analyses and where do they fit into the structure of the postulated model? Unfortunately, there are not many studies directly relevant to this topic, even with lenient criteria. For example, only about 10 studies can be selected from Rowe's (1977) reference list that pertain to the area of interest. Of these, only 5 (2%!) deal specifically with technological threat. Presumably, this rate truly reflected the efforts of studying the influence of the risk-generating system on people's judgments, attitudes and behavior in proportion to the efforts spent on studying the risk-generating system itself (risk estimation). At best the situation has only slightly improved since[8]. Technological hazards are still no big business for social psychologists[9]. Thus, it does not surprise to see that

8) If so, it would be primarily because of an enormous growht of interest in nuclear power.

9) Social scientists are also no big business yet for technology. Fischhoff et al. (1980) state that "Given the enormous stakes riding on acceptable-risk decisions, our investment in research seems very small. Considering the cost of a day's delay in returning a nuclear facility to service or in approving a pipeline proposal, a research project that offered a 0.1 chance of responsibly shortening the decision-making period would have an enormous expected return on investment. Similar bargains would be found in studies that might improve public involvement in project planning (so as to avoid mid-construction surprises), identify generic categories of new chemicals (so as to reduce testing costs), decrease the uncertainty in drug licensing (so as to encourage innovative research and development), or inform workers about occupational risks (so as to enable them to make better decisions on their own behalf). Such research could be a good place to invest society's venture capital".

the relatively few empirical investigations of how people deal with an uncertain technological environment are not embedded in a common larger theoretical framework. Fortunately, outside the specific scope of technology there are interesting results of fundamental research which we believe are highly relevant to our topic. In the next section we will discuss both types of studies in as far as they can be grouped under the common denominator of the assessment of threat (section 2.1.) and the assessment of control (section 2.2.). Studies that explicitly address themselves to ways of coping and acting will be discussed elsewhere (Tomas & Stallen, 1981).

2.1. THE ASSESSMENT OF THREAT

Within the social sciences technological risk assessment has mainly been studied from the point of view of the psychologist[10] (e.g., Slovic & Lichtenstein, 1980; Green & Brown, 1980; Vlek & Stallen, in press)[11]. The last authors studied how inhabitants of a heavily industrialized area (Rotterdam) judge the acceptability of and the riskiness of various risky activities, as diverse as "smoking in bed before sleeping", "landing liquified natural gas" and "receiving full anaesthesia before a medical operation". They concluded that subjects base their judgment of acceptable risk primarily on the believed personal necessity of the activity. According to the authors, "necessity" of the activity derives from the <u>need for its associated benefits</u>. As a secondary dimension, judgments about "acceptibility" seem to be based upon the assessment of the "scale of production and/or

---

10) Even when staying within the area of psychology there is still more to risk assessment than merely risk perception, as figure 3 shows. However, risk assessment is often designated as "risk perception". The Society for Risk Analysis, for example, has organized at her first annual meeting a "Workshop on the Analysis of Real versus Perceived Risks".

11) Sociologists, for example, seem to concentrate more on natural hazards (cf. Mileti, 1980).

distribution of benefits and of potential accidents.

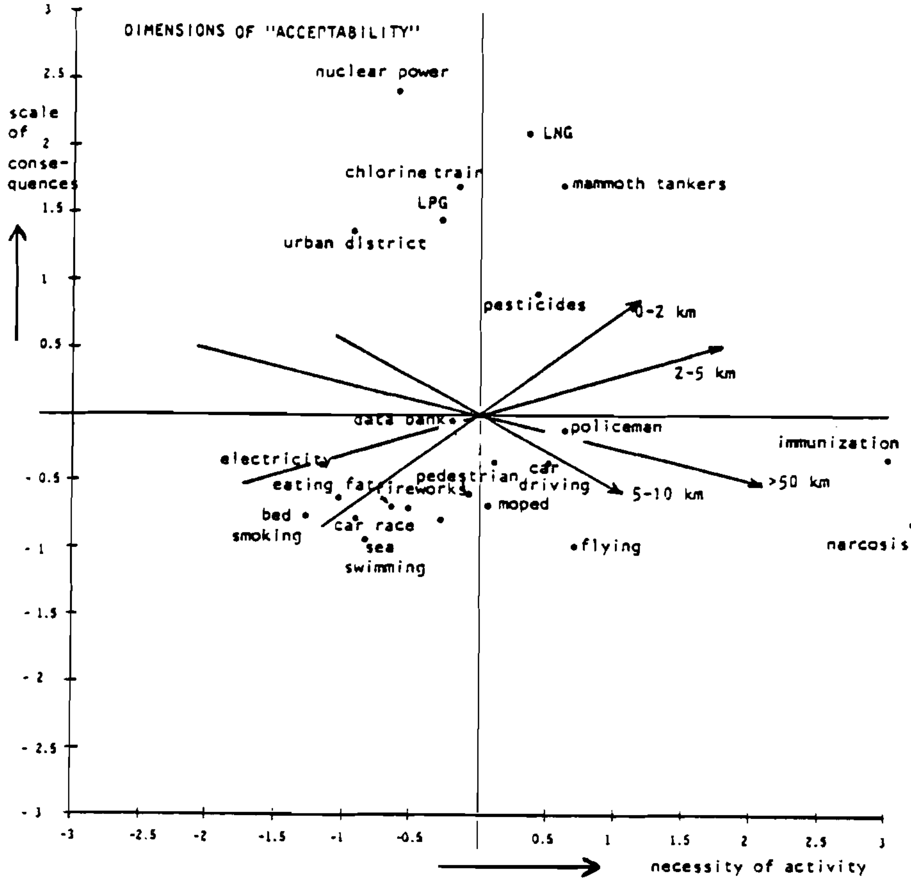


Figure 6. Two dimensional stimulus configuration based on analysis of rank orders of acceptable risks. Arrows represent average judgments for each of 4 groups living at varying distances from the industrialized area. (Source: Vlek & Stallen, in press).

Figure 6 shows these two major conceptual dimensions as the horizontal (= primary dim.) and vertical axis (= secondary dim.) respectively of a two dimensional space. The vectors indicate group averages in the weighing of the contributions of both dimensions to the overall judgment of acceptability[12]. Average group rank order of the 26 stimuli according to acceptibility can be found by projecting the stimulus points of figure 6 onto the respective (extended) vectors. Clearly, these results show that persons living closer to the industry tend to consider the 7 "large-scale" activities (all lying in the upper half of figure 6) as relatively more acceptable than persons living farther away from the industry.

A possible explanation for this may be that the former group (0-2 km) judges the benefits that accrue to them and/or to society in general to be greater. We can test for this hypothesis, as Vlek & Stallen also analysed judgments about the benefits of the activity. The dimensional structure recovered was virtually identical to Figure 6. However, in this two dimensional cognitive space of "beneficiality of risky activities" no such differences between distance-groups in weighing the two dimensions as shown in Figure 6 were found. Because Vlek & Stallen also did not find any such group specific differences in the judgments of riskiness (see below), the following explanation can be put forth. When confronted with the difficult question whether they believe the risks are acceptable or not, those subjects who in fact are most exposed to the large-scale industrial risks bolster their judgment by exaggerating the benefits associated with those activities.

The cognitive map of the riskiness of the various activities, as constructed by Vlek & Stallen, is represented in Figure 7. It shows that subjects probably base their judgments of riskiness of an activity primarily on its level of catastrophic potential (= horizontal axis) and, secondary, upon the degree to which protection is provided by institutional means (= vertical axis). Vlek & Stallen labelled the latter dimension "degree of organized safety",

---

12) The analysis used is based upon a point-vector unfolding model for interpreting the structure of the observations (rank order data).

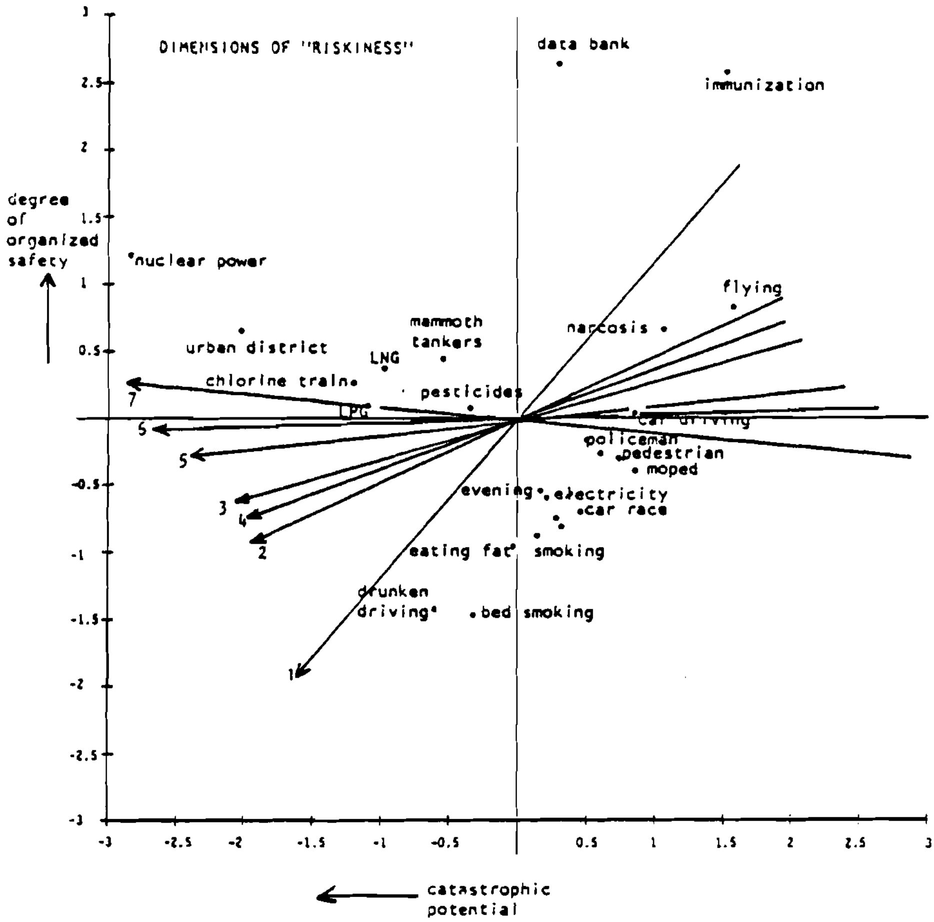


Figure 7. Two dimensional stimulus configuration based on analysis of rank orders of riskiness. Arrows represent average judgments for each of 7 groups of persons in the extend to which they feel insecure with respect to industrial risks. (Source: Vlek & Stallen, in press).

with positive values on the Y-axis indicating a high degree of organized safety. However, as they have suggested, an alternative interpretation may be in terms of personal avoidability as this too is in close agreement with their data. Their data also allow for an interpretation in terms of "imaginability of negative consequences". As can be seen from figure 7, persons high in feelings of insecurity with respect to industrial risks, base their judgments of riskiness almost exlusively upon the degree of catastrophic potential.

Regarding the cognitive determinants of judgments about risks, Slovic et al. (1980) have reported similar results. With a different set of risk-stimuli and a different technique of analysis[13), they interpreted their two dimensions as:

1. dread, i.e. catastrophic, hard to prevent, fatal etc., and
2. familiarity, i.e. observability, knowledge, immediacy of consequences.

Slovic et al. (1980) did try to further define the precise nature of their "dread-factor". Results of a small exploratory study led them to put forth the following explanation: "An accident that takes many lives may have little or no impact on perceived risk if it occurs as part of a familiar, well understood and self-limiting process". In contrast, a small accident may greatly enhance perceived risk and trigger strong corrective action because it may signal either a possible breakdown in safety control systems or the possibility that the mishap might proliferate. Thus, the number of people killed may be relatively unimportant in determining the degree of dread or catastrophic potential of risky activities.

However, the vast majority of research efforts in technical risk analysis is devoted to the calculation of numerical estimates of probable fatalities which in most cases are derived from figures of relative frequencies. Within the technical community, such estimates are generally regarded as to provide the rational measure of risk. The question that immediately arises, is how well represented are such relative frequencies in layman's mind? Using

---

13) The major differences are that Slovic c.s. 1. did not formulate all their stimuli as specific risky activities but as global activities, technical systems of devices; 2. they subjected their data to a type of external analysis. Considering the number of variables for classification of their stimuli, this is a rather vulnerable procedure.

different samples of causes of death and approaching different groups of people, Lichtenstein, Slovic, Fischhoff, Layman & Combs (1978), Green & Brown (1980) and Stallen & Vlek (Note 1) all report highly similar results: overestimation of low frequencies and underestimation of high frequencies. Moreover, the results of Stallen & Vlek show (see figure 8) that the elicitation of like estimates from experts in the field of risk analysis or risk regulation shows essentially the same bias. As a possible explanation of the general finding, Lichtenstein et al. suggest that people make use of the availability heuristic (Tversky & Kahneman, 1974): assessment of frequency or probability is based on the number and ease with which instances come to mind. As the number recalled per category (= cause of death) is relatively independent of the total number within that category, a flattening of responses is likely to occur.[14].

If, as Slovic et al. (1980) seem to suggest, uncertainty is experienced as threat depending upon its implications for future behavior, and if the number of fatalities due to an accident is not seen as a major determinant of judged seriousness of accidents, then it is worthwhile to explore in more detail what is known about people's abilities in <u>predicting</u> future and <u>explaining</u> present (or past) threat. We will discuss these abilities under the heads "foresight" and "hindsights" respectively.

---

14) Arguments justifying the logarithmic transformation of response are given by both Green & Brown (1980) and Stallen & Vlek (Note 1).

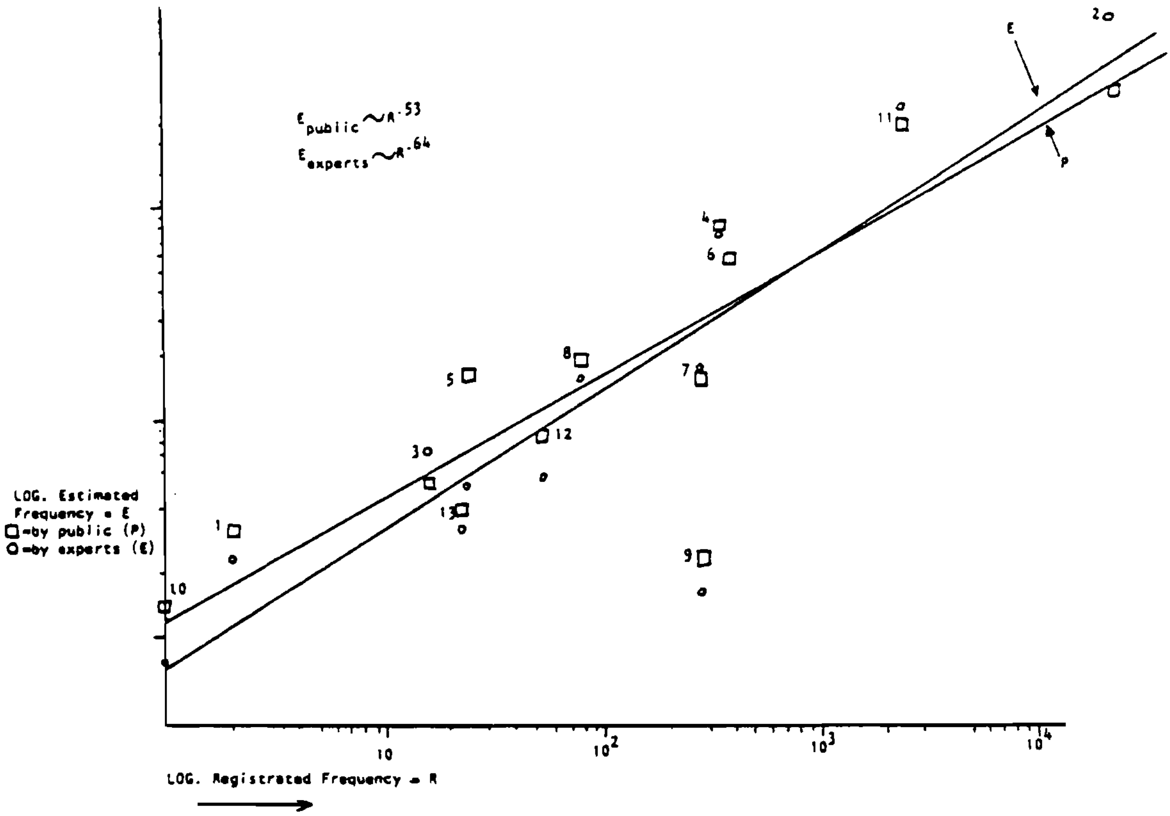


Figure 8. Relationship between registrated frequency and subjectively estimated frequency for 13 causes of death.

1. Poisoning as caused by spraying of agricultural crops
2. Heart disease
3. Do-it-yourself repairment of electrical wiring and installations
4. Motorbicycle accident
5. Murder with gun or bomb
6. Pedestrian accident in traffic
7. Drowning
8. Fire in house or building
9. Faulty anaesthetical treatment
10. Lightning
11. Car accident
12. Collision with train on crossing
13. A leaking gas pipe at home

FORESIGHT

Most work on prediction has typically been done in areas called human information processing and judgment under conditions of uncertainty or risk (here shortly referred to as judgment). It generally reveals people to be quite inept at all but the simplest inferential tasks - and sometimes even at them - Fischhoff (1976) writes. The following examples are taken from the specific field of hazard research and may illustrate this finding.

In an almost classical study, Kates (1962; see also Burton & Kates, 1964) found that floodplain dwellers misjudged the probabilistic nature of renewed flooding of their residential areas. Many viewed floods as repetitive and even cyclical phenomena, thus replacing randomness by a determinate order in nature. Another common view among residents was that the occurrence of severe flood in one year was seen as making it unlikely to have another severe flood the following year. Such biases resemble the better known gamblers fallacy. They may be caused ty the use of simplifying judgmental strategies (heuristics). For example, when given evidence regarding the specific case (= flooding) people consistently ignore base rate information, thus giving too much weight to the vivid evidence at the expense of adequately adjusting earlier stored statistics. However, as we will argue below, an alternative explanation for Kates' finding may be given in more explicit motivational terms.

With respect to uncertain about (consequences of) future events, Monat, Averill & Lazarus (1972) made the distinction between event-uncertainty and temporal-uncertainty. The former applies to cases where one knows when an accident may happen but not whether it actually will happen or not. Temporal uncertainty exists if it is only unknown when a threatening event may find place (and not whether it will occur or not). Their experiment - exposing subjects to the threatening event, i.e. a painful electrical shock - suggests that temporal uncertainty is experienced as the more threatening of the two types of uncertainty. As time wore on, subjects under the condition of temporal uncertainty engaged in avoidance-like activities like attention diversion. Although the authors wrote "To date, we know of no literature attempting to assess intrapsychic coping strategies employed under conditions of temporal uncertainty" (Monat et al., 1972, p. 238), as a matter of fact the studies in natural hazard management at the Department of Geography University of Chicago may be seen as dealing with such strategies. The judgmental strategies that the flood plain residents in Kates' study used, for example, just had the effect of making order out of disorder, thereby depicting the future as more controllable than in fact it is. We will discuss this motive in more detail further on in section 2.2.

Another example in studying human judgment is its insensitivity to varying sample size when estimating population parameters. Particularly when information about sample bias is pallid and information about the nature of the sample is vivid, people make unwarranted generalizations from samples to populations (see e.g. Hamill, DeCamp Wilson & Nisbett, 1980). Not only lay people are subject to such biasing information processes. Several studies indicate that such misperceptions also operate among experts like psychometricians, well trained statisticians or people when making decisions with grave social consequences (see e.g. Goldberg, 1968; Tversky & Kahneman, 1974; Slovic et al., 1976).

Although peoples probability estimates apparently violate basic laws of probability theory, people tend to view such laws as rational when they are questioned about their estimation competence or when asked to retrospect onto their own judgmental processes. Under these conditions, they exaggerate their own information processing sophistication. For example, they underestimate their actual reliance on only a few major variables or their use of heuristics in performing complicated multivariate judgments (Shepard, 1964; Slovic & Lichtenstein, 1971).

Nisbett & Borgida (1975) have suggested that perhaps only when we have rather well rehearsed schemata for dealing with certain types of abstract, data summary information, we process information in a fashion that the scientist would describe as rational. This may be particularly relevant given the generally low frequency of most natural and technological hazards within the human lifetime. Here, information at a higher level than the individual cases hardly exists and, if only for this reason, it will be difficult for the individual to fall back on such schemata. Thus, it would appear rational to see people rely more heavily on other resources in trying to come to grip with both past and future events like technological hazards.

"HINDSIGHT"

Results of laboratory studies suggest that people process information about past events in such a way as to systematically reduce its perceived surprisingness. Telling people that an event has occurred has been shown to increase their subjective probability that it was going to happen (Fischhoff, 1975). Subjects, told the correct solution to earlier problems (like the answer to almanac type questions, inadmissible evidence in court or debriefing information after participation in a psychological experiment) overestimated how much they actually knew before being told (Fischhoff, 1977). Walster (1967) reported that when confronted with news of an accident, people tended to exaggerate in retrospect its predictability, and more so with more serious accidents. This knew-it-all-along effect appears to be rather robust: debiasing instructions do not produce increased adjustment nor do they reduce bias. These findings also shed some light on important social aspects of the dynamics of appraisal. If, by exaggerating the predictability of the past, people underestimate how much they whould learn from it, they will find it even more difficult to reconstruct the uncertainties that actually have faced others. As an example, they may be very insensitive for the uncertainties that risk-regulators have to face. Thus, when confronted in such a social context with "unexpected" accidents, people may act on the basis of a "they-could-have-known-it-all" belief. At their turn the decision makers will come to fear such overreacting and, for example, are likely to develop an even more reserved attitude with respect to early informing the public about impending disasters.

A similar effect has been reported in studying people's response to the cancellation of threatening alarms. Breznitz (1976) observed lowering heart rates, skin conductances as well as diminishing beliefs in the threat, in short a generally lower level of emergency preparation, when subjects were exposed to new alarms after their first exposure to a false alarm. Breznitz hints at an I-knew-it-all-along - explanation of the FAE (= False Alarm Effect) when the suggests that "on the subjective level, people (...) might be particularly disturbed to discover that it was all unnecessary - that, in fact, they made fools of themselves" (p. 131 ; emphasis ours). Here, Breznitz too seems to assume that his respondents reacted in a rather deterministic way to the cancellation and, by implication, to the alarm. In hindsight, they may have come to view the alarm as signaling "almost certainly nothing to happen". Clearly then, a second similar alarm will not be as much fearful. To Breznitz, the credibility loss of the source of the threatening information is FAE's chief feature. In our opinion, however, it may be but one of the a posteriori arguments that support people's expectation of whether or not a new alarm will materialize.

2.2. THE ASSESSMENT OF CONTROL

"Perceived Choice" and "Perceived Control" are major themes of modern psychology (see, e.g., Harvey, 1976; Perlmutter & Monty, 1980). In section 1.2. we have argued that they are also essential aspects of the notion "stress". In Figure 4 (see p. 11) we have tried to illustrate that it is essentially the availability of psychological (re)sources that determines whether the perception of a threatening event will make for a psychological conflict. When the two demands for future behavior are conflicting, the individual experiences stress. In his review of experimental research on personal control over impending harm Averill (1973) shows that when subjects are given opportunities for control, decreased stress reactions have generallh been observed in comparison to conditions where no such control was possible. Thus, one would expect that any attempt to resolve that conflict by personally resuming control over outcomes of own behavior will (more or less effectively) reduce the stress.

MODES OF CONTROL

In section 2.1. we have already given examples of the need to control future outcomes, viz. the very act of interpreting (through inferences etc.) the threatening event. This motivation of responding to threat can be called cognitive control. To have explained events apparently builds up to the selfpimage of being knowledgeable and, as such, if satisfies the need to be in control of one's environment, to know what. Paradoxically, the hindsight experiments indicate that this very feeling that we have made sense out of an event may be a good guarantee that we will not improve our foresight or predictive efficacy. The role of cognitive control in facing threats is emphasized in Jordan's (1968) speculations about behavior under risk. Using Lewin's terminology, he argued that whether locomotion from one mental region to another will take place or not depends on the certainty characteristics of those regions. These are:

1. knowing whether negative events might occur to which I do not wish to be exposed when being in that region, and
2. knowing whether I can avoid undesirable consequences of such an event might it still occur.

If a region has both characteristics, the subject can move with psychological certainty even though not all the consequences of his act will be known. "All he has to know is that certain unwanted outcomes are excluded. When certainty exists, the taking of risks and of chances becomes exciting, otherwise threatening", (Jordan, 1968, p. 135). Burgers & Arkin (1980), for example, report that those subjects who could not predict the onset and who knew that they could not control the termination of loud noise, felt significantly more depressed in solving problems than those who could either control or predict, or could do both.

Of interest to the study of cognitive control in determining the level of stress is the assessment of warning signals. Experiments with both humans and animals have generally found that a warning signal by itself has little effect on the experience of stress. One of the reasons seems to be that warning signals often do not provide sufficient information regarding the onset of the direct threat. As a result, subjects must remain vigilant and responsive to all cues in their environment. Because the meaning of a warning signal is so imparted to cues in fact not associated with the threat, the stressfulness of the entire environment may have been increased. Thus, one would expect to see people strive for temporal certainty. Indeed, this preference has been observed when subjects were presented with relatively simple stimuli like electric shocks (cf. Monat et al., 1972) or bursts of loud noise. The mere knowledge of the conditions for a threat to materialize even makes subjects select higher levels of shock than when such information is not given (Bowers, 1968).

On the basis of a review of experimental research, Averill (1973) concluded that stress is primarily a function of the meaning of the control response for the individual and not just of its effectiveness in preventing or mitigating the impact of a potentially harmful stimulus. If this holds, believing one has meaningful control may still result in ineffective behavior. Weinstein (1980), for example, discussed various studies which indicate that people are generally unrealistically optimistic about the future. For a range of positive and negative events he examined the conditions under which such optimistic biases occur.

Among others, the following hypotheses relating to the role of perceived control were supported: The greater the perceived controllability of a negative event, the greater the tendency for people to believe that their own chances for not being harmed are better than average; also the greater the perceived controllability of a positive event, the greater the tendency for people to believe that their own chances are greater than average. Weinstein suggests the following explanation for this effect. If an event is perceived to be controllable, it signifies that people believe there are steps one can take to increase the likelihood of a desired outcome. Assuming in addition that people can more easily bring to mind their own actions than the actions of others, people are likely to conclude that desired outcomes are more likely to happen to them than to others.

In summary, available evidence suggests, that compared to behavioral control the need to reduce the uncertainty, which often accompanies such control, is the more potent determinant of stress. The general preference for clear expectancies, however inaccurate, steems to facilitate adaption and to reduce long term stress even though they may initially lead to increased reactivity.

If the question were put to most people, there are good reasons to expect that they would prefer to have a choice among alternatives rather than to have decisions made for them (cf. Brehm, 1972). Yet, as Averill (1973) notes, social commentators from Hobbes fo Fromm have emphasized man's willingness to relinguish such control, to "escape from freedom". In this and the following paragraphs we will devote our attention to this paradoxical relationship between decisional control and stress. Our starting point will be Kelly's (1955) fundamental observation that a man controls his destiny "to the extent that he can develop a construction system with which he identifies himself and which is sufficiently comprehensive to subsume the world around him. If he is unable to identify himself with this system [...] but he can experience no personal control".

Kelly's above statement leads us to expect that the individual must be able to agree with the degree of structuring that exists. On the one hand, as Kaufmann (1971) has emphasized, this requires us to look at the environmental determinants of personal control: the individual can only develop a sufficiently coherent construction system if his (social) environment is sufficiently stable. On the other hand, it suggests the importance of perceived congruity between individual belief systems and behavioral contraints in determining the experience of control and, consequently, of choice. Some evidence for this is to be found in an experiment by Lewis & Blanchard (1971), who reported that stronger identification with a role leads to the experience of greater decisional control. If subjects are placed in completely novel or unstructured settings, i.e., when behavior is not constrained by situation-bound cues, they will generally experience considerable stress.

The relevance of congruity between, on the one hand, expectations or beliefs and, on the other hand, external conditions for behavioral control is also evident from studies of the "illusión of control". According to Langer (1975), an illusion of control is an expectancy of a personal success probability inappropriately higher than the objective probability would warrent. Langer found that people who had been allowed to draw their lottery-ticket themselves were only willing to sell their ticket at a price which was considerably higher than of those people who had simply been given a ticket. Wortman (1975) conducted an experiment in which she asked crapshooters either before or after they had thrown the dice to bet on the number of eyes they were to throw and had thrown, respectively. The results strongly supported her hypothesis: those players wo "caused" their own outcome and knew beforehand what they hoped to attain, perceived themselves to have more control over the outcome, more choice about which outcome they received, and more responsibility for their outcome than players in the remaining conditions. Wortman argues that only if people know what they hope to attain, can they exert control. It is likely that langer's results are similarly mediated by her subjects differential attempts to exert control.

Related to the concept of role-identification is the notion of <u>commitment</u>, which has been defined as "pledging or binding of an individual to an act" (Kiesler, 1971). It means that the individual identifies with his action or, in other words, beliefs that he acts on the basis of a proper appraisal of both internal and external demands or constraints. As such, he believes his appraisal is causal of his action. Experiments have indeed supported the idea that attribution of self-responsibility for an act increases commitment to that act (see, e.g., Mayer, Duval & Hensly-Duval, 1980). One major variable that influences this attributional process and, consequently, determines commitment, is perceived choice. It presumably does so, Mayer et al. argue, primarily by affecting the salience of the self as a plausible cause. Harvey (1976) has summarized how some variables influence perceived choice (see Table 2)[15)]

Variable	Finding for variable
Similarity in attractiveness of options	Greater perceived choice for small than for large or zero difference in attractiveness
Uncertainty about outcomes of options	Greater perceived choice the more uncertain the decision maker about the outcomes of the options
Valence of options	Greater perceived choice when the outcomes of the options are positive than when they are negative in attractiveness
Number of options	Greater perceived choice the greater the number of options when decision maker thinks he has expeditiously evaluated options; greater perceived choice for moderate than for small or large number of options when decision maker thinks he has spent more than normal amount of time in evaluating options
Locus of control	Greater differences for internals than externals in response to options varying along dimensions of similarity in attractiveness and valence of outcomes
Variability in reinforcement	Greater freedom attributed to reinforcing agent who rewards and punishes on an intermittent schedule than to one who reinforces on a continuous schedule
Costs in taking an action	Less freedom is attributed to reinforcing agent or to decision maker the more costly the action taken or decision made
Acting in line with predisposition	Greater freedom attributed to person, the more the behavior was consistent with a relevant predisposition
Consequences of a decision	Relatively high self-attribution of choice for decisions having positive consequences and relatively low self-attribution of choice for decisions having negative consequences
Magnitude of negative consequences of an action	Less freedom attributed to self by actors and more freedom attributed to actor by observer the more serious the consequence of an action

Table 2: Some determinants of perceived choice with their respective direction of influence. (Source: Harvey, 1976, p. 90).

In summary, we may perceive personal control if we intend a certain outcome, if personal choice is salient to us, and, because of hindsight effects, perhaps mostly so if the intended outcome in fact occurs. In retrospect, the perception of such (illusory) control may lead via the attribution of causality to self, to commit ourselves to the act. Thus, commitment implies the perception of responsibility for the act. The major effect of commitment is to make that act resistant to change.

In a final paragraph, we will elaborate the conceptual relationship between causality of and responsibility for an accident. These variables - often confounded - may be important in explaining differential reactions to (technological) threat.

15) Of these the latter two influences seem to reflect self-serving tendencies, whereas the other determinants reflect mainly information-processing and perceptual tendencies.

ACCIDENT CAUSATION AND RESPONSIBILITY FOR ACCIDENTS

In the foregoing sections we have tried to argue that the answer to the question "do I feel that I have opportunities to control the threat?" (see p. 8), is an important determinant of stress or feelings of insecurity. These opportunities were supposed to be both cognitive and affective in kind, as illustrated by figure 4. They concern ways to understand one's technological environment, to protect against anxiety, to structure vague feelings and beliefs for a decision, to get compensation from a person or industry at fault, or to provide a sense of identity. All such functions are specific types of control and serve a common goal which could be called systems - maintenance: it are "ways of keeping oneself going in a difficult and unpredictable world" (Fischhoff, 1976). As such, the assessment of a threatening event is very much an <u>active</u> process. Of special interest to the process of how people appraise threatening events like industrial alarms and emission of pollutants is the area of research on attribution of responsibility for an accident. This is particularly important as the assignment of responsibility might be closely related to take action or demanding it from others.

The major impetus to the research on attribution of responsibility for an accident is a provocative study by Walster (1966). She presented subjects with a description of an accident in which some act of a stimulus person (perpetrator) led to harm to some other person (victim). Her experiment demonstrated that outcome severity determined the amount of responsibility assigned to the perpetrator. Walster explained this effect by reasoning that her subjects had attributed more responsibility in the serious accident to protect themselves from the idea that their lives too could be affected by such unfortunate events. To believe in chance happenings would be too threatening. This "defensive attribution hypothesis" has since stimulated a large number of studies. Despite its continued popularity, however, there has been observed a worrisome unevenness in growth of data collection and conceptual development (see, e.g., Fischhoff, 1976; Fincham & Jaspars, 1980).

In an earlier critical review of theoretical notions and empirical results, Vidmar & Crinklaw (1974) had already pointed at the absence of "any rationale that predicts whose fate subjects will identify with when both a perpetrator and victim are involved in an accident" (p. 114). One possible answer has been suggested by Pryor & Kriss (1977): with the fate of the subject who is most similar to the perceiver. If it is the victim with whom one identifies, the perpetrator will have the most dissimilar characteristics. Because of their saliency they will give rise to the attribution of causality to this act. If the perceiver identifies more with the perpetrator-role, he may attribute causality to environmental factors (chance). Indeed experimental results (Shaver, 1970; Crinklaw & Vidmar, 1971) indicated that the more similar the subject and the stimulus person are, the less is the responsibility assigned for the mishap. However, this only appeared true when the first of the following three specific orientations was present[16). This condition is that the perceiver has to be primarily interested in what the observed situation means affectively to him (value-maintenance set). When his orientation is causal-genetic, i.e. he is primarily interested in what the social, physical etc. conditions of the behavior/act are, or situation-matching, i.e. his main concern is the evaluation of the behavior of the stimulus person as it relates to norms appropriate to that situation, no differential assignment of responsibility with varying similarity was found.

---

16) The classification into these three perceptual sets was originally developed by Jones & Thibaut in their analysis of interpersonal perception.

In conducting one of the few experiments that has not at the outset confounded the above three inferential sets, Chaikin & Darley (1973) found that with a value-maintenance set:

1. In general, less responsibility is attributed to change (= environmental factor) when the consequences of the accident become more serious.
2. Perpetrator-like perceivers attribute responsibility to environmental factors (like chance; but they also derogated the victim!) more so than do those subjects who have to respond as are they victims.
3. This latter group attribute to the <u>same</u> extent the cause of both the minor and the serious accident to the perpetrator, that is to say they hold him equally responsible for both accidents.

To some extent, these results confirm a general finding of the attribution research, called "the fundamental attribution error" (see e.g. Harvey, Ickes & Kidd, 1976/1978). By this we mean thatpeople - particularly when observing somebody else's instead of one's own behavior - are inclined to overattribute causality to personal factors like dispositions, and under-estimate the impact of situational or environmental factors. One possible explanation of this bias is given in Gestalt-terms of Figure: Background. To the victim-like perceiver, the perpetrator is Figure, thus salient; to. the perpetrator-like perceiver, the environment is Figure.

However, this theory would at least need one extra premisse to explain the differential impact of varying seriousness on attribution by perpetrator-like versus victims-like perceivers (see Chaikin & Darley's 2nd and 3rd finding). As already mentioned, perpetrator-like subjects may make defensive attributions to avoid that they in such situation would be blamed for their "careless" act. Such defensive avoidance behavior is more likely to occur with more serious accidents. Apparently, a similar reasoning cannot be applied to victim-like subjects (the more threatening the situation is appraised by victim-like subjects, the more they may want to protect themselves from the knowledge that they too could be at the mercy of such an event). Vidmar & Crinklaw (1974) therefore suggest that only when subjects feel a perpetrator ought to have foreseen the consequences of his behavior they assign more responsibility for a serious rather than a minor outcome of his act[17]. Presumably, their victim-like subjects did not feel that way (their data indeed showed that they considered the perpetrator equally careful in both conditions). The fact that they hold the perpetrator responsible for his act, no matter how serious its consequences are, may be based on their belief that yet he <u>could</u> have done otherwise. The judgment that is being made is essentially a sanctioning judgment, not an explanatory judgment, and also not - as it is for perpetrator-like subjects - a judgment based on a value-maintenance set.

Hamilton (1980) argues that the use of such a moral-legal decision rule for atrributing responsibility instead of for example, applying the scientific principle of co-variation may also provide an alternative explanation of the "fundamental attribution error".

Fincham & Jaspars (1980) too have stressed the importance of the distinction between causal and moral responsibility. Holding someone responsibility by demanding that he rebut an accusation does not explain his actions but simply indicates liability for punishment or compensation (p. 104). It is not simply that people use a notion of causality different from the one advanced in general attribution theory. However, in attribution theories the causal questions involved deal with the relation between intention/

17) This is one of Heider's five possibilities of associating behavioral outcomes with individuals: 1. global association (= mere coincidence), 2. extended commission (= outcomes not foreseeable), 3. careless commission (= outcomes could have been foreseen), 4. purposive commission (= outcomes foreseen), 5. justified commission (= outcomes intended, (see Shaw & Sulzer, 1964).

disposition and behavior (actor-act chain), whereas in assigning responsibility the central relation is between act and outcome. Many conflicting interpretations of research results stem from the conceptual confusion about causality and responsibility and from differences regarding the part of the actor-act-outcome chain that is given attention to.

3. CONCLUDING REMARK

From a psychological point of view for both layman and politician alike technological risk assessment - i.e. the assessment of aversive consequences due to a certain degree of exposure to potentially harmful events - most often is a complex process[18)]. In this paper we have tried to give some idea of how people assess threatening events and how judgmental, atrributional and motivational processes together lead to a (intermediary) response to threat. This we called stress or specifically with respect to our research interest, feelings of insecurity concerning technological activities. One frequently raised argument in the debate about "how safe is safe enough?" is that there exists a gap between the factual, actuarial or objective risks and the way in which the public perceives the risks of technology, the so called subjective risks. With the foregoing analysis we hope to have convincingly shown that there is no (psycho-)logic according to which peoples assessment of technological safety is proportionally related to (can be predicted from) observed relative frequencies or statistically calculated probabilities of negative consequences of the technology concerned. Even disregarding the fact that for most activities only human death is the best defined and quantifiable of all hazard consequences and impacts to the ecosystem are at best difficult to judge (Harris et al., 1978, p. 9), the individual is not so much concerned with estimating uncertainty

18) Neither one should claim the exclusive use of the adjective rational to characterize his own risk assessment. Rationality is a quality of conflict resolution along the lines of prespecified rules for the allocation of one's analytic and synthetic resources in dealing with the various aspects of what one perceives as a problem (see e.g., Simon, 1978). Decision analysis, for example, offers different criteria, for evaluating such allocation of resources than psychoanalysis. Thus, one should be very careful calling someone else's response to risk "irrational".

parameters of a physical or material system as he is with estimating the uncertainty involved in his exposure to the threatening event and in opportunities to influence or control his exposure. Statistics are only marginally relevant to specific circumstances.

Reference note

1. Stallen, P.J.M. & Vlek, C.A.J. Probabilities, conditional probabilities and judged frequences of fatal accidents, Apeldoorn: TNO (mimeo).

REFERENCES

Averill, J. (1973), Personal control over aversive stimuli and its relationship to stress, Psychological Bulletin, 80 (4), 286-303.

Bezembinder, Th. & van Acker, P. (1979), Intransitivity in individual and social choice, in: Lanterman, E.D. & Feger , H. (eds.), Similarity and choice, New York: Wiley.

Bowers, I.S. (1968), Pain, Anxiety and Perceived Control, Journal of consulting and clinical psychology, 9, 205-209.

Brehm, J.W. (1972), Responses to the loss of freedom: a theory of psychological reactance, Morristown: General Learning Press.

Brounstein, P.J., Ostrove, N. & Mills, J. (1979), Divergence of private evaluations of alternatives prior to choice, Journal of Personality and Social Psychology, 37 (11), p. 1957-1965.

Burger, J.M. & Arkin, R.M. (1980), Prediction, Control and Learned Helplessness, Journal of Personality and Social Psychology, 38 (3), 482-491

Burton, I. & Kates, R.W. (1964), The perception of natural hazard in resource management, in: Natural Resource Journal, 3, 412-441.

Chaïkin, A.L. & Darley, I.M. (1973), Victim or perpetrator: defensive attribution of responsibility and the need for order and justice, Journal of Personality and Social Psychology, 25, 268-275.

Crinklaw, L.D. & Vidmar, N. (1971), Inferential sets, locus of control and attribution of responsibility for an accident, Ontario: University of Western Ontario (Res. Bull. 203).

Fincham, F.D. & Jaspars, J.M. (1980), Attribution of responsibility, in: Berkowitz, L. (ed.), Advances in experimental social psychology, vol. 13, New York: Academic.

Fischhoff, B. (1975), Hindsight & Foresight: The effect of outcome knowledge on judgment under uncertainty, Journal of Experimental Psychology: Human Perception and Performance, 1, 228-299.

Fischhoff, B. (1976), Attribution theory and judgment under uncertainty, in: Harvey, J.H., Ickes, W.J. & Kidd, R.F. (eds.), New directions in attribution research, Hillsdale: Lawrence Erlbaum.

Fischhoff, B. (1977), Perceived informativeness of facts, Journal of Experimental Psychology: Human Perception and Performance, 3 (2), 349-358.

Fischhoff, B., Lichtenstein, S., Slovic, P. Keeney, R. & Derby, S. (1980), Approaches to acceptable risk: a critical guide, Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Folkman, S. & Lazarus, R.S. (in press), An analysis of coping in a middle-aged community sample, in: Journal of Health and Behavior.

Green, C. & Brown, D. (1980), Through a glass darkly: perceiving perceived risks to health and society, Paper prepared for the workshop on Perceived Risk, Eugene, Or.

Hamilton, V.L. (1980), Intuitive psychologist or intuitive lawyer?, Alternative models of the attribution process, Journal of Personality and Social Psychology, 39 (5), 767-772.

Harriss, R.C., Hohenemser, C. & Kates, R.W. (1978), Our Hazardous Environment, Environment, 20 (7).

Harvey, J.H. (1976), Attribution of freedom, in: Harvey, J.H., Ickes, W.I. & Kidd, R.F. (eds.), New directions in attribution research, vol. 1., Hillsdale: Erlbaum.

Harvey, J.H., Ickes, W.J. & Kidd, R.F. (eds.) (1976/1978), New directions in attribution research, vol. I / vol. II, Hillsdale: Lawrence Erlbaum.

Ittelson, W.H. (1973), Environment perception and contemporary perceptual theory, in: Ittelson, W.H. (ed.), Environment and Cognition, New York: Seminar.

Janis, I.L. & Mann, L. (1977), Decision Making: a psychological analysis of conflict, choice, and commitment, New York: Free Press.

Jordan, N. (1968), Themes in speculative psychology, London: Tavistock.

Kanner, A., Coyne, J.C., Schaefer, C. & Lazarus, R.S. (in press), Comparison of two modes of stress measurement: daily hassles and uplifts versus mahor life events, Journal of Behavioral Medicin.

Kates, R.W. (1962), Hazard and choice perception in flood plain management, Chicago: University of Chicago (Dept. of Geography, Research Paper 78).

Kates, R.W. (1979), Summary Report, in: R.W. Kates (ed.), Managing Technological Hazard: Research needs and opportunities, University of Colorado (Monograph no. 25, Institute of Behavioral Science).

Keele, S.W. & Trammell-Neill, W. (1978), Mechanisms of attention, in: Carterette, E.C. & Friedman, M.P. (eds.), Handbook of Perception: perceptual processing, New York: Academic.

Krohne, H.W. (1978), Individual differences in coping with stress and anxiety, in: Spielberger, C.D. & Sarason, I.G. (eds.), Stress and Anxiety, vol. 5, New York: Wiley.

Lazarus, R.S. (1966), Psychological stress and the coping process, New York: McGraw-Hill.

Lazarus, R.S. (1976), Patterns of adjustment, New York: McGraw-Hill.

Lazarus, R.S. (1980), The stress and coping paradigm, in: Eisdorfer, C., Cohen, D. & Kleinman, A. (eds.), Theoretical bases for psychopathology, New York: Spectrum.

Mileti, D.S. (1980), Human adjustment to the risk of environmental extremes, Sociology and Social Research, 64 (3), 237-347.

Monat, A., Averill, J.R. & Lazarus, R.S. (1972), Anticipatory stress and coping reactions under various conditions of uncertainty, Journal of Personality and Social Psychology, 24 (2), 237-253.

Nisbett, R.E. & Borgida, E. (1975), Attribution and the psychology of prediction, Journal of Personality and Social Psychology, 32, 532-543.

Perlmutter, L.C. & Monty, R.A. (eds.) (1980), Choice and Perceived Control, Hillsdale: Lawrence Erlbaum.

Pryor, J.B. & Kriss, M. (1977), The cognitive dynamics of salience in the attribution process, Journal of Personality and Social Psychology, 35, 49-55.

Rowe, W.D. (1977), An Anatomy of Risk, New York: Wiley.

Shaver, K.G. (1970), Defensive attribution: effects of severity and relevance on the responsibility assigned to an accident, Journal of Personality and Social Psychology, 14, 101-113.

Shaw, M.E. & Sulzer, J.L. (1964), An empirical test of Heider's levels in attribution of responsibility, Journal of Abnormal and Social Psychology, 69, 39-46.

Shephard, R.N., On subjectively optimum selection among multiattribute alternatives, in: Shelley, M.W. & Bryan, G.L. (eds.), Human judgments and optimality, New York: Wiley.

Slovic, P. & Lichtenstein, S. (1971), Comparison of Bayesian and regression approaches to the study of human information processing in judgment, Organizational Behavior and Human Performance, 6, 649-744.

Slovic, P., Fischhoff, B. & Lichtenstein, S. (1976), Cognitive Processes and Societal risk taking, in: Carroll, J.S. & Payne, J.W. (eds.), Cognitive and Social Behaviour. Hillsdale: Lawrence Erlbaum.

Slovic, P., Fischhoff, B. & Lichtenstein, S. (1980), Perceived Risk, in: Schwing, R.C. & Albers, W.A. (eds.), Societal Risk Assessment: How safe is safe enough?, New York: Plenum.

Stallen, P.J.M. (1980), Risk of Science or Science of risk?, in: Conrad, J. (ed.), Society, Technology and Risk Assessment, New York: Academic.

Starr, Ch. (1969), Social benefit versus technological risk, Science, 165, 1232-1238.

Tomas, A. & Stallen, P.J.M. (1981), Risk, Stress and Decision Making, Paper prepared for the Conference on Subjective Utility and Decision Making, Budapest.

Tuller, J. (1978), The scope of hazard management expenditure in the U.S., Worcester, Mass.: Clark University (mimeo CENTED).

Tversky, A. & Kahneman, D. (1971), Judgment under uncertainty: heuristics and biases, Science, 185, 1124-1131.

Vidmar, N. & Crinklaw, L.D. (1974), Attributing responsibility for an accident: a methodological and conceptual critique, Canadian Journal of Behavioral Science, 6, 112-130.

Vlek, C.A.J. & Wagenaar, W.A. (1979), Judgment and decision under uncertainty, in: Michon, J.A., Eijkman, E.G. & de Klerk, L.F.W. (eds.), Handbook of Psychonomics, vol. 2, Amsterdam: North-Holland.

Vlek, C.A.J. & Stallen, P.J.M. (1980), Rational and Personal Aspects of Risk, Acta Psychologica, 45, p. 273-300.

Vlek, C.A.J. & Stallen, P.J.M. (in press), Risk Perception in the Small and in the Large, Organisational Behavior and Human Performance.

Walster, E. (1967), "Second-guessing" important events, Human Relations, 20, 239-250.

Wynne, B. (1980), Technology, Risk and Participation: on the social treatment of uncertainty, in: Conrad, J. (ed.), Society, Technology and Risk Assessment, New York; Academic.

Zajonc, R.B., Feeling and Thinking: Preferences need no Inferences, American Psychologist, 35 (2), p. 151-175.

Hamill, R., De Camp Wilson, T. & Nisbett, R.E. (1980) Insensitivity to sample bias: generalizing from a typical case, Journal of Personality and Social Psychology, 39 (4), 578-589.

Simon, H.A. (1978), Rationality as process and as product of thought, American Economic Review, 68, 1-16.

QUANTITATIVE RISK ASSESSMENT FOR HEALTH AND SAFETY REGULATION

Lester B. Lave

The Brookings Institution,
Washington, DC

A review of the methods for and limitations of quantitative risk assessment (QRA) is undertaken along with the analysis of four major and two minor case studies where this technique played a role in recent regulatory decisions and subsequent litigation: photochemical oxidants, benzene, coke ovens, ionizing radiation, chlorobenzilate, and food additives. Each case study attempts to evaluate the (government) agency's assessment of health risks, to determine how good a risk assessment has been done (when relevant), and examines the role of the assessment in the regulatory decision.

In the past decade, Congress created many agencies to regulate health and safety. These agencies have promulgated myriad regulations which have helped to decrease risk, but have also helped to increase bureaucracy, private sector costs, and litigation, and slowed productivity increases. However, public demands for increased health and safety remain high; the goals will not and should not disappear. The issue at hand is to translate these desires into workable goals and then to attain these goals efficiently.

Improving regulatory decisions will not be simple because of the inherent mistrust, scientific uncertainty, and complexity of a decision regarding billions of dollars of costs and benefits. Indeed, regulatory decisions have been treated far too casually to date, with guesses being substituted for observable facts and litigation being used too often as a device for delay or the forum for clarifying scientific issues. Even minor improvements in the scientific basis of the regulatory decisions might have saved society billions of dollars, which is many times what the additional knowledge would have cost.

Careful review of the scientific evidence and performance of quantitative risk assessment (QRA) have a central role in intelligent regulatory decisions. Regulation without these elements is uninformed, arbitrary, and is unlikely to withstand litigation, induce cooperation from those being regulated or produce the desired results. Scientific analysis has not been emphasized in most rulemaking; rather, of increasing dominance has been the cynical view that regulation is power politics, with the winners imposing their will on the losers. A change in administration should not be used to extend this cynicism; rather government must demonstrate that society's health and safety goals can be reconciled with a healthy industrial economy and can be implemented efficiently, making the greatest use of scientific data and analysis.

QRA is not a panacea; indeed it has played at best a secondary role in most regulatory decisions to date. A primary limitation is that it examines only what can be measured and quantified, neglecting other aspects. This limitation is more severe in practice since scientists tend to focus on aspects which are most easily measured, to the neglect of more difficult areas. Both decision makers and scientists must keep the goals and general picture in mind if the analysis is not to be misinterpreted or be too narrow to be useful.

Despite the limitations, there is no logical alternative to QRA. QRA is the only systematic tool for analysis of health and safety risk. The alternative to QRA is guessing the magnitude of risk or ignoring the level of risk, both of which are inappropriate where decisions involve hundred of lives and billions of dollars. Striving for zero risk is nonsense.

The case studies provide data on the process of analysis and evaluation used in each case. Sufficient data were available in all six cases for some party to carry a QRA. While no analysis reached a unique answer or would garner unanimous support, all provided important insights into the regulatory process. Current inadequacies in data and analysis will be repaired only when QRA occupies a more central role in decision making. Any institution will focus its resources on the areas most crucial to its decisions; since QRA occupied a secondary role or was out of the decision process completely, funding has been withdrawn from collection of scientific data and analysis. The mind set of the agency, and many of the statutes, must be changed to emphasize the scientific foundation of the issues.

Many scientists and voters believe that regulatory decisions are, or at least should be, based in scientific fact with value conflicts resolved by society through Congress. Yet, many scientists slide their personal values into the regulatory analysis. Blatant intrusion comes when "prudent" assumptions, rather than best judgments, are incorporated into these analyses. The resulting estimates and interpretations contain so many hidden assumptions that often they provide no useful information. Scientists should produce objective or best judgment analyses in doing scientific work; while they are free, and indeed encouraged, to lobby for their personal policy values, they should separate values from facts as much as possible.

Perhaps the most surprising discovery of the case study analyses was that the agencies often failed to engage in a careful, systematic review of the available scientific evidence. Perhaps because they did not have expert staff, agencies often seemed content with the author's summary and conclusion, rather than troubling to examine the method, statistical analysis, and corroborating evidence to determine what conclusions are appropriate. Confounding this sloppiness was the tendency to regard the risk analysis as a document that must be made to support an agency decision, even if that decision was reached by political judgment. Rather than attempting to determine the most probable estimate of risk and the range of uncertainty, agency risk assessments generally were structured to be arbitrarily conservative.

The type of careful review and QRA advocated need not be time consuming or expensive. The four major case studies were carried out by four graduate students, two in law and two in engineering. Each had access to the scientific literature and to senior scientists, including those in the agency. Each agency routinely devotes much more professional effort to its studies.

The emphasis on QRA is not meant to indicate there is some rule for decision making which antiseptically converts scientific data into finished regulations. The scientific analysis contains many uncertainties which require educated judgment in light of the partial information available. Political judgments are required as well. The objective of QRA is not to eliminate judgment, but to inform it.

No one should be under the illusion that QRA has a pro industry bias. In clarifying the scientific evidence and its implications, the result will not be to insulate industry from regulations, but there should be fewer inadquate or excessively costly regulations, as well as fewer neglected areas that require regulation.

The stress on careful review and on quantitative risk assessment brings with it ancillary benefits. This more analytic, less frenetic approach will raise alternatives to conventional regulation, some of which might be improvements or at least offer insights for improvement. Thoughtful analysis clarifies the implications of decisions, helps achieve goals at lower cost, identifies and eliminates bad alternatives, and generally emphasizes the fact that not all goals can be achieved. Indeed, the regulatory agency must be allowed and encouraged to recognize conflicts among goals explicitly if it is to be successful in achieving its mission. Analysis is needed to identify high risk groups and to set priorities for action. Perhaps most important is the fact that regulations are made in a world experiencing rapid change in social goals, in economic structure, and in science and technology. A half decade or more is required to investigate and establish a regulation; a similar delay occurs in implementing the regulation. Careful thought and good science are important inputs to effective regulation, or even regulation that focuses on the correct areas.

The cases revealed a lack of communication between the professionals in the agencies and their counterparts in the regulated companies. These professionals need not, and in this setting should not, discuss policy; however, they can clarify methods and results and explore common technical problems. The goal of both groups should be the resolution of most scientific issues with accuracy and a minimum of conflict.

The major case studies identified a need for clarification of the goals of the agency and its legislation. For example, instructing OSHA to enhance the health and safety of workers is too general a goal to be of help. Health or safety? Which workers in which industries? How safe? Clarifying these goals generated major debate and often led to litigation. The goals are best clarified by Congress, which is elected for this purpose.

While there are important problems in current agency regulation of health and safety, the solutions need not require either years of waiting or new legislation. While both might help, there is much that can be done in the short term to improve the process with existing resources. Careful review of the scientific evidence and QRA are important components of the solution.

I. The Potential Role of Risk Assessment in Social Regulation

Along with other developed nations, the United States has exhibited increasing concern for risks affecting health. While there is evidence that the magnitude of these risks has declined over time within the nation, the nature of the threat has changed. Risks from infectious diseases and disabling accidents have been reduced substantially or, in some cases, eliminated. They have been replaced by fears of chronic disease, particularly of cancer, although there is little evidence that these risks have been increasing (after adjusting for age), except for lung cancer due predominantly to cigarette smoking.

This widespread concern for lowering risks to health resulted in major new legislation in the 1970s and with more stringent standards for activities already regulated (for example, miners' exposure to coal dust). This legislation can be divided into two basic types. The first requires the regulators to lower risks from a substance identified as a carcinogen or more generally, as toxic, to zero or negligible levels without concern for the resulting costs; technological feasibility is the only constraint. The second requires the regulators to balance some measure of the benefits to society from lowering risk against the costs to society of that action. I have shown elsewhere that the first framework is self-contradictory (Lave, 1981). In each regulatory action there is at least an implicit weighting of costs and benefits; the second type of legislation differs from the first by making the balancing explicit -- and by clarifying who is to balance what.

Whether the balancing is implicit or explicit, a crucial piece of information is the magnitude of risk and how alternative regulations will affect the risk. Without being able to measure risks quantitatively and to estimate the effects of proposed standards, regulation is reduced to guesses as to what is a prudent judgment; these guesses generate value conflicts between those opting for greater safety, and are thus willing to accept less consumption, and their opposites. Without estimates of risk, guesses and value judgments are the only device for setting standards, and the inherent differences in values inevitably lead to maximal conflict.

The conceptual steps in discovering and regulating risks are shown in Figure 1. The data needed to support each decision are shown in the left hand column while the right hand column shows the judgments or expert opinions required for each stage. The process cannot begin until there is identification of a possible hazard.

Scientific evidence is usually the primary input in deciding if the possible hazard is worth further regulatory consideration. Those warranting further attention must be subject, at least inferentially, to risk assessment. Data are needed on exposure patterns and a judgment is needed about whether the observed association is causal, or simply a spurious correlation. If the risk appears to warrant some action, the next step is to identify the conceptual range of regulatory alternatives, from complete reliance on the market place, to developing and disseminating information, assessing effluent fees, or promulgating formal regulations. In developing the alternatives, it is important to develop information on incentives to currently employed workers, those

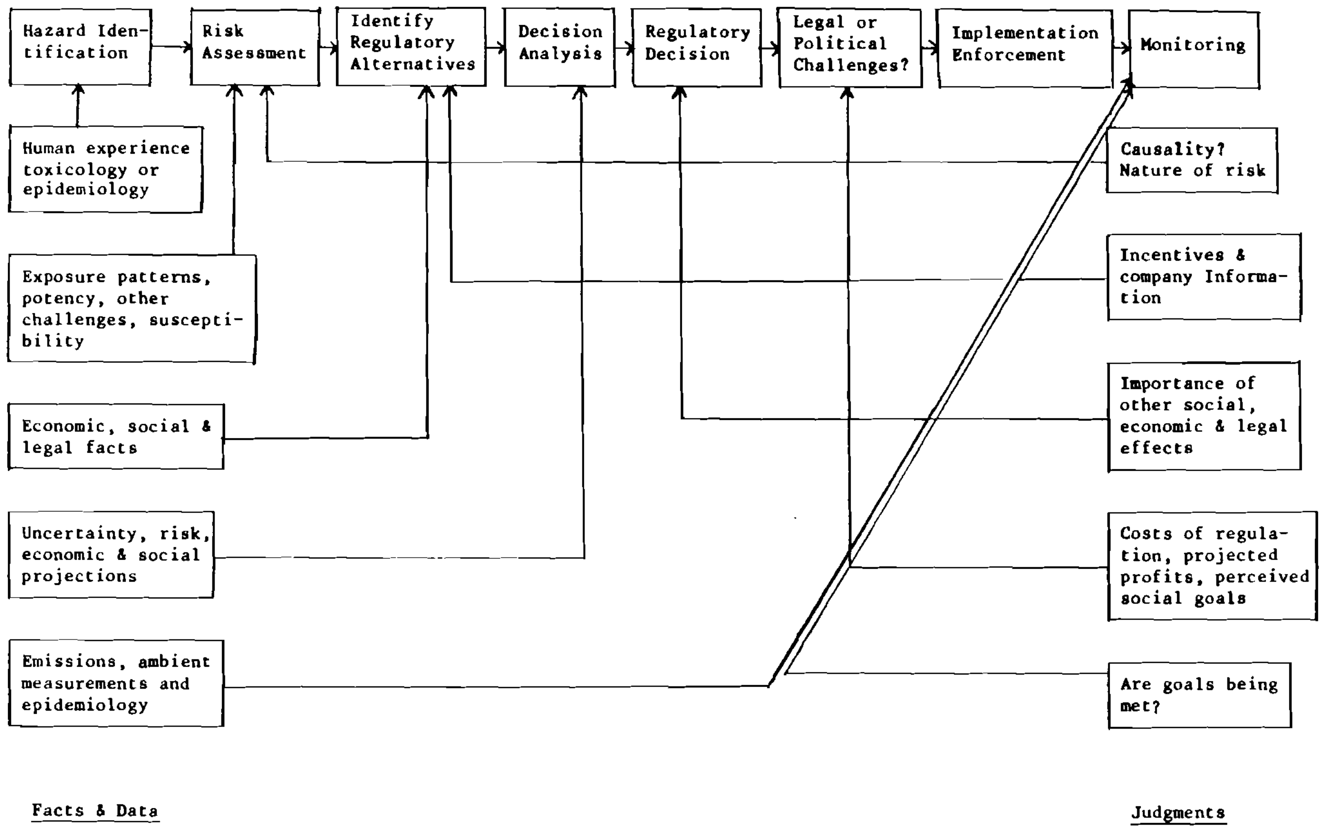


Figure 1 Conceptual steps in discovering and regulating risks.

seeking jobs, companies, as well as their current level of information. These alternatives are then analyzed via decision analysis in an attempt to specify the consequences of each alternative in terms of various benefits and costs and current and future uncertainties. A regulatory decision must then be made among the alternatives, based on the information and judgments concerning the importance of unquantified effects. As a virtual certainty, we can then expect to see legal or political challenges, influenced by private judgments about the costs of litigation and the value and probability of success, or at least of achieving delay, of a challenge. A large step in hazard management is in implementing and enforcing the decision; surprisingly little research has been done to clarify this step, although there is evidence that many regulations are modified significantly at this stage. The final stage is monitoring to ensure compliance. The regulatory agency must evaluate the change in exposure and change in health effects to ensure that the regulation is accomplishing its goal and that the analysis was correct.

The flow shown in the table progresses from top to bottom in a multistage, but orderly fashion. Regulatory processes are anything but orderly, however, since a fact or judgment at one stage can cause the process to begin over again, set it back several stages, or stall it indefinitely. Implicit in the figure is the decision at each stage to stop if the judgment is made that the hazard is insufficient to warrant proceding or the cost is too high to justify action (assuming the statute permits this decision).

The focus of this project has been the first two stages, hazard identification and risk assessment. The case studies attempted to be more complete, although the focus was still on the first stages. It is evident that the entire process of regulating risks is difficult. Many scientists argue that knowledge is so rudimentary that this process is, and can only be, a judgmental one in which the media, public opinion, and real or imagined disasters, such as occupational exposure to vinyl chloride and public exposure to toxic wastes at Love Canal, all play roles.

Certainly, there are major uncertainities, as elaborated below. However, there are powerful reasons for not surrendering to ad hoc decision making. Past regulatory controversies and ineffectiveness, as well as a growing mistrust of government, have led to low confidence in current institutions. Regulations involving hundreds of lives and billions of dollars should not be based on arbitrary guesses in which politics rather than science has the primary role. No one is surprised at value conflicts, but often these are cloaked in spurious disagreement about the science. Value conflicts and scientific uncertainties will persist, but scientific issues must be separated from social values as clearly as possible. A rule making procedure is a terrible place to attempt to resolve scientific conflicts; these are best resolved -- and perhaps can only be resolved -- in scientific forums which value conflicts are excluded.

Common sense tells us that some substances are more toxic than others, that some are more useful than others, and that regulation must take account of these differences. Without a scientific basis for measuring risk and usefulness, we are plunged into disagreements among opposing experts that confuse rather than enlighten, and cloud rather than clarify the issues.

II. The Methods of QRA for Health Hazards

Few scientists would disagree in principle with the theoretical value of quantitative risk estimates. However, some would argue that QRA is impossible at the current state of knowledge, since we are ignorant about many of the underlying biomedical mechanisms involving health hazards and must make crude guesses at each stage of the analysis. Doing a QRA requires knowing (1) the health effects from exposure, (2) the dose-response relationship, (3) the population at risk, (4) the distribution of doses of the toxic substance that are received, and (5) exposure to and the effects of confounding substances. For each item, there are major difficulties, both conceptually and empirically. However, despite its shortcomings, QRA provides useful inputs to regulatory decision making. Indeed, QRA is a necessary first step to systematic thinking about regulatory decisions.

A new chemical might cause any number of health problems, including cancers, chronic disease, acute disease, genetic change, and birth defects. A positive result in an animal bioassay could be due to a statistical fluke or some failure in method; a negative result could indicate no hazard or that the increased incidence of disease was too small to be significant under the test conditions. Highly toxic substances can be discovered easily, but a small increase in the incidence of a chronic disease is extremely difficult, often impossible, to detect. Unfortunately, neither animal bioassays nor epidemiological studies are powerful unless they are testing specific hypotheses about effects, for example, that vinyl chloride causes liver cancer. In addition, a substance cannot be proven to be safe; testing can only indicate whether exposure to a substance significantly increases the incidence of some effect. Thus, testing a new substance is painstaking, expensive, and often inconclusive.

The inability to show that a substance is safe, but rather only that it is not significantly harmful in particular settings, leads to a confusion of the interpretation of the science and of resulting policy. Policy makers can not conclude that a substance is safe because it failed to cause significant problems in one test or that is unsafe because one significant positive result was found. Unfortunately, instead of presenting the data and direct interpretation, scientists often give policy advice by interpreting insignificant positive results as more important than significant negative results. This muddles the scientific evidence and its interpretation. Occasionally, actual misstatements are made of what was found, but more generally the results are stated in a fashion which makes interpretation nearly impossible.

The inherent difficulty of not being able to prove a substance is safe is confounded by the expense and time required for each test and the difficulties of interpreting results. For example, the Ames test is quick and inexpensive, but its results are given little weight; animal bioassays take more than one year for chronic studies and are easily marred by defects in design and interpretation; epidemiological studies are time consuming, expensive, and inevitably controversial. Even the qualitative conclusion that a substance is carcinogenic is usually disputed. However, QRA requires an estimate of the quantitative relationship between risk and response, the dose-response curve.

The dose-response relationship is inescapably tied to the mechanisms by which the substance causes damage. However, the mechanisms are almost entirely unknown which means there is little basis for choosing among a large number of alternative functional forms in the statistical estimation. Often, there are large differences in estimated risk depending on which of several, equally plausible, dose-response curves are used. Usually, a procedure is choosen that gives high estimates of damage, or perhaps the highest estimated damage (worst case). Such a method for dealing with uncertainty suppresses information and papers over crucial questions concerning what substances should be regulated first and at what level standards should be set. Occasionally, assuming the worst case is the best decision; more generally, a careful examination of what is known and the costs of being wrong prompt a less extreme assumption.

For quantitative risk assessment, we must know how many people are exposed to a substance and the dose each receives. Generally, there is only gross information concerning who is exposed and little more than guesses concerning the dose. This information is not conceptually difficult to gather nor does it generally require elaborate, complicated methods. However, it does require painstaking, often costly data collection.

For epidemiological studies, and even for animal bioassays, identification of the effects of a substance is confounded by the presence of other substances. For example, the conclusion that cyclamates are carcinogenic may have been due to joint feeding of cyclamates and saccharin in the animal experiments. For laboratory experiments, much of this difficulty can be eliminated by going to elaborate lengths to purify air, food, and water, and to keep the animals in a sterile environment. However, the resulting sterile conditions are unrepresentative of those facing humans. Such artificiality can lead to over or underestimating risks if, for example, the sterile conditions prevent manifestation of a decrease in resistence to disease or the artificial surroundings cause animals to be more susceptible to the substance. Epidemiological studies are filled with confounding factors and it is impossible to control for all such factors. Thus, epidemiological studies are invariably controversial (along with other methods).

No one should underestimate the difficulties and uncertainties of QRA. The set of methods discussed here provides controversial, generally ambiguous results. At best, there will be a large amount of uncertainty surrounding the quantitative estimates of risk. In practice, uncertainty is much greater because critical experiments were not done, crucial information on the population at risk and dose are missing, or because an animal bioassay was marred by a flaw in experimental design or an epidemiological study was marred by failure to collect information regarding a critical variable such as cigarette smoking habits.

While most of the difficulties cited above stem from the current state of biomedical knowledge, many result from sloppy research or inadequate analysis. Flaws in experimental design can be found before half a million dollars are invested in an animal bioassay. However, the task of the analysis is to determine what can be concluded despite the weaknesses in the available data.

The risk assessment is of little use, or even of no use, unless attention is given to the sources of uncertainty and the effects each have on the resulting estimates. Each source of uncertainty must be specified and related to the final estimates. For example, when the functional form of the dose-response relationship is unknown, reasonable high and low estimates must be calculated in addition to a best guess estimate and this range of estimates carried through the analysis. Often, the resulting range will be so large that uncertainty dominates and QRA is of no direct help, even though it is of immense help in sorting out the issues and structuring the analysis. Where the issue is inherent randomness, such as the genetic susceptibility of the population to a substance, high and low estimates can be carried through the analysis. Where the issue is some question of fact, such as whether the substance causes a particular kind of cancer, the analysis can carry through twin calculations showing the implications of each assumption.

All of the uncertainty must be described and displayed in the final estimates of risk. By doing this, decision makers can decide how prudent they would like to be. Furthermore, this procedure identifies the most important uncertainties, providing a focus for future research and indicating how new results can be integrated into existing evidence.

Although the array of difficulties is formidable, many can be avoided by better experimental design and analysis. It is not evident that a marked increase in research funds would be required, since the effectiveness of current expenditures could be enhanced. Improvements in method offer the hope of quicker, cheaper results.

The formidable difficulties of QRA qualify the results but do not reject its use. Whatever the difficulties, QRA will be used until it is replaced by something better. The appeal of QRA is not its ease of use or the tightness and aesthetic appreciation of abstract mathmematics. Rather, QRA is used because there is no other tool currently available that can produce the information necessary for intelligent regulation.

III. Case Studies

Six recent regulatory decisions were studied. The four major ones examined risk assessments of photochemical oxidants, benzene, coke oven emissions, and ionizing radiation; three less extensive case studies examined the regulation of food additives and regulation of the pesticide chlorobenzilate. These case studies are formidable not only in bulk, but also in technical complexity; they involve scientific results and judgments on the frontiers of cancer research, statistics, epidemiology, toxicology, atmospheric chemistry and physics, pharmacology, and human factors.

A central fact in regulating risks of toxic substances is the incredible ability to measure minute amounts of such substances. Often, one part per billion can be reliably detected, equivalent to finding one person in a country four times as populous as the United States. We can detect substances at concentrations where we have no idea whether exposure would have any adverse consequences. Thus, regulators must confront the decision of what levels of substances such as arsenic or dioxin we choose to permit.

The reader of these case studies cannot escape the impression that each of the regulatory decisions is complicated, involving questions at or beyond the current frontiers of science; each involves areas where measurement is difficult, theory is incomplete, and judgment is required for answering many, if not most, of the scientific questions. In many cases, the perceived inability of scientists to answer all questions has led to a feeling that science will provide none of the answers, that answers can come only from yet more careful exegesis of the statutes and legislative history, from sampling public opinion and the media, or from political compromise. Yet, in each of the cases, the scientific investigation generally and the quantitative risk assessment in particular, played a crucial role in shaping the regulatory decision, its speed of implementation, or its form as actually implemented. Unfortunately, in some cases, the agency selected its policy and made its regulatory decision without the results of a scientific investigation; a frequent result was either an embarrassing change in policy or a standard vacated by the courts. Probably the agency would have progressed faster toward its goal if it had put more resources into the scientific investigation and risk assessment. More information and analysis would likely have: (a) made the hearings smoother and spared all parties the embarassment of revealing major flaws in the agency proposals, (b) avoided reproposals, (c) resulted, presumably, in more sensible standards that, together with the better scientific support, might have convinced companies and public interest groups not to challenge the regulations, caused the courts to sustain the agency regulation if it were challenged, resulted in those regulated implementing the standards more quickly, and provided protection from risk at an earlier date. While many of these statements are presumptions, some can be documented. If an agency can position itself so that it is left with conflicts in value, rather than conflicts in science, it is more likely to prevail.

Photochemical Oxidants

Perhaps the most striking result of the photochemical oxidant case study is the paucity of epidemiological research regarding the effects of this pollutant on health. Only a handful of small clinical investigations and epidemiological studies have been published since the standard was initially set in 1971. It is natural that an agency finds itself on the defensive when it is forced to rely on older studies whose flaws have been recognized for more than a decade.

Initial fears concerning the acute health effects of ozone were not borne out by the newer studies. Consequently, EPA proposed a slight relaxation of the standard. While some evidence had been gathered on acute reactions to ozone among both healthy and asthmatic volunteers, there was virtually no human evidence on long term exposures, particularly the effects on chronic disease, on the developing lung in children, and little research on possible cytogenic effects. The evidence on acute effects does not provide justification for a standard within a factor of two or three of the 1971 standard. Thus, the new evidence seems uniform in suggesting that ozone was much less of a threat than had been feared in 1971, but does not explore all biological effects of concern. Even with almost a decade of lead time, EPA failed to answer questions that remained unanswered at the time of the initial rulemaking. Although EPA initiated some research in 1976, when it was clear that they would be rquired by Congress to review all air pollution standards, the studies were not designed to answer the crucial questions.

A second point is the sloppiness of EPA's examination of each study. The agency relied upon the author's summary and conclusions, without inquiring whether the methods, analysis, and corroborating studies were sufficient to support them. Scientific review accepts results only when the underlying methods are worthy of confidence and there is corroborative evidence. Many of the studies had major flaws in apparatus design and use, measurement of levels, and the failure to consider the interaction of ozone with other pollutants; such flaws destroy confidence in the results. A careful review of each study is necessary in order to identify what conclusions are proven, which are good conjectures, and which are unlikely to be true.

A third point is that the scientific analysis and risk assessment seem to have been designed to support a standard arrived at by other means rather than to answer the question of what standard best fulfills the legislative requirement. Thus, the scientific analysis had at most a secondary role in the determination of the standard.

The fourth point stems from the third. In groping for supporting evidence, EPA cited the results of a highly preliminary exploration. Amidst attacks on using this study, the experts whose opinions were used disavowed EPA's use of the study; the agency was forced to back off and claim that it had never been relied upon. While the decision analytic approach used in this study is an interesting one and worthy of the further exploration it is receiving, no preliminary, explorative study should be used as a basis for supporting a major regulation.

The fifth point focuses on what constitutes an adverse health effect and how far society should go to avoid it. The new studies concerned acute respiratory problems experienced under physical stress due to heavy exercise, which were reversed quickly after the experiment was concluded. Since people usually can choose to exert themselves less and the effects of exposure are reversible, there is little need to set a standard more stringent than the level at which stress was experienced under moderate exercise. If, however, stress occurs at lower concentrations for more sensitive people or is not reversible for some people, then more stringent standards might be warranted. The experiments shed no light on these possibilities. If effects on chronic disease or on the developing lung occur at lower concentrations, there is reason for a more stringent standard, but again there is no evidence. One reading of the research published since 1971 is that it allays some of the earlier fears, but is largely irrelevant to answering the regulatory question about whether ambient concentrations of photochemical oxidants produce chronic ill health. Thus, decision makers must choose how much safety to build into current regulations in view of current uncertainty about health effects and the cost of stringent standards.

The sixth point is that most of the epidemiological studies, and many of the clinical studies, are marred by not accounting for the presence of other air pollutants. If these other pollutants are the true cause, or even a partial or contributing cause of any observed effects, ozone is being blamed incorrectly. There is some suggestion of a positive interaction effect (synergism) between ozone and sulfur oxides, but the evidence is contradictory.

This point is a subtle one because elevated levels of ozone are nearly always associated with elevated levels of other pollutants. If the experiments had been done with pollutants in addition to pure ozone, they might have detected effects at lower concentrations of ozone. Thus, in attempting to isolate the effect of a single pollutant, the experiments probably tended to understate the effects of ozone. An important synergism among pollutants argues for joint standards, rather than an individual ozone standard. The point is not to find an excuse for exonerating ozone, but rather to learn the source of any health problem so that regulation can focus on the precise problem and design a strategy which mitigates effects at least cost.

The seventh point is that EPA procedures did not lead to a full and explicit discussion of biological mechanisms and analogies by which photochemical oxidants might harm health. The focus was on evidence regarding somatic damage. Insofar as there is evidence concerning physiological mechanisms, air chemistry and physics, or animal bioassays that would help with the interpretation of current clinical and epidemiological studies, a forum should be provided for displaying this evidence and discussing its implications.

The final point is the level of safety society desires to incorporate in regulatory decisions. In each case there remains some residual risk that adverse effects could be much greater than those estimated. Reasonable people will differ in their judgments concerning how much safety to build into the standard. However, these disagreements must be made explicit, rather than hidden in scientific judgments concerning risk.

Benzene

The foregoing set of generalizations applies to many of the other case studies and thus their summaries will be more brief. For benzene, OSHA took a strong position that a quantitative risk assessment could not be done, or at least could not be done with sufficient confidence to warrant the effort. This position was taken in spite of analyses produced by EPA and Richard Wilson. Having neither dramatic epidemiological evidence nor a risk assessment, OSHA was unable to show that the existing standard permitted a significant risk to health. This led the Supreme Court to vacate the agency's standard. Apparently, the agency feared that a QRA would expose the standard to court challenges and increase the likelihood of it being reversed. However, the Supreme Court's opinions seem to indicate that it was aware of the inherent uncertainties in such an analysis and would give an agency deference to encourage greater effort to get at the scientific facts.[1]

The benzene case is complicated by the fact that the epidemiological studies were of poor quality because there are few data on the dose received by workers. The excess leukemia in workers could have been caused by exposure to benzene of less than 100 or of well over 100 parts per million. The level of exposure of these workers makes a large difference for the estimated dose-response curves and the implied risk at 10 parts per million. While problems with the epidemiological studies are to be expected, it is surprising that no animal bioassay has managed to produce leukemia from benzene exposures. Thus, one cannot have confidence in the estimates of risks to humans.

The exclusive attention given to leukemia by the agency seems to ignore better evidence as to benzene levels that cause other blood disorders. Better estimates of risk can be derived for blood disorders and a standard for these set with greater confidence. Presumably, a standard preventing blood disorders would also prevent leukemia.

---

1. The Supreme Court explicitly decided not to rule on the Court of Appeals' contention that benefits and risks had to be roughly commensurate. A ruling on this issue could emerge for the cotton dust case being heard this term.

The benzene case is a classic illustration of the cost of being unprepared. Three years after promulgating the standard, OSHA was reversed. Agency morale and credibiltity were injured and three years have been lost if the 10 ppm standard is not considered adequate. More careful analysis initially could have produced a better regulation as well as evidence that would have led to the standard being sustained or showed the existing standard to be adequate. This case shows the unfortunate consequences of a decision to base a standard on political grounds without careful analysis of the scientific support for such decisions.

Coke Ovens

OSHA's regulation of exposure to coke oven emissions was a more dramatic case than benzene since an American epidemiological study showed topside coke oven workers to be at extraordinary risk of lung cancer. The health problem was evident, but the issue was how much exposure had to be decreased in order to eliminate, or at least reduce, the excess risk.

In this case again, the epidemiology generated dispute since a study of British coke oven workers found no excess risk. However, a careful comparison of the two studies showed the American one to be superior and its conclusions more worthy of confidence. Yet, as with benzene, it was nearly impossible to get exact corroboration from animal data because coke emission substances cannot be produced in laboratory inhalation chambers. Animal studies had to rely on testing constituents of the emitted mixture but did find these materials to be highly carcinogenic. In addition, these constituents were known to be carcinogenic in humans. The scientific basis for concluding that coke oven emissions are carcinogenic at current levels was stronger than for benzene and it was evident that current levels of exposure to coke oven emissions posed an appreciable risk to workers.

The greatest source of uncertainty in the coke oven case was the dose-response relationship, particularly the uncertainty as to what level of exposure would produce little or no excess risk. The dose that workers received was not known with accuracy, nor was there evidence concerning contributing factors, such as cigarette smoking. Finally, the lag between when the dose was received and when lung cancer was detected was extremely important in estimating the health risks of lower doses. Although not totally clear, the evidence was sufficiently detailed that one could quantify the implications of various assumptions about exposure, cigarette smoking, the latency period, and the form of the dose-response relationship. Although there is remaining uncertainty, the analysis is sufficiently complete that one can explore the implications of each assumption and identify the place where additional research could make the greatest contribution.

Ionizing Radiation

Regulation of exposures of the general population to ionizing radiation from the nuclear fuel cycle is the most thoroughly researched of the areas studied. Large amounts have been spent to learn the effects of exposure to ionizing radiation and a good deal is known about the dose-response relationship for various types of radiation, at least at moderate and high levels of exposure. However, for long term exposure to very low levels of radiation, little is known, and little can be deduced from epidemiological studies. If the answers exist, they must come from understanding the mechanisms by which low doses of radiation produce cancer or other effects.

The case study shows a vast effort at attempting to characterize radionuclide emissions at each stage of the nuclear fuel cycle, to follow the emitted radionuclides through the environment to human exposure, and to estimate the resulting radiation exposure levels and health effects. While it is difficult to conceive of a more complete investigation, it is also evident that no investigation could conceivably provide precise answers to all of the questions. Any investigation will be characterized by areas where data could be more complete and additional analysis could be done. Presumably, the investigation should be stopped at the point where additional data collection and analysis adds only another digit, possibly of spurious accuracy, to the calculation.

Following such a careful investigation, it is disheartening to see that the regulatory goals were set so arbitrarily. Numbers were pulled out of the air in defining the acceptable level of exposure and the required safety factor. While I would not want to quarrel with the numbers chosen, I cannot help noting that they could easily have varied by a factor of five or ten, based on the data. Since, at the end of the calculation, small changes in these numbers produce large effects, a mechanism is needed for feeding back the final calculations to the initial estimation. Somewhat arbitrary initial goals must be matched with their implications; where a change in the assumptions would have no discernible effect on health, but a large effect on costs, they should be modified.

The level of effort expended in the scientific analysis for ionizing radiation is so great that it is instructive to examine what was gained from the process. First, it is evident that the analysis does pinpoint facilities that were causing more population exposure and show how that exposure could be averted relatively inexpensively. Thus, while the analysis does contribute, it often gets bogged down in useless detail, as in calculating pathways of secondary importance. Finally, the analysis cannot provide full and complete answers; an element of judgment is required. The purpose of the scientific analysis is to identify and isolate those areas where judgment is needed and to ensure that the result is informed judgment.

Implications

A few conclusions from the case studies are worth repeating. In none of the cases was the risk assessment sufficiently complete that it could have provided an automatic mechanism for making decisions. In each case there was large scientific uncertainty and need for informed judgment. QRA is not a panacea for current regulatory problems, but it can be a helpful tool contributing to the improvement of the regulatory decision making process.

Emphasizing QRA would have pushed each agency away from frenetic, crisis oriented action into behavior more appropriate to the long term importance of each risk. Worker and general population risks could have been lowered more quickly (if warrented) by a more thoughtful approach that developed the risk and cost information and attempted to convince rather than immediately trying to compel.

While rulemaking hearings generated useful information, the adversarial nature tended to obscure legitimate criticisms, suggestions for change, and the implications of different scientific viewpoints. The process would have proceeded more quickly and smoothly had an initial attempt been made, in a nonadversarial setting, to discover areas of scientific agreement and to identify the ranges of and reasons for disagreement. In particular, it would have been helpful to the process to have had communication between experts in the academic, business, and government communities.

In the four major case studies, the quality of information supplied to regulators, and presumably the resulting regulatory decisions, would have been improved markedly by better analysis. Despite the ambiguous goals provided by Congress and the uncertainty and generally poor quality of biomedical evidence, QRA could have improved estimates of the risks and could have helped the agency to design better standards. The case studies indicate that better scientific studies and more precise clarification of goals by Congress would be invaluable.

DEVELOPING SAFETY CRITERIA*

F. Niehaus and E. Swaton

International Atomic Energy Agency,
Vienna, Austria

Present-day controversies about the acceptability of technologies definitely demonstrate the need to establish rational criteria and formal procedures which would allow one to determine which technologies are "safe enough".

Any attempt to establish such criteria is part of an evaluation process and thus necessarily subjective. The presentation will review some of the methods which are being applied, will elaborate in more detail on a modified cost-effectiveness approach which was developed by the joint IAEA/IIASA risk assessment project, and will review current trends in safety-related decisions which try to neglect public perception of risks.

*Partly published in: F. Niehaus: Developing criteria to compare the safety of energy systems, *Angewandte Systemanalyse*, Vol. 1(4), pp. 149–157, Verlag TÜV Rheinland Köln, 1980.

In the absence of absolute criteria which would define acceptable levels of risk such evaluation processes can be based on putting risks of a specific technology into perspective with other natural or man-made risks. Early studies (1) in this area tried to establish criteria for acceptable individual levels of risk based on risk/benefit relations obtained for various technologies and activities. It was concluded that depending on the benefits such levels should range between the risks of dying from natural hazards and diseases.

Later studies, analysing hypothetical low probability accidents of nuclear power plants, evaluated the obtained cumulative probability distributions for accidents involving multiple fatalities by comparing them to those derived for other natural or man-caused events (2). Recently, it has been proposed to establish a safety goal for nuclear power not to exceed 1% of the total risks of all man-caused events (3).

Whereas these studies give a good indication of whether the risks from a particular technology are within a range accepted for other technologies, some studies have pointed out that the public does not perceive these technologies and their risks in accordance with these results.

Fischhoff et al. (4) analysed the acceptable risk and the perceived risks and benefits for 30 activities and technologies as characterised by a set of nine descriptive risk-related attributes. They found that the correlation between acceptable levels of risk and the perceived benefits was low, and that the nine descriptive attributes could be reduced to two basic dimensions of risk. One dimension was associated with "new, involuntary, highly technological items, which have delayed consequences for masses of people". The second dimension was described as being "associated with events whose consequences are certain to be fatal (often for large numbers of people) should something go wrong". The various activities and technologies are widely scattered in the plane defined by these two factors, indicating the difficulty to directly compare the risks of very different technologies.

Fagnani (5) used a questionnaire-based approach assuming that the concern about nuclear power and other issues of debate have to be viewed in a more general context. Therefore, opponents and proponents have been analysed with regard to their social, philosophical, and political positions. It was found that the attitudes of the public towards various technologies (including nuclear energy and solar power, did not highly correlate with those general topics of debate in France.

It is because of these considerations that recent studies of risk have concentrated on comparing technologies which serve the same purpose. Here an attempt is made to present an account of the risks of electricity production systems by investigating their total fuel cycle (6,7,8,9,10). The purpose of such studies is threefold:

- to demonstrate that all energy carriers, i.e., fossil, nuclear and renewable sources, involve risks to man and his environment, and to put the risks of particular technologies into perspective with those systems serving the same purpose, namely the production of energy,

- to determine criteria for acceptable levels of risks, and

- to apply knowledge and experience in safety accumulated in one area to similar problems in other areas.

This paper will discuss the criteria and limitations of such comparisons, and will place emphasis on cost-effectiveness considerations. If the resources which society can spend on safety are limited, they should be spent most cost-effectively, i.e., in those areas where the largest risk reduction can be achieved with the same amount of investments. It is also pointed out that a practical limit to risk reduction does exist, because excessive expenditures will actually increase the risk to society. Since most of these considerations are based on expected values, the final part of the paper will review current trends in safety-related decisions which try to reflect public perception of risks.

COMPARISON OF RISKS OF ENERGY PRODUCTION

Based on epidemiological studies and on atmospheric dispersion models, Hamilton (11) has estimated the total risks from energy production in the U.S. in 1975. The number of plants have been normalised to the equivalent size of 1000 $MW_{(e)}$. The estimates given in Table 1 include the total fuel cycle and occupational and public effects. It should be noted that large uncertainties remain, which is demonstrated by the fact that the uncertainty in the given number of total estimated deaths is about one order of magnitude higher than the lower estimate.

It is revealing to compare such estimates with accident statistics of other sources of risk within society. Table 2 gives some data for the U.S. for the time period from 1967 to 1970, which do not change drastically from one year to the next. Comparing Table 1 and Table 2 it can be seen that the estimated deaths caused by electricity production would fall between those caused by "Poisoning" and "Falls". They are definitely much lower than the deaths caused by Motor Vehicles and would thus not be out of proportion with other risks.

As mentioned above, this type of comparison should only be viewed with caution since the various causes of death do not have

Fuel	Equivalent No. 1000-MW(e)plants	Estimated deaths	Estimated disabilities
Coal	128	1900-15 000	25 000-39 000
Oil	44	88-4400	4000-7900
Gas	45	6	600
Nuclear	26	18-42	130-470
TOTALS	243	2000-19 000	29 000-48 000

TABLE 1: Estimated health effects in 1975 associated with production of electric power (11)

Accident	Total Deaths			
	1967	1968	1969	1970
Motor Vehicle	53,100	55,200	56,400	54,800
Falls	19,800	19,900	19,000	17,500
Fires, burns	7,700	7,500	7,100	6,700
Drowning	6,800	7,400	7,300	7,300
Firearms	2,800	2,600	2,600	2,300
Poisoning	2,400	2,400	2,500	3,000
Cataclysm	155	129	NA	NA
Lightning	110	162	NA	NA

NA = Not available

TABLE 2: Some U.S. accident death statistics 1967-1970 (2).

much in common; also the number of fatalities clearly depends on the number of facilities available. In order to avoid these problems the following comparison considers energy production technologies which are similar in that they produce electricity in centralised systems. As a common basis for the comparison the production of 1 $GWa_{(e)}$ has been defined.

Five technologies have been chosen for this study which has been described in more detail in (9).

Coal

The analysis is based on data from the U.S. where, in 1975, 55% of the coal was produced in surface mines and 45% by deep mining. On the average, the coal is transported for 500 km, 65% by rail, 21% by truck and 13% by barge. The 2 x 700 MWe plant is assumed to operate on a load factor of 71% with 38% efficiency. Flue gas desulfurisation is considered to be equivalent to a 0.5% sulfur content in coal. Public health effects are based on a stack height of 305 m and consider an average population of 2.2×10^6 people within a distance of 80 km.

Oil

A plant of similar size and operating parameters, fuelled by residual oil, is used. The sulfur content is assumed to be 0.2%. The fuel is transported by tanker.

Gas

The SO_2 emissions are assumed to be 24 $t/GWa_{(e)}$. This may be compared to the 31,000 $t/GWa_{(e)}$ estimated for coal with 0.5% sulfur. The gas is transported by pipelines and data on pipeline accidents have been allocated accordingly.

LWR

Results are based on a 1350 MW(e) light-water reactor operating at a load factor of 0.74 assuming 33% efficiency. The fuel cycle considers reprocessing. Health effects of storage of nuclear waste are assumed to be close to zero and are not considered. Regarding fuel requirements and economic implications no credit is given for the recovered plutonium.

STEC

For solar thermal electric conversion systems, 100 $MW_{(e)}$ (peak) plants are considered with 6 hours rock and oil storage, operating at a 54% capacity factor. Thus, 18.5 plants are needed to supply 1 $GWa_{(e)}$/year. No back-up systems have been considered. Based on most favourable conditions in the South-Western desert of the U.S. with an average annual insolation of 8 kWh/m^2 x day, each 100 $MW_{(e)}$ plant would consist of 28,600 heliostats with 30.4 m^2 surface. In total, each plant would cover 3.5 km^2 of land.

All plants are assumed to have a lifetime of 30 years.

The estimated health effects of these systems are summarised in Table 3. In order to stress the uncertainties involved and to point out national differences, the range of values which can be found in the literature is also given. The data have been kept separate for occupational and public health effects and for accidental death, accidental injuries and fatal diseases. Because of insufficient data base, diseases which lead to temporary or permanent disabilities were not considered. It should be mentioned that permanent disabilities among coal-miners are probably about a factor of 10 higher than the number of deaths listed in Table 3.

OCCUPATIONAL	Accident Injuries (in MDL) This Study	Literature	FRG	Accident Deaths This Study	Literature	FRG	Fatal Diseases This Study	Literature	FRG
COAL									
Fuel Supply	3020-3090	1490-8900	5410	0.66 -0.73	0.45 -2.71	3.66	0.097	0.008-6.4	2.77
Transport	710-880	19-4400	1550	0.351-0.381	0.073-3.07	2.89			
Normal Operation	213	150-2400	81	0.016	0.013-0.46	0.04			
Construction	240	-	92	0.055	-	0.1			
TOTALS	4200-4400	1660-14000	7130	1.08 -1.10	0.54 -6.2	6.7	0.10	0.008-6.4	2.8
OIL									
Fuel Supply	2640	430-6600	41	0.387	0.027-1.7	0.04			
Transport	470	53-750	936	0.068	0.04 -1.8	1.8			0.026
Normal Operation	130	50-171	59	0.013	0.013-0.052	0.04			
Construction	230	-	76	0.054	-	0.07			
TOTALS	3500	530-7520	1110	0.52	0.08 -3.6	2.0			0.03
GAS									
Fuel Supply	1770	200-3100	41	0.22	0.036-0.4	0.04			
Transport	100	44-193	936	0.02	0.026-0.034	1.80			
Normal Operation	140	68-210	59	0.012	0.012-0.053	0.04			
Construction	210	-	76	0.049	-	0.07			
TOTALS	2200	310-3500	1110	0.30	0.07 -0.49	2.0			
LWR									
Fuel & Reprocess	190	180-1180	71	0.094	0.071-0.57	0.091	0.28-0.3	0.003-0.67	0.187
Transport	7	3-47	1	0.002	0.0026-0.015	0.003	0.0006	0.0008-0.115	0.0016
Normal Operation	140	44-140	8	0.014	0.013-0.02	0.012	0.13-0.18	0.024-0.14	
Construction	235	-	190	0.055	-	0.12			
TOTALS	570	230-1370	190	0.17	0.087-0.60	0.23	0.42-0.49	0.028-0.92	0.19
SOLAR THERMAL									
Material Supply	290	900-1200		0.055	0.18				
Transport Mat.	82	630-2380		0.021	0.77 -2.52				
Construct Plant	4620	5990-7780		1.07	1.91				
Construct Storage	30	130-8300		0.012	0.030-0.91				
Normal Operation	3450	2660		0.96	0.92				
TOTALS	8500	10330-22300		2.12	3.8 -5.4				

TABLE 3: Effects from accidents and diseases from supply of 1 GWa(e) (8.76×10^9 kWh).

PUBLIC	Accident Injuries (in MDL) This Study	Literature	FRG	Accident Deaths This Study	Literature	FRG	Fatal Diseases This Study	Literature	FRG
<u>COAL</u>									
Fuel Supply								1.3 -14	
Transport	610-740	60-765		0.57 -1.30	0.15 -1.9				
Normal Operation							3.2 -22	0.1 -140	
Construction							0.008 -0.059		
TOTALS	610-740	60-765		0.57 -1.30	0.15 -1.9		3.2 -22	1.4 -150	
<u>OIL</u>									
Fuel Supply									
Transport	2			0.0008-0.0019					
Normal Operation							1.1 -7.5	0.8 -140	
Construction							0.005 -0.034		
TOTALS	2			0.0008-0.0019			1.1 -7.5	0.8 -140	
<u>GAS</u>									
Fuel Supply	1770			0.15					
Transport	1000			0.20					
Normal Operation							0.0025-0.017		
Construction							0.0028-0.019		
TOTALS	2800			0.35			0.005 -0.036		
<u>LWR</u>									
Fuel & Reprocess							0.073	0.001 -0.13	
Transport	6	8		0.003 -0.006	0.006-0.012		0.0006	0.0002 -0.0012	
Normal Operation							0.19	0.013 -0.23	
Construction							0.008 -0.057		
TOTALS	6	8		0.003 -0.006	0.006-0.012		0.27 -0.32	0.014 -0.36	
<u>SOLAR THERMAL</u>									
Material Supply							0.07 -0.47	0.02 -0.03	
Transport Mat.	77	112		0.03 -0.08	0.6 -1.4				
Construct Plant									
Construct Storage									
Normal Operation									
TOTALS	77	112		0.03 -0.08	0.6 -1.4		0.07 -0.47	0.02 -0.03	

TABLE 3 contd/...

The estimates used are generally within the range found in the literature or are lower than these values. The reason for lower estimates is that not today's average technologies were compared but modern technologies for all energy systems. Thus recent trends in statistics on health impacts have been extrapolated to describe effects of large-scale modern technologies. In the case of solar power remote siting was assumed, and public fatal diseases are caused by coal needed to melt metals, etc.

There are still large areas of uncertainties in these estimates and many possible health effects had to be omitted because either a dose-effect relationship has not yet been established or because no adequate methodology exists which would allow the integration of these effects. The main areas of these uncertainties are:

Coal. The given estimate represents optimistic extrapolation of the available data to modern large coal mines. Estimates of public fatal diseases are based on two epidemiological studies. The lower boundary uses the median value from Lave and the upper boundary is based on the lower (linear) results from Winkelstein as summarised in (12). It should be noted that Hamilton (13) gives a range from 36 to 240 public fatal diseases based on 100 currently used sites in the U.S. and integrating over all distances (not only up to 80 km).

Data on emissions of trace elements and the effects from emissions of benz(a)pyrene (about 6% increase of lung cancer per 1 ng/m^3 (14) have not been included.

Radioactive emissions from coal-fired plants were not included in Table 3.

Oil and Gas. The occupational risks of oil and gas supply from the North Sea would be considerably higher than listed in Table 3. The low frequency/high consequence risk of destroying large fixed off-shore platforms and the risk of destroying population centres by gas clouds from LNG tanks has not been included.

LWR. Effects are based on an average risk factor of 2×10^{-4}/men-rem which include cancers plus genetic effects. Low-frequency hypothetical reactor accidents (2) are not included, and would contribute negligibly to the expected values given.

Solar. Remote siting of solar plants was assumed. Because of lack of experience data had to be extrapolated from related activities in other industries.

Some risks of energy production can in principle not be included in such a comparison, since they depend non-linearly on total production rates. An example is given by the risks of climatic change, caused by CO_2-emissions from fossil fuel consumption.

Since it is difficult to compare the data across Table 3 and since the structure of risk is very dissimilar, the next step of this comparison aggregates injuries and fatalities by assuming that one death is equivalent to 6000 lost man-days. The results of this aggregation, which certainly does contain a value judgement, are displayed in Fig. 1. Whereas the greatest risks to the public are posed by energy systems operated on coal and oil, the construction of solar thermal electric conversion facilities appears to represent the highest occupational hazard.

COST/BENEFIT ANALYSIS

The above-described data give expected health effects normalised to the production of 1 $GWa_{(e)}$ of electricity; the benefits are given by different electricity production costs and other parameters which are difficult to quantify. Consequently, a cost/benefit analysis requires that risks and their financial impact on society and benefits be expressed in common units. If monetary terms are used as such a common basis, it poses the difficult question of assigning a monetary value to a human life and to workdays lost. Several approaches can be used to derive such a value.

Implicit values are derived from past decisions concerning mortality risk reduction and imply that these decisions have been opti-

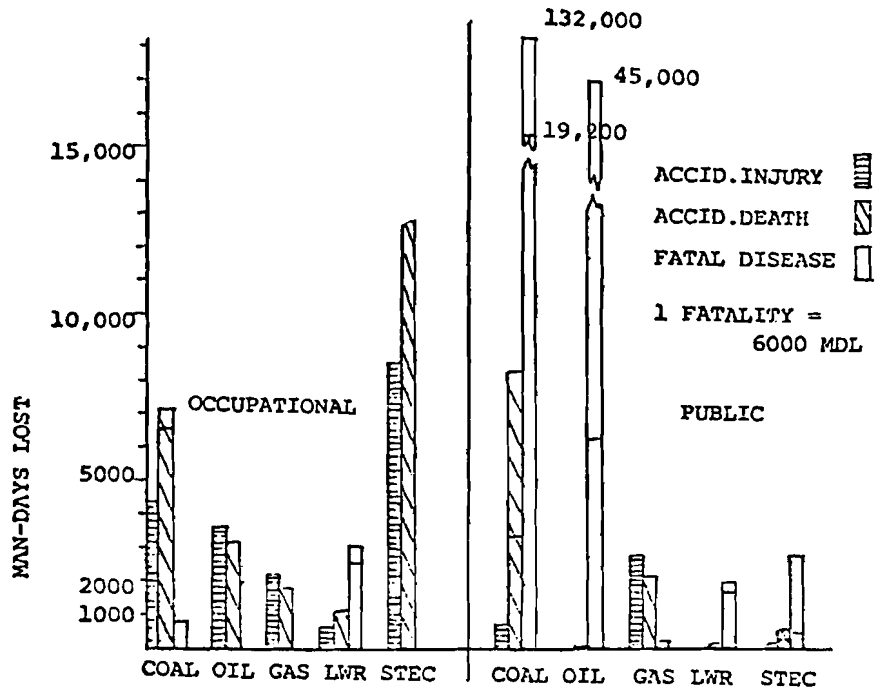


FIGURE 1: Occupational and public man-days lost per GWa(e) for each energy system (9)

mal. The most commonly used Human Capital Approach evaluates a life with the discounted future life-time earnings of those at risk and, therefore, depends on age and social status. The Willingness-to-pay Approach uses the public's willingness to pay for reduction of specific risks. The monetary values assigned to a life, derived by these various methods, seem to centre around \$ 300,000. This value reflects a trade-off between the two objectives of maximising GNP and reducing risks, and it is only meaningful in the context of risk/benefit analyses.

For the following calculations this value of \$ 300,000 has been used. At an average expected work-loss of 6000 man-days per fatality, this is equivalent to \$ 50 per man-day. In the case of injury and illness, society loses the productive work and also incurs expenditures, therefore a total value of \$ 100 per man-day has been chosen (15).

Results of such a calculation are given in Table 4, which demonstrates that the total health costs (external cost), as quantified by this procedure are about 1% or less than internal costs (16), and are less than the uncertainties in estimates of electricity production costs. Thus, it seems that cost/benefit analysis is not an adequate methodology to answer the problems put forward in the introduction.

	Coal	Oil	Gas	LWR	STEC
Capital	158	132	132	228	580-710
O & M	17.5	8.8	8.8	17.5	98
Fuel	114	228	199	61.3	50 (1)
Abatement	79	(2)	(2)	1.9 (3)	140-175 (4)
Internal Costs	368	369	340	309	865-1030
Occupational Effects	0.77-0.82	0.51	0.31	0.23-0.26	1.49
Public Effects	1.2 - 7.1	0.33-2.25	0.39-0.4	0.08-0.1	0.04-0.17
Total health costs	2.0 - 7.9	0.8 -2.8	0.7	0.31-0.36	1.5 - 1.7
% of internal cost	0.5 - 2.1	0.2 - 0.8	0.2	0.1 - 0.12	0.17

(1) Cost of electricity transmission, 2000 km to load center.
(2) Oil and gas desulfurization at refinery, natural gas price still controlled in 1977.
(3) Near-zero Rad-waste system, LWR includes decommissioning waste disposal.
(4) Extra cost for dry cooling towers required in desert areas.

TABLE 4: Costs of electricity production (million US$ in 1977/GWa).

COST-EFFECTIVENESS OF RISK REDUCTION

The methodologies outlined above have severe limitations when applied to make a decision on whether or not a given technology should be made safer. A method better suitable to deal with such a problem realistically is cost-effectiveness analysis (marginal cost/benefit analysis).

Safety expenditures generally follow an economic law of diminishing returns. The general relationship of this law is outlined in Fig. 2 (16) and case studies have been given in (15,17). The figure indicates that it is possible to reduce a relatively high risk to a much lower level (e.g. ΔR_1) at rather low additional costs (e.g. ΔC_1). However, it becomes more and more expensive to reduce the risk even further (e.g. from S_5 to S_6). The relation $\Delta R / \Delta C$ (i.e. the first derivative) at each point of the curve is a measure of the cost-effectiveness of further risk reduction from the level of safety represented by that point. Marginal costs of risk reduction are measured in human health effects avoided per unit cost of risk reduction (e.g. lost man-days avoided per million $). Two main conclusions can be drawn from this figure:

- the marginal cost of risk reduction increases with the level of safety achieved; and

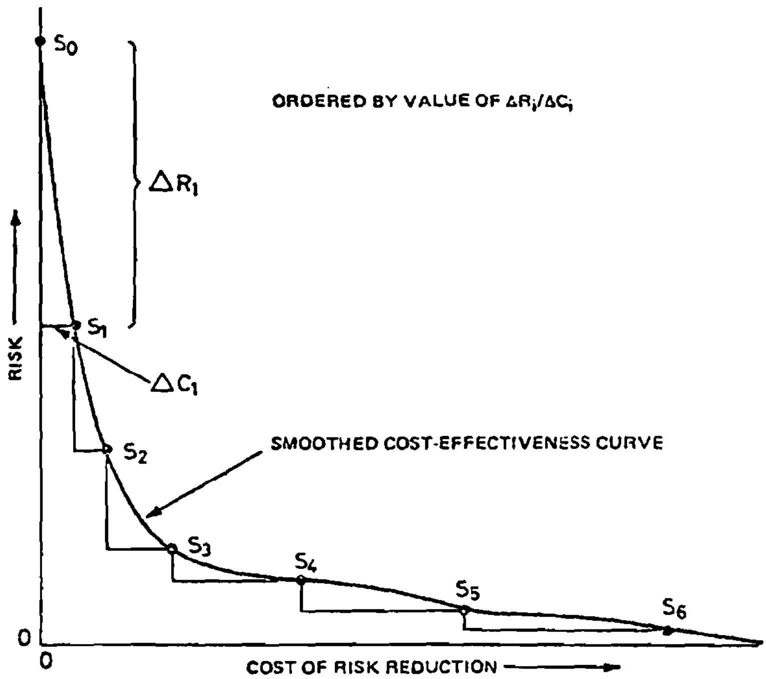


FIGURE 2: Cost-effectiveness of risk reduction (16)

- for any given safety level it is possible to reduce an existing risk even further; however, it is not possible to reduce the risk to zero.

Several implications of these findings need further discussion. Firstly, should technologies be made as safe as technically achievable? Though this would be a very appealing approach at first glance, our daily experience demonstrates that this is not feasible. In the case of automobiles, for example, there exist innumerable opportunities to increase safety. But it is obvious that not all streets can be protected by a set of crash-fences or supplied with streetlights, that not all grade-crossings can be replaced by underpasses, etc. Decisions on safety, therefore, have to be made in such a manner as to spend the limited resources of society in a cost-effective way. The two conclusions drawn from Fig. 2 imply that "safe" is always determined by a compromise between the two objectives of using limited resources most effectively (minimising cost) and of achieving the highest level of safety (minimising risk).

Secondly, any point on the curve in Fig. 2, which might be chosen as a limit where no further risk reduction is considered, is characterised by specific expenditures per unit of risk reduction. In particular, any mortality risk averted implies a monetary value per human life saved.

This ratio has the same dimensions as the "monetary value of a human life" discussed above. However, in this context it does not try to establish such a value but rather serves the purpose of comparing marginal cost of risk reduction in various areas. Thus, it can be decided where to spend the limited resources of society most cost-effectively.

An example of such a relationship is given in Fig. 3 for the nuclear fuel cycle of PWRs (17). Similar relationships have been established for BWRs. No such studies do yet exist for the fuel cycles of other energy systems though some estimates exist for particular risk reduction measures, e.g. desulfurisation of flue gas (15).

THE RISK OF PRODUCING SAFETY EQUIPMENT

Cost-effectiveness calculations allow for a comparison of marginal costs of risk reduction, and can identify areas where the same amount of safety investments would result in the highest reduction of risk. However, they do not answer the more general question about total expenditures on safety since, as suggested by Fig. 2, any existing risk may be reduced beyond any given limit at very high costs. Nevertheless, the following will demonstrate that a

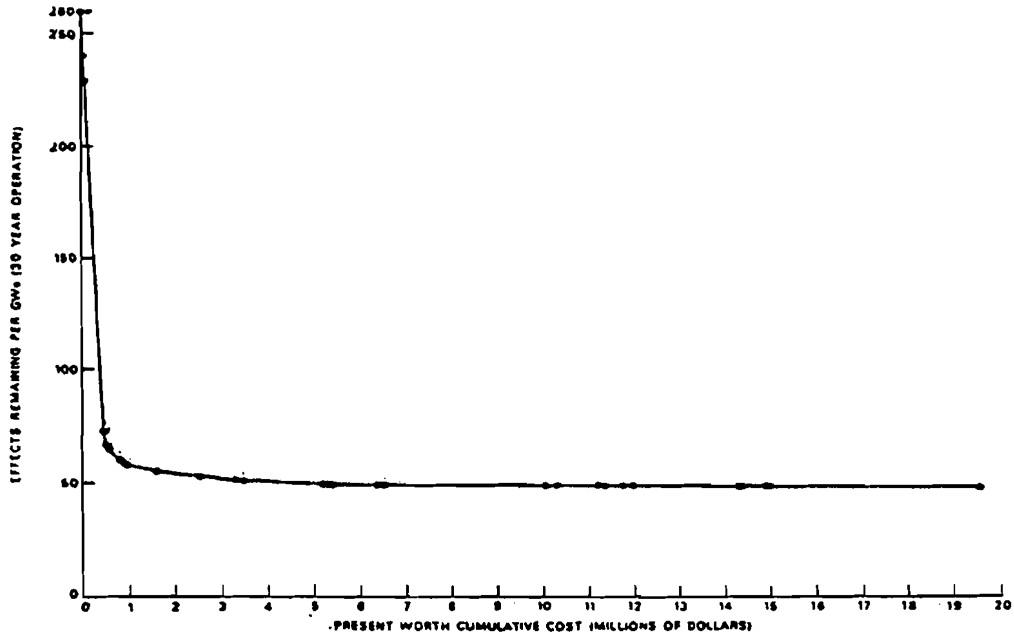


FIGURE 3: Risk reduction vs. cost for the fuel cycle of PWRs (17). Each dot represents a specific measure for risk reduction.

practical limit to risk reduction does exist because excessive expenditures for risk reduction will actually increase the total risk to society.

For safety measures at extremely high marginal costs of risk reduction it becomes important to account for the occupational and public risk involved in the production of the safety equipment itself, which has not been considered in Fig. 2. This suggests that the curve should be slightly modified. As shown in Fig. 4, a linear term should be added to include the risk due to the production of safety equipment. This does not modify the relationship in Fig. 2 if the marginal costs are relatively low. However, for much higher values, this linear term, when added to the original curve, results in a summed curve for total risk that passes through a minimum. At high costs the total risk curve no longer approaches the zero-level of risk, but approaches the risk of producing safety equipment. The minimum occurs when the marginal costs of risk reduction (that is the first derivative of the operation curve) are equal to the specific risk of production of safety equipment (i.e., the steepness of the linear term).

Calculating this risk is identical to determining the slope of the straight line in Fig. 4, representing health effects per unit cost of safety equipment. For the following calculations, it was assumed that installed safety equipment consists of 30% construction work, 10% services, and 60% machine tools plus electrical equipment.

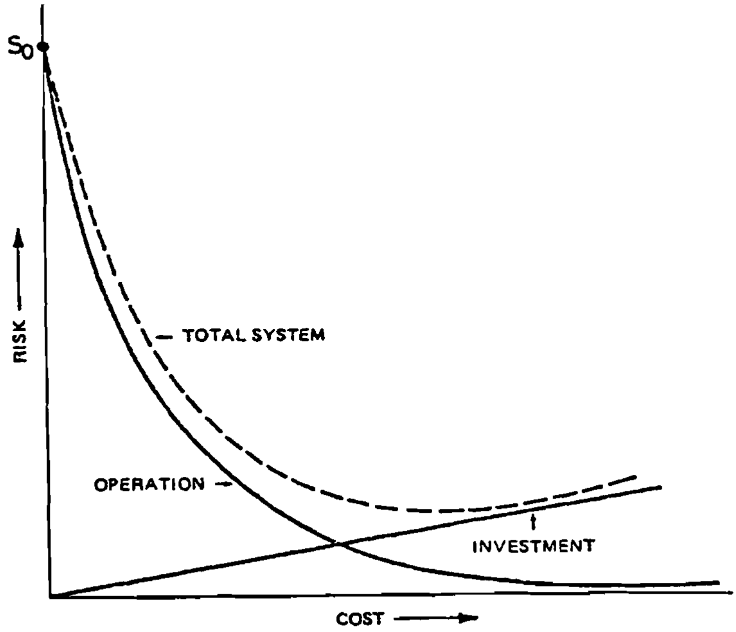


FIGURE 4: Principal relationship of cost-effectiveness of risk reduction considering the total economic system.

Using accident statistics of various branches of industry and economic input/output tables of a country it is possible to construct a matrix illustrating health-effect flows instead of monetary flows. A simple mathematical procedure (the inverse Leontief Matrix) allows one to sum the risk involved in all steps of preprocessing. The occupational effects used for the following calculations are derived from the 1973 data for the Federal Republic of Germany. Table 5 shows sample results for some branches of industry. It can be seen that mining causes the largest health effects per unit value of goods produced, though it requires less total working hours than construction. Job-related driving fatalities are largest for construction.

Taking the composition of safety equipment mentioned above, the total occupational risk and the required hours of work are given in Table 6. The data include fatalities and lost working hours due to illnesses. They have been aggregated by assuming that one death is equivalent to 6000 lost man-days.

Whereas the quality of the data on occupational accidents is rather good, no such data exist for the risks to the general public. A rough estimate suggests that the public risk adds about 50% to the occupational risk. Thus, the specific risk of producing safety equipment (r_p) is estimated to be about 3×10^{-2}

Industry	Total working hours	Occupational accidental deaths (10^{-2})	Job-related driving fatalities (10^{-2})	Occupational chronic deaths (10^{-3})	Lost working hours
Machine tools & electrical equipment	82 000	0.470	0.354	0.302	416
Mining	76 600	1.916	0.340	8.740	1040
Stone and earth	63 200	1.182	0.356	0.894	438
Textiles and clothing	119 600	0.270	0.314	0.232	336
Services, provisions & fine goods	75 000	0.566	0.210	0.206	118
Construction	101 000	1.492	0.592	0.344	630

TABLE 5: Total working hours and occupational health effects for production of goods and services having a value of one million dollars.

Total working hours	87 000
Lost working hours	450
Occupational accidental deaths	7.86×10^{-3}
Driving fatalities	4.12×10^{-3}
Occupational chronic deaths	0.306×10^{-3}
Total deaths	12.28×10^{-3}
Σ equivalent death*	21.6×10^{-3}
or	
Σ equivalent lost working days*	130

*death = 6000 lost man-days.

TABLE 6. Total occupational risk of producing safety equipment worth one million dollars

equivalent deaths or 180 equivalent lost man-days per million dollars of equipment. More specific details of the calculations leading to this value of r_p are described in (18,19).

The specific risk r_p, sets the slope of the straight line in Fig. 4. It also implies that expenditures of $ 33 million for safety equipment would cause 1 equivalent death during construction and installation. This value can now be used to determine the minimum risk of the total system curve. This minimum occurs where the marginal cost of risk reduction (the "Operation" curve) has the same slope, though opposite in sign, as the "Investment" line. At this point the production and installation of safety equipment would result in one equivalent health effect among the workers and the public in an attempt to prevent one estimated equivalent effect among the public at some future time. In other words, one statistically certain death is caused at the present time to prevent one hypothesized death at a later time. Consequently, any expenditures on safety measures which exceed this minimum will cause more health effects than they prevent. Thus, the level of about $ 33 million per equivalent life saved seems to establish an absolute limit in physical terms for reducing risk. (It should be noted that such a principle is also used in medical practice, e.g., recommendations for vaccination against smallpox have been withdrawn since the risk of the vaccination itself became higher than the risk of catching that disease).

Certainly, risks to the workers and the public would also occur if instead of safety equipment other goods were produced. However, this does not suggest that only net effects should be considered, since the production of other goods would have some benefit for society, and thus the risks created by the production of these goods should be compared.

However, it is not proposed that the marginal cost of risk reduction actually be increased to this level of $ 33 million per equivalent life saved. Calculating from Table 6 about 1400 man-years of labour requirements would be associated with shifting one equivalent death (or 6000 equivalent lost man-days) from the time period of operation (or later) to the time period of construction without achieving any net benefit.

Therefore, the question remains how many man-days of labour requirements should be used to prevent one man-day of health effects. It is obvious that this problem needs considerable study; a final solution cannot be provided here. As a rough estimate, it was assumed that society could expend one man-year of work to gain one man-year of life. In this case the loss of one equivalent life can be aggregated with 59 work-lives (1400 man-years) per $ 33 million resulting in a total investment of 60 man-lives or an effective r_p(eff) of 1 equivalent life per $ 0.5 million. This value is clearly dominated by labour requirements. With regard to radiation protection it should be noted that this value would be equivalent to $ 100/man-rem.

In order to compare the value of r_p to the relationship given in Fig. 3, the first derivative of this curve is displayed in Fig. 5 in logarithmic scale. It can be seen that at total cumulative costs of about $ 12 million, the marginal cost of risk reduction, considering the total economic system, would reach the minimum described in Fig. 4. The combined r_p(eff) based on health effects plus labour requirements is also plotted in the diagram.

PUBLIC ATTITUDES TOWARDS ENERGY SYSTEMS

So far the term "risk" has been used to describe the estimated expectancy value of human health effects. It has been recognised by most of the authors cited in this paper that the term "risk" has additional dimensions or attributes. However, it is not yet possible to actually quantify them. Therefore, as one step in the direction of identifying these dimensions, studies analysing public attitudes towards various energy systems have been undertaken.

The attitude concept has been chosen since it provides a framework for analysing preferences and furthermore helps to understand

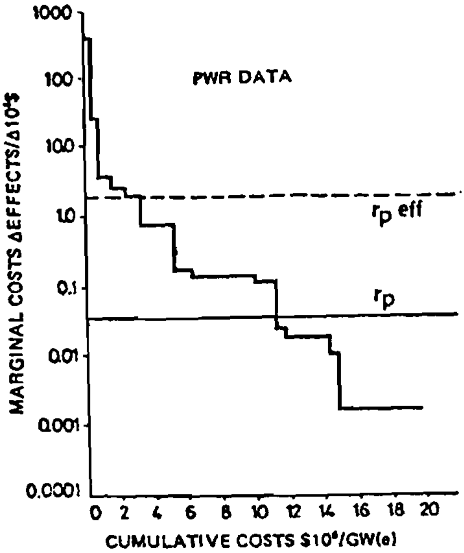


FIGURE 5: Comparison of r_p with marginal costs of risk reduction as derived in (17)

public perception of risk-related issues. ATTITUDE is here defined as representing a person's general feeling of favourableness or unfavourableness toward a given object. It is composed of beliefs about the relation of an object to a set of good or bad attributes. A BELIEF (as the cognitive component) represents the information a person has about a given object, measured in terms of a probability judgement indicating whether an attribute is or is not, and to which degree, associated with the object in question. The EVALUATION of the set of attributes (as the affective component) represents the feeling of goodness or badness for each single attribute. According to this concept, attitude is captured as a combination of an affective and a cognitive component (20).

Factor-analytical treatment of the given set of attributes leads to a grouping of issues with high intercorrelations, i.e., factors. Determining the respective contributions of beliefs, evaluations and of the combined terms can provide information about the particular structure of attitudes toward a given object. Application of this procedure with data derived from a sample (N=224) of the Austrian public, yielded a four-factor structure of their attitude toward the use of nuclear power (21).

Table 7 summarises the contributions of these four factors to attitudes of sub-samples PRO and CON the use of nuclear energy from the Austrian public. It can be seen that the attribute evaluations

TABLE 7 (21)

SUMMARY OF COMPUTED FACTOR SCORES+

	-9 $\overline{eb}$ +9	-3 $\overline{b}$ +3	-3 $\overline{c}$ +3
I: Psychological Aspects	-1.62** -6.36	0.75** 2.66	-2.05 -2.34
II: Economic and Technical Aspects	3.23** 0.22	1.78** 0.13	1.80* 1.16
III: Socio-Political Implications	-1.20* -3.21	1.83* 2.50	-0.73* -1.24
IV: Environmental and Physical Risks	1.88** 1.40	0.90** 0.56	-1.67 -2.22

pro group (white bar)
con group (black bar)

* difference significant at 0.05 level

** difference significant at 0.01 level

+ obtained by averaging across the five items loading highest on each factor did not differ strongly between both groups though they were generally more negative (or less positive) for the CON group. The main difference is caused by differing beliefs that these attributes are related to nuclear power. Multiplication of the average belief and evaluation scores for each factor determines their relative contribution towards attitudes. Considering the CON group, their attitudes are determined most significantly by those attributes which have psychological aspects, second by items with socio-political implications, and third, though not very strongly, by negative environmental aspects which they relate to nuclear power. This probably reflects current discussions which centre around the risk aspects.

The opposite picture emerges for the PRO group. The benefit factor contributes most significantly towards their attitudes. Second are positive environmental aspects which this group relates to the use of nuclear energy. The other two factors make relatively small, though negative, contributions.

These results appear to reflect some of the major problems encountered in the public debate about nuclear power, where mutual understanding is inhibited by the fact that both concentrate on the risk aspects while opponents defy the benefits and proponents take them for granted.

Based on the experience of the study described above, the questionnaire has been modified and is now being applied in various countries, first with smaller pilot samples, and later on with large representative samples. This cross-national approach is expected to provide informative insights about issues perceived similarly and those which are country-dependent. First analyses show that the methodology for attitude measurement and the given set of attributes are applicable in different countries. Table 8 gives the correlation coefficients between three independent measures of attitude toward the use of nuclear power for several countries: (a) Σ eb denotes the attitude measure described above, (b) A_o denotes a measure based on the Semantic Differential (22), (c) P/C denotes a rating on a simple "favourable/unfavourable scale". Generally these correlations can be considered quite high demonstrating the relevance of the attributes. In addition importance ratings with regard to the ongoing nuclear debate were elicited to obtain information about the extent to which the attributes listed in the questionnaire did reflect the issues of major concern. It cannot necessarily be expected that these issues are of similar importance in all countries. Out of the whole set of 30 attributes only those are listed in Table 9 which deal with risk aspects. To enable comparison, the mean values of the importance ratings were taken to rank-order the attributes. The three samples shown lend themselves for this type of comparison because all the respondents were university students, i.e., had a similar educational background.

TABLE 8

CORRELATIONS BETWEEN VARIOUS ATTITUDE MEASURES

(THE USE OF NUCLEAR POWER)

N		$\sum EB \leftrightarrow P/C$	$A_0 \leftrightarrow \sum EB$	$A_0 \leftrightarrow P/C$
147	AUSTRIA (STUDENTS)	0.72	0.81	0.81
34	PHILIPPINES (EMPLOYEES)	0.68	0.80	0.77
174	PHILIPPINES (STUDENTS)	0.48	0.53	0.65
84	JAPAN (STUDENTS, OSAKA)	0.58	0.74	0.63
36	JAPAN (STUDENTS, TOKYO)	0.82	0.66	0.84
73	BRAZIL (EMPLOYEES)	0.67	0.69	0.77
100	F.R.G. (GEN.PUBL., JÜLICH)	0.74	0.81	0.81
100	F.R.G. (GEN.PUBL., KERPEN)	0.79	0.79	0.84
720	BRAZIL (STUDENTS)	0.60	0.58	0.72
150	F.R.G. (STUDENTS 2)	0.74	0.81	0.87

TABLE 9

IMPORTANCE RANKING OF RISK ATTRIBUTES

	AUSTRIA (Students)	PHILIPPINES (Students)	JAPAN (Students)
Health impact	1	1	4
Impact on future generations	2	6	6
Management of wastes	3	7	1
Large-scale accidents	4	2	2
Environmental pollution	5	4	5
Controllability	6	3	7
Detection by senses	7	5	3
Postponing alternatives	8	12	12
Long-term climate	9	8	8
Threats from terrorists	10	10	10
Dependency on experts	11	9	11
Proliferation	12	11	9

AUSTRIA - PHILIPPINES R = .75**

AUSTRIA - JAPAN R = .73**

PHILIPPINES - JAPAN R = .74**

Results indicate that there seems to be an international agreement on the importance of risk related issues (23). Comparisons of larger samples on a cross-national basis are expected to provide further and more detailed insights into the perceived benefits and risks of energy technologies.

RECENT DEVELOPMENTS IN SETTING SAFETY STANDARDS

To our knowledge there are two main new developments in the area of setting safety standards. Whereas generally, safety standards are derived by a deterministic approach, recent trends in risk assessment have led to proposals for probabilistic safety criteria (24) such as those mentioned in the introduction.

Such standard values take into account public concerns about those accidents which go beyond the design base accident and which are estimated to occur with very low probabilities, however, large potential consequences. An example within the chemical industry is given by the Canvey Island study (25) where, based on a probabilistic risk assessment, preventive design measures have been taken. The second main development in standard setting directly takes into account a model of the rational, risk-averse individual which has been summarised as follows (26):

(a) He prefers a lower risk of injury or death to a higher risk.

(b) He assesses a large increase in risk as a higher cost than a small increase.

(c) At very low levels of risk he is content to cost the risks at some constant value.

(d) As the levels of risk increase above the point at which he feels concerned he progressively increases the cost he places upon them.

These principles have been applied to determine a variable value which could be used for the purpose of a cost/benefit analysis in the area of radiation protection. In applying the ALARA principle (as low as reasonably achievable), this variable (α) is usually treated as a constant and denotes the cost of unit collective dose equivalent. Thus α has the dimension $/man-rem and can be interpreted as the cost of investment which should be spent to avoid one man-rem. Attempts to quantify this α-value fall within the range from about $ 10/man-rem to some $ 1000/man-rem.

The consultative document cited above suggests to apply a variable α-value which would stadily increase with the individual level of risk, i.e., the individual dose equivalent. A subsequent document recommends a stepwise approximation (27).

Conclusions

Three methods to define acceptable levels of risk have been discussed in this paper, and it has been proposed that direct comparison of risks of similar systems and cost-effectiveness analysis of risk reduction measures are suitable methods to determine safety criteria. However, it has been pointed out that there is a need to develop a more complex measure of risk. Many of those parameters, which should be taken into account, are known. But it is left to future work to actually quantify them in such a way that they can be used for safey related decision.

REFERENCES

(1) Starr, C. (1969) Social Benefit versus Technological Risk. Science 165: 1232-1238.

(2) U.S. Nuclear Regulatory Commission (1975) Reactor Safety Study. An Assessment of Accident Risks in the U.S. Commercial Nuclear Power Plants. WASH-1400 (NUREG-75/014). Washington D.C.

(3) Rippon, S. (1980) Report on the International Public Affairs Workshop held in Stockholm, June 15-18. Nuclear News, Vol. 23, 10: 114-121.

(4) Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., and Combs, B. (1978) How Safe is Safe Enough? A psychometric study of attitudes towards technological risks and benefits. Policy Sciences 9: 127-152.

(5) Fagnani, F. Le debat nucleaire en France. (Acteurs sociaux et communication de Masse). Rapport de synthese. A.D.I.S.H. (Association pour le developpement de l'informatique dans les sciences de l'homme) and I.R.E.P. (Institut de recherche economique et de la planification). France, 1977.

(6) U.S. Nuclear Regulatory Commission (1974) Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy. WASH-1224, Washington D.C.

(7) Inhaber, H. (1978) Risk of Energy. Report AECB-1119/Rev. 2, Atomic Energy Control Board, Canada.

(8) Holdren, J.P., Anderson, K., Gleick, P.H., Mintzer, I., Morris, G., and Smith,K.R., (1979) Risk of Renewable Energy Sources: A Critique of the Inhaber Report. Report # ERG-79-3, University of California, Berkeley.

(9) Black, S.C. and Niehaus, F. (1980) Comparison of Risks and Benefits Among Different Energy Systems. Published in the Proceedings of the International Workshop on "Energy/Climate Interactions" held in Münster, March 3-7. W. Bach, J. Pankrath, and J. Williams (eds.), Interactions of Energy and Climate, Reidel Publishing Co., Dordrecht, Boston.

(10) Proceedings of the"Colloque sur les risques des différentes énergies" (1980) held in Paris, January 24-26, organised by the Societé française d'énergie nucléaire, 48 rue de la Procéssion, F-75724 Paris. Forthcoming.

(11) Hamilton, L.D., and Manne, A.S. (1977) Health and Economic Costs of Alternative Energy Sources. In: Nuclear Power and Its Fuel Cycle. Proceedings of an International Conference held in Salzburg, May 2-13. Nuclear Power and Public Opinion and Safeguards 7: 73-93. IAEA-CN-36/448.

(12) Hamilton, L.D. (1979) Areas of Uncertainty in Estimates of Health Risks. Presented at Symposium on Energy and Human Health: Human Costs of Electric Power Generation, held in Pittsburgh, March 19-21.

(13) Hamilton, L.D. (1977) Alternative Sources and Health. In: CRC Forum on Energy. Report BNL-24852, Brookhaven National Laboratory.

(14) Vohra, K.G. (1977) A Perspective on the Radiation Protection Problem and Risk Analysis for the Nuclear Era. In: Nuclear Power and Its Fuel Cycle. Proceedings of an International Conference held in Salzburg, May 2-13. Nuclear Power and Public Opinion and Safeguards 7: 295-308. IAEA-CN-36/395.

(15) Sagan, L. (1976) Public Health Aspects of Energy Systems. In: H. Ashley, R.L. Rudman, and C. Whipple (eds.), Energy and the Environment. New York: Pergamon Press.

(16) Rowe, W.D. (1977) An Anatomy of Risk. John Wiley & Sons, New York.

(17) U.S. Environmental Protection Agency (1976) Environmental Radiation Protection Requirements for Normal Operations of Activities in the Uranium Fuel Cycle. EPA-520/4-76-016. Washington D.C.

(18) Black, S.C., Niehaus, F. and Simpson, D. (1979) How Safe is "Too" Safe? International Institute for Applied Systems Analysis, WP-79-68, Laxenburg, Austria.

(19) Black, S.C. and Niehaus F. (1980) How Safe is "Too"Safe? IAEA-Bulletin, Vol. 22, 1: 40-48.

(20) Fishbein, M. and I. Ajzen. Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research. Addison-Wesley: New York, 1975.

(21) Otway, H.J. and Fishbein, M. Public Attitudes and Decision-making. RM-77-54. International Institute for Applied Systems Analysis, Laxenburg, Austria, 1977.

(22) Osgood, C.E., Suci, G.J. and P.H. Tannenbaum. The Measurement of Meaning. University of Illinois Press: Urbana Ill., 1957.

(23) Swaton, E. Attitudes Towards Risk: A Cross-Cultural Comparison. Presented at the Status Seminar on Tasks, Methods and Predictive Power of Risk Research, organised by the University of Bielefeld, November 24-25, 1980. To be published in the Proceedings by Ballinger Publishing, Cambridge, Mass.

(24) Harrison, J.R. and P.A. Cockerton. A Comprehensive Approach to Nuclear Safety. Paper presented at the International Conference on Current Nuclear Power Plant Safety Issues, held in Stockholm, 20-24 October 1980. IAEA-CN-39.

(25) Canvey: An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area. Health & Safety Executive, Her Majesty's Stationery Office, London, 1978.

(26) National Radiological Protection Board. The Application of Cost-Benefit Analysis to the Radiological Protection of the Public: A Consultative Document. ISBN 0 85951 120 0. NRPB, Harwell, Didcot, Ocon, OX11 ORQ, March 1980.

(27) Clark, M.J, Fleischman A.B. and Webb, G.A.M., Optimisation of the Radiological Protection of the Public. NRPB, Chilton, Didcot, Oxon OX11 ORQ, July 1981. NRPB-R120.

RISK WITH ENERGY FROM CONVENTIONAL AND NONCONVENTIONAL SOURCES*

Herbert Inhaber

Atomic Energy Control Board,
Ottawa, Ontario, Canada

Risk to human health was compared for five conventional and six nonconventional energy systems. The entire cycle for producing energy was considered, not just part. The most important conclusion drawn is that the risk to human health from nonconventional sources can be as high as, or even higher than, that of conventional sources. This result is produced only when the risk per unit energy is considered, rather than the risk per solar panel or windmill. The risk from nonconventional energy sources derives from the large amount of material and labor needed, along with their backup and storage requirements. Risk evaluation is a relatively new discipline, and therefore the results presented here can be considered only a beginning. However, society should keep relative risk in mind when evaluating present and future energy sources.

*Reprinted with permission from *Science*, Vol. 203, 1979, pp. 718–723.

For each type of energy production there is a risk, and it may be defined as the magnitude of health and safety consequences times the probabilities of these consequences. More practically, in energy production, the risk to human health is accidents and disease resulting in injury or death. This risk is part of the social costs of energy production, which include air and water pollution, land abuse, depletion of resources, and other factors.

The risks associated with so-called conventional energy sources—such as coal, oil, nuclear power, and natural gas—have been compared. However, in the past few years there has been an upsurge of interest in "nonconventional" or "renewable" energy sources, such as solar, wind, methanol, and ocean thermal gradient. An indication of this interest is shown by the approximately 750 abstracts on solar energy alone in a recent annual survey of energy studies (*1*). Nonconventional sources—defined as those not now producing large amounts of energy—are frequently characterized as benign or soft (*2*). The object of this article is to evaluate and compare risk arising from major existing or proposed energy sources, both conventional and nonconventional. It also summarizes information contained in a longer report (*3-11*), and extends risk analyses that have been made in recent years on conventional systems (*12*).

Many individuals, when thinking about energy risk, conclude or assume that such risk is, by and large, due to operation of an energy facility. For example, consider the risk of nuclear accidents or air pollution. My study shows that when the entire fuel or energy cycle, rather than only one part of it, is evaluated, the risks from nonconventional energy systems can be substantially higher than those of some conventional systems.

Main Assumptions

Eleven methods of generating electricity or energy were considered. Five were conventional sources: coal, oil, natural gas, nuclear, and hydroelectricity. Six were nonconventional: solar thermal electric, solar photovoltaic, solar space heating, methanol, wind, and ocean thermal. To put the systems on an equal basis, a unit energy output of 1 megawatt-year was assumed for each.

There are, of course, many other energy systems in public prominence. Some of them depend on shale oil, tar sands, wave energy, tidal energy, coal gasification, large-scale wood burning, geothermal energy, nuclear fusion, garbage-burning, and so-called breeding in nuclear reactors. These are not considered here because one or more components of essential data were not available, often because no models or prototypes have been analyzed. As is noted below, a wide variety of data on materials and labor requirements, public risk, and other factors were needed to perform a complete calculation for each system. If and when full data are available for any energy system not evaluated here, it should be possible to evaluate its overall risk by the methodology described here.

All but two of the energy systems were assumed to produce electricity as the final product. For solar space heating, the thermal energy produced was taken to correspond to the electrical energy that would have been required to heat a building; such an assumption leads to an underestimation of risk from this system by a few percent. For methanol, it is assumed that the mechanical energy it produces is equivalent to the electricity that could have been used to drive vehicles.

The example of solar space heating is an illustration of my general tendency or policy to give nonconventional energy systems the benefit of the doubt, in terms of risk, wherever possible. This policy was adopted to avoid any claims of inadvertent bias. Further examples include assigning lifetimes to nonconventional systems much longer than has been experimentally proved and assumptions of capacity (or load) factors probably higher than justified.

Public attention to risk is often focused on past or potential catastrophes. Release of radioactivity from nuclear reactors, failure of oil or gas pipelines, bursting of hydroelectric dams—these are what capture headlines. It is customary to notice one event that kills 100 people rather than to notice 100 events that each kill one person.

Catastrophes do take place. The actual or estimated risk to the public of dam failures and accidents at reactors, while low, can never be zero. However, as is shown below, the largest proportion of risk to human health from all the energy systems considered is either from industrial and occupational sources or pollution effects. That is, risk generally is incurred by one person or a small group.

In the calculation of overall risk, that resulting from catastrophes is added to that of a noncatastrophic origin. In one sense, apples are being added to oranges, but in another sense like things are being added, since the cost to society, as measured by the number of deaths, is the same. The risk of both catastrophic and noncatastrophic sources has been described (*3*).

The data used were generally from the United States, although much information on solar space heating, hydroelectricity, and methanol were from Canadian sources. Inevitably, data applying to only one or two countries are limited in scope. However, a study of this type can, in principle, be applied to other nations if appropriate data substitutions are made.

Data sources were of at least three major types: statistics on (i) health damage due to pollutants, (ii) industrial accident and disease statistics, and (iii) materials and labor used for energy systems. Health effects probably do not differ internationally, in that they are based presumably on human biology. Industrial accident rates can vary between industries and nations (*13; 14*, p. 22). Because these rates are not always as disaggregated by industry as in the United States, application of the methodology described here to other countries may require approximations (*15*). Finally, while materials and labor requirements are generally known for conventional systems like coal or nuclear power, our knowledge is less for nonconventional systems. In consequence, one model, believed to be representative of nonconventional systems, was chosen. If another model of solar panel or windmill were chosen, it is possible that the results would be somewhat different from those shown here. Only further research can resolve this question.

Some risk data are controversial. In particular, health effects of fossil fuel burning are not known to a high degree of accuracy (*7, 9*), and this is reflected in the wide error bars (as is shown later) for public risk due to these systems. Even more controversy has been produced by the Rasmussen report (*10*) on light water nuclear reactor safety and public risk. The report has recently been reevaluated because of the criticisms directed toward it (*16*). To avoid any bias in favor of nuclear power, I used the highest values of public risk from reactors taken from a wide number of sources (in some of these, Rasmussen's values were used). This procedure was not followed for other energy systems.

An important assumption is that present-day technology, models, and systems, with their corresponding risk, are used. In essence, this compares more established technologies with less established ones, an unavoidable requirement. However, the length of time that an energy system has existed does not necessarily imply anything about its degree of risk. For example, natural gas and coal-burning are both relatively old technologies: in the first, the risk value is low and in the second it is high.

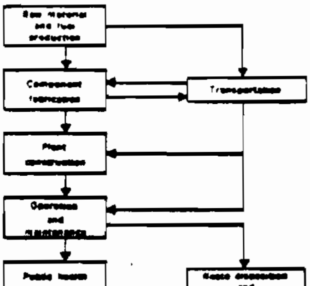


Fig. 1. Sources of risk in energy production. The relative importance of each component depends on the energy system. For example, there will be no fuel requirement for most nonconventional systems. All, however, require raw materials. Public health risk attributable to coal will be primarily from air pollution, and that attributable to nuclear power from the possibility of reactor accidents. Transportation plays a crucial part in many components.

Reliance on present-day technology avoids the need to assume that the future will take any particular course. Risk for some conventional energy sources is to a large degree dependent on the effects of pollution they release. Pollution standards may change. Breakthroughs may be made in wind or solar technology, accompanied by a reduction in the amount of steel, glass, and other materials required, and, therefore, the risk may also be lessened. In my study, I do not assume breakthroughs for some technologies and not for others, as has sometimes been done for other energy analyses.

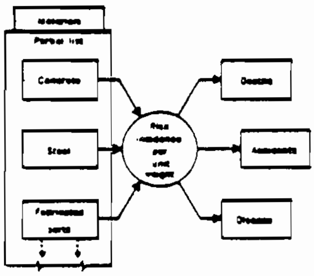


Fig. 2. Risk from material acquisition. Each of the materials that go into an energy system has an associated calculable risk. The risk depends on the accident, illness, and death rate per unit weight produced in the appropriate industry. For example, on average a ton of steel has associated with it a determinable number of deaths, accidents, and diseases. The dashes indicate that other materials are used. A similar diagram can be shown for construction risk.

Making comparisons between energy systems requires a knowledge of their relative efficiencies. Between 30 and 40 percent of the energy produced at a thermal power station is delivered to the consumer as usable power. Apart from transmission losses, almost all the power generated by solar electricity plants would be deliverable to the consumer. The following calculations take these efficiencies into account.

In the last few years the relative advantages of centralization of energy sources has been the subject of much discussion. Some commentators have suggested inherent positive features of decentralized systems like solar space heating. These features were claimed to include lower cost, greater reliability, and less dependence on political and economic authority. However, the analyses here show that low risk is not inherent in decentralized systems. Highly centralized systems such as natural gas and nuclear power production have a far lower risk than do decentralized systems like solar space heating. While decentralized systems may offer political and economic benefits, an inherently low degree of risk to human health is not one of their advantages.

For the purposes of the discussions offered here, energy units are given in terms of megawatt-years over the lifetime of the system, occasionally referred to as unit energy. By "lifetime" is meant the average length of time that the system lasts before replacement is necessary. One megawatt-year supplies all the annual energy requirements for 84 Canadians.

Risk Evaluation

Risk evaluation is similar in many ways to energy accounting, in which the energy inputs to a physical system are summed. In risk evaluation, all the risk of accidents, disease, and death incurred in producing a unit of energy are added together.

The seven sources of risk shown in Fig. 1 probably comprise almost all the risk in energy production. These are material and fuel production, component fabrication, plant construction, operation and maintenance, public health, transportation, and waste disposition.

Consider two technologies: solar heating and coal-fired electricity plants. Solar heating requires the mining of copper for tubing, while the coal-fired plant requires the mining of coal as fuel, iron ore for building turbines, and so on. All technologies require raw materials.

The components such as copper tubing, steam turbines, and all other parts of each system are then fabricated. In terms of transportation, raw materials and components must be moved. Transportation is shown as interacting with four components in Fig. 1.

The energy plants are then constructed, incurring further risk. Operation and maintenance of these systems is often overlooked in risk analysis.

Public health risk is produced by some systems, such as coal, oil, and nuclear power. Finally, there is risk inherent in the disposition of waste. Most public attention to this aspect has focused on nuclear wastes, although there have been disasters associated with coal wastes in the United Kingdom.

For the most part, the detailed risk calculation presented is centered on three of the items of Fig. 1—material and fuel production, component fabrication, and plant construction. The calculation proceeds as follows. The amount of materials required to produce a component is determined. The number of man-hours required to produce this material is then found. If construction, rather than material acquisition, is being considered, then the time required to install or build a component is estimated.

Statistics that show the number of deaths, injuries, or time lost due to disease per unit time worked are available. The number of man-hours required per operation is then multiplied by the deaths, accidents, or disease per man-hour to produce the occupational risk. As an example, suppose mining X tons of coal required Y man-years. If the number of man-days lost per year of work is Z, then the number of man-days per ton of coal is YZ/X. The risk associated with each part of the system is added to produce the total (Fig. 2).

Risk of transportation, operation and maintenance, public health, and waste disposition were calculated along different principles. For transportation, estimates were available for risk incurred in conventional energy systems, such as coal (5). This risk could be transformed into risk per unit weight of material transported. The risk for other systems is assumed to be proportional to coal risk per unit weight and distance transported.

Operation and maintenance risk has been estimated for conventional technologies (5) and for certain nonconventional technologies (11). Other systems had their maintenance requirements estimated in analogy to those already well known.

Public health risk fell into two categories, namely, air pollution, by far the largest, and potential catastrophic accidents. Nuclear power and hydroelectricity are generally acknowledged to fall into the latter category, although the risk is small. To avoid inadvertent bias in estimating nuclear public health risk, values from a well-known nuclear critic (17) were used as part of the data base.

Risk of waste disposition was calculated for nuclear power. Other energy sources were assumed to have little or no risk from this source.

The risk from nonconventional systems was calculated in the same general way as for conventional systems. However, some points deserve emphasis. First, emissions produced from acquiring construction materials can produce substantial public health risk. This source, derived from coal used in smelting steel, is fairly small for conventional systems. This emission can be called "pre-building" risk, since it occurs before the energy system starts rather than after. Second, some nonconventional energy sources, such as solar and windpower, require comparatively large backup and storage systems when their energy source is unavailable because the

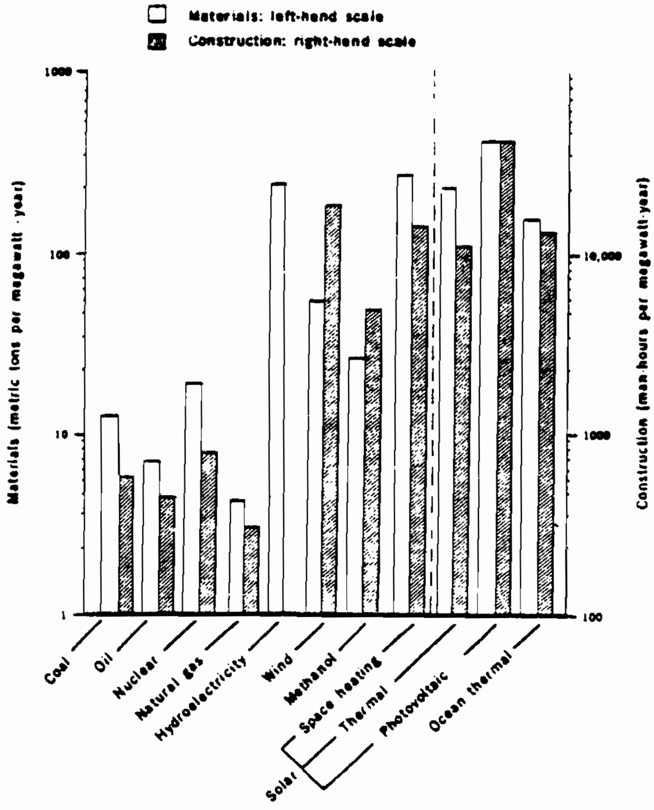


Fig. 3. Summary of material acquisition and construction requirements. Both material and construction time requirements are greater for nonconventional systems as compared to conventional systems. Natural gas has the lowest requirements of both types. Solar photovoltaic has the highest material requirements: the system also has the highest construction times. In this figure, a variety of construction trades and materials are lumped together to provide a simplified overall picture. For example, trades include those of plumbing, electrical work, sheet metal work, and so on: materials include cement, steel, glass, aluminum, and the like. Similar graphs could be devised for particular trades or materials. The ratio between the highest and lowest values in each category is between 100 and 200. Construction time for hydroelectricity is not available.

sun does not always shine and the wind does not always blow. The construction and operation of these storage and backup systems must be taken into account when computing risk. In equalizing energy systems this way, we are following the philosophy of Lovins (2):

> compare the total cost (capital and life-cycle) of the solar system with the total cost of the other complete systems that otherwise would have to be used in the long run.

Only by considering storage and backup can we ensure that the Lovins philosophy is carried out.

What energy source should be used for backup? The report of Herrera (11), which supported nonconventional energy systems, specified coal for solar thermal electric and solar photovoltaic systems: my estimations are also based on the use of coal in connection with wind, the only other nonconventional system requiring backup. It is also possible to have other systems, such as nuclear power (which is shown to be a relatively low-risk system), used as backup, although advocates of nonconventional energy might find this philosophically difficult. Results of both options are shown in the concluding figures.

How can we compare or combine deaths and less severe health problems, such as accidents and disease-related disabilities? While there is no simple method for assessing the impact of a death, some studies have equated it to 6000 man-days lost (6, 8). This simplifying assumption is used here. A sensitivity analysis showed that the ranking of systems in terms of total man-days lost per unit energy was not dependent on the exact value of man-days assigned per death.

The age at death from chronic ailments (disease) is probably higher than that caused by industrial accidents. While this will influence the total number of man-days lost per death, its effect could not be calculated from available data.

Assessing the Results

When the entire fuel or energy cycle is considered, nonconventional energy systems can have substantial risk to human health. This surprising result comes about by considering factors that are sometimes ignored.

The amount of materials used per unit energy output is a significant factor in computing risk. In addition, construction times play a key part (Fig. 3). The first four technologies all have low material use and construction times.

Solar photovoltaic requires large amounts of aluminum and concrete for construction and therefore has the highest material utilization. The weight of materials is 150 percent higher than any other nonconventional technology. It also has the highest construction time. Both material and construction requirements are generally higher for nonconventional as compared to conventional systems. This result will be reflected in higher occupational risk.

Conventional technologies generally have their risk categorized as gathering and handling of fuels, transportation, and electricity production (Fig. 4). Nonconventional technologies had six analogous categories. For simplicity, gathering and handling of fuels in conventional systems was equated with material acquisition and construction for nonconventional systems.

Natural gas incurs most of its risk in gathering and handling fuels. It is followed closely in its proportion of risk from this source by nuclear and ocean thermal. Most of the risk of coal and oil is incurred in electricity production, and is a consequence of air pollution. Only nuclear power has calculated risk due to waste management, constituting about 6 percent of the total. Coal also has waste management risk, due to slag and fly ash, but this is not included in the computations because quantitative data are lacking.

Wind, solar thermal, and solar photovoltaic have much of their risk produced by the backup they require. Ocean thermal has the highest proportion in material acquisition of all the nonconventional systems.

The summarizing figures can be divided into (i) occupational risk, borne by those who construct, fabricate, and maintain the energy sources, (ii) risk to members of the public, and (iii) the total risk, or the sum of the occupational and public risk. Figure 5 shows the occupational man-days lost per unit energy averaged over the lifetime of the system, which for most is assumed to be 30 years. This concept is used to average the initial construction risk over the lifespan. The maximum number of occupational man-days lost results from methanol, followed by windpower. Two other nonconventional technologies, solar thermal and photovoltaic, follow. Lowest is natural gas, followed by nuclear. For most of the nonconventional systems, the cause of large values is high material acquisition and construction risk.

Figure 6, showing risk to the public, is different. Two of the conventional tech-

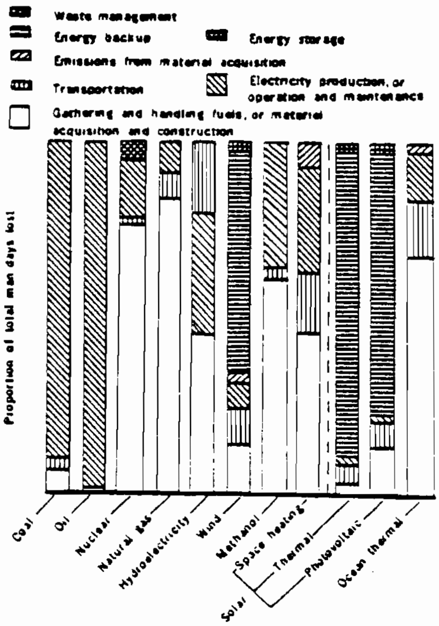


Fig. 4. Proportions of risk by source. Sources of risk vary considerably from one energy system to the next. The maximum value of the range for each component of total risk was used. A similar graph could be constructed for minimum values of the range. For coal and oil, most of the risk is due to electricity production (air pollution), whereas for natural gas, nuclear sources, and ocean thermal sources most of the risk is due to fuel or material acquisition. Wind, solar thermal electric, and solar photovoltaic sources have a large risk proportion from energy backup, assumed to be coal. The total risk for each system has been normalized in order to show the differences clearly.

nologies, coal and oil, lead the list because of emissions produced by burning fuel. However, some nonconventional technologies, such as wind, also have relatively high public risk. This risk derives from emissions as well, although not from air pollutants generated from operation. As far as is known, solar and wind systems are pollution-free during normal operation. However, steel is used in building many nonconventional systems, and coal is used in making most steel. Coal is the source of most sulfur dioxide produced industrially, and the pollutant is believed to cause much of the damage to health from polluted air.

A second source of public risk for three of the six nonconventional systems lies in the coal used for backup energy. Figures 5 to 7 show what happens when low risk backup, such as natural gas or nuclear, is substituted. The public risk is reduced substantially when low risk backup is employed, but the relative order of the systems remains about the same (Fig. 6).

The total risk for both occupational

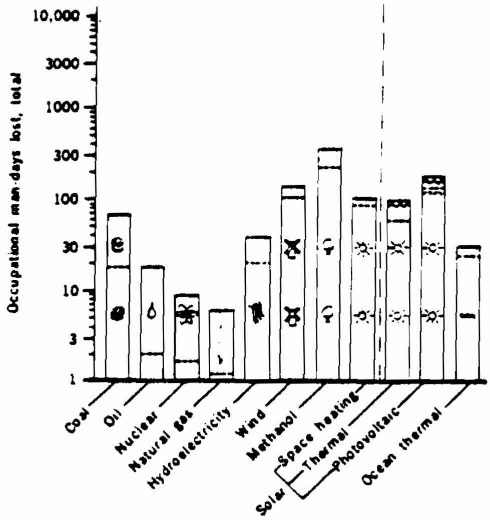
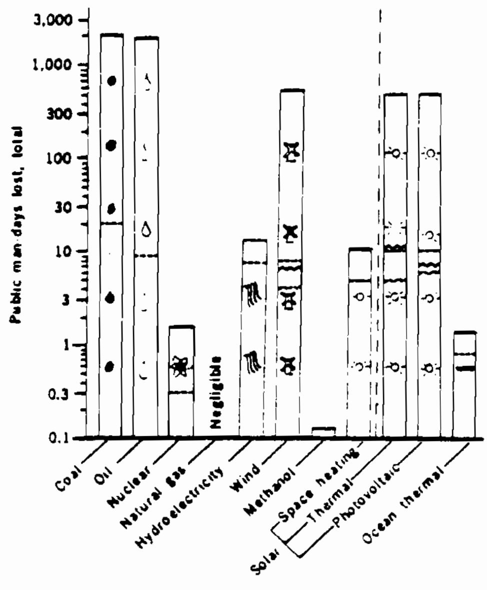
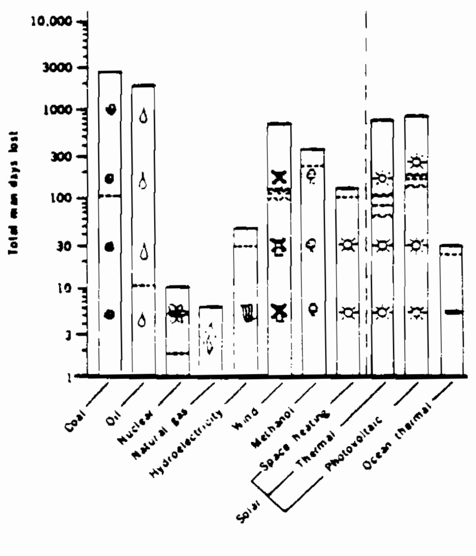


Fig. 5 (upper left). Occupational man-days lost per megawatt-year net output over lifetime of system. The top of the bars indicates the upper end of the range of values; the horizontal dotted lines within the bars, the lower. For example, coal would have a maximum value of about 70 man-days lost per megawatt-year output over the 30-year system life. The jagged lines within the bars indicate values when low-risk backup, such as nuclear or natural gas, is used. Where jagged lines (solid for maximum, broken for minimum) are not shown, values from low-risk backup are similar to those for standard backup. Bars to the right of the vertical dotted lines indicate values for technologies less applicable to Canada, due to climatic conditions. This scheme of notation is followed in Figs. 6 and 7. Most nonconventional systems have higher values than conventional systems. Note the vertical logarithmic scale. Fig. 6 (lower left). Public man-days lost per megawatt-year net output over lifetime of system. (See explanation in legend to Fig. 5). Much of the risk is produced by emissions created after fuel is gathered (for conventional systems) or by production and backup (for nonconventional technologies). Methanol has the lowest maximum of the nonconventional technologies. This is due to the lack of a requirement for energy backup and storage, with their accompanying air pollutants, and the relatively low requirement for materials. Fig. 7 (lower right). Total man-days lost per megawatt-year net output over the lifetime of the system (see explanation in legend to Fig. 5). The public and occupational risk is combined here. Natural gas power has the lowest value, followed by nuclear. Most nonconventional technologies have risk comparable to coal and oil. This somewhat surprising result is due to three factors: (i) the large amount of materials they require, (ii) the risk associated with backup energy; and (iii) risk associated with energy storage.





and public categories is shown in Fig. 7. Because the number of public man-days lost is higher than occupational for most of the systems, it dominates. The total risk from four of the six nonconventional technologies is comparable to that of coal and oil. Only ocean thermal has risk substantially lower than that of the others. However, its risk is about two to three times as high as that of nuclear power, and five to seven times that of natural gas.

The data shown in Figs. 5 to 7 indicate a range of values, rather than a single point. The top of the bars indicate the maxima, and the horizontal dotted lines show the minima. This follows traditions well established in the field of risk (7, 9). These traditions have persisted because much risk data are not accurately known. For example, the relation between air pollution and health effects is subject to wide variation. This is shown in Fig. 6, where the maxima and minima for coal and oil vary considerably. In addition, the precise materials, labor, backup, and storage requirements for future standardized nonconventional systems are not known. Those evaluated here are believed to be reasonably representative, but their design may change in the future. The ranges of uncertainty should be kept in mind when these results are evaluated.

Thus, if the entire fuel or energy cycle is considered, nonconventional energy systems apparently have risk to human health substantially different from that expected on the basis of intuition. The results shown do not, of course, imply that a particular technology should or should not be used.

It is entirely possible that the calculated risk values will change in future years. A better understanding of risk and its sources may produce public pressure to reduce it for all energy sources. This could be accomplished by either technological or administrative measures, or both. In addition, personnel using newer energy technology systems will probably become more familiar with their operation, and it is likely that occupational risk will decrease. Design of energy systems may become more standardized than they have in the past, so that the risk due to unfamiliarity will become lower. Other considerations could be listed which may shrink risk values in the future for many energy systems.

These considerations can be applied to particular systems. For example, coal production will probably shift more to strip mining (generally low risk) in opposition to underground mining (generally high risk). Coal slurry pipelines (generally low risk) are being suggested as partial replacements for rail transport (generally higher risk). A similar listing may be made for each of the eleven systems considered.

However, it should not be assumed that all risk will monotonically decrease in the future. As examples of contrary trends, liquefied natural gas, as opposed to the gaseous form evaluated in this article, may pose in coming years public risk that is not negligible. As oil deposits become more difficult to find, the risk associated with each unit of energy will probably rise. Finally, industrial accident rates can rise as well as fall. Of 23 industries reporting injury frequency rates in the United States for 1971 and 1976, 18 showed an increase (14, p. 27).

The large differences in risk between many of the energy systems discussed make it likely that, while the absolute values of man-days lost per unit energy will probably change in the future, the relative rankings of systems will not change substantially. Only time and a deeper understanding of these systems can verify this contention.

The field of risk accounting is only beginning. While the risk due to energy generation forms only one part of selection criteria, without this knowledge we cannot make a fully informed judgment.

References and Notes

1. *The Energy Index 1977* (Energy Information Center, New York, 1978).
2. A. B. Lovins, *Foreign Affairs* 55, 65 (October 1976).
3. H. Inhaber, *Risk of Energy Production* (Atomic Energy Control Board, Ottawa, Canada, 1978) (AECB 1119).
4. More than 150 sources of information are listed in (3). The following are some of the major data sources, arranged by the energy systems to which they apply. Sources relating to more than one energy system are listed under only one. (i) Coal: K. R. Smith *et al.* (5): *Occupational Injuries and Illnesses in the United States, by Industry, 1973* (Bureau of Labor Statistics, Washington, D.C., 1975): AEC Report WASH-1224 (6): C. L. Comar and L. A. Sagan (7). (ii) Oil: Hittman Associates (8): L. D. Hamilton (9). (iii) Natural gas: K. A. Hub, *A Study of Social Costs for Alternative Means of Electrical Power Generation for 1980 and 1990* (Argonne National Laboratory, Argonne, Ill., 1972): *Energy and the Environment: Electrical Power* (Council on Environmental Quality, Washington, D.C., 1973). (iv) Nuclear: Nuclear Regulatory Commission, Report WASH-1400 (10): S. C. Morris, *Comparative Effects of Coal and Nuclear Fuel on Mortality*, presented at 137th Annual Meeting, American Statistical Association, Chicago, 15 to 18 August 1977: L. A. Sagan, *Science* 177, 487 (1972). (v) Solar thermal electric: R. Caputo, *An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems*, Report 900-780 (Jet Propulsion Laboratory, Pasadena, Calif., March 1977): JPL Report 900-782 (11): Martin-Marietta Corp., *Central Receiver Solar Thermal Power Systems, Phase I*, Report SAN/1110-76/T1 (Energy Research and Development Administration, Washington, D.C., April 1976): Committee on advanced energy storage systems, *Criteria for Energy Storage R & D* (National Academy of Sciences, Washington, D.C., 1976). (vi) Solar photovoltaic: R. Marvi, *Terrestrial Solar Power Plant Performance*, Report EM 3341 (Jet Propulsion Laboratory, Pasadena, Calif., March 1977): C. Bell, *Assessment of a Solar Photovoltaic Power Conversion System for Central Station Application*, Report 900-702 (Jet Propulsion Laboratory, Pasadena, Calif., 1975): *Solar Program Assessment: Environmental Factors, Photovoltaics*, Report ERDA 77-47/3 (Energy Research and Development Administration, Washington, D.C., March 1977): *An Examination of the Potential for Solar Energy Utilization in Ontario*, Report 75092 (Ontario Hydro, Toronto, 1975): M. Berkowitz, *Implementing a Solar Technology in Canada: The Costs, Benefits and Role of Government* (Institute of Policy Analysis, University of Toronto, Toronto, 1977): *Solar Heating and Cooling of Buildings, Phase 0*, Report NSF-RA-N-023D (Westinghouse Electric Corporation, Baltimore, Md., 1974). (vii) Wind: *Solar Program Assessment: Environmental Factors, Wind Energy Conversion*, Report ERDA 77-47/6 (Energy Research and Development Administration, Washington, D.C., March 1977). (viii) Ocean thermal: W. G. Pollard, *Am. Sci.* 64, 424 (1976): J. L. Boot and J. G. McGowan, *Feasibility Study of a 100 Megawatt Open Cycle Thermal Difference Power Plant* (Univ. of Massachusetts, Amherst, 1974): *Solar Program Assessment: Environmental Factors, Ocean Thermal Energy Conversion*, Report ERDA 77-47/8 (Energy Research and Development Administration, Washington, D.C., 1977. (ix) Methanol: Intergroup Consulting Economists, *Economic Pre-Feasibility Study: Large-Scale Methanol Production from Surplus Canadian Forest Biomass*, Part 1, Summary Report, Part 2, Working Papers (Fisheries and Environment Canada, Ottawa, September 1976). (x) Hydroelectricity: H. H. Thomas, *The Engineering of Large Dams* (Wiley, New York, 1976), part 1: M. Potier, *Energie et Securite* (Mouton, Paris, 1969): A. O. Babb and T. W. Mermel, *Catalog of Dam Disasters, Failures and Accidents* (U.S. Department of the Interior, Bureau of Reclamation, Washington, D.C., 1968).
5. Coal: K. R. Smith, J. Weyant, J. P. Coldren, *Evaluation of Conventional Power Plants*, Energy and Resources Program, Report ERG 75-5 (University of California, Berkeley, July 1975).
6. "Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy," Report WASH-1224 (Atomic Energy Commission, Washington, D.C., 1974).
7. C. L. Comar and L. A. Sagan, *Annu. Rev. Energy* 1, 581 (1976).
8. Hittman Associates, *Environmental Impacts, Efficiency and Cost of Energy Supply and End-Use*, Report HIT-593 (Hittman Associates, Inc., Columbia, Md., 1974–1975).
9. L. D. Hamilton, Ed. *The Health and Environmental Effects of Electricity Generation—A Preliminary Report* (Brookhaven National Laboratory, Upton, N.Y., 1974).
10. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, Report WASH-1400 (Nuclear Regulatory Commission, Washington, D.C., 1975).
11. G. Herrera, Ed., *Assessment of R, D & D Resources, Health and Environmental Effects, O & M Costs and Other Social Costs for Conventional and Terrestrial Solar Electric Plants*, Report 900-782 (Jet Propulsion Laboratory, Pasadena, Calif., January 1977).
12. R. L. Gotchy, *Health Effects Attributable to Coal and Nuclear Fuel Cycle Alternatives*, Report NUREG-0332 (Nuclear Regulatory Commission, Washington, D.C., 1977): D. J. Rose, P. W. Walsh, L. L. Lekojvan, *Am. Sci.* 64, 291 (1976): Nuclear Energy Policy Study Group, *Nuclear Power: Issues and Choices* (Ballinger, Cambridge, Mass., 1977).
13. Countries like Austria and France have total accidental death rates about 40 percent higher than that of the United States (see 14, p. 22). Determining what proportion is due to industrial accidents is not simple.
14. *Accident Facts—1977 Edition* (National Safety Council, Chicago, 1977).
15. P. M. S. Jones, United Kingdom Atomic Energy Authority, October 1978, private communication.
16. H. W. Lewis, *Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission*, Report NUREG/CR-0400 (Nuclear Regulatory Commission, Washington, D.C., 1978).
17. John Holdren, as noted in Smith *et al.* (5). Some of the articles in which antinuclear statements are made are: J. Holdren and P. Ehrlich, *BioScience* 19, 1065 (1969): J. Holdren, *Bull. Atom. Sci.* 30, 14 (1974).

18. I thank M. Weatherburn for gathering some of the data for this report, including most of the information on hydroelectricity; P. Hamel for encouragement; and D. Head, F. Campbell, D. Smythe, J. Elks, P. Cockshutt, P. Dyne, H. Spence, A. Danilov, H. Stocker, and others for their comments and suggestions.

PART IV

METHODOLOGICAL ISSUES IN RISK

MARGINAL VALUE AND INTRINSIC RISK AVERSION

David E. Bell and Howard Raiffa

Harvard Business School,
Boston, Massachusetts 02163

We examine the connection between, and distinction between, marginal value — strength of preference for incremental changes — and risk aversion. Strength of preference is interpreted via gambles and via an additive conjoint measurement structure; and finally, it is analyzed as a primitive concept.

Value functions having strength-of-preference properties are then extended to incorporate risk aversion. As a result, we introduce a method of defining a persons's intrinsic aversion to risk that is not confounded with differences in marginal values. A new protocol for utility function assessment that may be more acceptable to decision makers than existing methods is a result. Possible experiments are suggested.

0. Introduction

We examine the connection between, and distinction between, decreasing marginal value (whatever that may mean) and risk aversion (from [6]). When a decision maker (DM henceforth) declares indifference between $1500 for certain and a 50-50 lottery with payoffs $0 and $5000, the DM may have two concerns: (1) a feeling that going from $0 to $2500 is "worth far more" than going from $2500 to $5000, and (2) being "nervous" about the uncertainty in the gamble. We'll call the first concern: "strength of preference"; the second concern: "intrinsic risk aversion". How much of the $1000 difference between the arithmetical average of the gamble payoffs and the certainty equivalent is due to each of these concerns? Apart from a natural curiosity of such things we have other motivations:

a) Many utility-assessment procedures currently rely heavily on answers to questions about gambles (e.g., [5]); but decision makers are often uncomfortable with making choices among risky alternatives. Can alternative procedures that do not rely heavily on gambling questions be used justifiably?

b) Many value-assessment procedures rely exclusively on strength-of-preference protocols (e.g., by comparing increments of gain or loss) and never confront subjects with risky choices. But some of these studies are then used to guide risky-choice options. How bad is this non-justifiable procedure?

c) We wish to explore the possibility of talking about a particular person's "risk-aversion parameter" without having this contaminated with his or her preferences for incremental changes — again, whatever that may mean.

Dyer and Sarin [2,3] have explored some of these topics. They take strength of preference (they refer to this as measurable value) as a primitive notion and derive decompositions of multiattribute strength of preference functions by considering the effects of various independence assumptions between attributes. Here we concentrate specifically on attempting to explain strength of preference for a single attribute. Our conclusions are consistent with their results.

1. Value Functions, Strength-of-Preference Functions, and Utility Functions

Consider a single attribute like money or time and assume the DM has a well-structured ordinal preference over this attribute.

Definition 1: A value function, v(.), reflects (ordinal) preferences if and only if

$$b \succsim c \implies v(b) \geq v(c) \quad (1)$$

(where $\succsim$ is read: "preferred or indifferent to").

If v is a value function so is $\sqrt{v}$, log v, or any strictly monotonic increasing function of v. Ordinal comparisons reflect the notion that the DM would "rather have" b than c.

Subjects are quite often willing to make a different kind of preference judgement such as: It is more important to me to go from a to b than to go from c to d. Or, symbolically, we'll write

$$[a \rightarrow b] \succ [c \rightarrow d].$$

If v is a value function we can not use it to talk meaningfully about these value differences. The reason is that the relation

$$v(b) - v(a) > v(d) - v(c)$$

is not necessarily invariant for all strictly monotonic transformations of v. For the time being, we'll not try to interpret such statements about increments but treat them as primitives. We shall assume that the DM can consistently assess preferences for incremental changes; furthermore, without the embellishments of an axiomatic presentation, we shall assume that there is a function S that assigns a real number to any increment [a -> b]. Thus S [a -> b] will be interpreted as the DM's preference-value for the increment [a -> b].

We assume

$$\{[a \to b] \succsim [c \to d]\} \Rightarrow \{S[a \to b] \geq S[c \to d]\} \tag{3a}$$

$$S[a \to a] = 0, \quad \text{for all } a, \tag{3b}$$

$$S[a \to b] = -S[b \to a] \tag{3c}$$

and

$$S[a \to b] + S[b \to c] = S[a \to c]. \tag{3d}$$

Definition 2. We will say that s(.) is a strength of preference function if and only if

$$\{[a \to b] \succsim [c \to d]\} \Rightarrow \{[s(b) - s(a)] > [s(d) - s(c)]\}. \tag{4}$$

Note that if S were given, we could define s by arbitrarily setting $s(a) = 0$ for some a and then defining $s(b) \equiv S[a \to b]$. A strength-of-preference function is unique up to positive linear transformations.

By assumption (3d) if $[a \to b]$ is preferred to $[a \to c]$, then $[d \to b]$ is preferred to $[d \to c]$ for all choices of d. Hence it is reasonable to assume that in this case the DM would "rather have" b than c. Therefore s(.) is also an ordinal value function.

Our aim in this paper is to relate strength-of-preference functions to utility functions and in order to do this we shall first have to introduce some notation for gambles. Discrete gambles will suffice for our purposes. Consider a gamble which will result in one of the outcomes $x_1, \ldots, x_i, \ldots, x_m$ with probabilities $p_1, \ldots, p_i, \ldots, p_m$ respectively. In this case, we shall talk about a gamble with uncertain outcome $\tilde{x}$ (a random variable) where the tilde above $\tilde{x}$ implies that there is a well-specified probability mass function for x. We assume that the DM has a well-structured set of preferences for gambles that satisfy the usual von Neumann-Morgenstern axioms (see [7] or [1]) and that the DM behaves as if he were maximizing expected utility. More precisely, we assume the existence of u(.) function such that an index of relative desirability of $\tilde{x}$ is

$$E\, u(\tilde{x}) \equiv \Sigma_i p_i u(x_i) \tag{5}$$

where the expectation operation E is taken with respect to the probability mass function of $\tilde{x}$.

Definition 3. A utility function u reflects preferences for gambles if and only if a preference for gamble $\tilde{x}'$ over $\tilde{x}''$ means that $\tilde{x}'$ has a higher expected utility than $\tilde{x}''$; symbolically ,

$$\tilde{x}' \succsim \tilde{x}'' \Leftrightarrow E\, u(\tilde{x}') \geq E\, u(\tilde{x}'')$$

(where $Eu(\tilde{x}')$ and $Eu(\tilde{x}'')$ are defined as in (5)).

A utility function u(.) is meaningful up to positive linear transformations. It's well known, of course, that a utility function is a bonafide value function but not conversely.

The remainder of the paper will attempt to relate these three concepts of preference. The next section discusses two interpretations of the concept of strength of preference, the first in relation to choices over gambles, the second in relation to ordinal comparisons.

There is a dilemma however. Statements by the DM about ordinal comparisons or about choices among gambles may, in principle at least, be checked by actually offering real choices. This possibility may not be available for statements concerning preference for increments. Therefore, it is inevitable that some people will have strength-of-preference functions that are not compatible with either of our interpretations and may not wish to conform to them.

In section three we treat strength of preference as a primitive concept and with only a modest amount of additional structure, relate strength-of-preference functions with utility functions in a way that is compatible with our earlier interpretations.

Our concluding section summarizes why we feel our arguments about strength-of-preference are compelling and show how these would affect, and enhance, preference assessment protocols for the future.

2. Interpreting Strength of Preference

Imagine a decision maker who has a coherent set of preferences for lotteries involving incremental monetary payoffs -- coherent in the sense that his basic preferences can be captured by a utility function u(.). Utility is not a primitive but a derivative concept. What is primitive is that for the given DM one lottery is preferred or indifferent to another lottery. Utilities may be introduced as a derivative notion whenever the set of preferences satisfy certain desiderata.

Now let us consider the question of whether going from a to b is "worth more" than going from c to d. The difficulty is that we cannot receive an increment of a to b unless we happen to be at a. Therefore the question may be meaningless (in non-primitive terms) if a is not the same as c - which would reduce the problem to an ordinal comparison of b and d.

But suppose that we start out with a 50-50 lottery between a and b, let us denote this by $\langle a,b \rangle$, and ask whether adding $\Delta (> 0)$ to a is more valuable than adding Δ to b. It seems possible to argue that if

$$\langle a + \Delta, b \rangle \succ \langle a, b + \Delta \rangle$$

then

$$[a \rightarrow a + \Delta] \succ [b \rightarrow b + \Delta].$$

One might feel confident in feeling this way not because of any gambling interpretation, but just because adding Δ to x is more important the lower the value of x is.

Therefore the statement $[a \rightarrow b] \succ [c \rightarrow d]$ could be interpreted, by analogy with the argument above, to mean that $\langle b, c \rangle \succ \langle a, d \rangle$. If a utility function exists this statement is equivalent to

$$\frac{u(b) + u(c)}{2} > \frac{u(a) + u(d)}{2}$$

or to

$$u(b) - u(a) > u(d) - u(c). \qquad (6)$$

These inequalities are clearly invariant with respect to positive linear transformations and from Definition 2, $u(\cdot)$ is a strength-of-preference function.

Interpretation 1: The increment from a to b is preferred to the increment from c to d if the 50-50 gamble between b and c is preferred to that between a and d.

Using notation, we have

$$\langle b, c\rangle \succ \langle a, d\rangle \iff [a \rightarrow b] \succ [c \rightarrow d]. \tag{7}$$

Operationally, it does not make sense to ascertain the validity of the left-hand side of (7) in order to conclude the validity of the right-hand side of (7). The other way around, however, may make some sense.

For example, suppose that c is the certainty equivalent of $\langle a, b\rangle$. Presumably the particular choice of c involves two cognitive considerations for the DM:

i) the "intrinsic worths" of a, c, and b -- admittedly this is vague -- and

ii) the DM's attitude towards risk.

The von Neumann theory of utility chooses not to dissect and identify these two components. There is no need to do so for the purpose of the theory. But still if

$$c \sim \langle a,b\rangle \tag{8}$$

we could now conclude from Interpretation 1 that

$$[a \rightarrow c] \sim [c \rightarrow b], \tag{9}$$

i.e., going from a to c is equally valuable as going from c to b.

A number of economics textbooks explain why $c \neq (a+b)/2$ by saying that the increase in satisfaction gained from $(a+b)/2$ to b is not as great as gained from a to $(a+b)/2$. This implies that they believe $s(\cdot)$ is identical to $u(\cdot)$. (As an example see [10, p. 35 ff.].)

While (8) is operationally more meaningful than (9), some subjects might think that a query based on (9) is, cognitively speaking, more basic than a query based on (8); they also might think (9) while responding to (8). The danger, of course, is that a direct response to a query based on (9) might abstract out risk attitudes, and it would then be inappropriate to equate (9) and (8) and base a utility function on such responses.

The following experiment would be interesting: with naive subjects, ask preference for increment type questions (without specifying the equivalence of (9) and (8)) and test how appropriate these responses are for gambling choices.

2.2 Preferences for Increments: A Conjoint Interpretation

A natural way to compare a to b versus c to d is by considering how much one is prepared to "pay" of some other attribute (dollars or hours of labor) for the increment (see [9] for example). The problem with this approach is that dollars, for example, may have a different marginal value in the two increments. Therefore we seek an attribute that has constant marginal value — whatever that means.

Instead of thinking solely of a single attribute X, let us now introduce a second attribute Y and suppose for the moment* that these are the only two attributes that are ever of concern to the DM. Assume that our DM has a completely ordered preference relation ($\succsim$) on ordered pairs (x, y) — ordinal preference under certainty — and suppose these preferences satisfy all the necessary requirements to admit an additive value representation, viz:

$$V(x, y) = v^*(x) + w^*(y). \qquad (10)$$

*This assumption is relaxed in the appendix.

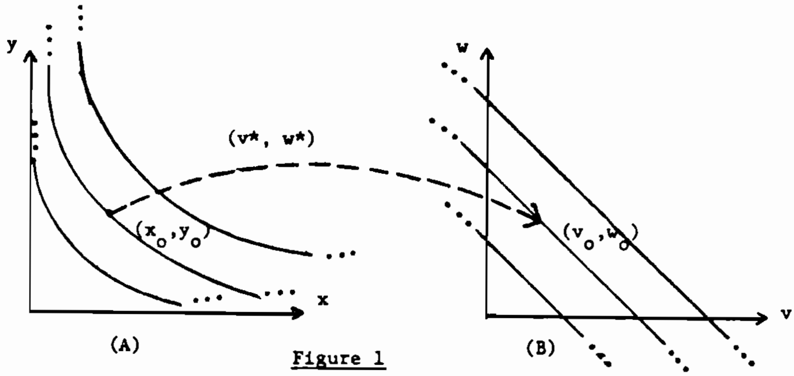


Figure 1

In this case the set of iso-preference curves are considerably constrained. (See Fig. 1A). If we now transform (x, y) points into (v, w) points by defining[+]

$$v = v^* (x) \quad \text{and} \quad w = w^* (y), \tag{11}$$

where v* and w* are defined in (10), then the transformed iso-preference curves in the (v, w)-plane are parallel straight lines. The transformations v* and w* straighten out the indifference curves in the (x, y)-plane in a way that is not related to risky disincentives. Now the attribute v has constant marginal value -- as measured in units of w -- and w has constant marginal value -- as measured in units of v. This effectively removes the problem of measuring the marginal value of one attribute in terms of another which itself has variable marginal value.

[+] In what follows it is helpful to distinguish the function v* from the functional value v. In other words: v* sends an x-value into a transformed v-value. Similarly with w* and w.

The functions v^* and w^* in (10) are not unique — each is determined up to a positive linear transformation where the multiplicative constants are linked together. The incremental value $v^*(x_2) - v^*(x_1)$ is not meaningful by itself but what is invariant is the comparison of $[v^*(x_4) - v^*(x_3)]$ versus $[v^*(x_2) - v^*(x_1)]$.

We can interpret this more directly by suppressing v^* in the following way: Suppose we start with (x_1, y_o) and ask how much of the second component the DM would be willing to give up to go from x_1 to x_2. Suppose the answer is Δ' where Δ' depends on x_1, x_2, and y_o. We have

$$(x_1, y_o) \sim (x_2, y_o - \Delta').$$

Now we ask: Starting with (x_3, y_o) — the same y_o — how much would you just be willing to give up in the y-component to go from x_3 to x_4 in the x-component? Suppose the answer is Δ'' where Δ'' depends on x_3, x_4 and y_o. We would then have

$$(x_3, y_o) \sim (x_4, y_o - \Delta'').$$

We could then argue that if Δ' were greater than Δ'', then going from x_1 to x_2 could be considered more valuable than going from x_3 to x_4; symbolically:

$$\{\Delta' > \Delta''\} \Rightarrow [x_1 \rightarrow x_2] \succ [x_3 \rightarrow x_4]. \tag{12}$$

Intuitively this is saying that if, starting at y_o, the DM is willing to give up more of the y-component in going from x_1 to x_2 than going from x_3 to x_4, then $[x_1 \rightarrow x_2]$ is preferred to $[x_3 \rightarrow x_4]$. It is important to observe that given an additive structure the argument that leads to (12) <u>does not depend on the choice of y_o</u>.

<u>Interpretation 2</u>: If X and Y have an additive representation, i.e., $V(x, y) = v^*(x) + w^*(y)$, then the increment from x_1 to x_2 is preferred to the increment from x_3 to x_4 -- symbolically

$$[x_1 \rightarrow x_2] \succ [x_3 \rightarrow x_4] \quad \text{if} \quad v^*(x_2) - v^*(x_1) > v^*(x_4) - v^*(x_3).$$

To motivate further the strength-of-preference interpretation, suppose that we introduce three attributes, X, Y, and Z and assume an additive representation:

$$V(x, y, z) = v_1(x) + v_2(y) + v_3(z).$$

If x_2 is the mid-value point of x_1 and x_3, by Interpretation 2, this means that

$$v_1(x_2) - v_1(x_1) = v_1(x_3) - v_1(x_2).$$

Suppose that y_o, y_1, z_o and z_1 are values such that

$$v_1(x_2) - v_1(x_1) = v_2(y_1) - v_2(y_o) = v_3(z_1) - v_3(z_o)$$

then we can say that

$$[x_1 \rightarrow x_2] \sim [y_o \rightarrow y_1] \sim [z_o \rightarrow z_1].$$

Since $[x_1 \rightarrow x_3]$ is indifferent to $[y_o \rightarrow y_1]$ <u>and</u> $[z_o \rightarrow z_1]$ (more correctly stated $[(x_1, y_o, z_o) \rightarrow (x_3, y_o, z_o)] \sim [(x_1, y_o, z_o) \rightarrow (x_o, y_1, z_1)]$) this suggests more concretely that the increment $[x_1 \rightarrow x_3]$ is "worth twice" the increment $[x_1 \rightarrow x_2]$. This statement is reflected by the value differences.

We have been most careful in the above arguments to maintain that the value function was additive over <u>all</u> the attributes that the decision maker might consider. The reason for this is that if X and Y are only additive conditionally on other attributes being held constant at particular values then the strength-of-preference interpretation of $v^*(x)$ might not be invariant. For example, if $V(x, y, z) = v_3(z)\ (v_1(x) + v_2(y))$, the strength-of-preference measure is $v_1(x)$ if X is measured against Y but log v_1 if measured against Z. This problem does not arise if the multiattribute value function is completely additive. We defer discussion of less restrictive conditions on the choice of a suitable Y to an appendix.

In this section we have given two possible interpretations of strength of preference. In a study of the value of recreational facilities, Sinden [8] compared these two interpretations and found them to have different implications.

3. From Strength of Preference to Utility

In this section, we attempt to identify a relation between strength-of-preference functions and utility functions. We will do this in two ways; first of all by interpreting strength of preference via Section 2 and then by treating strength of preference as a primitive. We will show that both viewpoints lead to the same conclusion!

3.1 Strength of Preference: Using the Derivative Concept

If we use Interpretation 1, there is nothing to discuss since in that case the strength-of-preference function is identical to the utility function. But can we conclude in general that if $[x_1 \to x_2] \sim [x_2 \to x_3]$ then $x_2 \sim \langle x_1, x_3 \rangle$? The answer, of course, in general, is <u>negative</u>.

Let us consider attributes X and Y chosen in accordance with Interpretation 2, namely that

$$V(x, y) = v^*(x) + w^*(y)$$

and let us also assume that X is utility independent[+] of Y . Suppose we consider a lottery, as in Fig. 2, which with probability p_i, results in outcome (x_i, y_o) for $i = 1,\ldots,n$. For simplicity, we write v_i for $v^*(x_i)$.

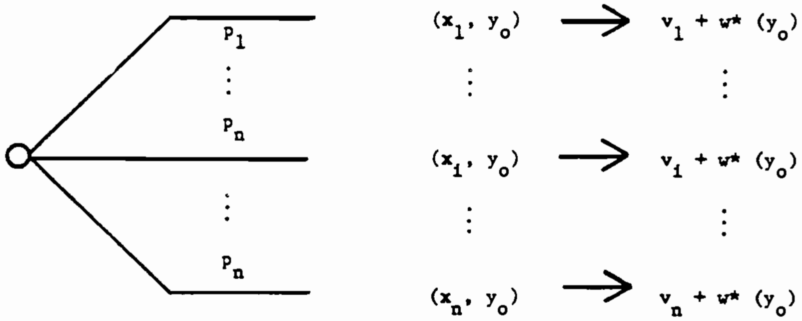


Figure 2

A suitable utility function, which assigns $u(x_i, y_o)$ to (x_i, y_o) may, for example, be very concave because the concavity reflects both the DM's strength of preferences for the x_i's and the DM's intrinsic risk aversion.

[+] The appendix uses the condition X utility independent of Y as an additional restriction on the choice Y for the purpose of Interpretation 2.

The utility function $u(.,.)$ now induces a new utility function $u^*(.)$, of one argument, where we define

$$u^*[v_i + w^* (y_o)] \equiv u(x_i, y_o). \tag{13}$$

The function $u^*(.)$ may now exhibit far less local risk aversion at $v_i + w^*(y_o)$ than $u(.,y_o)$ exhibits at x_i, because the transformation sending x_i into v_i eliminates one source of the concavity of u, namely the strength of preferences for the x_i's.

Suppose the certainty equivalent of the lottery in Fig. 2 is $(\hat{x}, y_o)$, i.e.,

$$u(\hat{x}, y_o) = \Sigma p_i u(x_i, y_o).$$

Notice that since X is utility independent of Y, then the value $w^*(y_o)$ in (13) does not affect the certainty equivalent so that u* would have to exhibit constant risk-aversion (i.e., to be linear or negative exponential).

Thus, for example, suppose x_1, x_2, and x_3 are transformed via v* into v_1, v_2, and v_3. If we now assumethat the DM is indifferent between x_2 and a p-chance at x_3 and a (1-p) chance at x_1, where $p \neq 1/2$, then in terms of the v_i's this would mean that

$$u^* (v) = -e^{-cv} ,$$

where the risk aversion parameter, c, is determined from the equation

$$-e^{-cv_2} = -pe^{-cv_3} - (1-p) e^{-cv_1}.$$

Illustration: Suppose that the DM believes that, in dollars, $[0 \rightarrow 30K] \sim [30K \rightarrow 100K]$, that is \$30K is the intrinsic mid-value point between \$0 and \$100K. Converting dollars into a strength-of-preference scale we can let $v^*(0) = 0, v^*(30K) = 1$ and $v^*(100K) = 2$. But now suppose the DM also says that \$30K outright is preferred to a 50-50 gamble between \$0 and \$100K. Then even in the strength of preference scale, risk aversion is exhibited. Suppose that the DM says \$30K is indifferent to a .6 chance at \$100K and a .4 chance at \$0. Then we would have

$$e^{-c} = .6e^{-2c} + .4e^{-0c}$$

for which $c \approx .4$. Therefore a suitable utility function for the v-space is $u^*(v) = -e^{-.4v}$.

It's not difficult to see that if additivity holds and if X is utility independent of Y then we also get that Y is utility independent of X and, much more excitingly, in the transformed w-space, where $w = w^*(y)$, the induced utility function for w-values (holding x's constant), is also negative exponential (or linear) with the same risk aversion parameter c. This says that if we transform the x and y scales by squeezing out preferences for increments -- a certainty notion -- we are left in the transformed spaces with a problem of pure risk aversion and the structures in the v and w spaces are negative exponential with the same risk parameters. This risk parameter can then be thought of as a basic psychological (personality) trait of the individual.

Empirically, it would now be desirable to try the following types of experiments. Start with money. Transform money into a strength-of-preference scale (using certainty tradeoffs) and then explore whether the subject has constant risk aversion (or approximately so) in the transformed scale. Then go to some other frequently used numeraire, like time (or remaining life years). Transform this scale into a strength-of-preference scale; next normalize the units of measurements of the transformed monetary scale and time scale by a conjoint tradeoff; and then investigate: (a) whether the subject has constant risk aversion in the transformed time scale, and (b) whether the subject's constant risk aversion parameters for the transformed monetary and transformed time scales are the same -- of course, all this within reasonable experimental error. How exciting it would be if each subject would exhibit roughly the same risk aversion parameter for time as well as for money!

In closing this subsection, let us observe that if we are solely interested in the X-attribute, we can ask strength-of-preference questions directly on x's without explicitly bringing the second attribute, Y, into the picture. The Y-attribute gets into the act solely as a hypothetical construct that helps us to rationalize why an assumption of constant risk aversion is reasonable for the transformed X-attribute.

3.2 Strength of Preference: Using the Primitive Concept

Our only assumption about preferences for increments is, for the moment, that the DM can give consistent answers in accordance with the structure imposed by equations (3).

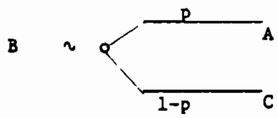
Suppose that consequences A, B, C, and D are such that

$$[A \rightarrow B] \sim [B \rightarrow C] \sim [C \rightarrow D].$$

Without any loss of generality we can therefore introduce a strength-of-preference function that assigns

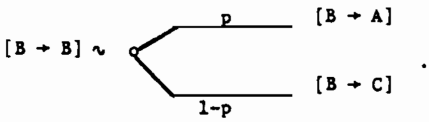
$$s^*(A) = 0, \quad s^*(B) = 1, \quad s^*(C) = 2, \quad s^*(D) = 3.$$

Suppose further that the DM feels that B is indifferent to a p-chance at A and a complementary chance at C, viz:



(14)

This indifference relation in (14) can also be interpreted as follows: If the DM were in state B, he would be indifferent between remaining in B or taking a p-chance of going from B to A and a complementary chance of going from B to C, viz:

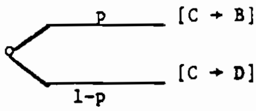


(15)

Now substituting

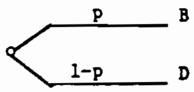
$[C \rightarrow C]$ for $[B \rightarrow B]$,		(from (3b)),
$[C \rightarrow B]$ for $[B \rightarrow A]$,		(from (31) and (3c)),
$[C \rightarrow D]$ for $[B \rightarrow C]$,		(from (31))

the indifference relation (15) becomes

$[C \rightarrow C] \sim$ 

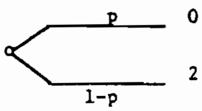
,

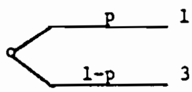
which can be reexpressed as

$C \sim$ 

. (16)

Finally, reexpressing (14) and (16) in terms of s-values (remembering the s-values of A, B, C, and D are respectively 0, 1, 2, and 3) we get

$1 \sim$ 

and
$2 \sim$ 

This implies that if $u^*(.)$ is a utility function on s-values, then $u^*(.)$ must be linear or negative exponential, i.e.,

$$u^*(s) = s \quad \text{or} \quad u^*(s) = -e^{-cs}.$$

for some risk aversion parameter c.

Note that this is the same conclusion reached via Interpretation 2. Interpretation 1, which was more restrictive, led to just the linear case, $u^*(s) = s$.

Of course we have used an additional assumption, that of substitutability of preference increments for lotteries (after (15)). This, to us, is not unrealistic. Our assumption that strength of preference is a primitive notion means that in comparing $[a \rightarrow b]$ with $[c \rightarrow d]$ the DM has some sensation in mind associated with these exchanges. By assuming that the DM obeys the von Neumann-Morgenstern axioms for lotteries (since we assume a utility function exists) it seems only a small leap to extend the substitutability argument to other rewards such as increments.

4. Summary and Conclusions

Strength of preference is a well-known, well-studied (e.g., [4]) notion and our reasoning cannot be said to be "correct" unless empirical studies suggest close agreement to observed responses or unless many people who wish to behave rationally feel these arguments to be compelling.

We have suggested that strength of preference for a given attribute can be measured in a derivative fashion in terms of tradeoffs with some other attribute that does not interact with the one being measured. This led to a utility function showing constant risk aversion in terms of the strength of preference measure.

We have shown that, regardless of how strength of preference is defined -- treating it as a primitive concept — that if a utility function exists (and if the substituion principle can be extended to increments) it should also, logically, show constant risk aversion with respect to strength of preference. From this we are led to the following conclusions:

(i) We regard that strength of preferences for increments is a tangible (if somewhat elusive) concept that can, in some circumstances, be defined explicitly and

(ii) that constant risk aversion <u>relative to strength-of-preference values</u> is an appealing idea;

(iii) that an <u>intrinsic risk-aversion</u> parameter (defined in terms of the utility function on the transformed strength-of-preference scale) can be meaningfully introduced for an (idealized) "coherent" subject, where this parameter is independent of the particular underlying attribute over which the gamble is expressed -- provided, of course, the various strength-of-preference scales are appropriately normalized.

REFERENCES

1 D.E. Bell and H. Raiffa, "Risky Choice Revisited" manuscript.

2 J.S. Dyer and R. Sarin, "Measurable Multiattribute Value Functions"; to appear in Operations Research.

3 J.S. Dyer and R. Sarin, "Measurable Preference Aggregation Rules" manuscript.

4 D. Ellsberg, "Classic and Current Notions of Measurable Utility", Economic Journal, 64, pp. 528-556, 1954.

5 R.L. Keeney and H. Raiffa, Decisions with Multiple Objectives; Wiley, New York, 1976.

6 J.W. Pratt, "Risk Aversion in the Small and in the Large", Econometrica 32, pp. 122-126, 1964.

7 J. von Neumann and O. Morgenstern, "The Theory of Games and Economic Behavior", Princeton University Press, New Jersey, 1944.

8 J. A. Sinden, "A Utility Approach to the Valuation of Recreational and Aesthetic Experiences," American Journal of Agricultural Economics, Volume 56, pp. 61-72, 1974.

9 P. Suppes and M. Winet, "An Axiomatization of Utility Based on the Notion of Utility Differences," Management Science, Volume 1, pp. 259-270, 1954.

10 J. R. McGuigan, R. C. Moyer, Managerial Economics, The Dryden Press, Illinois, 1975.

APPENDIX

We have attempted to relate the strength-of-preference function $s(\cdot)$ to ordinal value by conjoint tradeoffs (section 2.2) and to utility by the arguments of sections 3.1 and 3.2. These three subsections are mutually consistent if there exist only two attributes of interest to the decision maker X and Y, and if X is utility independent of Y.

An example, that illustrates that other potential attributes cannot be ignored involves 3 attributes X, Y and Z and where

$$u(x,y,z) = u_1(x) + u_2(y) + u_3(z) + k_1u_1(x)u_2(y) + k_2u_2(y)u_3(z).$$

With Z fixed, X and Y are conditionally additive and utility independent. Our interpretations of strength of preference lead to $s(x) = \log(1 + k_3u_1(x))$ (where k_3 is a constant that depends on the particular value of Z). With Y fixed, X and Z are conditionally additive and utility independent. From this we deduce $s(x) = u_1(x)$. Such a contradiction is evidently unsatisfying.

Therefore, we must make more stringent requirements of an attribute Y, against which to measure the strength of preference for X. The attribute Y must be value additive with respect to all attributes of interest to the decision maker. In addition it must be utility independent of all these attributes. We find this latter restriction unfortunate since it requires us to include some consideration of choices under risk in measuring strength of preference. But since we wish to relate strength of preference to utility, perhaps this is inevitable.

With this new requirement our theory is internally consistent. If Y_1 and Y_2 are two attributes that satisfy the conditions and if Z represents all other attributes (including X) then we have Z and Y_2 preferentially independent of Y_1, Z and Y_1 preferentially independent of Y_2 from which we deduce ([5, p. 105]) that

$$v(z,y_1,y_2) = v_0(z) + v_1(y_1) + v_2(y_2).$$

This additive ordinal structure means that Y_1 and Y_2 yield the same strength of preference function for Z (and X).

To summarize, we are not saying that people do arrive at preferences for increments by conjoint tradeoffs, nor are we suggesting that they should (though we find it compelling). We show only that via sections 2.2, 3.2 and this appendix our interpretations of strength of preference are internally consistent and, we hope, individually appealing.

INFORMATION AND MODELING IN RISK ASSESSMENT*

Robert L. Winkler

Indiana University, Bloomington, Indiana, and
INSEAD, Fontainbleau, France

An important aspect of risk assessment is the estimation of probabilities for various events of interest. If an estimate is received from a single source, it can be taken at face value or the information source can be modeled. If probabilities are received from multiple sources, the probabilities can be combined by using some relatively simple combination rule or modeling of the information sources can be considered. The normal model for log odds provides not only an estimate of the desired probability, but also an indication of the uncertainty about that probability. The model also can be used in an ex ante fashion to attempt to determine optimal combinations of information sources, taking into account their cost as well as the potential "value"of their information for a risk assessment.

*This research was supported in part by the U.S. National Science Foundation under grant NSF – IST8018578.

1. Introduction

In risk assessment an attempt is made to identify the possible outcomes that might occur if a particular action is taken and to estimate the chances that these outcomes will occur. For example, if a nuclear power facility is built at a certain location, potential impacts upon the local population and the environment might be considered, both under the scenario of normal operation of the facility and under various scenarios involving accidents or other problems that could arise (see Keeney, 1980, for a discussion of siting energy facilities). If a standard is set for a particular pollutant, possible short-term and long-term health effects should be considered (see Winkler and Sarin, 1981, for a discussion of risk assessment and standard setting).

Although the identification of possible outcomes is an important problem, the concern in this paper is with the probabilistic aspects of risk assessment: the estimation of the chances that outcomes will occur. The specific focus is on a particular well-defined issue, the assessment of the probability that a single event will occur. This event could be a particular type of accident at a nuclear power plant, an adverse health effect as a result of exposure to a high level of a pollutant, or yet some other event of interest.

The purpose of this paper is to discuss some aspects of the roles of information and modeling in risk assessment. The paper is brief, with emphasis on some general ideas and mention of a specific model involving normal distributions for log odds. In Section 2, some types of information that might be sought are listed. The case in which the information itself consists of a probability for the event of interest is examined in Sections 3 and 4. Section 3 concerns information from a single source, while Section 4 concerns information from multiple sources. The information could be taken at face value or some modeling could be considered, and examples of modeling are provided in Sections 3 and 4. A short summary is given in Section 5.

2. The Search for Information

In order to assess the probability of an event E, what sort of information might be sought? Three potentially valuable types of information are data, results from models, and expert judgments. The availability and relative values of these types of information vary from situation to situation, of course.

The tradition in the "hard" sciences is to seek out data. Indeed, many scientists brought up in this tradition are very reluctant to accept any conclusions that are not based on data. Here the term "data" refers to actual observations from some population or process. Ideally, one would like to have a large amount of data regarding past occurrences and non-occurrences of the event E which is of interest. Such information would yield a very accurate estimate of the probability of E. In risk assessment problems, however, data of this sort are usually not available or not feasible to collect. Not enough experience with nuclear power facilities is available to provide reliable data concerning the chances of various possible accidents. For another example, it is physically possible to design an experiment in which people are exposed to extremely high levels of a pollutant under carefully controlled conditions, but ethical considerations rule out such experiments. And even if ethical considerations did not pose a roadblock, data regarding long-term effects (e.g., certain cancers) would take many years to collect.

If data regarding past occurrences of E cannot be obtained, perhaps data regarding similar events are not out of the question. The effects of pollutants on rats, pigs, and other animals are studied, for instance. Effects on humans are most likely different, but information from animal studies is useful nonetheless. Another possibility would be data regarding factors that are related to E. A certain type of accident at a nuclear power facility may involve, among other things, the failure of a particular valve. A considerable amount of data may be available concerning the reliability of the valve under various conditions.

With data not directly pertinent to E (e.g., data regarding similar events, data regarding other factors), it is necessary to relate the data to the chance of E occurring. Sometimes this step must be purely judgmental, but other times models can be valuable. A time-honored approach is to use statistical methods to relate E to other factors or to similar events. For example, a regression model might be used to generate a probability for E. On the other hand, theoretical models may provide the link between E and related factors. With recent advances in computing and quantitative methods, realistic empirical or theoretical models may be feasible to consider and results from such models may provide valuable information.

The consideration of data or results from models is seldom entirely free of judgment. The choice of data and the model-building process almost invariably involve subjective input. Thus, the consideration of expert judgments as a source of information is not as large a step from the preceding discussion as might be thought at first glance. Furthermore, for many events of interest in risk assessment, very little information is available other than expert judgments.

Experts may assess directly a probability for the event of interest, just as weather forecasters in the U.S. assess probabilities of precipitation. Or they may find it easier to think about similar events or factors related to the event of interest. Various levels of decomposition can be considered. For example, different scenarios leading to an accident at a nuclear power facility might aid the expert in thinking about possible accidents, and assessing probabilities for the component events making up the scenarios may be more appealing intuitively than assessing a probability directly for the accident.

Regardless of the type or source of information, the question of how to obtain and process the information is very important. For data collection, the extensive work in areas such as experimental design and survey design is relevant. For model building, statistical methodology and operations research offer many possibilities. For expert judgments, psychological work on probability assessment and cognitive processes is useful. As for processing the information, the question of interest is what to do with the information after it is obtained. This question is addressed in Sections 3 and 4 for the situation in which the information consists of a probability for the event of interest.

3. Information From a Single Source

If information I is obtained from a single source, the probability of interest is $P(E|I)$. Here the case in which I itself consists of a probability is denoted by r. (Note that the source of r could be data regarding E, a model that yields a probability, or an expert.) Thus, the probability of interest can be expressed in the form $P(E|r)$.

The most straightforward alternative is simply to take r at face value. That is, let $P(E|r) = r$. This approach expresses confidence in the reliability of the source of information. If one has no reason to modify r, this is probably a reasonable course of action.

If some evidence about the past performance of the information source is available, this information might be used to calibrate the source. In the approach of Morris (1977), the probability r is multiplied by a calibration function C(r) to arrive at $P(E|r)$. Of course, the calibration function might be based on subjective judgment instead of empirical results.

Calibration can be thought of as a special case of modeling an information source. In general, Bayes' theorem can be used to revise the initial probability of E before seeing the information r to arrive at a posterior probability $P(E|r)$. The likelihood function for this probability revision is of the form $f(r|p)$, where $p = p(E)$ is now a model parameter.

Many different models might be considered, and a convenient possibilty is to transform to log odds,

$$t = \ln \frac{r}{1-r}$$

and

$$u = \ln \frac{p}{1-p} \quad .$$

Suppose that the likelihood function can be expressed in the form of a normal distribution for t with mean $u + \delta$ and variance σ^2. Here δ represents a systematic bias on the part of the information source and σ^2 represents the "accuracy" of the information source, with everything being expressed in log-odds space instead of probability space. Then if the prior distribution of p is diffuse relative to the normal likelihood function, the posterior distribution of u given r is a normal distribution with mean $t - \delta$ and variance σ^2. From this distribution, a transformation back from u to p will yield $f(p|r)$, the posterior distribution of p after seeing the information r. The desired probability $P(E|r)$ is now equal to the posterior mean $E(p|r)$, and other summary measures of $f(p|r)$ can be determined to find out the degree of posterior uncertainty about p.

For example, suppose that the probablity provided by the information source is $r = 0.08$. Furthermore, suppose that $\delta = 0$ and $r = 0.5$ (these values might be based on past evidence or on subjective judgment). Then $t = -2.4423$, and u is normally distributed with mean -2.4423 and standard deviation 0.5. This implies, for instance, that the posterior mean $E(p|r)$ is 0.089. Also, the median of p is 0.08, and with probability 0.95, p lies between 0.0316 and 0.1881.

The log-odds model illustrates the idea of modeling an information source. other models might be considered, of course. The likelihood function $f(r|p)$ might be taken as a beta distribution with mean p. Here the dispersion of the beta distribution would provide an indication of how "shaky" the estimate is. The point is to model the information source in order to react to the information $I = r$ provided by this source.

4. Information from Several Sources

If it is useful to expend the time, effort, and cost to obtain information from a single source, it may be worthwhile to obtain information from several sources. Data from several experiments, results from different models, judgments from a number of experts, or some combination thereof may be obtained. To base a risk assessment on all available information, it is necessary to combine, or aggregate, the information from various sources.

Suppose that there are k sources, and let I_i represent the information obtained from source i, with $i = 1,\ldots, k$. Furthermore, as in Section 3, consider the case in which each I_i consists of a probability for E. Denote the probability from source i by r_i, so that $I_i = r_i$. Then the probability of interest for a risk assessment is $P(E|r_1,\ldots, r_k)$.

In the surprising but pleasant case in which $r_1 = r_2 = \ldots = r_k = r$, an appealing alternative is to set $P(E|r_i,\ldots, r_k)$ equal to the common probability r. Such agreement among sources is the exception rather than the rule, however, and it is more of an exception as k increases. The problem, then, is to determine $P(E|r_1,\ldots, r_k)$ when $r_1,\ldots, r_k$ are not all equal.

Various combination rules have been proposed to arrive at a single probability from the set of k probabilities $r_1,\ldots, r_k$. Perhaps the simplest such rule is to take an arithmetic average, thereby setting $P(E|r_1,\ldots, r_k) = \Sigma r_i/k$. If it seems reasonable to place more emphasis on some information sources than on others, the simple average can be generalized to a weighted average, $\Sigma w_i r_i$, where $\Sigma w_i = 1$. The weights might correspond to the perceived "accuracy" of the information sources. Within a fairly wide range of sets of weights, however, weighted averages tend to be quite insensitive to shifts in the weights. Other combination rules, such as the median of the r_i's or some type of trimmed mean, could also be considered.

In Section 3 it was noted that a probability r might be multiplied by a calibration function C(r) to arrive at $P(E|r)$. With several information sources, each source could be calibrated (separately), yielding $r_i^\circ = C_i(r_i)r_i$ for source i. The calibrated probabilities could then be combined in terms of a simple average, $P(E|r_1,\ldots, r_k) = \Sigma r_i^\circ/k$, a weighted average, or some other combination rule.

By analogy with Section 3 once again, modeling the information sources can be considered. The likelihood function with k sources is $f(r_1,\ldots, r_k|p)$, where $p = P(E)$ is a model parameter. Generalizing the log-odds transformation to k sources yields

$$t_i = \ln \frac{r_i}{1-r_i}$$

for $i = 1, \ldots, k$. Suppose that the likelihood function can be expressed as a multinormal distribution for $\underset{\sim}{t} = (t_1, \ldots, t_k)'$ with mean vector $u\underset{\sim}{e} + \underset{\sim}{\delta}$ and covariance matrix $\underset{\sim}{\Sigma}$, where

$$u = \ln \frac{p}{1-p}$$

(as in Section 3), $\underset{\sim}{e} = (1, \ldots, 1)'$, $\underset{\sim}{\delta} = (\delta_1, \ldots, \delta_k)'$, the prime denotes transposition, and $\underset{\sim}{\Sigma}$ is a positive-definite symmetric k x k matrix. The term δ_i represents any systematic bias for information source i. The variances on the diagonal of $\underset{\sim}{\Sigma}$ represent the "accuracy" of the individual information sources. The covariances reflect the degree of dependence among information sources, and an attractive feature of the model is its ability to take into account such dependence.

If the prior distribution of p is diffuse relative to the likelihood function, the posterior distribution of u given r is a normal distribution with mean

$$\underset{\sim}{e}'\underset{\sim}{\Sigma}^{-1}(\underset{\sim}{t}-\underset{\sim}{\delta})/\underset{\sim}{e}'\underset{\sim}{\Sigma}^{-1}\underset{\sim}{e}$$

and variance

$$1/\underset{\sim}{e}'\underset{\sim}{\Sigma}^{-1}\underset{\sim}{e} \ .$$

A transformation back from u to p will yield the posterior distribution of p after seeing $r_1, \ldots, r_k$. The desired probability $P(E|r_1, \ldots, r_k)$ is then equal to the posterior mean $E(p|r_1, \ldots, r_k)$, and other summary measures of the posterior distribution can also be determined. The posterior variance, for example, indicates the degree of uncertainty about p. This degree of uncertainty is relevant in the contemplation of obtaining information from additional sources.

To continue the example of Section 3, consider a second information source providing $r_2 = 0.05$. Thus, $t_1 = -2.443$ and $t_2 = -2.9444$.

Suppose that $\delta_1 = \delta_2 = 0$, $\sigma_1 = 0.5$, $\sigma_2 = 0.3$, and $\rho = 0.4$, where ρ represents the correlation between t_1 and t_2. Then the posterior distribution of u is normal with mean -2.8759 and standard deviation 0.2931. Transforming back to a distribution for p yields $E(p|r_1,r_2) = 0.055$. Moreover, the posterior median of p is 0.0534, and with probability 0.95, p lies between 0.031 and 0.091. This provides an idea of the degree of uncertainty about p after the two pieces of information r_1 and r_2 are observed.

REFERENCES

Keeney, R.L. (1980), Siting Energy Facilities. New York: Academic Press.

Morris, P.A. (1977), "Combining Expert Judgments: A Bayesian Approach", Management Science, vol. 23, 679-693.

Winkler, R.L., and Sarin, R.K., "A Risk Assessment Methodology for Environmental Pollutants", Conceptual Approaches to Health Risk Assessment for Alternative National Ambient Air Quality Standards. Research Triangle Park, N.C. : U.S. Environmental Protection Agency.

TOWARD A POSITIVE THEORY OF CONSUMER CHOICE*

Richard Thaler**

Cornell University,
Ithaca, NY 14853, USA

The economic theory of the consumer is a combination of positive and normative theories. Since it is based on a rational maximizing model it describes how consumers *should* choose, but it is alleged to also describe how they *do* choose. This paper argues that in certain well-defined situations many consumers act in a manner that is inconsistent with economic theory. In these situations economic theory will make systematic errors in predicting behavior. Kahneman and Tversky's prospect theory is proposed as the basis for an alternative descriptive theory. Topics discussed are: underweighting of opportunity costs, failure to ignore sunk costs, search behavior, choosing not to choose and regret, and precommitment and self-control.

*Reprinted with permission from *Journal of Economic Behavior and Organization*, Vol. 1, 1980, pp. 39–60. © North Holland, 1980.

**The author wishes to acknowledge the many people who have made this paper possible. Colleagues, too numerous to name individually, at the Center for Naval Analyses, Cornell University, The National Bureau of Economic Research-West, Decision Research, and the University of Rochester have contributed importantly to the final product. Special thanks go to Daniel Kahneman, Amos Tversky, H.M. Shefrin, Thomas Russell, and particularly Victor Fuchs who has supported the research in every possible way. Of course, responsibility for remaining deficiencies is the author's. He also wishes to acknowledge financial support from the Kaiser Family Foundation, while he was a visiting scholar at NBER-West.

1. Introduction

Economists rarely draw the distinction between normative models of consumer choice and descriptive or positive models. Although the theory is normatively based (it describes what rational consumers *should* do) economists argue that it also serves well as a descriptive theory (it predicts what consumers in fact do). This paper argues that exclusive reliance on the normative theory leads economists to make systematic, predictable errors in describing or forecasting consumer choices.

In some situations the normative and positive theories coincide. If a consumer must add two (small) numbers together as part of a decision process then one would hope that the normative answer would be a good predictor. So if a problem is sufficiently simple the normative theory will be acceptable. Furthermore, the sign of the substitution effect, the most important prediction in economics, has been shown to be negative even if consumers choose at random [Becker (1962)]. Recent research has demonstrated that even rats obey the law of demand [Kagel and Battalio (1975)].

How does the normative theory hold up in more complicated situations? Consider the famous birthday problem in statistics: if 25 people are in a room what is the probability that at least one pair will share a birthday? This problem is famous because everyone guesses wrong when he first hears it. Furthermore, the errors are systematic — nearly everyone guesses too low. (The correct answer is greater than 0.5.) For most people the problem is a form of mental illusion. Research on judgment and decision making under uncertainty, especially by Daniel Kahneman and Amos Tversky (1974, 1979), has shown that such mental illusions should be considered the rule rather than the exception.[1] Systematic, predictable differences between normative models of behavior and actual behavior occur because of what Herbert Simson (1957, p. 198) called 'bounded rationality':

> 'The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world — or even for a reasonable approximation to such objective rationality.'

This paper presents a group of economic mental illusions. These are classes of problems where consumers are particularly likely to deviate from the predictions of the normative model. By highlighting the specific instances in which the normative model fails to predict behavior, I hope to show the kinds of changes in the theory that will be necessary to make it more descriptive. Many of these changes are incorporated in a new descriptive model of choice under uncertainty called prospect theory [Kahneman and Tversky (1979)]. Therefore I begin this paper with a brief summary of prospect theory. Then several types of predicted errors in the normative theory are discussed. Each is first illustrated by an anecdotal example. These examples are intended to *illustrate* the behavior under discussion in a manner that appeals to the reader's intuition and experiences. I have discussed these examples with hundreds of friends, colleagues, and students. Many of the examples have also been used as questionnaires — I can informally report that a large majority of non-economists say they would act in the hypothesized manner. Yet I am keenly aware that more formal tests are necessary. I try to provide as many kinds of evidence as possible for each type of behavior. These kinds of evidence range from questionnaires, to regressions using market data, to laboratory experiments, to market

[1] Some of these studies have recently been replicated by economists. See Grether and Plott (1979) and Grether (1979).

institutions that exist apparently to exploit these actions. I hope to gather more evidence in future experimental research. For readers who remain unconvinced, I suggest they try out the examples on some non-economist friends.

2. Prospect theory

Not very long after expected utility theory was formulated by von Neumann and Morgenstern (1944) questions were raised about its value as a descriptive model [Allais (1953)]. Recently Kahneman and Tversky (1979) have proposed an alternative descriptive model of economic behavior that they call 'prospect theory'. I believe that many of the elements of prospect theory can be used in developing descriptive choice models in deterministic settings. Therefore, I will present a very brief summary of prospect theory here.

Kahneman and Tversky begin by presenting the results of a series of survey questions designed to highlight discrepancies between behavior and expected utility theory. Some of these results are presented in table 1. A prospect is a gamble (x, p, y, q) that pays x with probability p and y with probability q. If $q=0$ that outcome is omitted. A certain outcome is denoted (z). N refers to number of subjects who responded, the percentage who chose each option is given in parentheses, and majority preference is denoted by *. Subjects were also given problems such as these:

Problem 11. In addition to whatever you own you have been given 1,000. You are now asked to choose between

A: (1,000, 0.5) and B: (500) $N=70$.
(16) (84)

Table 1

Preferences between positive and negative prospects.[a]

	Positive prospects			Negative prospects	
Problem 3	(4,000, 0.80)	$<(3{,}000)$	*Problem 3′*	$(-4{,}000, 0.80)$	$>(-3{,}000)$
$N=95$	(20)	(80)*	$N=95$	(92)*	(8)
Problem 4	(4,000, 0.20)	$>(3{,}000, 0.25)$	*Problem 4′*	$(-4{,}000, 0.20)$	$<(-3{,}000, 0.25)$
$N=95$	(65)*	(35)	$N=95$	(42)	(58)
Problem 7	(3,000, 0.90)	$>(6{,}000, 0.45)$	*Problem 7′*	$(-3{,}000, 0.90)$	$<(-6{,}000, 0.45)$
$N=66$	(86)*	(14)	$N=66$	(8)	(92)*
Problem 8	(3,000, 0.002)	$<(6{,}000, 0.001)$	*Problem 8′*	$(-3{,}000, 0.002)$	$>(-6{,}000, 0.001)$
$N=66$	(27)	(73)*	$N=66$	(70)*	(30)

[a]*Source:* Kahneman and Tversky (1979).

Problem 12. In addition to whatever you own, you have been given 2,000. You are now asked to choose between

C: $(-1{,}000, 0.5)$ and D: (-500) $N=68$.
(69) (31)

The results of these questionnaires led to the following empirical generalizations.

(1) Gains are treated differently than losses. (Notice the reversal in signs of preference in the two columns in table 1.) Except for very small probabilities, risk seeking is observed for losses while risk aversion is observed for gains.
(2) Outcomes received with certainty are overweighted relative to uncertain outcomes. (Compare 3 and 3′ with 4 and 4′.)
(3) The structure of the problem may affect choices. Problems 11 and 12 are identical if evaluated with respect to final asset positions but are treated differently by subjects.

Kahneman and Tversky then offer a theory that can predict individual choices, even in the cases in which expected utility theory is violated. In expected utility theory, an individual with initial wealth w will value a prospect $(x, p; y, q)$ as $EU = pU(w+x) + qU(w+y)$ if $p+q=1$. In prospect theory the objective probabilities are replaced by subjective decision weights $\pi(p)$. The utility function is replaced by a value function, v, that is defined over changes in wealth rather than final asset position. For 'regular' prospects (i.e., $p+q<1$ or $x \geqq 0 \geqq y$ or $x \leqq 0 \leqq y$) then the value of a prospect is given by

$$V(x, p; y, q) = \pi(p)v(x) + \pi(q)v(y). \tag{1}$$

If $p+q=1$ and either $x>y>0$ or $x<y<0$ then

$$V(x, p; y, q) = v(y) + \pi(p)[v(x) - v(y)]. \tag{2}$$

The value function is of particular interest here since I will discuss only deterministic choice problems. The essential characteristics of the value function are:

(1) It is defined over gains and losses with respect to some natural reference point. Changes in the reference point can alter choices as in Problems 11 and 12.
(2) It is concave for gains and convex for losses. The shape of the value function is based on the psychophysical principle that the difference

between 0 and 100 seems greater than the difference between 1,000 and 1,100 irrespective of the sign of the magnitudes. This shape explains the observed risk-seeking choices for losses and risks averse choices for gains.[2]

(3) It is steeper for losses than for gains. 'The aggravation that one experiences in losing a sum of money appears to be greater than the pleasure associated with gaining the same amount.'[3]

A hypothetical value function with these properties is pictured in fig. 1.

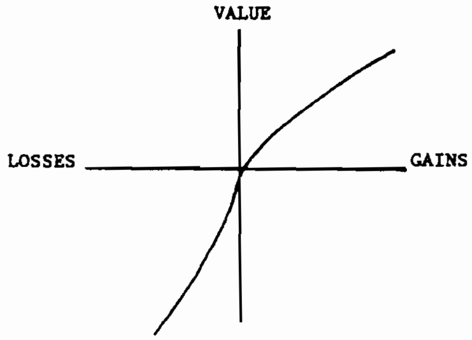


Fig. 1. A hypothetical value function.

Insurance purchasing and gambling are explained through the π function which is regressive with respect to objective probabilities and has discontinuities around 0 and 1. For details, of course, the reader is encouraged to read the original paper.

Example 1. Mr. R bought a case of good wine in the late '50's for about $5 a bottle. A few years later his wine merchant offered to buy the wine back for $100 a bottle. He refused, although he has never paid more than $35 for a bottle of wine.

Example 2. Mr. H mows his own lawn. His neighbor's son would mow it for $8. He wouldn't mow his neighbor's same-sized lawn for $20.

Example 3. Two survey questions: (a) Assume you have been exposed to a disease which if contracted leads to a quick and painless death within a

[2]The loss function will be mitigated by the threat of ruin or other discontinuities. See Kahneman and Tversky (1979, p. 279).

[3]Kahneman and Tversky (1979, p. 279).

week. The probability you have the disease is 0.001. What is the maximum you would be willing to pay for a cure? (b) Suppose volunteers were needed for research on the above disease. All that would be required is that you expose yourself to a 0.001 chance of contracting the disease. What is the minimum payment you would require to volunteer for this program? (You would not be allowed to purchase the cure.)

The results. Many people respond to questions (a) and (b) with answers which differ by an order of magnitude or more! (A typical response is $200 and $10,000.)

These examples have in common sharp differences between buying and selling prices. While such differences *can* be explained using income effects or transactions costs, I will argue that a more parsimonious explanation is available if one distinguishes between the opportunity costs and out-of-pocket costs.

The first lesson of economics is that all costs are (in some sense) opportunity costs. Therefore opportunity costs *should* be treated as equivalent to out-of-pocket costs. How good is this normative advice as a descriptive model? Consider Kahneman and Tversky's Problems 11 and 12. In Problem 11 the gamble is viewed as a chance to gain while in Problem 12 it is viewed as a chance to avert a loss. We know the problems are viewed differently since the majority responses are reversed. Kahneman and Tversky incorporate this in their model by focusing on gains and losses (rather than final asset positions which are identical in these two problems) and by having the loss function steeper than the gains function, $v(x) < -v(x)$. This shape of the value function implies that if out-of-pocket costs are viewed as losses and opportunity costs are viewed as foregone gains, the former will be more heavily weighted. Furthermore, a certain degree of inertia is introduced into the consumer choice process since goods that are included in the individual's endowment will be more highly valued than those not held in the endowment, *ceteris paribus*. This follows because removing a good from the endowment creates a loss while adding the same good (to an endowment without it) generates a gain. Henceforth, I will refer to the underweighting of opportunity costs as the *endowment effect*.

Clearly the endowment effect can explain the behavior in Examples 1–3. In Example 1 it works in two ways. First, as just mentioned, giving up the wine will induce a loss while purchasing the same bottle would create a (less highly weighted) gain. Second, the money paid for a bottle purchased might be viewed as a loss[4] while the money received for the sale would be viewed as a gain.

[4]More about the psychology of spending appears in section 4.

The endowment effect is a hypothesis about behavior. What evidence exists (aside from Kahneman and Tversky's survey data) to support this hypothesis? Unfortunately, there is little in the way of formal tests. One recent study by SRI International does provide some supporting evidence. Weiss, Hall and Dong (1978) studied the schooling decision of participants in the Seattle–Denver Income Maintenance Experiment. They found that variation in the out-of-pocket costs of education had effects which were 'stronger and more systematic than that of a controlled change in opportunity costs'.[5]

An experimental test was conducted by Becker, Ronen and Sorter (1974). They asked MBA students to choose between two projects that differed only in that one had an opportunity cost component while the other had only out-of-pocket costs. The students systematically preferred the projects with the opportunity costs. However, some problems with their experimental design make this evidence inconclusive. [See Neumann and Friedman (1978).]

Other kinds of evidence in support of the endowment effect hypothesis are less direct but perhaps more convincing. I refer to instances in which businesses have used the endowment effect to further their interests.

Credit cards provide a particularly clear example. Until recently, credit card companies banned their affiliated stores from charging higher prices to credit card users. A bill to outlaw such agreements was presented to Congress. When it appeared likely that some kind of bill would pass, the credit card lobby turned its attention to form rather than substance. Specifically, it preferred that any difference between cash and credit card customers take the form of a cash discount rather than a credit card surcharge. This preference makes sense if consumers would view the cash discount as an opportunity cost of using the credit card but the surcharge as an out-of-pocket cost.[6]

The film processing industry seems also to have understood the endowment effect. Some processing companies (notably Fotomat) have a policy whereby they process and print any photographs no matter how badly exposed they are. Customers can ask for refunds (on their next trip if they wish) for any pictures they don't want. The endowment effect helps explain why they are not beseiged by refund requests.

[5] Weiss, Hall and Dong (1978).

[6] In his testimony before the Senate Committee on Banking, Housing and Urban Affairs, Jeffrey Bucher of the Federal Reserve Board argued that surcharges and discounts should be treated the same way. However he reported that 'critics argued that a surcharge carries the connotation of a penalty on credit card users while a discount is viewed as a bonus to cash customers. They contended that this difference in psychological impact makes it more likely that surcharge systems will discourage customers from using credit cards...'. This passage and other details are in United States Senate (1975).

Other marketing strategies can be understood with the use of the endowment effect. Consider the case of a two week trial period with a money back guarantee. At the first decision point the consumer thinks he can lose at most the transactions costs of taking the good home and back. If the transactions costs are less than the value of the utilization of the good for two weeks, then the maximizing consumer pays for the good and takes it home. The second decision point comes two weeks later. If the consumer has fully adapted to the purchase, he views the cost of keeping the good as an opportunity cost. Once this happens the sale is more likely. Of course, it is entirely possible that were the good to be stolen and the price of the good refunded by his insurance company he would fail to repurchase the good.[7]

A final application of the endowment effect comes from the field of sports economics. Harold Demsetz (1972) argues that the reserve clause (which ties a player to a team for life) does not affect the distribution of players among teams. His argument is as follows. Resources go to their highest valued use. Teams are free to sell or trade players to other teams. Thus if a player is owned by one team but valued more highly by another, a transaction will take place. Since the transaction costs appear to be low, the argument seems correct, but the facts clearly contradict the conclusion!

Consider first the free agent draft in football. Teams take turns selecting players who have finished their collegiate eligibility. The teams pick in a specified order. Demsetz (and economic theory) would suggest that teams should draft at their turn the player with the highest market value and then trade or sell him to the team that values him most. Thus we should expect to see a flurry of trades right after the draft. Instead, while drafting rights (i.e., turns to pick) are frequently traded, players drafted are virtually never traded during the period between the draft and the start of the season. Why? Before offering an answer, consider another empirical observation. In baseball over the last few years the reserve clause has been weakened and many players (starting with 'Catfish' Hunter) have become free agents, able to sign with any team. If players are already on the teams where their value is highest these free agents should all re-sign with their former teams (at new higher salaries that give the rents to the player rather than the owner). Yet this has not happened. Instead, virtually all of the players who have become free agents have signed with new teams.

[7]Suppose your neighbors are going to have a garage sale. They offer to sell any of your household goods for you at one half of the original purchase price. You must only tell them which goods to sell and they will take care of everything else, including returning any unsold items. Try to imagine which goods you would decide to sell and which goods you would decide to keep. Now imagine that some of the goods you decided to keep are stolen, and that your insurance will pay you half the original price. If you could also replace them at half price how many would you replace? (Assume identical quantity.) Many people say that there would be some items which they would not sell in the first case *and* wouldn't buy in the second case, even though transactions costs have been made very low in this example.

I believe that the endowment effect can explain at least part of these puzzles. When a player is drafted he becomes part of the fans' endowment. If he is sold or traded this will be treated by the fans as a *loss*. However, when a player is declared a free agent he drops out of the endowment, and the fans will recognize that he can only be regained at substantial *out-of-pocket* expense. Similarly, trading the rights to draft a player will be preferred to trading the player since he will never enter the fans' endowment.

4. Sunk costs: Modeling psychic costs

Example 4. A family pays $40 for tickets to a basketball game to be played 60 miles from their home. On the day of the game there is a snowstorm. They decide to go anyway, but note in passing that had the tickets been given to them, they would have stayed home.

Example 5. A man joins a tennis club and pays a $300 yearly membership fee. After two weeks of playing he develops a tennis elbow. He continues to play (in pain) saying 'I don't want to waste the $300!'

Economic theory implies that only incremental costs and benefits *should* affect decisions. Historical costs should be irrelevant. But do (non-economist) consumers ignore sunk costs in their everyday decisions? As Examples 4 and 5 suggest, I do not believe that they do. Rather, I suggest the alternative hypothesis that paying for the right to use a good or service will increase the rate at which the good will be utilized, *ceteris paribus*. This hypothesis will be referred to as the *sunk cost effect*.

Gathering evidence to test this hypothesis is complicated by problems of selectivity bias. People who have paid to join a tennis club are likely to enjoy tennis more than those who have not, and thus they are likely to use it more than another group who didn't have to pay the membership fee. This problem makes market tests difficult. Other evidence does exist, however, and it is generally supportive.

First, some of Kahneman and Tversky's survey questions indicate a sunk cost effect. For example, one set of subjects preferred (0) to (−800, 0.2; 200, 0.8), while a different set preferred (−1,000, 0.2) to (−200). This suggests that the 200 subtracted from the first problem to obtain the second is not viewed as sunk by the subjects. Kahneman and Tversky also cite the empirical finding that betting on longshots increases during the course of a racing day, again implying that bettors have not adapted to their losses. Similar behavior is well known to anyone who plays poker.

Second, social psychologists have done experiments on a related concept. Aronson and Mills (1959) tested to see whether people who had to undertake considerable effort to obtain something would like it better. Their procedure was to advertise for students to participate in a discussion group. Subjects were then assigned to one of three groups: severe initiation, mild initiation and control. Those in the severe initiation group had to read aloud an embarrassing portion of some sexually oriented material. Those in the mild condition read aloud some more timid material. Those in the control group had no initiation. Basically, the results confirmed the hypothesis of the experimenters. Those in the severe initiation group reported enjoying the subsequent group discussion (which, in fact, was deadly dull) more than those in the other group. These results were later replicated by Gerard and Mathewson (1966).[8]

Third, there are many examples of the government failing to ignore sunk costs. A dramatic example of this was revealed in a Congressional investigation of the Teton Dam disaster.[9] One part of the hearings was devoted to an analysis of the *theory of momentum* — 'that is, the inclination on the part of the Bureau of Reclamation to continue dam construction, once commenced, despite hazards which might emerge during the course of construction...'.[10] The commissioner of the Bureau of Reclamation denied that such a problem existed. However, when asked to 'give an example of any dam whose construction was halted or even paused or interrupted temporarily once the physical construction processes actually began on the dam itself',[11] the Commissioner came up empty handed.

Finally, perhaps the strongest support for the sunk cost hypothesis can be found in the classroom. Anyone who has ever tried to teach this concept knows that it is not intuitively obvious, even to some experienced businesspeople.

4.1. Modeling sunk costs

If the sunk cost effect does exist, it is interesting to speculate on the thought process that produces it. A reasonable explanation can be offered using prospect theory. First, however, we must consider the individual's psychic accounting system. To do this it is necessary to introduce a psychic equivalent to debits and credits which, for lack of better terms, I will call pleasure and pain. In terms of prospect theory, pleasure can be thought of as the value function in the domain of gains while pain corresponds to the value function in the domain of losses. (Henceforth, for expository purposes,

[8] I also plan some experiments to test the sunk cost effect. In one pilot study undertaken by one of my students, Lewis Broad, customers at an all-you-can-eat pizza restaurant were randomly given free lunches. They, in fact, ate less than the control group who paid the $2.50 normal bill.

[9] This example was suggested by Paul Slovic.

[10] U.S. Government (1976, p. 14). This issue was raised because the Bureau had in fact received such warnings about the Teton Dam.

[11] *Ibid*, p. 14.

I will refer to the value function for losses as $\tilde{v}$.) When will a customer feel pain? Pain will *not* be felt when a purchase is made for immediate consumption (like buying a hamburger for lunch) as long as the price is 'reasonable'. If the value of the hamburger is g and the cost is c, then the net pleasure will be $v(g)+\tilde{v}(-c)$.[12] Only in the event of a loss will there be actual net pain.

Now, however, consider the case described in Example 4. When the basketball tickets are purchased the consumer just exchanges cash for an asset (the tickets). At this point the consumer *could* experience \$40 worth of pain with the expectation of feeling pleasure at the game as if the tickets had been free, but this seems unlikely. A much more plausible story is that no pain or pleasure is felt at this point except perhaps in anticipation of the game. Then when the game is attended the consumer feels net pleasure as in the case of the hamburger. The snowstorm, however, creates a problem. If the tickets aren't used then their value has become zero and the consumer should feel a \$40 loss ($\tilde{v}(-40)$). But, the economist would say, how does going to the game help? Let's assume that the cost of going to the game through the snow is c and the value of seeing the game is g. (I will ignore uncertainty about getting to the game as it would add nothing to the analysis.) Further, assume that had the tickets been free, the consumer would have been indifferent about going, i.e., $v(g)=-\tilde{v}(-c)$. In this case the \$40 paid for the tickets will induce the consumer to go since $v(g)+\tilde{v}(-(c+40)) > \tilde{v}(-40)$ due to the convexity of $\tilde{v}$.

4.2. *Sunk costs and multipart pricing*

Example 5 can be used to illustrate an application of the sunk cost effect in microeconomics. The tennis club uses a two-part pricing scheme. The membership fee is \$300 and the court fees are \$10 per hour. Suppose the membership fee is raised to \$400 keeping the court fees fixed. The standard theory would predict the following effects: (i) some members will drop out, (ii) those who remain will use the club slightly less because of the income effect of the increased membership fee (assuming tennis playing is normal), and (iii) *average* utilization will rise if the change in the mix of members toward higher demanders outweighs the income effect, otherwise average utilization will fall. Total utilization will certainly fall.

If the sunk cost effect is valid then the analysis of effect (ii) must be changed. The sunk cost effect will increase utilization, which is in the

[12]What if the price is 'unreasonable'? In this case the consumer will feel pain that is a function of the difference between the price paid and some reference (or just) price. Similarly if the price is especially low there will be extra pleasure that is related to the difference between the reference price and the price paid. A complete analysis of these issues will be presented in a future paper.

opposite direction of the income effect. If the sunk cost effect is large enough in magnitude, then raising the membership fee could increase *total* utilization. Given the wide ranging uses of multipart pricing this analysis could have many important applications.

5. Searching and the psychophysics of prices

Example 6. (a) You set off to buy a clock radio at what you believe to be the cheapest store in your area. When you arrive, you find that the radio costs $25, a price consistent with your priors (the suggested retail price is $35). As you are about to make the purchase, a reliable friend comes by and tells you that the same radio is selling for $20 at another store ten minutes away. Do you go to the other store? What is the minimum price differential which would induce you to go to the other store? (b) Now suppose that instead of a radio you are buying a color television for $500 and your friend tells you it is available at the other store for $495. Same questions.

On the second page of his price theory text, George Stigler (1970) states a traditional theory of consumer search behavior:

> 'To maximize his utility the buyer searches for additional prices until the expected saving from the purchase equals the cost of visiting one more dealer. Then he stops searching, and buys from the dealer who quotes the lowest price he has encountered.'

Example 6 suggests an alternative to Stigler's theory. The alternative theory states that search for any purchase will continue until the expected amount saved as a proportion of the total price equals some critical value.

This hypothesis is a simple application of the Weber–Fechner law of psychophysics.[13] The law states that the just noticeable difference in any stimulus is proportional to the stimulus. If the stimulus is price then the law implies that

$$\Delta p/p = k,$$

where Δp is the just noticeable difference, p is the mean price, and k is a constant.

Again this hypothesis is difficult to test empirically. However, a recent paper by Pratt, Wise, and Zeckhauser (1977) studied price dispersions of consumer goods and found nearly a linear relationship between the mean price of a good and its standard deviation. They interpret this result as inconsistent with the standard search theory: 'if search costs were constant,

[13]For more on the Weber–Fechner Law see Stigler (1965).

we might expect that the expected gains from searching would lead to ratios between standard deviation and price that declined rather rapidly with mean price'.[14] While these results are supportive, they are inconclusive because the observed price dispersions represent an equilibrium resulting from both buyer *and* seller behavior. Thus even if consumers searched optimally, firm behavior could produce this result. A cleaner test may only be possible experimentally.

Because of its psychophysical foundation, prospect theory can be used to model search behavior as observed in Example 6. To see how, reconsider eq. (2) (repeated here for convenience),

$$V(x,p;y,q)=v(y)+\pi(p)[v(x)-v(y)]. \tag{2}$$

Notice that the decision weight given to the chance of winning, $\pi(p)$, is multiplied by the difference in the variation of the alternative prizes $(v(x)-v(y))$ rather than the value of the monetary differences $(v(x-y))$. Because of the concavity of $v, v(x)-v(y)<v(x-y)$. Similarly, the value of obtaining the clock radio at $20 instead of $25 would be $\tilde{v}(-25)-\tilde{v}(-20)$ which is greater than $\tilde{v}(-500)-\tilde{v}(-495)$ because of the convexity of $\tilde{v}$. Put simply, $5 seems like a lot to save on a $25 radio but not much on a $500 TV. Needless to say, it would be virtually unnoticed on a $5,000 car.

Market behavior consistent with this hypothesis is easy to find. An old selling trick is to quote a low price for a stripped-down model and then coax the consumer into a more expensive version in a series of increments each of which seems small relative to the entire purchase. (One reason why new cars have whitewall tires and old cars do not is that $20 seems a small extra to equip a *car* with whitewalls but a large extra for a new set of *tires*.) Funeral parlors, as well as automobile dealers, are said to make a living off this idea.[15]

6. Choosing not to choose: Regret

Example 7.[16] Members of the Israeli Army display a resistance to trading patrol assignments, even when it would be convenient for both individuals to do so.

[14]Pratt, Wise, and Zeckhauser (1977, p. 22).

[15]Madison Avenue also seems to understand this principle. An advertisement appeared on television recently for a variable month car loan (46 months, say, instead of the usual 48). The bank wanted to stress the amount of interest that could be saved by financing the car over two fewer months. In the advertisement an actor had about $5,000 in bills stacked up on a table to represent the total amount of money repaid. He then took $37 representing the interest saved, removed it from the pile, and said, 'It may not seem like a lot here...' (pointing to the pile) '...but it will feel like a lot here' (pointing to his wallet).

[16]This example is due to Daniel Kahneman and Amos Tversky.

Example 8.[17] Mr. A is waiting in line at a movie theater. When he gets to the ticket window he is told that as the 100,000th customer of the theater he has just won $100.

Mr. B is waiting in line at a different theater. The man in front of him wins $1,000 for being the 1,000,000th customer of the theater. Mr. B wins $150.

Would you rather be Mr. A or Mr. B?

This and the following section discuss situations where individuals voluntarily restrict their choices. In section 5 the motive is self-control. Choices in the future are reduced because the current self doesn't trust the future self. In this section we consider a motive for reducing choice which is a special kind of decision-making cost. Here the act of choosing or even just the knowledge that choice exists induces costs, and these costs can be reduced or eliminated by restricting the choice set in advance. These costs fall into the general category of *regret* which will be defined to include the related concepts of *guilt* and *responsibility*.

That responsibility can cause regret is well illustrated by Example 7. If two men trade assignments and one is killed, the other must live with the knowledge that it could (should?) have been he. By avoiding such trades these costs are reduced. Since the opportunity to exchange assignments must surely be a valued convenience, the observed resistance to trading suggests that the potential responsibility costs are non-trivial.

Sometimes just information can induce psychic costs. This is obvious, since it is always possible to make someone feel terrible just by relating a horror story of sufficient horror. Example 8 illustrates the point in a more interesting way. There seems little doubt that were the prizes won by Mr. A and Mr. B the same, Mr. A would be better off. The knowledge that he just missed winning causes regret to Mr. B, enough to cause some people to prefer Mr. A's position in the example as stated!

Whenever choice can induce regret consumers have an incentive to eliminate the choice. They will do so whenever the expected increase in utility (pleasure) derived from making their own choices is less than the expected psychic costs which the choices will induce.

Regret, in prospect theory, can be modeled through induced changes in the reference point. In Example 8, Mr. A simply gains $100 or $v(100)$. Mr. B however must deal with the near miss. If, for example, the person in front of him cut into the line he may feel he has gained $150 but lost $1,000 yielding $v(150)+\tilde{v}(-1{,}000)$.

Two markets seem to have been strongly influenced by this preference for not choosing: the health care industry, and the vacation and recreation industry.

[17] This example is due to Ronald Howard.

Choosing not to choose is apparent at many levels in the health care industry. It explains, I believe, two major institutional features of the health delivery system. A puzzle for many economists who have studied the industry is the popularity of shallow, first dollar (no deductible or low deductible) coverage which is precisely the opposite pattern which would be predicted by a theoretical analysis of the problem. Many economists have criticized the system because the insurance creates a zero marginal cost situation for most consumers and this, it is argued, helps create the massive inflation we have experienced in this sector in recent years. The analysis may be correct, but an important issue seems ignored. Why do consumers want the first dollar coverage? I believe the reasons involve regret. Most consumers find decisions involving tradeoffs between health care and money very distasteful. This is especially true when the decision is made for someone else like a child. A high deductible policy would force individuals to make many such decisions, at considerable psychic costs. The costs can occur no matter which way the decision is made. Consider a couple which must decide whether to spend $\$X$ for a diagnostic test for their child. There is some small probability p that the child has a serious disease which could be treated if detected early enough. There will surely be regret if the decision is made not to get the test and the child later is found to have the disease. If the disease can be fatal, then the regret may loom so large that the test will be administered even for very large values of X or very small values of p. Yet once the test is ordered and the likely negative result is obtained, the couple may regret the expenditure, especially if it is large relative to their income. Obviously, these costs are avoided if all health care is prepaid, via either first dollar coverage or a prepaid health organization.

Though many individuals seem averse to explicit tradeoffs between money and health, money does not have to be at stake for regret to enter the picture. The health industry has frequently been criticized for failing to involve the patient in the decision-making process, even when no out-of-pocket expenses are involved. Again, regret seems to provide an attractive explanation for this characteristic of the system. Suppose that a patient must have an operation, but two different procedures are possible. Assume that only one of the procedures can ever be attempted on any individual, that each has the same probability of success and (to make the case as clean as possible) that physicians know that if one procedure doesn't work the other would have. Clearly in this situation a rational consumer would want the physician to make the choice and furthermore, he would not want to know that a choice existed! In less dramatic examples there will still be an incentive to let the physician choose, particularly if the physician knows the patient well (and thus can do a good job of reflecting the patient's preferences).

Of course the physician must then bear all the responsibility costs so there may be advantages to further delegation. One method is to obtain a second opinion, which at least divides the responsibility. Another is to utilize rules-of-thumb and standard-operating-procedures which may eliminate the costs altogether.[18]

The other major example of the market yielding to consumer preferences to not choose is the recreation industry. An excellent case in point is Club Med which is actually not a club but rather a world-wide chain of resort hotels.[19] One heavily promoted characteristic of the resorts is that they are virtually cashless. Almost all activities including food and drink are prepaid, and extra drinks are paid for via poppit beads which are worn necklace style.[20] This example presents an interesting contrast with the health example. Consumers may feel guilty about not buying health and guilty about spending on their vacation. Having everything prepaid avoids decisions about whether to *spend* to do something, and reduces the psychic costs of engaging in the costly activities. The reduction in psychic costs may be enough so that a consumer would prefer to spend $1,000 for a vacation than to spend $400 on plane fare and another $500 in $20 increments, especially given the hypothesis of the preceding section. Club Med has taken the prepaid concept furthest, but the basic idea is prevalent in the recreation industry. Other examples include ocean cruises, 'package travel tours', and one price amusement parks such as Marriot's Great America.

7. Precommitment and self-control[21]

Example 9. A group of hungry economists is awaiting dinner when a large can of cashews is opened and placed on the coffee table. After half the can is devoured in three minutes, everyone agrees to put the rest of the cashews into the pantry.

Example 10. Professor X agreed to give a paper at the AEA meetings 'to assure that the paper would get written by the end of the year'.

[18] I should add here that these comments about the health sector are strictly of a *positive* nature. I am simply offering an explanation of why the institutions are structured as they are. Policy implications must be drawn carefully.

[19] This example was suggested by Paul Joskow.

[20] 'Cash is useless at Club Med. You prepay your vacation before leaving home. Included in the price are room accommodations, three fabulous meals each day, all the wine you can drink at lunch and dinner, scores of sports activities, plus expert instruction and use of rent-free sporting equipment. The only extras, if there are any, are totally up to you. Drinks at the bar, boutique purchases, optimal excursions, beauty salon visits — simply sign and then pay for them before leaving the village. And there's no tipping. So it couldn't be easier to stick to your vacation budget' (from a Club Med Brochure).

[21] The ideas in this section are explored in detail in Thaler and Shefrin (1979). Details on the formal model appear in Shefrin and Thaler (1979). Others who have written in this area are Ainslee (1975), Schelling (1978), Elster (1977) and Scitovsky (1976).

A basic axiom of economic theory is that additional choices can only make one better-off (and that an additional constraint can only make one worse-off). An exception is sometimes made due to decision-making costs, a concept that was expanded to include regret in the previous section. This section demonstrates that the axiom is also violated when self-control problems are present.

The question examined now is why individuals impose rules on themselves. This question was brought to economists' attention by Strotz (1955/56) in his now classic paper on dynamic inconsistency. Strotz begins his article with a famous quote from the Odyssey:

> '...but you must bind me hard and fast, so that I cannot stir from the spot where you will stand me . . . and if I beg you to release me, you must tighten and add to my bonds.'

Strotz described Ulysses' problem as one of *changing tastes*. He now would prefer not to steer his ship upon the rocks, but he knows that once he hears the Sirens he will want to get closer to their source and thus to the rocks. The solution Ulysses adopts is to have his crew tie him to the mast. Strotz refers to this type of solution as *precommitment*.

Strotz's formal model concerns savings behavior. How should an individual allocate a fixed exhaustible resource over his lifetime? The major finding in Strotz's paper is that unless the individual has an exponential discount function, he will not follow his own plan. That is, if at time t the individual reconsiders a plan formulated at time $t' < t$, he will change the plan. Thus people will be *inconsistent* over time. While changing tastes can explain inconsistency, they cannot explain precommitment. Why should the person with changing tastes bind himself to his *current* preferences, knowing that he will wish to break the binds in each succeeding period? Yet there is no denying the popularity of precommitment devices. One such device which has always been an enigma to economists is Christmas clubs which currently attract over one billion dollars a year in deposits from millions of depositors. Other examples of precommitment are discussed below.

The key to understanding precommitment is to recognize that it is a device used to solve problems of *self-control*. While this seems obvious, it has not been incorporated in the formal models of dynamic choice behavior. Yet it is not difficult to do so. The concept of self-control suggests the existence of a controller and a controllee. To capture this, the individual can be modeled as an organization with a *planner* and a series of *doers*, one for every time period. Conflict arises because the current doer's preferences are always myopic relative to the planner's. This conflict creates a *control problem* of the same variety as those present in any organization. Since the planner's preferences are consistent over time it does make sense for him to adopt rules to govern the doers' behavior. These rules are adopted for the same reasons employees are not given complete discretion: the existence of a conflict of interest.

Since the full details of the model are available elsewhere I will limit my discussion here to the predictions of the model regarding market behavior. One immediate implication of the model is that self-control problems will be most important for those consumption activities which have a time dimension. Since the planner maximizes a function that depends on the doers' utilities, if all the costs and benefits of a particular activity occur in the present there will be no conflict. Of course, as long as there is a finite budget constraint, any current consumption will reduce future consumption, but the conflicts are likely to be greatest for saving *per se* and for those activities which have an explicit time dimension. For lack of a better term, I will refer to such activities as *investment goods*. Further, goods whose benefits accrue later than their costs (such as education and exercise) are termed *positive investment goods*, while those with the opposite time structure (such as tobacco and alcohol) are termed *negative investment goods*.

Since precommitment usually requires external help (Ulysses needed his crew to tie him to the mast), if it is an important phenomenon we should expect to see evidence of market provision of precommitment services in the investment goods industries. Indeed, such evidence is abundant.

Negative investment goods provide the most dramatic examples: Alcoholics Anonymous, drug abuse centers, diet clubs, 'fat farms', and smoking clinics. Note that addiction is not the only factor involved in these services. Calling food addictive is stretching the definition somewhat, so the diet clubs and fat farms can be considered pure self-control administrators. Even the drug examples such as Alcoholics Anonymous perform most of their activities for individuals who are 'on the wagon'. The problem is not that they are addicted to alcohol, rather that they would quickly become re-addicted. The problem is to avoid the first drink, and AA helps them do that. One extreme technique of precommitment used by alcoholics is taking the drug antabuse which makes the individual sick if he ingests any alcohol.

The most obvious positive investment good is saving itself, and here we find an industry dominated by precommitment devices. Christmas clubs, which have already been mentioned, were particularly noteworthy in previous years because they paid no interest and were thus a 'pure' self-control device.[22] Another curious savings institution is the passbook loan. A typical example would be of an individual who had $8,000 in a savings account and wanted to buy a $5,000 car. Rather than withdraw the $5,000 and lose the $5\frac{1}{2}\%$ interest it was earning the individual uses the money in the

[22]The vice president of one savings bank has reported to me the results of a survey his bank completed on Christmas club users. They found that the average savings account balance of Christmas club users was over $3,000. This suggests that Christmas clubs should not be considered as a device for people who can't save but as a tool of people who do!

account as collateral for a loan at 8%. These loans are reasonably popular, in spite of the obvious interest costs, because they guarantee that the money in the savings account will be replaced and not spent. A final example is whole life insurance which is often alleged to be a bad investment but again provides a specific savings *plan.*

Other investment goods such as education and exercise evidence self-control considerations in their pricing policies. Virtually all such services are sold via prepaid packages. This device lowers the cost to the doer of engaging in the investment activity on a day-to-day basis. If the sunk cost effect is also present then the membership fee will also act as an actual inducement to go.

8. Conclusion

Friedman and Savage (1948) defend economic theory as a positive science using an analogy to a billiard player:

> 'Consider the problem of predicting, before each shot, the direction of travel of a billiard ball hit by an expert billiard player. It would be possible to construct one or more mathematical formulas that would give the direction of travel that would score points and, among these, would indicate the one (or more) that would leave the balls in the best positions. The formulas might, of course, be extremely complicated, since they would necessarily take account of the location of the balls in relationship to one another and to the cushions and of the complicated phenomena introduced by 'english'. Nonetheless, it seems not at all unreasonable that excellent predictions would be yielded by the hypothesis that the billiard player made his shots *as if* he knew the formulas, could estimate accurately by eye the angles etc., from the formulas, and could then make the ball travel in the direction indicated by the formulas. It would in no way disprove or contradict the hypothesis or weaken our confidence in it, if it should turn out that the billiard player had never studied any branch of mathematics and was utterly incapable of making the necessary calculations: unless he was capable in some way of reaching approximately the same result as that obtained from the formulas, he would not in fact be likely to be an expert billiard player.'[23]

I would like to make two points about this passage and the relationship between Friedman and Savage's position and mine. First, I do not base my critique of the economic theory of the consumer on an attack of the assumptions. I agree with Friedman and Savage that positive theories should be evaluated on the basis of their ability to predict behavior. In my

[23] Friedman and Savage (1948, p. 298).

judgment, for the classes of problems discussed in this paper, economic theory fails this test.

Second, Friedman and Savage only claim that their mathematical model would be a good predictor of the behavior of an *expert* billiard player. It is instructive to consider how one might build models of two non-experts.

A novice who has played only a few times will mainly be concerned with the choice of what ball to try to sink, which will depend primarily on the *perceived* degree of difficulty of the shot. (In contrast, an expert can make nearly any open shot and is likely to sink 50 or more in a row. Thus he will be concerned with planning several shots ahead.) The novice will use little or no 'english', will pay little attention to where the cue ball goes after the shot, and may be subject to some optical illusions that cause him to systematically mishit some other shots.

An intermediate player who has played an average of two hours a week for twenty years may only average 4 or 5 balls per turn (compared with expert's 50). He will have much less control of the cue ball after it strikes another ball and will have some shots that he knows cause him trouble (perhaps long-bank shots or sharp angles). He will plan ahead, but rarely more than one or two shots.

Clearly, descriptive models for the novice or intermediate will have to be quite different than the model for the expert. If one wanted to model the behavior of the *average* billiard player, the model selected would be for some kind of intermediate player, and would probably resemble the model of the novice more than the model of the expert. Rules-of-thumb and heuristics would have important roles in this model.

It is important to stress that both the novice and intermediate players described above behave rationally. They choose different shots than the expert does because they have different technologies. Nonetheless, the expert model has a distinct normative flavor. The model chooses from all the shots available the *best* shot. Thus the novice and intermediate players choose rationally and yet violate a normative model. The reason, of course, is that the model is not an acceptable normative (or positive) model for *them*. The novice model (aim at the ball that seems easiest to sink — don't worry about much else) is also a normative model. It is the best the novice can do. Clearly the relationship between rationality and normative models is a delicate one.

How does consumer behavior relate to billiard behavior? Again there will be various classes of consumers. Some will be experts (Ph.D's in Economics?), others will be novices (children?). What I have argued in this paper is that the orthodox economic model of consumer behavior is, in essence, a model of robot-like experts. As such, it does a poor job of predicting the behavior of the average consumer.[24] This is not because the

[24]Some related issues have been discussed in the literature on the theory of the firm. See, for example, Winter (1975) and the references cited therein.

average consumer is dumb, but rather that he does not spend all of his time thinking about how to make decisions. A grocery shopper, like the intermediate billard player, spends a couple of hours a week shopping and devotes a rational amount of (scarce) mental energy to that task. Sensible rules-of-thumb, such as don't waste, may lead to occasional deviations from the expert model, such as the failure to ignore sunk costs, but these shoppers are doing the best they can.

Prospect theory and the planner–doer model attempt to describe *human* decision-makers coping with a very complex and demanding world. Failure to develop positive theories such as these will leave economists wondering why people are frequently aiming at the balls lined up right in front of the pockets rather than at the three ball carom their computer model has identified as being iptimal.

References

Ainslie, George, 1975, Specious reward: A behavioral theory of impulsiveness and impulse control, Psychological Bulletin 82, no. 4, July, 463–496.

Allais, M., 1953, Le compartement de l'homme rationnel devant le risque, critique des postulats et axiomes de l'ecole Americaine, Econometrica 21, 503–546.

Aronson, Elliot and Judson Mills, 1959, The effects of severity of initiation on liking for a group, Journal of Abnormal and Social Psychology 59, 177–181.

Becker, Gary S., 1962, Irrational behavior and economic theory, Journal of Political Economy, Feb., 1–13.

Beeker, S., J. Ronen and G. Sorter, 1974, Opportunity costs — An experimental approach, Journal of Accounting Research, 317–329.

Demsetz, Harold, 1972, When does the rule of liability matter, Journal of Legal Studies, Jan., 13, 28.

Elster, Jon, 1977, Ulysses and the sirens: A theory of imperfect rationality, Social Science Information XVI, no. 5, 469–526.

Friedman, M. and L.J. Savage, 1948, The utility analysis of choices involving risks, Journal of Political Economy 56, 279–304.

Gerard, Harold B. and Groves C. Mathewson, 1966, The effects of severity of initiation on liking for a group: A replication, Journal of Experimental Social Psychology 2, 278–287.

Grether, David M., 1979, Bayes rule as a descriptive model: The representativeness heuristic, Social Science Working Paper no. 245 (California Institute of Technology) Jan.

Grether, D. and C. Plott, 1979, Economic theory of choice and the preference reversal phenomenon, American Economic Review, Sept., 623–638.

Kagel, John and Ramond Battalio, 1975, Experimental studies of consumer behavior using laboratory animals, Economic Inquiry, March, 22–38.

Kahneman, Daniel and Amos Tversky, 1979, Prospect theory, an analysis of decision under risk, Econometrica 47, March.

McGlothin, W.H., 1956, Stability of choices among uncertain alternatives, American Journal of Psychology 69, 604–615.

Neumann, B.R. and L.A. Friedman, 1978, Opportunity costs: Further evidence through an experimental replication, Journal of Accounting Research, Autumn, 400–410.

Pratt, John, David Wise and Richard Zeckhauser, 1977, Price variations in almost competitive markets (Harvard University, Kennedy School of Government, Cambridge, MA).

Schelling, T.C., 1978, Egonomics, or the art of self-management, The American Economic Review 63, no. 2, May, 290–294.

Scitovsky, Tibor, 1976, The joyless economy (Oxford University Press, New York).

Shefrin, H.M. and Richard Thaler, 1979, Rules and discretion in intertemporal choice (Cornell University, Ithaca, NY) June.

Simon, Herbert, 1957, Models of man (Wiley, New York).

Stigler, George, 1965, Essays in the history of economics (University of Chicago Press, Chicago, IL).

Stigler, George, 1970, The theory of price (Macmillan, New York).

Slovic, Paul, Baruch Fischhoff and Sarah Lichtenstein, 1977, Behavioral decision theory, Annual Review of Psychology 28, 1–39.

Strotz, Robert, 1955/56, Myopia and inconsistency in dynamic utility maximization, Review of Economic Studies 23, 165–180.

Thaler, Richard and H.M. Shefrin, 1979, An economic theory of self-control (Cornell University, Ithaca, NY) June.

Tversky, Amos and Daniel Kahneman, 1974, Judgment under uncertainty: Heuristics and biases, Science, 1124–1131.

United States Congress Committee on Government Operations, 1976, Teton dam disaster, Union Calendar no. 837, House Report no. 94–1667, Sept., 23.

United States Senate Hearings before the Subcommittee on Consumer Affairs of the Committee on Banking, Housing and Urban Affairs, 1975, Oct. 9.

Von Neumann, J. and O. Morgenstern, 1944, Theory of games and economic behavior (Princeton University Press, Princeton, NJ).

Weiss, Y., A. Hall and F. Dong, 1978, The effect of price and income in the investment in schooling: Evidence from the Seattle–Denver NIT experiment, SRI International.

Winter, Sidney, 1975, Optimization and evaluation in the theory of the firm, in: Richard Day and Theodore Groves, eds., Adaptive economic models (Academic Press, New York).

PART V

APPROACHES FOR MANAGING RISK

DECISION ANALYSIS FOR THE EVALUATION OF RISK IN NUCLEAR WASTE MANAGEMENT*

John W. Lathrop**
International Institute for Applied Systems Analysis, Laxenburg, Austria

Stephen R. Watson
Emmanuel College, Cambridge, UK

The implementation of a nuclear waste management technology raises several issues concerning the regulation of social risk. The most basic of those issues are how to regulate a technology when the uncertainties in social consequences are important, and how to incorporate the relevant social values in the regulations. This paper presents a decision analytic approach to resolving these issues, based on the development of radiological risk evaluation indices. While it is essentially a case study, describing work carried out for the U.S. Nuclear Regulatory Commission, this case is used to discuss the more general issues involved.

We begin by discussing the need for risk evaluation to provide a clear and defensible basis for regulating technologies involving social risk. We then present a development of risk evaluation indices for the regulation of nuclear waste management. The indices developed are expected utilities, based on preferences elicited from groups of people. The use of the indices developed is illustrated in a hypothetical example, and the usefulness of the methodology evaluated.

*A version of this paper is to appear in the *Journal of the Operational Research Society*. This version appears here with the kind permission of that journal.
**Authors are listed in alphabetical order.

INTRODUCTION

Over the past two decades or so there has been increasing concern over the use of many modern technologies. While much of this concern results from the demonstrable and existing deleterious side effects of these technologies (for example, the effect on animal and plant life of pollution from many chemical plants, or the cumulative effects in the food chain of insecticides like DDT), there are some technologies for which the cause for concern is potential rather than actual (for example the depletion of the ozone layer by chlorofluorocarbons and by the exhaust gases of supersonic transports, or potential radiation releases from buried nuclear wastes). Governments are concerned to control both kinds of technological side-effects, but the appropriate regulatory action is much more difficult to determine in the latter case, where there is considerable uncertainty about the possible nature of the consequences of the technology, and where they can occur in the distant future.

In this paper we discuss how the paradigm of decision analysis might be used to establish an index which can evaluate the risk associated with activities of the latter kind; in particular we shall exemplify our suggestions throughout by reference to the problem of regulating nuclear waste management. At the outset we ought to stress that we are not using 'risk' in the sense normally used in decision analysis. In bringing together decision analysis and risk evaluation, we must adopt terms that clearly distinguish concepts often confused between the two fields. In particular, 'risk' will be used to describe the potential for deleterious consequences associated with a technology, while 'uncertainty' will be used to describe the lack of information available concerning what the impacts of a technology might be.

The need for risks to be analyzed if they are to be adequately managed is beginning to be widely recognised. The important studies by Rowe[1] and Lowrance[2] on the nature and management of risk have been followed by a collection of papers outlining research needs and opportunities in this area, edited by Kates[3]. Our goal in this paper is to add to the emerging literature of this discipline by describing a particular approach to risk assessment, using decision analysis. This is a controversial area; for example, the criticisms by Lovins[4] and Cochran[5] of the decision analysis of alternatives for electricity generation carried out by Barrager et al[6], are paralleled by Hoos' attack[7] on the use of risk analysis for nuclear waste management and the critical comments of Tocher[8] concerning the use of decision analytic concepts in any social planning activity. These authors give many detailed arguments against particular quantitative methods; the reader is urged to consult them as an antidote to overconfidence in the methods of systems analysis, and decision analysis in particular. However, it is fair to say that most of their criticisms are destructive in nature and often might easily be paralleled by similar criticisms of alternative informal and traditional methods of decision making and regulation setting. It is our strong belief that if used properly, the quantitative methods of decision analysis, while subject to some valid criticism, improve decision making in that they provide a consistent base for analysis and improve communication. In many cases the informal methods share all the flaws of the formal approach; it is just that their very informality obscures the fact that these flaws exist.

In the next Section we describe in detail a decision analytic approach to the evaluation of risk and how this method was used to construct risk evaluation indices for the regulation of nuclear waste management. The following section describes the results of our work in terms of a hypothetical example, which also serves to illustrate the role of the approach in the development of regulations. The last section briefly comments on the present and potential usefulness of the approach. This work was carried out for the U.S. Nuclear Regulatory Commission (NRC) under the direction of Lawrence Livermore Laboratory. Larger reports (Lathrop [9],Watson and Campbell[10]) contain more detailed descriptions of the project and the results of the study.

DEVELOPMENT OF A RISK EVALUATION INDEX

Quantitative approaches to risk measurement have quite a long history. (See Farmer[11], Starr[12] and the bibliography of Clark and Van Horn [13].) Broadly speaking, they have all recognized that a measure of risk should be an increasing function of the probabilities of deleterious consequences, and the severity of those consequences. A measure often chosen has been expected fatalities. Shortcomings of this criterion include its inability to cope with attitudes toward uncertainty (Who feels that a 50-50 chance of two deaths is just as bad as one certain fatality?), and the exclusion from consideration of consequences other than death (which in the case of radiation exposure includes effects as significant as genetic mutations). Papp et al[14] recognized this inadequacy and suggested that it should be rectified by using utility theory; the present paper describes how we have followed this suggestion for nuclear waste management.

Very briefly put, our approach consists of developing a multidimensional utility function over the health-effect consequences of a nuclear waste management system, separately assessing a probability distribution over those consequences for each alternative system, and then calculating the risk index for each system as its expected utility. Because our utility function increases with the severity of negative consequences (contrary to convention), the risk index is an increasing function of probability and severity of consequences, as desired. As explained by Howard,[15] the expected utility represents preferences for uncertain outcomes on a cardinal scale, ranking complex alternatives in a manner consistent with preferences revealed in comparisons of simple alternatives. While the basic ideas of this approach are relatively straightforward, there are several steps in its implementation. We shall now describe those steps as we encountered them in our development of a risk index, some of the problems each step entailed, and how we dealt with them.

Consequence Scope

In constructing a utility function describing consequences, we first had to specify the important possible consequences of a nuclear waste repository. The most significant possible effects are, clearly, health effects on humans, but there are many others, such as effects on animal and plant life, restrictions of civil liberties and restrictions on land use. We made a modeling decision at this stage to limit attention to health effects on humans. This limits, of course, the use to which our risk index can be put, since in comparing repositories any of the other possible consequences may be of significance. However, the purpose of this study was not to analyze specific decisions on the location and design of repositories, let alone whether or not radioactive waste should be generated; it had the lesser, but still important goal of providing a measuring device for only one aspect of the waste management problem, namely the health risk to humans. Here is an example of the methods of decision analysis contributing to public policy formation by analyzing part of the problem. In our experience, such partial analyses are much more likely to be used and useful than any attempt to bring the whole decision making process for an issue of public policy under the hammer of hard analytic methods.

Value Source

The idea of using decision analysis on public policy issues is, of course, not new. Both Howard[15] and Edwards[16] have proposed schemes for social decision analysis. One of the problems which such schemes raise, however, is the determination of whose values should be represented in the utility function. In an evaluation of the risk in waste management it would seem desirable somehow to reflect public values; but these may differ importantly from person to person--how may such differences be combined into one index? It should be helpful here to find some method of aggregating individual utility functions to create a group utility function. While there are difficulties in specifying such a procedure (as Seaver[17], p 14, observes, "no entirely satisfactory method for devising group utilities exists"), the work of Keeney and Kirkwood[18] cites theoretical support for the idea of using a weighted sum of utility functions as a group utility function, the weights to be determined by a "benevolent dictator" or an "honest broker". At the same time, the weights given to people with markedly different stands on a policy issue represent trade-offs perhaps best made in the course of the political process, not in the risk analysis.

The relevant political process in this case centers on the NRC, which is effectively charged with balancing the political interests of any conflicting parties. There is always reason to suspect that any regulatory agency is subject to disproportionate pressure from the industry it is supposed to monitor, so that such an agency may not be an ideal umpire of conflicting interests (see, e.g., Hoos[7]). However, the goal of the approach described here is not to reform the political process, but simply to develop a risk evaluation methodology that incorporates social values into the existing political process. Consequently, we drew the bounds between the evaluation and the process it is to serve, and decided to represent separately the values for four groups, described below. The groups chosen were ones to which the NRC is responsive, which span the political spectrum of interests faced by the NRC, and within which values could be expected to be relatively homogenous. While this strategy avoids aggregating values across conflicting groups of people, values must still be aggregated across individuals within each homogenous group to arrive at a group utility function. That aggregation is explained later.

In the study, 58 people were interviewed and utility functions elicited from each of them. They were divided into groups as follows:

a. National Advisors (13 respondents)

   This group consisted of persons who had the ear of the Federal policy-makers in that they either served on nuclear waste advisory bodies, or their views were published or otherwise consulted by Government policy-makers.

b. Concerned Citizens (33 respondents)

   The intent in this case was to select citizens who were at least somewhat abreast of social issues and who were concerned that Government actions should reflect the general public interest.

c. Nuclear Power Opponents (7 respondents)

   These were persons who were known publicly to oppose further development of nuclear power, at least until safety problems have been resolved.

d. Nuclear Power Advocates (5 respondents)

These were persons who had been identified as advocates of the further development of nuclear power. Some of the respondents in this group maintained that they did not consider themselves as advocates of nuclear power.

Group utility functions for each of these four groups were calculated as weighted sums of the individual utility functions. Then these were combined with example probability distributions describing different repositories, producing four distinct risk evaluation indices for each repository. We return to the results of these calculations later. Because of our decision to elicit utility functions from so many people, it was necessary to construct a simple standard form for the utility functions, which called for several approximations in the following steps.

Consequences

One of the basic problems of approximation concerned how to describe health effects. The first widely used and definitive discussion on the health effects of radiation is the 1972 report of the U.S. National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation[19] (the BEIR report). It is apparent from this and other documents (see ICRP #26[20]) that the health consequences of radiation exposure are many and varied. Despite this, there is a fairly obvious categorization, as portrayed in Figure 1. The first distinction is between 'stochastic' and 'non-stochastic' effects. To quote ICRP #26 [20], p.2:

"Stochastic effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold. Non-stochastic effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur."

Stochastic effects can be further categorized as either somatic, if they become manifest in the exposed individual himself, or genetic, if they affect his descendants. It is clear that within each category there is a very large number of possible effects. The modeling decision that now faced us was how many of these to include in a list of attributes for a utility function. Here a balance had to be drawn, as always in applied decision analysis, between analytic simplicity and completeness. We needed to find a set of attributes which included everything important in the evaluation of risk, and yet was small enough for a utility function over the attributes to be elicited reasonably easily from a large number of people in a short time. We selected the following five variables, as indicated in Figure 1.

x_1 - Number of fatal cancers

x_2 - Number of nonfatal cancers

x_3 - Number of mutations

x_4 - Number of acute fatalities

x_5 - Number of cases of impaired fertility

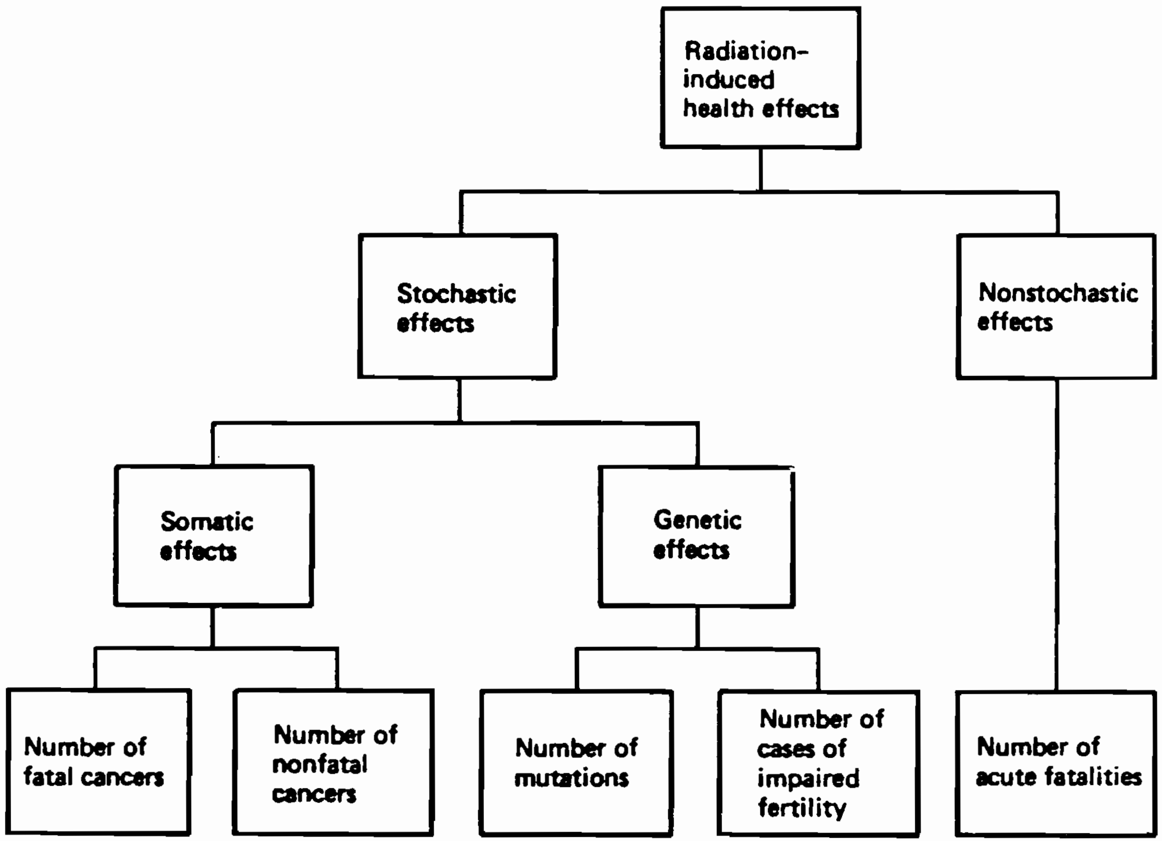


Figure 1. Categorization of health effects.

Acute fatalities here refers to those that occur shortly after exposure, and so correspond to incidents of very high dose associated with pre-seal accidents.

Several approximations and assumptions about the respondents' value structure are implied by the above list. First, the use of the total number of cases of a particular kind implies that any such case is as bad as any other such case. Second, there are other known radiation effects which do not appear on the list, such as cataracts or retarded development in children. Third, some of these categories cover a very wide class and in order to enable trade-offs between such effects to be accessible psychologically to our respondents, it was necessary to particularize them considerably; thus the class of mutations was represented by a mentally sub-normal person, who needs some extra care throughout his life. This last approximation will only be good if this case is an approximate certainty equivalent of the class of all possible mutations; this in turn depends upon the nature of the probability distributions with which the utility function will be used, and we had to complete this study without a good idea of those probabilities.

We are not satisfied that this list of attributes is the best set to describe health effects, and we feel that more work should be done on determining a good set. However, this seems to us a reasonable first attempt, and does satisfy some of the criteria for choosing attributes: sufficient complexity to cover the important structure of the problem, yet sufficient simplicity for elicitations of the trade-offs to be believable and available in a reasonably short period of time.

The next point concerns the circumstances in which the radiation doses arise. As Fischhoff et al[21] discovered, the circumstances of risks do affect their importance as judged by members of the public. Of the many possible circumstances, the two we judged to be significant enough to include explicitly in the utility function were whether or not the risk was undertaken as part of a person's occupation, and the time at which the radiation dose might arise. Figure 2 illustrates this categorization. Notice that occupational risk can only be suffered by workers in the current generation, since after sealing no further operation of the repository will be necessary.

We define an index i to indicate the circumstances of the dose giving rise to a particular health effect according to the following scheme:

i = 1: Effects due to occupational exposure before sealing.

i = 2: Effects due to nonoccupational exposure, to the current generation.

i = 3: Effects caused by a dose in the two thousand years following repository sealing.

i = 4: Effects caused by a dose more than two thousand years following repository sealing.

Each of the five health effects can occur as a result of circumstances in each of the four categories above. There are, therefore, twenty variables x_{ij} which describe the possible effects caused by a nuclear waste repository, where $i = 1,\ldots,4$ indicates the cause of the dose and $j = 1,\ldots,5$ indexes the type of health effects (e.g., x_{32} is the total number of nonfatal cancers arising from doses received from the nuclear waste in the two

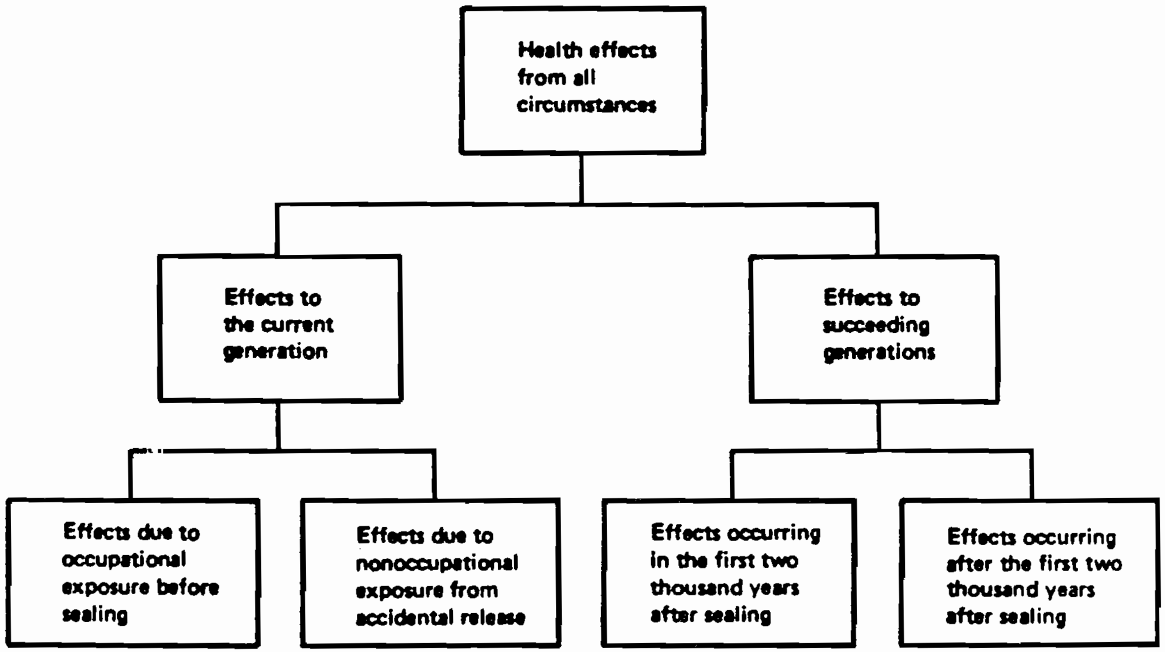


Figure 2. Categorization of the circumstances of radiation exposure.

thousand years after the repository has been sealed). Note that the time division here is somewhat coarse. Once again, a balance had to be struck between capturing the essential elements of the respondents' value structures and keeping the model reasonably simple.

Individual Utility Functions

The next problem was to establish a parametric structure for the utility function of each individual. We chose to construct first a value function $v(\mathbf{x})$ (where $\mathbf{x}$ is the vector whose twenty components are x_{ij}), which would have the property that any possible set of health effects $\mathbf{x}$ judged to be equivalent to or worse than any other $\mathbf{y}$ would have $v(\mathbf{x}) \geq v(\mathbf{y})$. The form we adopted was

$$v(\mathbf{x}) = \sum_{i=1}^{4} \sum_{j=1}^{5} \alpha_i \beta_j x_{ij}$$

This form makes some rather sweeping assumptions about preference structures. First, the linearity implies that, for example, if one extra acute fatality is as bad as two extra mutations at one level of all the variables, the same is true at all other levels of the variables. Second, the fact that the constant coefficient of each variable x_{ij} is a product $\alpha_i \beta_j$ implies that trade-offs among health effects do not depend on the circumstances of the dose, and trade-offs between the same effects in different circumstances do not depend on which health effect is considered. Although these assumptions are fairly strong, our respondents' preference structures seemed to be consistent with them to an adequate approximation.

The final stage in the construction of a von Neumann-Morgenstern utility function for each of our respondents was to reflect uncertainty preference (our synonym for the more usual 'risk preference,' which we shall avoid to prevent confusion with the more general use of the word 'risk' in this paper). We constructed a single-argument utility function reflecting uncertainty preference, whose argument was $v(\underline{x})$. In our detailed reports[9,10] we used an exponential family of utility functions, which has the advantage of being a single- parameter family. This proved to be an inadequately rich family to describe the uncertainty preferences of many of our respondents, at least as they were assessed in this study. In a re-analysis of our work, a two-parameter family of utility functions would be desirable.

Note that this utility function incorporates a very straightforward solution to a central problem with risk evaluation of nuclear waste management: how much relative weight to give health effects to future generations as opposed to health effects to the current generation. This is an exceedingly important question, which in many analyses is answered by the choice of a discount rate. Many authors have criticized this approach; a good account is given by Goodin [22]. He points out that the economic opportunity-cost arguments for discounting do not readily apply to the long time periods involved in nuclear waste management, since an appropriate rate of return on resources saved is extremely difficult to estimate, even in the form of a subjective probability distribution. Goodin goes on to describe and attack various other rationales for discounting. The strength of our approach is that it does not presume any particular prescriptive rationale. It simply asks respondents, in a trade-off format explained below, for their relative weights between current and future health effects. A respondent is free to take a stand that future health effects should be weighted equally to current ones, or to ascribe to a discounting rationale and set his or her own rate of discount (positive or negative). If there were a clear consensus from a broad community of experts as to some correct, non-intuitive approach to relative evaluations of health effects over time, our value elicitation could be attacked. But clearly, as Goodin's article attests, there is no such consensus, so it could be argued that our respondent's answers to this particular trade-off question represent as good a basis for setting policy as conflicting expert opinions.

Value Elicitation

Having developed the structure of the utility function, the values of the parameters had to be elicited from each individual respondent. One of our team sought out and interviewed 58 respondents (as described above) and made estimates of the parameters $\{\alpha\}$ and $\{\beta\}$ for each person interviewed. He did this by first asking the respondent to order the five health effects as to seriousness, and then making pairwise comparisons. For example, if the respondent stated that a fatal cancer was worse than an acute fatality, he was asked how many acute fatalities was as bad as one fatal cancer. By such comparisons and associated cross-checks the parameters were estimated. Finally, lottery type questions were asked of the respondents, from which their uncertainty preference was assessed.

Because of time limitations it was only possible to spend an hour or so with each respondent. Given the known effects of expressed value changing over time and depending on the type of questions asked (the problem of labile values, Fischhoff et al[23]), we have considerable doubts as to whether our results would have been the same if a longer time had been taken in eliciting values.

Value Aggregation Within Groups

The next step in the calculation of risk indices for each of the four groups mentioned above was the determination of the weights to apply to the utility function of each individual within each group to obtain the group utility function as a weighted sum. As mentioned before, according to Keeney and Kirkwood[18], and Keeney and Raiffa[24], p.539, one reasonable approach to determine the weights in an additive group utility function is to use the judgments of a "benevolent dictator" or "supra decision-maker," who makes a fair balance between the intensities of preference of the group members. This would seem a particularly appropriate approach in this case, since the U.S. Nuclear Regulatory Commission has the responsibility of regulating the nuclear industry in the U.S. in the balance of the public interest. One could ask the Commissioners themselves to determine relative weights between individuals within each group. The nature of our study, however, precluded us approaching the Commissioners. We had to resort, therefore, to a procedure for determining weights based on the concept of equal weighting of calibrated utility functions.

The process of calibrating individual utility functions consists of weighting each function so that a utile on one is in some sense comparable to or commensurate with a utile on another. Even this limited operation involves interpersonal comparisons of utility, and so has no fully satisfactory methodology. Our approach was to standardize the utility functions on a unit interval: one fatal cancer caused by a pre-seal nonoccupational low dose. This standard was chosen because it was the most clearly understood health effect, so that the effect of differing individual interpretations of a health effect on calibration error was minimized. In addition, this standard involved the dose circumstance generally used as a basis by the respondents against which other dose circumstances were discounted, so that the effect of differing discounts on calibration error was minimized.

Probability Distributions

Now that we had constructed four utility functions over the twenty-component health effects vector $\mathbf{x}$, each derived from different groups of people, we could combine these utility functions with probability distributions over $\mathbf{x}$ describing the uncertainty in the consequences from any particular repository. Here we faced a further problem. Although the theory of subjective probability implies that probability distributions can be constructed describing any degree of uncertainty, the implication of the methods of social decision analysis suggested by Howard[15] and Edwards[16] is that the best available expertise should be harnessed to construct probability distributions on the outcomes of alternative repositories. Lawrence Livermore Laboratory was at the time of this study engaged in an extensive project to produce the necessary expert knowledge of the likely consequences of any particular repository site and design, but the appropriate results were not available at the time our reports[9,10] were completed. Instead, in order to test the implications of our utility functions, we elicited example subjective probability distributions from two staff members at Lawrence Livermore Laboratory who had considerable personal experience in the assessment of radiation hazards, and in the possible consequences of geological disposal of radioactive waste. They produced probability distributions for two hypothetical repositories, differing from each other in a way that was meant to represent the effects of a hypothetical regulation requiring an increased amount of waste packaging. It was hypothesized that the regulation would increase the probability of pre-seal health effects slightly (due to increased handling), and decrease the probability of post-seal health effects (due to increased isolation). It should be emphasized that these probability distributions are for example purposes only, and are in no way based on the results of the physical repository modeling effort conducted at Lawrence Livermore Laboratory.

RESULTS

The results of our work fall into two categories: features of the elicited values and characteristics of the risk evaluation index itself, as generated from the assessed preferences of the four respondent groups and applied to the example probability distributions mentioned above.

Elicited Values

The two most interesting features of the elicited values happen to coincide with the two main imprcvements of expected utility over expected fatalities as a risk measure: the representation of attitudes toward uncertainty and the evaluation of more dimensions of health impacts than fatalities alone. Concerning attitudes toward uncertainty, half of the respondents were uncertainty preferring (i.e., risk seeking) in that they preferred a one percent chance of 100 fatal cancers over one fatal cancer for certain. About one quarter of the respondents were uncertainty averse, one quarter uncertainty neutral. In every one of the panels, taken separately, less than half of the panel members were uncertainty averse. These preferences indicate that a group utility function that assumes individual uncertainty attitudes to be neutral would match or overstate the aversion to uncertainty of about three-quarters of the respondents. Because the risk evaluation index is intended to measure the risk of repositories relative to the risk of standards involving less uncertainty, and because any errors in the estimates of repository impacts are apt to understate their uncertainty (see Goodin[22]), an index based on a group utility function that overstates aversion to uncertainty could be considered desirably conservative. For these reasons, and because of several advantages for implementation of an uncertainty neutral group utility function, that form of function was adopted for the risk index calculations performed in this study.

Concerning evaluation of health impacts other than fatalities, value trade-offs between fatal and nonfatal health effects were such that nonfatal health effects contributed significantly to the risk evaluation index.

As one example, more than half of the respondents considered a mutation as worse than or equivalent to a fatal cancer.

Characteristics of the Index

The clearest way to present the risk index, and the implications for that index of the elicited values, is to demonstrate its use. The following paragraphs will step through a few simple example calculations to that end. The calculations are oriented toward answering three basic questions: does the proposed regulation decrease overall risk, by how much is the overall risk decreased, and does the regulation decrease the risk to an acceptable level.

The most elemental question these risk evaluation indices can help to answer is: Does the proposed regulation decrease overall risk? For a regulation requiring increased packaging of wastes, for example, the answer is not immediately clear, since it would decrease post-seal risk at some expense in increased pre-seal risk. The risk indices (expected utilities) calculated according to the scheme outlined in the previous section are given in Table I, for repositories with and without the regulation, for each of the four respondent groups. Since we adopted an uncertainty neutral (linear) form for the group utility functions, and because of the particular normalizations we used, the numbers in Table I are not only expected utilities; they are also equivalent pre-seal nonoccupational fatal cancers. As the column differences in Table I make clear, the example regulation does in fact increase overall safety for each respondent group. Differences in index value between groups can be explained in terms of preference differences in discounting of future health effects and in the relative importance of different health effects. However, there is no direct operational significance of the differences within rows in Table I. All that matters as far as regulation selection is concerned are the differences within columns.

There is one basic concept perhaps not stressed enough in this report that Table I helps make clear. The differences in numbers within either row of the Table should not be interpreted as measurement error. We have not constructed a single risk evaluation index, but a set of four such indices, each capturing, in some way, the attitudes of one of the four panels. The risk evaluation index of a repository is not some physical attribute of that repository; rather, it is an evaluation of the impacts of that repository, as judged from a particular set of personal values.

The second basic question the risk evaluation index can help to answer is: How effective is the proposed regulation? Table II presents three different ways to scale the difference in risk evaluated between repository A (without the regulation) and repository B (with the regulation). These differences are measures of the effectiveness of the proposed regulation. The first row of Table II is simply the set of differences between rows from Table I: the reduction of risk in utiles caused by the regulation. The second and third rows of Table II can be useful for comparing the effectiveness of a regulation with other regulations or technical alternatives on convenient dimensions. For example, if an alternative regulation to the one used in the example would have the sole effect of

TABLE I

Expected Utilities of Four Respondent Groups for two Repositories

Repository	National Advisors	Concerned Citizens	Nuclear Opponents	Nuclear Advocates
repository A, without new regulation	2.4	9.1	5.2	.46
repository B, with new regulation	2.0	7.3	4.2	.41

TABLE II

Measures of Risk Reduction due to the Proposed Regulation

Measure of Risk Reduction, Difference in Equivalent:	National Advisors	Concerned Citizens	Nuclear Opponents	Nuclear Advocates
...pre-seal non-occupational fatal cancers	.44	1.8	.96	.05
...occupational dose (man-rem)	12,000	34,000	14,000	3,000
...pre-seal nonoccupational dose (man-rem)	5,300	19,000	8,800	800

reducing occupational dose, Row 2 would offer a very direct comparative measure.

The effectiveness of the regulation could be measured in terms of reduction in expected fatalities, a very different measure from a reduction in equivalent fatal cancers. For the hypothetical probability distributions used in this example, the reduction in expected fatalities due to the regulation comes to .23 expected lives saved. It is interesting to compare this figure with the first row of Table II. For every group except Nuclear Advocates, the fact that the reduction in equivalent fatal cancers incorporates nonfatal health effects leads to measures of regulation effectiveness more than twice as large as the less comprehensive "expected lives saved" measure. On the other hand, the fact that the Table II - Row 1 measure incorporates the Nuclear Advocates' discount factors for future and occupational fatalities leads to a measure of regulation effectiveness much smaller than the undiscounted "expected lives saved" measure. These examples should make clear that the "expected lives saved" measure is not at all "value-free." It in fact makes specific assumptions concerning value trade-offs that seem to be importantly at variance with the value trade-offs assessed from our respondent groups.

The third basic question the risk evaluation index can help to answer is: Does the regulation reduce the risk of the repository to an acceptable level? The definition of acceptable risk is quite involved and will not be addressed here (see Lathrop[9] and Watson and Campbell[10]). But whatever the definition of acceptable risk, the risk evaluation index can play a key role in its determination by providing a common scale on which to compare risks, and on which to set an acceptable risk limit. For example, suppose some analysis finds that a repository is acceptable if its risk is less than the risk due to a particular occupational population dose. For any given risk evaluation index, this dose can be expressed in utiles as a limit on that index scale. Any repository can be evaluated using the risk evaluation index on the same utile scale, and so directly compared with the acceptable risk limit.

DISCUSSION

The purpose of this paper has been to describe an attempt to use the techniques of decision analysis to establish risk indices for nuclear waste repositories which reflect public values. The novel aspect of our approach, which we have not noticed reported elsewhere, has been the creation of utility functions representing segments of public opinion by first constructing utility functions for a sizeable number of individual respondents and then combining them to form group utility functions. One problem of this approach was that difficulties in eliciting values from so many respondents required us to make rather more approximations in the methodology than would normally be necessary in a study of this kind.

The two primary elicitation results call for some discussion. First, the small fraction of uncertainty averse respondents suggests that if a risk evaluation index is to reflect the popularly observed aversion to catastrophe, it must represent that feature in some other way than the uncertainty aversion of utility theory. Second, the large weight given to nonfatal health effects in our study demonstrates the importance of a risk evaluation index comprehensive enough to include them.

Several interesting results came out of this research and are presented above. However, the most valuable results are the two very general aspects of risk evaluation that our approach has made clear by example. First, risk is not some physical quality of a physical system; it is a function of both the physical system and the group of people evaluating the risk. Second, there is no value-free measure of risk; even the commonly used expected fatalities measure assumes particular values.

In light of the further development required in our methodology as mentioned in our description, we must pose the question: Can we recommend that the NRC use the risk evaluation methodology described here to form a basis for the regulation of nuclear waste management, or are the problems so great that this whole approach to risk evaluation should be abandoned? Our answer is a positive recommendation to apply our methodology, but only after further development. It is clear, because of the difficulty of the problems outlined above, that considerable further work needs to be done before we can be confident that the risk evaluation indices created adequately represent the relevant social values, and provide a satisfactory means for incorporating those values into the risk management process. As challenging as those problems are, the fact remains that risk must be evaluated before it can be managed, and we feel that the risk evaluation methodology described here is an improvement over the less explicit process of risk evaluation that would probably be used in its stead. While the value elicitation questions called for in our approach were very difficult to answer, the fact remains that those questions must be answered in the course of nuclear waste risk management, either explicitly with a methodology such as the one described here, or implicitly without any formal analysis. All our methodology does is force people to confront these difficult trade-offs directly, rather than leave them to be determined implicitly by a process that manages risk without defining it.

Note that the methodology presented here is not intended to depoliticize what is clearly a political process. The determination of an acceptable level of risk is left entirely to the political domain. All that is suggested here is a measuring rod, so that the political debate surrounding the regulation of social risk is clarified. Even more than that, the concepts of risk proposed here are not normative in nature, but are based on social values elicited from groups of people to which the regulatory agency is normally responsive. As several people have pointed out (see for example Otway et al[25]) other issues, such as centralization of power, may be at stake in political debates ostensibly concerned with technological risk. But if risk is more clearly defined, then those other issues will be brought more clearly into focus, instead of being obscured in ill-defined notions of social risk.

On the basic argument that an improvement in the present level of information about public values concerning risk is necessary for the proper regulation of nuclear waste management, we maintain that our approach is worth pursuing. At the very least, it will provide a rational basis for proposed regulations put forward by the staff of the NRC at the start of the long chain of review. But beyond that, we believe that as society presses more toward democratic involvement in the regulatory process, the methodology presented here will become more and more attractive as a fair and just means to reflect social values in regulatory decisionmaking.

ACKNOWLEDGEMENTS

The work on which this paper is based was undertaken while Dr. Watson was on leave of absence with Decisions and Designs, Inc., McLean, Virginia, and Dr. Lathrop was with the Lawrence Livermore Laboratory, Ca., and was supported by subcontract 9693603 from Lawrence Livermore Laboratory. The authors wish to acknowledge the valuable assistance of Vince Campell, of Decisions and Designs, Inc. Dr. Campbell performed the value elicitations described in this paper, and made several helpful comments concerning earlier drafts of the paper. The authors also wish to acknowledge several helpful criticisms by referees on an earlier draft.

REFERENCES

[1]W.D. Rowe, *An Anatomy of Risk*, New York, N.Y., Wiley, 1977.

[2]W.W. Lowrance, *Of Acceptable Risk: Science and the Determination of Safety*, Los Altos, Ca., W. Kaufmann, 1976.

[3]R.W.Kates, Ed., "Managing Technological Hazard: Research Needs and Opportunities," Monograph 25, Institute of Behavioral Science, University of Colorado, Colo., 1977.

[4]A.B. Lovins, pp.104-115 of (6), below.

[5]T.B. Cochran, pp.93-94 of (6), below.

[6]S.M. Barrager, B.R. Judd and D.W. North, "The Economic and Social Costs of Coal and Nuclear Electric Generation," NSF 76-502, National Science Foundation, Washington, D.C., 1976

[7]I.R. Hoos, "Assessment of Methodologies for Radioactive Waste Manage-

ment," in W.P. Bishop, et.al., *Essays on Issues Relevant to the Regulation of Radioactive Waste Management*, NUREG-0412, U.S. Nuclear Regulatory Commission, Washington, D.C., 31-46, 1978.

[8]K.D. Tocher, "Planning Systems," *Philosophical Transactions of the Royal Society of London A.* 287, 425-441, 1977.

[9]J.W. Lathrop, ed., "Development of Radiological Performance Objectives, Interim Results: Trade-offs in Attitudes Toward Radioactive Waste,"UCID-17925, Lawrence Livermore Laboratory, Livermore, Ca., 1978.

[10]S.R. Watson and V.N. Campbell, "Radiological Performance Objectives for Radioactive Waste Derived from Public Values," Final Report PR78-10-80, Decisions and Designs, Inc., McLean, Va., 1978.

[11]F.R. Farmer, "Reactor Safety and Siting: A Proposed Risk Criterion," *Nuclear Safety 8*, 539-548, 1967.

[12]C. Starr, "Social Benefit Versus Technological Risk," *Science 165*, 1232-1238, 1969.

[13]E.M. Clark and A.J. Van Horn, "Risk-Benefit Analysis and Public Policy: A Bibliography", Brookhaven National Laboratory, Upton, N.Y., 1976.

[14]R. Papp, P.E. McGrath, L.D. Maxim, and F.X. Cook, Jr., "A New Concept in Risk Analysis for Nuclear Facilities," *Nuclear News*, *pp*. 62-65, November, 1974.

[15]R.A. Howard, "Social Decision Analysis," *Proceedings of the IEEE 63*, 359-371, 1975.

[16]W. Edwards, "How to Use Multi-Attribute Utility Measurement for Social Decision-Making," *IEEE Transactions on Systems, Man and*

Cybernetics SMC- 7, 326-339, 1977.

[17]D.A. Seaver, "Assessment of Group Preferences and Group Uncertainty for Decision Making," Technical Report 001597-4-T, Social Science Research Institute, University of Southern California, Los Angeles, Ca., 1976.

[18]R.L. Keeney and C.W. Kirkwood, "Group Decision Making Using Cardinal Social Welfare Functions," *Management Science 22*, 430-437, 1975.

[19]National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation" (known as the BEIR Report), National Research Council, Washington, D.C., 1972.

[20]International Commission on Radiological Protection, *Annals of the ICRP #26*, Pergamon Press, Oxford, 1977.

[21]B. Fischhoff, P. Slovic, S. Lichtenstein, S. Read and B. Combs, "How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits," *Policy Sciences 8*, 127-152, 1978.

[22]R.E. Goodin, "Uncertainty as an Excuse for Cheating our Children: The Case of Nuclear Wastes," *Policy Sciences 10*, 25-43, 1978.

[23]B. Fischhoff, P. Slovic and S. Lichtenstein, "Knowing What you Want: Measuring Labile Values," in T. Wallsten, *Cognitive Processes in Choice and Decision Behavior*, Lawrence Erlbaum, Hillsdale, N.J., 1980.

[24]R.L. Keeney and H. Raiffa, *Decisions With Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York, N.Y., 1976.

[25]U.S. Nuclear Regulatory Commission, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*,

WASH-1400 (NUREG 75/014), U.S. Nuclear Regulatory Commission, Bethesda, Md., 1975.

[26]Ad Hoc Review Group, H.W. Lewis, Chairman, *Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission*, (known as the Lewis Report), NUREG/CR-0400, U.S. Nuclear Regulatory Commission, Bethesda, Md., 1978.

[27]M. Kamins, "A Reliability Review of the Reactor Safety Study," Rand Paper P-5413, The Rand Corporation, Santa Monica, Ca., 1975.

[28]H.J. Otway, D. Maurer and K. Thomas, "Nuclear Power: The Question of Public Acceptance," *Futures*, pp. 109-118, 1978.

COMMUNICATING ENVIRONMENTAL HEALTH RISK ASSESSMENT AND OTHER RISK INFORMATION: ANALYSIS OF STRATEGIES*

Ilan Vertinsky and Patricia Vertinsky

Faculty of Commerce,
University of British Columbia,
Vancouver, Canada

To aid in the preparation of communication strategies of risk assessments in the field of environmental health, this paper focuses upon the development of risk-communication models. The models link existing scientific knowledge about communications, risk-information processing and decision making with the major attributes of an information strategy. A decision table is derived in which channels, modes of presentation, intensity and distribution of risk communications are prescribed.

*Support for preparation of this paper was gratefully received from the Environmental Health Directorate, Health Protection Branch, Health and Welfare Canada. The contents of the paper, however, are the responsibility of the authors alone. The authors are grateful for constructive comments received from Ms. S. Jessen, Mr. V. Kanetkar, Dr. P. Nemetz and Dr. C. Smart.

Introduction

Almost every decision that is made entails some risk taking. Seldomly, however, are risks considered explicitly in daily activities. When risks are considered, decisions concerning them frequently involve inconsistencies, miscalculations and misinformation. These characteristics are magnified when more than one person participates in the decision process. Indeed, when decisions concerning risks involve the public, strong emotions and polarization often arise in the process, making a reasoned calculated decision almost an impossibility.

Widespread public concerns about risky technologies and other hazards created by man have broadened the scope of government's role in risk management as well as expanding the domain of what is perceived as government responsibility to protect the public.

There is a variety of mechanisms at the disposal of a government to manage risks (e.g. economic measures, education, direct regulation). Irrespective of what mechanism or mix of mechanisms is chosen, the basic effectiveness of government management of risks will depend on the ability of the policy formulation, decision and implementation processes to receive from different sources, process, evaluate and transmit information to different participants. Effective communication means that receivers of information interpret it in correct and predictable ways (i.e. in the way senders of information intended and without side effects).

Unfortunately there is mounting evidence to suggest that information resulting from risk assessments is interpreted in widely different ways by various groups. There is also evidence that the communication channels and style employed by different participants in the process affect the responses of others in different ways (i.e. diverse groups respond differently to the same message when received in the same channels, and the same group may change its response to a message when different channels or communication styles are used for transmission). Inappropriate choice of communication style or channel may lead to surprising and counter-productive results.

The deliberate choice of an appropriate communication strategy, which depends on the purpose of the communication, the nature of the message and the receiving target population, is an important step in improving public risk management.

The Messages of Risk Assessments: Decisions Concerning the Content of Risk Information

An important area of ambiguity which is a source of conflicting expectations between risk assessors and those with whom they communicate concerns the nature of the risk assessment message. Indeed there are different "products" which are called risk assessments. First, one must consider the variety of definitions used to identify risks. Second, one must consider the role of values in assessment, what part they play and are expected to play in the risk assessment message. Achieving an alignment of expectations between risk assessors and users of risk assessments with respect to the nature and content of risk assessment information is an important element of an appropriate communication strategy. The audience of a risk assessment information would tend to find what it expects in a message, even if it were not placed there by the assessor. Expectations which are frustrated would tend to lead to lower attention being paid in the future to the assessor and may seriously erode his credibility.

Risks are defined in many ways. One can identify three classes of definitions. One class focuses upon the likelihood of events which lead to losses of some kind (e.g. accidents, death, illnesses). A second class focuses upon the size of possible losses. The third class recognizes the tradeoffs which can be made between size of losses and their likelihood of occurrence.

Risk assessments which focus upon the likelihood of losses tend to assume a narrow technical focus. Risks are often defined as the probability of occurrence of particular events (e.g. premature death or increase of morbidity rates by some predetermined percentage). The assumptions often made by those who accept this definition is that some standards of loss are universally accepted (or are acceptable) as reference outcomes for comparisons and decision making. For example, Starr et al. (1976) use the death of one person during one hour of involvement in a risky activity as a standard for assessing acceptable levels of risk in different types of activities. Under the guise of technical narrowness, however, important value judgments are made implicitly (and possibly unintentionally). Vlek and Stallen (1980) suggest that such definitions of risks seem quite plausible whenever losses are small and rather similar in size, and while probabilities are well specified.

In contrast, many risk assessments tend to ignore the likelihood of losses, focusing instead upon their size. The major problem facing risk assessors who are concerned with the possible undesirable consequences of an activity or a state of affairs is the arbitrary nature of the choice of "bounding" or "stopping" rules. Since what is possible often depends upon the limits of the imagination of an assessor more than upon reality, the assessor must make some judgment about what is or is not a "credible" risk (i.e. what bounds should be placed upon the analysis). This judgment may be influenced by a mixture of implicit motives and assumptions (e.g. what do others consider credible? what is the likelihood of different events? etc.) Unless there is a universal consensus about what is credible, the preoccupation with the size of losses without using likelihood is bound to create suspicion or doubts about the message of the risk assessment. Indeed,when the risk assessor, in public debate admits that a particular loss which was not included in the analysis is possible, though in his opinion not credible, those disagreeing with the implications of the analysis will use the admission to discredit it. Vlek and Stallen (1980) point out, however, that when probabilities are very small and hard to assess, while negative consequences are large, the use of the size of losses as measures of risks has an overwhelming psychological significance.

The class of risk definitions which considers both the likelihood and the magnitude of the loss is the most satisfactory from an intellectual point of view. "There seems to be general agreement that decisionmaking depends to a great extent upon the response to two questions: what are the possible event outcomes and their evaluation and how likely is the occurrence of the event outcome" (Sage and White, 1980:427). The problem arises in deciding how to integrate these two measures into one risk index. For example, if one assumes that the only loss attribute is life lost, would a situation where there is a high probability of few deaths be equal in value to a situation where there is a very low probability of a catastrophe with many deaths. The rational approach requires the derivation of an index of outcomes in a way where all such value judgments are reflected in the index. It is quite clear that deriving a valid index is difficult even for one individual (see Keeney and Raiffa, 1976 for an example of such a procedure, or Fischhoff et al., 1980 for a variety of approaches available). Explaining the index to others and convincing them of its validity (especially if it is not their values which are used) may be totally infeasible. One, and perhaps the only, effective way to communicate the results of risk assessment that includes such integration of values and probabilities is through the direct participation of decision makers and other participants in the risk management process in the derivation of the subjective loss indexes.

The focus so far has been upon the nature of risk information for a given loss attribute or a set of attributes. The question of what constitutes a loss and what are the indicators of loss is an important source of conflicting expectations with respect to the content of the risk assessment message. For example, if one is preoccupied with risk to life, it is possible to use a variety of indicators such as rates of premature deaths, shortening of life expectations, and adjusted life expectations. While there are interrelationships between these different aspects of risks to life, results and policy implications may vary significantly if one aspect or another is chosen to represent the risk problem. The problem of what attributes of risk should be included in the risk assessment message becomes more complicated when distributional and time aspects are considered. (Who is at risk, how one describes the equity of the distribution of risks, how the impact upon future generations should be considered and reported, etc.).

The risk assessor in novel situations may, by his choice of attributes, unintentionally influence the agenda and values of decision makers and the public. In other cases, incompatible problem definitions (e.g. public concern with the possibility of local catastrophes and assessors' concern with expected mortality rates in the larger population) may lead to a breakdown in communications.

Aligned expectations with respect to content are especially important in situations which involve potential conflicts or situations where an overload in communication requires a high degree of information filtering. One procedure of screening employed by busy executives is to scan reports for the "insignia of expertise". This is done by using a mental check list of subjects and facts which the report should include. Reports which do not include these subjects tend to be ignored. The costs of "omissions" in such situations may be higher than the costs of message complexity caused by inclusion of more information. For example, an engineer may check certain technical details concerning modes of failure and, if they check out, accept the rest of the argument uncritically. Technical inaccuracies, even if not significant, will lead to a total discounting of the information in the assessment.

Knowledge of what a user expects in a message may be utilized to form a basis from which to educate the user (e.g. establishing validity in areas familiar to the user).

The alignment of expectations with respect to content is one basic step to ensure effective communication. Another essential step is to ensure that the message content fits the purposes of the communication. There are many possible purposes for risk assessments. They are used, for example, to establish regulatory safety standards; to modify the behavior of specific target groups; or to reassure decision makers or the public. Different purposes may require different information content. For example, the establishment of regulatory standards of safety may require the consideration of potential losses, and also the costs of avoiding these losses (e.g. benefits lost from the banning of a particular pesticide). Information which is provided to users about the risks associated with a particular substance, and which is intended to modify user behavior, should include data about the change in risks resulting from different precautionary measures. Knowledge of how the message is interpreted and used can be applied to improve the effectiveness of the communication process. However the reception, processing and application of information not only depends on the content of the message, but also upon the characteristics of the sender and the receiver of the message, the channel used, the style of communication, the situation and the characteristics of the system (organization) within which the communication takes place. To simplify the analysis, we consider first the communication process dealing with risk information between risk assessor and different target populations, and then add to the analysis the organizational and interorganizational factors (e.g. how does the communication network in a single ministry affect the impact of risk assessment communications? What are the consequences of using different communication strategies for risk assessments when informing other public agencies or the public at large?)

The Communication Strategy: Major Decision Variables

The fact that a message may transmit more or less than its intended content is widely recognized among communication experts (McLuhan, 1964). A transmitted message becomes subject to three processes of selection. There is selection in exposure or attention, selection in perception and interpretation and selection in retention of the message. An effective communication strategy utilizes predictable processes of selection by a particular audience to obtain optimal responses. If it is known, for example, that a particular group of decision makers tend to ignore quantitative information, such as probabilities or expected values, the sender may supplement such information with non-quantitative data, including narratives of specific outcome scenarios or graphs.

The choice of appropriate language is another example. It is known that a majority of people seem to understand odds rather than probabilities (Edwards, 1968). A minor change in the way which the likelihood of losses is reported, i.e. using odds instead of probabilities, may improve significantly the effectiveness of communication.

The variables that an assessor may control in forming a communication strategy include: (i) channel type, (ii) form and (iii) intensity of communication and mode of distribution.

(i) Channel Selection

The choice of a channel of communication includes formal and informal channels. Formal channels may be regular or special in nature. Often the choice of formal channels is tightly regulated by organizational standard operating procedures. The advantage of regular channels lies in the relatively low cost of using them, the predictability of flow rates and predictability of the degree of noise in these channels. The assessor, having had experience with the regular communication channel, would know the screening procedures that his message would be subjected to when transmitted through the decision hierarchy. Being familiar, for example, with his superiors, the assessor can foresee their responses to some extent and take special measures to draw their attention to the appropriate information. The disadvantage of regular channels is rooted in their tendency for overload resulting frequently in lack of proper attention being given to a message. Special formal channels such as emergency meetings or departmental hearings, tend to focus attention, but often are more costly to use. Formal channels tend also to be inflexible since they require particular modes of presentation and impose severe constraints upon content, intensity of communication and distribution. For example, a monthly committee meeting of the ministry executive committee can be used as a forum to communicate some risk information, but such a forum would place serious constraints on the length and form of presentation and would neither permit easy exclusion of committee members lacking direct interest in the information nor the inclusion of non-members in the proceedings. Formal channels to the mass media and interest groups are often constrained by legal requirements and the existing structure of authority.

<u>Informal channels</u> require a large investment in building and maintenance. They are constructed through an exchange system (i.e. exchange of favors) and rely on a personal network of relationships. They offer flexibility of communication but lack the legitimacy and possibility of control associated with formal channels. Informal channels may maintain the anonymity of the source of a message (e.g. leaks and statements without attribution). Furthermore, they may provide shortcuts in communication lines, avoiding the filtering system of a cumbersome hierarchy. They are most frequently used as complements to formal channels.

The choice of channels determines exposure to the message. This fact is especially important when the communication is directed to mass target populations rather than a specific set of persons. Knowledge of media utilization patterns by different groups is essential to ensure effective, economical communication. While television and radio are considered by many experts to have greater flexibility than print, studies have suggested that more information of certain kinds may be learned from newspapers than from television and radio (see for example, Larsen and Medalia, 1962; Wade and Schramm, 1969; and Vertinsky, 1979). Television and radio may prove to be effective channels in triggering interest and mobilizing the public to action. Newspapers (and other printed media such as books and reports), while achieving a more selective exposure, provide the intellectual inputs for public responses (perhaps by providing information to opinion leaders who then use interpersonal networks to disseminate their perception of the message to groups of followers).

(ii) Form and Mode of Presentation

There is substantial evidence that the form of a message has an impact upon the use of its content in decision making (see for example, Gerritg, 1971; Benbasat and Schroder, 1977; and Lucas and Nielsen, 1980). There are many studies which demonstrate that the manner in which risk information is presented affects the way decision makers define their problems and interpret information (see for example, Tversky and Kahneman, 1981; Kahneman and Tversky, 1979).

The important parameters of a message form are: (1) the language and analytical level of a message, and (2) the order and manner of presentation (e.g. What facts are presented first? Are conclusions explicit? Are assumptions presented? Are alternative conclusions and assumption presented? Are graphs or pictures used?)

A language barrier is an important factor in the failure of many communication efforts. A message which does not take account of the shared interpretations of key words and concepts by a target audience will be ignored or misinterpreted. In a multi-cultural country with a diversity of population, one must not only be concerned with a formal knowledge of the language (e.g. French or English), but also with differential meanings attached to words (e.g., "probabilities", "possibilities", "risk") by groups seeking the same language. Lichtenstein and Newman (1967), and Vertinsky and Wong (1975) have demonstrated the wide range of probability values which different people assign to particular verbal descriptions of likelihood ("frequent", "impossible", "highly likely", etc.).

The analytic level of the risk assessment and the presentation of results determine in part the attitude of people toward the message and their attention to it. Messages including highly intuitive judgments without the clear presentation of data may command attention but create conflict. True experimental data interpreted through a sophisticated analytic framework may reduce conflict, but receive little attention from decision makers (see for example, Hammond, 1978; and Mason and Mitroff, 1973). There is evidence that people tend to pay attention to vivid, concrete information, ignoring probabilistic information (Bar-Hillel, 1973; Borgida and Nisbett, 1977; Kahneman and Tversky, 1972; Lyon and Slovic, 1976). This explains why highly analytical, comprehensive information included in a risk assessment may have little impact upon the decision process as opposed to the recitation of anectdotal experience based on a sample of one. The assessor who is perplexed about the attention that politicians and the public pay to the story of one victim of a risk (as opposed to the many exposed but not harmed), while ignoring the assessor's comprehensive statistical risk study, should remember that form of presentation is often as important as the content of his message.

Order of presentation is another factor in the effectiveness of a message. There is evidence that the first items in a sequential presentation may receive more attention while, in other circumstances, the last items draw more attention (Slovic and Lichtenstein, 1971). Knowledge of the circumstances under which a particular order magnifies the impact of certain items can be utilized to improve the form of a message. Data displays (e.g. logical devices, graphical presentations, summary tables, or cartoons) also have an important but variable impact upon access to the information contained in the message and, therefore, upon decision making (see for example, Ronen, 1973).

(iii) Intensity of the Message and Its Distribution

The intensity of the message may have an important impact upon the receiver. A person who is constantly reminded of the subject matter of the message is more inclined to worry about it and thus act upon it. Intense dissemination of a message may, however, contribute to information overload. Overload and the emotional stress which it entails reduces the care with which the information is processed, and sometimes causes complete blockage by the receiver. Groups of decision makers exposed to intense pressure may be inclined to make panic judgments (Janis and Mann, 1977). For example, intense dissemination through the media of risk information (e.g. concerning contaminated fish in specific locations) may not bring about an appropriate, marginal decision to avoid the particular hazard (e.g. switching from the consumption of one kind of fish to another), but may result in a panic judgment demanding a ban on all activities in the same class as the hazard (e.g. closing all fisheries). This more extreme response may impose unnecessary costs. Intensive dissemination of specific risk information has a strong influence upon the judgments of the audience concerning the likelihood of the risks. It is a well documented phenomenon that the frequency of well publicized incidents are overestimated (Lichtenstein et al. 1978; Tversky, 1973).

In considering the intensity of a message, one must account for indirect dissemination of the information through other channels. The message may be received through a formal channel (say a report sent to a supervisor), and reinforced through interpersonal channels (other people receiving the report relay its content to the same supervisor). Control and manipulation of distribution is difficult and costly. Attempts to control distribution may be counterproductive, leading to a more intense search for information by outsiders and suspicion of the motives for the controls. If the control measure fails (a leak occurs) or the message is released for wider distribution at a later stage, the likelihood of misinterpretation and biased selectivity of attention is very high (e.g. the parts of a leaked report that describe potential risks may be believed and attended to, while those parts of the report demonstrating perhaps the effectiveness of available safety measures may be ignored). Distribution of a message may serve a tactical move to foster a better climate either internally in the organization or externally with regard to interrelationships between the organization and its constituencies.

The Strategic Choice

The strategic choice of communication consists of: (i) identification of goals, (ii) assessment of constraints, (iii) generation of communication alternatives, and (iv) evaluation of alternatives, choice and implementation. The two preliminary assessments which are required consider (1) the purposes of the communication, and (2) the target audience and its potential response attributes.

(1) The Purposes of Communication of Risk Information

There are a number of different reasons why risk assessment information is disseminated: a) to feed different regulatory decision processes; b) to support particular regulatory decisions; c) to complement a strategy of behavioral modification, or to trigger some desired action from its audience; and d) to facilitate general climate management or crisis management.

a) Risk information for regulatory decision processes - There is a wide range of circumstances where information is provided as an input to a decision process. At the one extreme one can identify situations where the risk assessor is asked to provide specific information concerning the likelihood of particular consequences. Even in such circumstances, the risk assessor often must apply professional judgment as to the appropriate methodology needed to obtain the information required for likelihood assessments and to guarantee its quality. The criterion by which communication effectiveness can be judged is the reliability of transmission and interpretation; for example, when the assessor reports that no proven significant danger was established, the decision maker interprets it appropriately as a probabilistic statistical statement and does not consider the message to mean the certainty of safety.

Another role of risk assessment in the regulatory process is attention focusing. The risk assessor often serves in an intelligence capacity, monitoring the environment for possible candidates for the regulatory agenda. From a communication perspective, the difficulty which arises in this role is the maintenance of a proper balance of alertness and allocation of attention among decision makers.

Crying "wolf" once too often may reduce the credibility of the assessor; yet keeping information, without alerting a decision maker, may lead to strong criticism about lack of vigilance. In an "intelligence"-attention focusing role, the timing of the message, and its ability to trigger the appropriate state of readiness in the decision process (i.e. to maintain the appropriate priority in the agenda) are the most important factors in the design of a communication. From a content point of view, the message must attempt to convey the level of doubt or certainty with respect to a possible hazard. It also should prescribe specifically what actions are required (e.g. the collection of more information, and the alerting of certain groups or individuals). Since information concerning monitoring often represents interim results, the message should specify the stage of the inquiry, the most likely conclusion from the information collected to that point, and possible conclusions that may still result. For example, if results of short term tests of a suspected carcinogen are positive but inconclusive, the decision maker should be notified about the suspicion, but emphasis should be placed upon presenting the alternative possible future scenarios of the experimental process (i.e. mammal experiments may yield negative, inconclusive or positive results) and the policy consequences.

The communication of risk information to focus attention must consider carefully the consequences of an unintended distribution of the information (such as a leak which may cause a costly panic response) and the impact of biased attention selection processes. Within an office (e.g. the ministry) a classification of risk-related alerts and priorities should be developed jointly by risk assessors and their organizational and inter-organizational clients (e.g. superiors, regulators in other agencies which develop regulations or implement regulatory standards, and producers' and users' groups). The classification can be reflected in modes of presentation of the risk message (e.g. through the use of different colors of background paper to indicate the priority and urgency of the message).

b) Risk information for behavior modification - Information concerning risk assessment may be disseminated in order to modify the behavior of audiences. For example, information concerning the contamination of some lakes may be disseminated to change public use patterns (e.g. switching to other lakes for recreation, or preparing fish caught in lakes in special ways etc.). The level of behavior modification may range from specific instruction as to appropriate behavior to attempts to change values and develop cognitive skills to deal with problems.

The objective of providing specific information about appropriate behavior may include "how to" pamphlets with technical instructions and online information services (e.g. open phone lines, computer interactive networks, files on television-information networks). Behavior modification may, however, be directed at changing values or modifying perceptions and attitudes. For example, a risk message may attempt to reduce the tendencies of certain groups in the population to respond with great emotion to particular risks without considering the full range of relevant information. Providing information about the benefits of an activity and the indirect risks associated with the deprivation to society of such benefits may aim at modifying costly extreme risk averse attitudes of certain audiences. In this case the message must impart the recognition that risks are unavoidable and one must therefore consider appropriate tradeoffs. The communication of information concerning comparisons of the average cost of lives saved in different fields of hazardous activities is a good example of an attempt to change a value system which appears to make distinctions between types of hazards rather than between consequences (e.g. death from a nuclear accident as opposed to death from a car accident). Attempting to change values through communications is a complicated process requiring an excellent understanding of the culture (e.g. symbols and values), social processes and the psyche of individuals. These requirements for a fine tuned manipulation of values, however, are prohibitive for most subject matters and groups.

The use of rational arguments as value modifiers, such as the comparative information of costs of lives saved, seldom has an impact upon individuals and groups. Values, however, are modified by certain information about risk in unpredictable and at times counterproductive ways. Attempts to demystify a particular technology by providing information about it (e.g. nuclear energy production) may lead to an intensification of fears associated with its application, even among audiences who up to that point have shown little interest in the technology.

When uninformed audiences who have not formed opinions about a problem are presented with risk information, the presentation may invest them with a particular perspective about a problem and with certain values. These imprinted perspectives may be difficult to change. For example, risk information which attempts to change the harmful and careless use of some pesticides by pointing out their dangers, may develop a long term resistance to all pesticides, even in circumstances where the dangers are minimal. The audience which was imprinted with a problem definition emphasizing costs in some circumstances may not be willing, or able, to make cost-benefit calculations in other circumstances. Instead of attempting to use risk information to provide a particular problem definition, the communication may attempt to develop risk information processing and decision skills. Indeed, the development of a skilled risk-taking society may be the only basis for a long term, effective communication strategy in a diverse democratic society.

c) Risk information for triggering action - Facilitating mechanisms or triggering cues are often critically important in helping groups and individuals make the final adjustment from knowledge to action. The use of risk information to prompt action (e.g. using safety devices in the work environment or passing a local zoning law to reduce environmental risk to health) can be achieved in several ways. Sheer saturation of information, particularly through the mass media, can provide a behavioral trigger to a group or an individual who has understood and accepted the importance of a piece of information about a risk but has not acted upon it. By constantly focusing upon this information, action is often triggered. It should be noted, however, that the same phenomenon may result in unintended consequences. Sustained attention focusing upon a particular topic may trigger actions by those who have received contradictory information from other sources but have not yet responded. As an example, campaigns to disseminate information about nuclear reactor safety may trigger actions from individuals who have received and assimilated information from anti-nuclear groups but who so far have not joined their activities.

Marketers have long been aware of the power of placement upon spur of the moment behavior (Bettman and Zins, 1977). Supermarkets and department stores have used this idea to good effect upon last minute buying. Risk information provided at the appropriate decision point (e.g. safety posters in the work environment) in a clear, crisp manner with indications for an on-the-spot response may be a very effective trigger to action.

d) Risk informaton to improve decision making during a crisis - Many examples of a pathological lack of response, even to a convincing and clear warning of a critical hazard,are cited by Janis (1972). In other circumstances, panic may set in when a community faces a serious risk (e.g. derailment of a train carrying highly toxic chemicals). The purpose of providing risk information during a period of high social stress is to combat tendencies of decision pathologies of both kinds (lack of response or panic response) while providing current information for decision making.

(2) The Target Audience and Its Potential Response Attributes to Risk Information

The diversity of purposes involved in the communication of risk information and the numerous audiences addressed requires an understanding of the different response patterns of various groups to that information. To simplify the presentation, this section will consider separately two models of communication

(a) individual decision making and processing of risk communications; and

(b) organizational and interorganizational communications concerning risks.

These models will be used in the next section of the paper to derive a matrix of strategies for the diverse objectives of communication given different attributes of target audiences.

a) Individual Decision Making and Processing of Risk Communications

Communication directed at an individual is filtered through three processes of selection: exposure, perception and retention. As a result of these processes, an individual may ignore a message completely, revise his prior knowledge of a subject matter and use it in the decision making process, and/or file in his memory the revised information for use in other circumstances. The message may also enter the decision/behavior model as a pure trigger, i.e. releasing an action or decision previously made without causing the individual to revise his knowledge. The information may arouse emotions, such as fear, and contribute to attitude information and future attention patterns (e.g. changing exposure patterns to avoid emotionally unpleasant information).

Model 1 (see Figure 1) describes the major subprocesses of information selection and processing. The outputs of these subprocesses are fed to a decision/action process and/or memory (where knowledge is stored for future reference). Model 2 (see Figure 2) describes the decision/action processes which deal with risk information triggers. The outputs of the model are decisions, deferred actions and immediate actions.

Important characteristics of a target audience with respect to risk information depicted in the model are:

(1) prior knowledge and beliefs held by the audience (including beliefs in causal links);

(2) attitudes toward the subject matter and the source channel (e.g. trust in source reliability);

(3) cognitive skills and biases (including imprinted problem formulations, skills at dealing with quantitative-

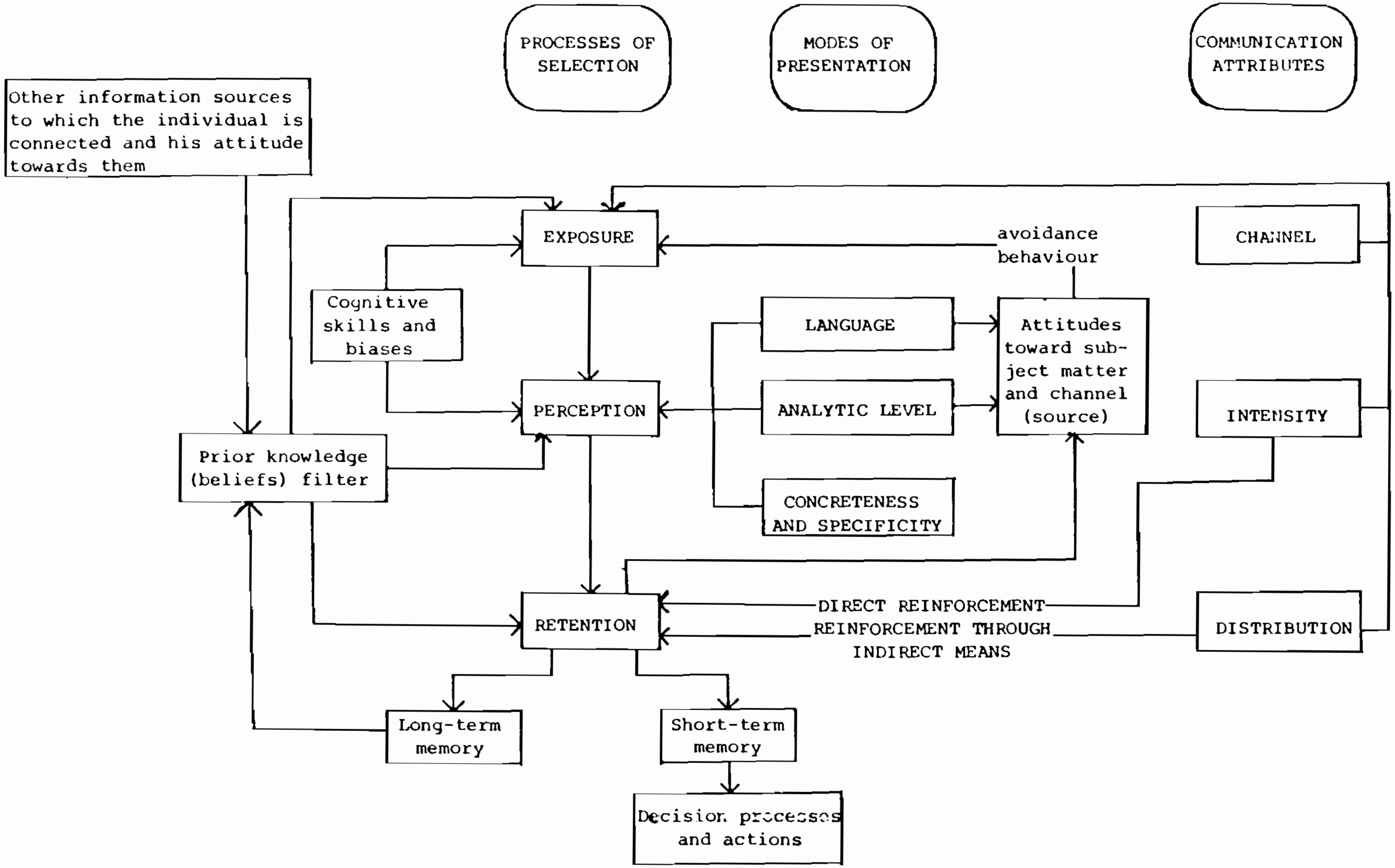


Figure 1: Model 1 - Important Characteristics of a Target Audience with Respect to Risk Information

probabilistic information); and

(4) other information sources to which the audience is linked and the pattern of use of these alternative channels (e.g. interpersonal networks of communication, media use, etc.)

The selection of direct exposure to a message depends upon the channel utilization pattern of the audience. For example, it is impossible to disseminate information through a meeting if the target audience does not participate in it, or communicate through a written report if the audience chooses not to read reports. While this is an obvious observation, standard operating procedures in many organizations ignore the fact that channels are used differently by audiences depending on the subject matter and the source of the communication. Emotional content of past messages on a channel (e.g. fear arousal) may lead to avoidance of that channel in future instances where it is used to communicate information with respect to that subject matter. Preferences for a channel can serve to extend the exposure of a message through externalities created by other messages. By way of example, a message may be interwoven with other messages in a way which prevents avoidance behavior.

It is important to note that attitudes toward a subject matter also tend to induce selective exposure. People seek information consistent with the views they already hold (Wason, 1960) and avoid information in conflict with their perceptions. It is possible, however, that indirect exposure would magnify the exposure to a message or compensate to a certain degree for lack of direct exposure. Katz and Lazarsfeld (1955) have emphasized the relationship of the social setting to the reception of information from mass media channels. They have suggested that certain individuals, by virtue of characteristics such as superior intellect or level of education, became opinion leaders for certain segments of society and serve as filters through which information is transmitted indirectly. Robinson (1976) has further developed their theories and outlined a system of interpersonal information dissemination that considers not only communication to an audience but also communication between sources of information and between different audiences. Uncertainties remain, however, as to the precise relationship between those attentive to information and those who are not (Harik, 1971; Katz, 1957). Friendship or occupational similarity in networks in society may facilitate information diffusion more than opinion leaders, and there is some evidence that there are particular opinion leaders for different types of information (Laumann and Guttman, 1966). Within organizations, strong networks of informal communications, norms of information sharing and professional ties are factors which facilitate indirect exposure. A climate of distrust and secrecy inhibits the flow of information.

The attitude toward a source of information, and not just the channel used, tends to determine, in part, the attention it receives. Respect, trust or even fear may command attention. Whyte and Burton (1981:61) report, for example, "that in Canada university scientists are generally regarded as the most reliable source of scientific hazard information. Members of Parliament and government agencies are among the least believed information sources, usually falling well behind mass media in the credibility with which the public invests them". They furthermore report the results of an Ontario Ministry of the Environment study (1979) which suggests that people tended to pay attention and believe the ministry when it said something was dangerous but disbelieved the ministry when it stated that something was safe.

Clearly, the impact of the credibility of a source is reduced when the source is not accessible. The university scientist hiding in his laboratory may be credible, but inaccessible, and therefore have little influence. The university scientist whose message is transmitted through the mass media, in contrast, may be the most highly sought after source for hazard information by the public.

Finally, language barriers and constraints of analytical skills available to receive a message may prohibit the use of a channel. In a multilingual country, the need to reach decision makers and the public in the language they are most comfortable with is well recognized. Less recognized are barriers of technical knowledge and cognitive skills needed to assimilate risk information. Audiences without basic technical understanding may avoid messages which are rich in technical jargon. Intuitive decision makers would tend to pay little attention to messages cast in complex quantitative language, while scientists may ignore intuitive information.

Perception is the process through which an individual or a group acquires information, processes it and responds to it. It is the process through which the message becomes information. Prior knowledge and beliefs are important filters through which data contained in the message are perceived. Prior knowledge tends to draw attention to specific problem definitions and, therefore, to certain aspects of the information contained in the message. Within organizations the parochial interpretation of information is a well documented phenomenon (Dearborn and Simon, 1958). Particular professional experiences will tend to promote certain problem definitions and data interpretations. It is highly likely, for example, that engineers and physicians reading the same risk assessment would interpret the report differently, each interpreting according to the conventions or standard procedures of his profession.

Prior beliefs tend to weigh heavily in assimilating new information. There is evidence which suggests that people tend, in probability re-estimation, to be conservative when presented with new data (Ducharme, 1970; Edwards, 1968). Frequently, people rely upon old beliefs as anchors from which adjustments are made in response to new information (Tversky, 1974; Tversky and Kahneman, 1974). This means that new information is viewed from the same perspective as the stored information. While permitting certain economies in processing information, anchoring may also have the effect of conservatism in re-estimating the likelihoods of events or lead to the disregarding of qualitatively new facets of the information. Prior information tends to bias what is perceived, since one is likely to see what one expects or wishes to see (Bruner and Postman, 1949; Hogarth, 1975).

The limitation of cognitive skills is another factor which tends to bias the interpretation of information received and probabilistic information in particular. People are uncomfortable with information containing concepts of uncertainty. They are ill equipped to interpret probabilistic information (Vertinsky and Wong, 1975; Hogarth, 1975) and often ignore uncertainty. Hogarth (1975:273) suggests that "the extent of man's natural ability to assess probability distributions may be gauged by considering experiments which have tested his intuitive appreciation of fundamental statistical concepts and, in particular, of distributions, independence and randomness, and measures of central tendency and dispersion".

In presenting information about risks in terms of probabilities, one must consider: (1) the wide range of probability values associated with different verbal concepts of likelihood (e.g. some people consider a probability of less than 0.1 as representing an impossibility) and (2) preferences for certain probability values (e.g. culturally prominent fractions such as $\frac{1}{2}$ and $\frac{1}{4}$ seem to be more intuitively understandable than other fractions. The use of certain numbers tend to bias the intended likelihood message). One remedy to these problems is the presentation of information in terms of odds or the use of visual devices such as probability wheels.

A more difficult cognitive problem lies in the communication and assessment of very small probabilities, especially smaller than 10^{-4}. People tend to have a limited capacity to compare small probabilities and understand differences among them intuitively (Sjöberg, 1979). Selvidge (1975) proposed to use reference events to provide intuitive anchors to interpret small probabilities. For example, the communicator can match the likelihood of certain hazards with the likelihood of certain illnesses.

We have already noted that information conveyed by means of probabilities receives less attention than concrete information. There are many factors which combine to strengthen the impact upon likelihood judgments of few but specific cases as opposed to abstract probability information. Concrete cases improve the ability of the audience to imagine an event and therefore increase its perceived likelihood (Tversky and Kahneman, 1973). The ability to attach meaning to an event and relate it to other events tends to reduce the weight given to purely statistical information concerning the event (Bar-Hillel, 1980).

Hogarth (1980:42-43) observed that "the crucial difference between probability theory and intuitive processes ... is the following: whereas people might distinguish whether data are causal, indicative or incidental, probability theory does not. Data are judged strictly on their informativeness. However, experiments have shown that people give more weight to data they consider causally related to a target object than data perceived to be indicative or diagnostic. Furthermore, they give little weight or ignore data which are seen by them to be incidental. In other words, despite the fact that it is normatively incorrect, people do not weigh information according to its informativeness, they weigh information according to the 'level of meaning' they attach to it". The communicator must make the information contained in the probabilities meaningful through the use of illustrative case data, comparisons, and as much intuitive causal explanation as possible. Competing with other sources of information such as the mass media requires what can be called "defensive communication". Audiences often judge likelihoods by considering frequencies of events rather than relative frequencies, they consider what has occurred rather than what has <u>not</u> occurred (Estes, 1976). For example, the information weight of one accident in a nuclear plant is higher than the fact that hundreds of plants did not have an accident. Once the accident has occurred and information revision has taken place, the introduction of background statistics (of "non-occurrences") is ineffective and often filtered out as a propoganda device. As a long term measure, defensive communication must educate the audience about accidents while teaching about the complete statistics involved.

There are cognitive biases in the interpretation of risk data that cannot be uprooted in the short-run and require a long term educational strategy to increase the ability of society to deal rationally with uncertainties. Widespread biases such as high weight given to small samples (Tversky and Kahneman, 1971), ignorance of regression effects (Campbell, 1969, Kahneman and Tversky, 1977), and lack of understanding of randomness and independence (Cohen and Hansel, 1955), are examples of man's limited natural abilities as a statistician (Hogarth, 1975).

The manner in which data are presented may affect, not only selectivity of exposure, but also the interpretation of the data and related validity. The order of facts presented may (even when not intended to) suggest an underlying conceptual model of relationship to the audience. This order can influence their problem definition and mold the way in which the audience will interpret subsequent data communicated to it. It is not unusual, for example, that a series of reports, the order of which is determined by irrelevant factors (e.g. delays by printers or editors), are interpreted as reflecting priority of interests by the ministry which issued them. Randomness often presents an (illusory) pattern to the eye which searches for a pattern!

Displays which simplify presentation of data may improve comprehension by the audience and reduce chances of attention distraction by irrelevant details. Simplicity may also reduce the likelihood of overconfidence in the completeness of information presented in the message. Logical devices such as fault trees (often used for risk assessment presentation) can blind people to critical omissions (Fischhoff, Slovic and Lichtenstein, 1978). Using computer models (e.g. interactive simulations) to communicate results of risk assessments often distracts the attention of decision makers from the strong assumptions which underly these models. Similarly, "scenarios which tell a 'good story' by burying weak links in masses of coherent detail may be accorded much more credibility than they deserve" (Slovic, Fischhoff and Lichtenstein, 1976:178).

The context of presentation influences interpretation. People are influenced by frequencies of co-occurrences and ignore possible disconfirming evidence (Einhorn and Hogarth, 1981). The presentation of data in a simultaneous or sequential way affects attention to disconfirming evidence (Ward and Jenkins, 1965). Other studies cited by Einhorn and Hogarth (1981:23) show that although subjects fail to search for disconfirming information in abstract tasks (e.g. evaluation of probabilities), "when structurally identical problems are formulated with familiar contexts the tendency not to seek disconfirming information is considerably reduced".

The perception of what is abstract and what is concrete and familiar varies according to professional training and experience. One problem of communication is the failure to appreciate differences in values and habits. To the toxicologist, the probability language is vivid and concrete since he must deal daily with probabilistic events. The engineer tends to abhor uncertainty since he deals with closed, well-defined systems with a high degree of certainty of knowledge. For him, technical relationships and terms are familiar and concrete.

The housewife or the factory worker may have little contact with either technical terms or notions of probability. It is not surprising that a message from a toxicologist filtered through an engineer to the housewife or factory worker may lead to the compounding of misunderstandings and consequent communication breakdown. It is a difficult problem, since even communication experts tend to develop professional stereotypes of target audiences for whom they design the message (irrespective of the attributes of the "real" audience). Feedback and evaluation of message designs are necessary to ensure effective dissemination. Two-way channels are often the solution _if_ designed with internal controls. Uncontrolled and unprogrammed two-way communication lines can increase misunderstanding since having such a line does not necessarily mean that two-way communications indeed take place.

The retention process consists of sorting outputs of perceived information. Two classes of outputs can be identified (1) mobilizing information for active use (short memory), or (2) using new information to revise long held beliefs, conceptual frameworks (e.g. problem definitions, causal models) and attitudes. The use of information for these two classes of outputs is not mutually exclusive. The communicator who is looking for action is interested in active, short term memory. However, a comprehensive communication strategy may be more concerned with long term impact and the costs associated with obtaining an immediate response. Fear, for example, may trigger an immediate reaction but can also develop an aversion to using a particular channel in the future. The communicator must consider the balance of costs and benefits associated with the use of particular communication tactics.

Educational psychologists once thought that an individual remembered those things that he used most and forgot those he used least (Thorndike, 1914). Later findings show that learned information is better retained for long run use if there is no interfering knowledge or activity before or after the acquisition of this information which might cause forgetting (Underwood, 1957). Conflicts between different pieces of information stored in the memory concerning similar subject matters tend to reduce the time that information is stored. Conflict between knowledge (data) and values tends to create a process of reconciliation (called dissonance reduction) where either attitudes or held knowledge are changed to achieve consistency (Lewin, 1938). Other unpleasant aspects associated with information also cause forgetting.

To induce long term learning the communicator must attempt to relate new data to held beliefs and wishes and minimize the unpleasantness associated with a change in beliefs and values. As was already indicated, information which is tied to a coherent conceptual framework and which is understood tends to receive more attention and to be retained for a longer term in the memory of its audiences. Conflicts may be reduced by changing the way audiences define labels. For example, identifying a wide range of different phenomena (such as cancers) with one label increases perceived conflict in data. Reducing the width of categories of subject matters reduces problems of conflicts but at a cost of more expensive processing. Intensity and distribution of a message are also factors which may keep certain knowledge alive in the memory. Low intensity communication spread over time may contribute to gradual and smooth learning, allowing the audience to adjust prior knowledge without the distortions resulting from stress. Wide distribution may provide for the emergence of social forces which sustain, through sharing, the acquired beliefs and attitudes. It is interesting to note that such forces can create a difficulty for the communicator when they evolve to protect erroneous beliefs. For example studies by Chapman and Chapman (1967) illustrated the existence of a sub-culture among clinical psychologists who held erroneous similar beliefs and reinforced each other against outside criticisms. Sjöberg (1979:42) suggests that it is natural to assume that external threats in the form of criticism will tighten the social bonds within the threatened group. The intensity of corrective information in these cases (e.g. by communicating to a misinformed group of activists) may have the counterproductive impact of strengthening the wrong beliefs. "Beliefs of central importance to a person are more easily distorted because they are more closely connected to his emotions. . . . Very strong chronic beliefs may result and this type of person may in some instances, be an efficient leader because of his extremely strong and consistent convictions" (Sjöberg, 1979:42). Leadership and mutual support in small active groups provide a special long term challenge for a communicator, who must use group values to bring about change.

The manipulation of short term memory is simpler than the achievement of long term learning. To activate information for decision making and action several conditions must be attained (see for example Rosenstock, 1960; Vertinsky et al. 1972):

(1) the target audience must perceive itself as affected by the risk information (e.g. a decision maker must consider it relevant to his decision role, a politician must feel the information concerns an opportunity or possible threat to his career, and the public must feel susceptible to the risk);

(2) the target audience must perceive the consequences of the subject matter (the risk) to be serious; and

(3) the target audience must perceive itself capable of some action to control the state of affairs. The action may be direct (e.g. banning a hazardous product) or indirect (e.g. appealing to others for action by means of political protests).

Perceived susceptibility and seriousness can be established by providing appropriate information content and relating it in concrete ways to the target population. However, the more stressful such information becomes, the more pressure develops to ignore it. The communicator must simultaneously ensure that the audience believes there is a line of beneficial action open to it. The simplest way to achieve this objective is to include in a statement an outline of possible actions, or at least the promise that a beneficial type of action will be proposed in subsequent communications.

The communicator must, however, avoid what Langer (1975) has called "the illusion of control". People tend to overestimate human ability to avoid accidents, placing higher emphasis upon consequences of human (especially their own) skills over chance events. Reporting, for example, to a regulator that a product is safe if used properly may reduce his inclination to take strong measures of protection.

It is difficult to achieve a balance between sufficient beliefs in controllability which ensure active consideration of action and "illusions of control" which reduce the likelihood of action. A message which outlines possible paths of action must also provide information about the dangers associated with these paths. A public which is asked to rely on government safety measures and not panic must also be made aware that there are limits to the ability of government to protect them, and that some individual risk taking and responsibility always remains.

As was noted, a communication, in addition to supplying information for decision making, can act as a trigger to stimulate actions which, although planned, have not been implemented. The impact of the communication as a trigger lies mainly in focusing attention on the subject matter. The impact may be contradictory to expectations, given the content of the message (since the content, if in conflict with the decided path of action, is likely to be ignored). Many saturation media campaigns (e.g. anti-smoking campaigns) act as triggers and seem to be effective tools of behavior modification. However, their performance usually affects the timing of behavioral change and depends upon the dissemination of information to change basic attitudes and provide information for improved decision making. The intensity of presentation, emotional content, and supply of action guidelines at appropriate times are the levers through which the communicator can trigger actions.

The next stage in the analysis of communication strategies of risk information must consider the ways in which perceived information retained in short (or active) memory affects the decision making of individuals (see Figure 2). There is evidence that decision making in situations involving risks often contradicts the predictions of so-called rational models. Tversky and Kahneman (1981) and Kahneman and Tversky (1979) have provided experimental data demonstrating many instances of such deviations. They presented the following types of problem to different group of subjects: (Tversky and Kahneman, 1981:453)

"Problem 1[N = 152]: Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 6000 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimate of the consequences of the programs are as follows:

If Program A is adopted, 200 people will be saved. [72 percent of the respondents chose this option]

If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved. [28 percent]

Which of the two programs would you favor?

Problem 2[N = 155]:

If Program C is adopted 400 people will die. [22 percent]

If Program D is adopted there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die. [78 percent]

Which of the two programs would you favor?"

Although these questions are probabilistically equivalent, the choice of the majority of the respondents in the first problem was Program A. The certainty of saving 200 lives seems more attractive than a one in three chance of saving 600 lives. The majority choice in problem 2 was Program D: the certain death of 400 was less acceptable than the two in three chance that 600 will die. It is easy to see that the problems are identical but with one framed as life gains and the other as life losses. The way a problem is presented to a decision maker will thus affect his choices.

Other characteristics of risk decision making include tendencies to underweigh outcomes that are probable in comparison to certain outcomes. This tendency and the tendency of people to discard components of a choice shared by all alternatives leads to inconsistent choices. The decision model proposed by Tversky and Kahneman (1981) consists of two phases:

(1) editing of alternatives (or, as they call them, "prospects"), and (2) an evaluation of modified alternatives where probabilities affect the values of choices in nonlinear ways and values are defined with respect to some target references.

From the communicator's point of view, the message he presents may affect both the editing and evaluation processes. The editing process consists of: (a) coding, where reference norms are chosen to define gains and losses; (b) combination, in which probabilities are aggregated for outcomes considered identical; (c) segregation, in which risky components are separated from riskless components, (d) cancellation, in which components shared by all alternatives are eliminated; (e) simplification, where probabilities and outcomes are simplified; and (f) elimination, where dominated alternatives are discarded (Sage and White, 1980).

The editing process can be manipulated by providing suggested reference norms from which losses and gains can be defined. For example, background natural concentrations or their impacts can be emphasized as natural reference points for evaluation. A common way of influencing the editing or problem definition of decision makers is associating words such as "normal" or "acceptable" with the reference point, and providing data as a deviation from this point of reference.

The message can affect the way in which outcome probabilities are aggregated. For example, the use of more refined labels may reduce the inclination to define outcomes as identical in the editing process. Changing the outcome attribute definitions (e.g. substituting mortality rates for a reduction of expected life spans) may make outcomes which seem identical, dissimilar. Similarly, the inclination not to consider components shared by all alternatives can be corrected by adding alternatives or redefining these components.

The skillful communications expert, by changing the formulation of problem definition (e.g. suggesting choice among gains rather than losses, and changing the definition of a gain or a loss), can affect the decision. The expert should control for biases resulting from editing processes in order to improve the quality of decisions.

The process of risk evaluation depends to a large extent on the type of risk involved. Rowe (1977) identified the following situational factors which affect risk taking tendencies:

(1) voluntariness of exposure;

(2) controllability of consequences;

(3) distribution of consequences in time; and

(4) distribution of consequences in space.

Vlek and Stallen (1980) elaborated further upon these important factors which influence attitude toward risks.

Voluntariness of exposure was associated with factors such as: (a) perceived availability of options, (b) perceived personal influence on the decision, (c) the perceived ability to correct chosen actions, and (d) the perceived importance of the intended benefits. Voluntariness of risk exposure was shown in several studies to increase the tendencies of people to accept risks (Starr, 1972; Otway and Fishbein, 1977).

Controllability of consequences reflects factors such as: (a) the belief that safety measures can effectively reduce risk probabilities; (b) the perception that the severity of consequences can be reduced by

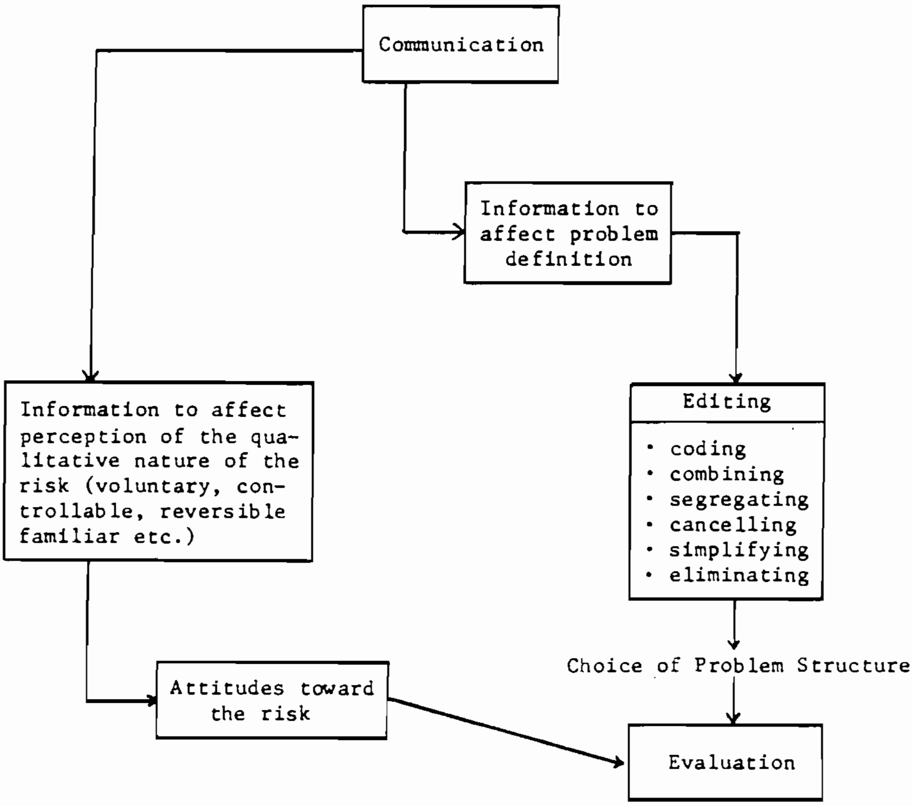


Figure 2: Model 2 - Decisions and Communications

rescue operations; and (c) the perception that consequences are reversible. Controllability tends to increase the willingness of people to accept risks (Cohen and Hansel, 1959; Walesa, 1975).

The distribution of consequences in time and space reflects perceptions of vulnerability -- the further in time and space are the costs and the closer in time and space the benefits, the lower the level of observed risk aversion.

Other factors which affect attitudes toward a risk include familiarity with the hazard and the perceived severity of its consequences (e.g. the severity of death from cancer is magnified by other fears). The more familiar people are with a risk and the less they fear the consequences, then the more risks they may take.

By providing information about these situational factors and recognizing the personal factors (e.g. differential treatment of losses and gains, and uncertainty avoidance) in structuring the message and defining the problem context of the information, the communicator has an important influence on the inclination of his audience to accept or reject certain risks.

b) The Organizational Environment and Communication Strategies

This paper has focused thus far upon the responses of individuals receiving a communication. Much of the communication of risk assessment takes place within or between organizations. The organizational environment influences the content, form and context of communications. To develop a comprehensive communication strategy, one must, therefore, evaluate the impact of the organizational environment upon communication, information processing and decision making concerning risks.

The analysis of the impact of organizational environment upon risk assessment communication can be divided into three related types of communication networks: (a) the communication network within an organization (within and between departments), (b) communication to other organizations (e.g. other governments, industry, and public interest groups), and (c) communications with the public through institutional channels (e.g. public hearings, litigation, participatory formats, such as study circles, schools).

Most organizations (e.g. a government ministry) consist of a collection of units with different and sometimes conflicting parochial objectives. The division of labor between units is imperfect and therefore the existence of overlaps and gaps in responsibilities is inevitable. The coordination of activities is achieved by the imposition of rigid standard procedures and programs, arrangement of the units in a hierarchy, or partial hierarchy, and the exercise of control through an incentive system (e.g. promotions).

To ensure coordination, economical information processing and efficient routine responses, organizations develop standard operating procedures (SOP's). SOP's promote predictability of responses to messages. The standardization of communication procedures is achieved at a price of inflexibility in responding to novel situations (Smart and Vertinsky, 1977). Standardization leads to a restricted repertoire of messages and meanings. In a rapidly changing environment, the risk assessor who uses formal channels must often fit information about qualitatively new situations into old molds of communications. Often the response of the audience is to ignore those attributes of the situations which are new. "The new situation triggers the responses the old situation merits or no response at all" (Smart and Vertinsky, 1977:646). Allison (1971) suggested that most SOP's in an organization are highly resistant to change since they are grounded in the operating styles of its members. The organizational-communication strategy must anticipate and utilize predictable responses of audiences, and fine-tune the communication by using informal and more flexible channels.

It should be noted that many SOP's in professionally oriented units are partially based on professional values and perspectives. Medical units, for example, would communicate with medical jargon, while financially oriented units may employ economic or accounting languages and frameworks of reporting. To ensure flexibility and accuracy of communications between units, it is desirable to employ interdisciplinary personnel to bridge disciplinary gaps. Joint appointments or overlapping responsibilities are another device to improve communications through the development of informal channels of communication between different units.

The second mode of coordination -- the development of a hierarchy, is another contributor to the distortion of information. Downs (1967) noted that information is subject to hierarchical distortion in both quantity and quality. The quantity of information received by senior decision makers is reduced as it filters through the hierarchy. The quality of information is distorted due to perceptual differences resulting, in part, from specialization of individuals at different levels of the organization. The incentive system in the organization also plays an important role in the distortion of information. It is well known that bearers of bad news are frequently held responsible for their messages. There is therefore a tendency when information is filtered up through an organization, to reduce the emphasis upon threatening aspects. Similarly, the insistence of the decision maker upon knowing exactly about risks leads to pressures on those who relay the risk assessment message to distort or ignore it. For example: "[j]ust prior to hearing a blue ribbon panel of scientists report that they were 95% certain that cyclamates do not cause cancer, [U.S.] Food and Drug Administration commissioner Alexander M. Schmidt said, 'I'm looking for a clean bill of health, not a wishy-washy, iffy answer on cyclamates'" (Slovic, 1978:101). David (1975) reports Senator Muskie's desire to deal with "one armed scientists who did not respond 'on the one hand ... but on the other hand'".

Risk assessors face a problem inherent in the different time scales of science and policy making. They are asked to provide information before it is subjected to a rigorous time-consuming system of checks (i.e. controlling for rival hypotheses). Not providing information about risks is interpreted by policy makers and the public as implying safety. The risk assessor must therefore learn to communicate partial knowledge. In doing so, however, he exposes himself to a problem of "hindsight" criticism. Advice he provides on the basis of the available knowledge at the time of communication will be evaluated later on the basis of facts which were not known earlier.

People tend to reconstruct their perceptions of what was their judgment or what would have been their judgment in hindsight, ascribing higher accuracy and validity to their judgments (Fischhoff and Beyth, 1975). If the risk assessor, for example, suggests that a particular test does not imply the risk of cancer, but subsequent tests prove him wrong, then his judgment will be evaluated as if results of all tests were known when he rendered his opinion.

This phenomenon tends to reduce the inclination of people along the hierarchy to transmit information which can accomodate the policy making process. Organizations which manage risks must protect the risk-assessor from "hindsight" judgments. The development of appropriate risk-assessment audit procedures may correct the impact of "hindsight evaluations" upon the risk assessment communication process.

Another problem which the risk assessor may face is the need to compete in the provision of knowledge with confident but ignorant sources of alternative information (for example, a group of activists outside the organization). Lichtenstein and Fischhoff (1977) have discovered in their experiments that often those who know less are more confident about their knowledge than those who know more. The confident, but perhaps misinformed, source tends to receive more weight in the political decision process than the uncertain, but informed, expert.

The communication of risk information during a period of crisis faces additional challenges. Crisis is often characterized by an overload of communication lines and high stress for both the communicator and his audience. An overload of channels means an intensification of information filtering and a higher degree of distortion. Since a crisis demands an immediate and accurate response; communication lines must be shortened. To bypass the authority structure without undermining the hierarchy, a crisis management committee may be struck to bring the experts and the decision makers together in a joint problem solving process.

Communications between organizations tend to be even more vulnerable to distortion and inattention. Differences in perspectives from which information is viewed may reflect differences in objectives, values and standard operating procedures. It is not surprising, for example, that employees of a firm producing chemicals would have a high stake in protecting the manufacture of certain chemicals which are important to that firm. he perspective from which they view risk data concerning the chemical is likely to magnify attention upon the benefits of the chemicals in question and resolve uncertainties, giving the benefit of the doubt with respect to risks to the firm. Since people tend to have "illusion of complete control" with respect to subject matters where they have only partial control, the employees tend to develop strong beliefs of safety predicated upon unreasonable assumptions of control.

A government toxicologist, in contrast, may be more sensitive to the risk aspects of the data than the reported benefits of the same chemicals. Professional norms and public demands require him to resolve doubts in favor of safety. Reasonable error on the side of safety is likely to influence his career less adversely than an error which results in underprotection. It is not surprising that in viewing the content of the same message, the government regulator and the employee of the chemical producer will pay attention to, interpret and retain different aspects of the message. What may be seen to an outsider as conscious partisan behavior may be indeed a natural process of selection where each party exercises, in his own mind, an "objective" perspective. In many situations, advice by the toxicologist is attended to and interpreted only when cast in extreme terms (e.g. instead of proposing reduction in acceptable contamination standards, a total ban is proposed).

Professionally shared norms (e.g. the government toxicologist talking to the company toxicologist), may somewhat correct the bias but cannot remove it completely. In other cases, the differences in outlook between professions may widen the communication gap. A lawyer representing industry who communicates with a government scientist may have a tendency to misinterpret the meaning of uncertainty in the scientific data. A safety engineer communicating with a toxicologist about hazards with latent, long term risks may discount their seriousness, reflecting the time-horizon which characterizes most of the decisions he makes in his professional capacity.

Different organizational climates and communication habits also increase the costs of interorganizational communication. Devices which to some degree solve these problems include: permanent joint committees, long term task forces and advisory boards. They serve as means for mutual-education, and the expansion of informal, interpersonal communication networks between organizations.

There is a certain element of instability in joint interorganizational permanent structures. While acting as members of these extra-organizational structures, members tend to conform to group norms. Once they are subjected to peer pressures in their usual organizational environment, they may deny their original interpretations of communications received and transmitted, and in their minds, reconstruct the proceedings to fit the perspectives and values which characterize their dominant environment. It is not a rare phenomenon to observe an industry representative in a joint government-industry task force who agrees with all the task force deliberations, but, upon the completion of a report and his return to his firm, rejects some of its conclusions. The small group exerts high pressures for conformity. The conformity, however, in short lived groups is not a lasting one.

It is important to note that there is evidence that small groups involved in risk decision making tend to behave in different ways than their members would individually. Some studies (Cartwright, 1971; Pruitt, 1971) have concluded that groups are more risk prone than their individual members. This finding contradicts the finding of other studies which have demonstrated a conservative shift in values in group decision making (Wilpert et al., 1976). Reviews of studies of group decision making have related risk taking shifts to the manner in which information was presented during group discussions (Sage and White, 1980).

When communications between organizations are made in public (through media reports, public attendance etc.) the channels selected are often utilized to relate a message to the larger public as well. The danger inherent in communications which are also intended for a third party is that there may be a breakdown of communication between the two principal parties as each "plays to the galleries".

In communicating with the public through institutional structures (i.e. not directly through the mass media), three alternative foci can be established for the information flow:

(1) a data seeking focus,

(2) a conflict focus, or

(3) an information dissemination and teaching focus.

Litigation, public debates, and Boards of Review are examples of conflict-oriented channels. Advisory boards, public hearings and comissions of inquiry have information seeking as their prime focus. Study circles, workshops and seminars are primarily channels of information dissemination and education. Clearly, each channel may have more than one orientation. For example boards of inquiry may use quasi-judicial procedures to validate information received through confrontation or challenges. Debates can be used as dramatic means for education.

Conflict-oriented channels are especially inappropriate for the presentation of risk assessment information by scientists. Fischhoff et al. (1980:51) state: "The constraints of legal settings (Bazelon, 1980; Piehler, Twerski, Weinstern and Donaher, 1974), the exigencies of the political arena, and the provocations of the news media all encourage adversarial encounters that are inhospitable to properly qualified scientific evidence (Mazur, 1973)". Debates, litigation and other conflict-oriented channels are useful, however, in raising the consciousness of the public with regard to a subject matter. (Since the dramatic appeal focuses attention). These types of channels also present a forum in which assumptions underlying different views can be revealed through the conflict (Nelkin, 1977). Conflict, however, may induce public cynicism about the supposed expertise of experts providing testimony (Mazur, 1973).

Information-seeking public channels (e.g. public hearings) permit the exposure of the public to different points of view, provide a possibility for limited two-way communications, and help to improve the credibility of a decision process by permitting participation and promoting an openess of communications.

Information-seeking public channels offer a more passive means of public education. Experiences with more active educational channels in the risk management area are limited and involved mainly in the energy field. For example, "in 1973, the Swedish government initiated a major project of public information. The mechanism chosen was that of "study circles" (Nelkin, 1977). The Swedish version of this mechanism was comprised of small study groups run by educational committees of various organizations, such as political parties, trade unions, and religious organizations. The government provided financial resources and documentation to participating organizations. The government also established a specialized communication channel in the form of an independent resource group consisting of experts in the relevant fields. The mass media were used only as a means of focusing attention on the problems and on the opportunities to acquire information. Not surprisingly, the majority of the 80,000 "participants came from the already well-educated, well-informed politically-active population groups, not from the groups who were perhaps most in need of knowledge" (OECD, 1978, p. 26).

Efforts to educate the public, however, are often considered with suspicion by parts of the public who regard the effort as government propaganda at tax payers' expense.

The Decision Matrix: Matching Communication Strategies and Audiences

The relationships between the characteristics of risk communications and responses of different audiences can be utilized to improve the effectiveness of risk information dissemination. The major guides in choosing communication strategies which meet specific objectives in particular communication environments are given in the Strategic Decision Matrix (see Table 1). There are certain general principles that underlie the relationships depicted in the table.

Table 1

A Decision Matrix: Matching Communication Strategies and Audiences

Purpose of Communication	Type of Information	Target Population	Channels	Message: Content	Message: Mode of Presentation	Intensity and Distribution
Risk Information for Regulatory Processes:						
- Attention directing	Intuitive (e.g. unconfirmed suspicions)	Decision makers	Formal-routine supplemented by informal channels	An alert (to subject matters), sources of alert and their reliability	Simple routine reporting. Informal channels (face to face) to fine tune attention	Low intensity
	Experimental-preliminary	Decision makers	Formal-routine supplemented by informal channels (e.g. special briefings, task forces)	Alternative experimental scenarios	Degree of priority reflected in presentation of concrete examples and dramatic display	Low intensity
- Decision and action	Experimental-conducive	Decision makers	Formal-special channel supplemented by informal channels	Problem definition, alternatives and consequences, guide for specific actions	Statistical evaluation of consequences supplemented by concrete examples, simple displays of alternatives and consequences. Counter biasing devices especially to correct for editing errors	High if action is required. Distribution can be wide to muster support and reinforce priority
- Attention directing	Intuitive, experimental (preliminary)	Public - people at risk, opinion leaders (e.g. physicians)	Preferences for two way interactive channels (e.g. seminars, task forces). Use third parties (e.g. university scientists) to provide public information	Familiarize public with subject matter. Provide a conceptual framework. Complete balanced presentation of state-of-art and emphasis on cost benefit tradeoff. Discussions of future possible scenarios for alerting the public to possible options	Concrete scenarios of the consequences of alternative options. Likelihood of different scenarios represented through graphical dramatic displays. Presentation of highly detailed information on request is required to inspire confidence	Low intensity. Distribution aimed at opinion leaders and mass media
- Action (short term)	Experimental (conducive)	Public - educators, appropriate professionals	Direct: mass media (written) Indirect: through opinion leaders using two-way communication channels (seminars, study circles, hearings). Conflict-oriented channels should be avoided except where attention to subject matter is pertinent (see section on use of risk information as trigger for action)	Options and consequences, specific information about benefits of actions and consequences of lack of action. Relate information in a coherent conceptual model	Concrete examples specifically related to the target audiences. Building message on the familiar and demystifying technical details. Extensive use of simple, logical devices for problem presentation. Emphasize nature of risks (e.g. involuntary, irreversible etc.)	High intensity to muster support for regulatory actions. Wide and open distribution

Table 1 (cont'd)

Purpose of Communication	Type of Information	Target Population	Channels	Message: Content	Message: Mode of Presentation	Intensity and Distribution
Risk information for behavior modification: motivation and awareness	Scientific information and cost benefit information	Public at large - people at risk, community activists, interest groups	Two way channels to opinion leaders (e.g. physicians), public interest groups, and other community facilitators, mass-media to reach the population at large	Cost-benefit information: Familiarization with technical details	Use professional and other value systems to increase awareness. Build upon existing knowledge expanding marginal data bases and modifying conceptual frameworks. Use dramatic, simple displays and concrete examples	Continuity should be emphasized over intensity to minimize information overload and emotional stress
Risk information for achieving specific behavior (e.g. using safety devices)	Technical and scientific information about specific hazards, susceptibility and means of control	Public - professional	Two-way advisory channels to the public. Written detailed information to community facilitators. Also use action triggers (e.g. labels on hazardous products, warning signs)	Specific information concerning susceptibility and controllability of the hazard. Specific control measures (costs and benefits)	Detailed information to facilitators at appropriate technical level. Use graphical displays to identify susceptibility. Concrete examples with which the target population can identify to demonstrate seriousness of hazard and consequences of control measures. Use prevailing images and values to relate required actions to the general perspective of the audience with regard to the target matter	Continuous exposure with episodes of intense exposure
Information to improve cognitive skills for dealing with risks	Conceptual information	Decision makers	(1) Routine channels (2) Informal two-way communications (3) Special educational channels (briefings, seminars, continuing education)	Messages should include measures to correct for editing biases (e.g. provide alternatives in different forms). Messages should improve natural statistical skills (e.g. demonstrate concept of likelihood by graphical means). Messages should help decision makers evaluate and revise new information by exploring the rules through which new evidence leads to new conclusions from the existing data base	Use of logical displays with specific concrete examples to demonstrate concepts. Emphasis on multiple parallel approaches to problem definition and demonstration of their consequences. Employment of dramatic means such as debates in educational channels to develop flexibility and critical approach	Continuous low intensity for routine channels. Intense episodic reinforcement through educational channels followed by low intensity continuous exposure
	Conceptual information	Public - opinion leaders (e.g. physicians, professionals, adult educators)	To opinion leaders using written mass-media and other educational channels (e.g. continuing education, study circles)	as above	as above	as above

Table 1 (cont'd)

Purpose of Communication	Type of Information	Target Population	Channels	Message: Content	Message: Mode of Presentation	Intensity and Distribution
Information to improve cognitive skills for dealing with risks	Conceptual information	Public at large Special audiences (community activists, concerned consumers) Teacher training institutions. School teachers. Children	(1) Use community facilitators and opinion leaders as indirect channels (2) Use the written mass-media (in particular science columns) to familiarize the public with relevant concepts and appropriate problem definitions (3) Use other media (e.g. TV, public meetings) to familiarize the public with basic concepts and alternatives (4) Use schools to improve statistical and decision making skills	- Problem definitions - Statistical and decision concepts (e.g. probabilistic evaluations) - Familiarization with alternative options of control - Familiarization with sources of hazards and benefit-cost concepts - Familiarization with the scientific risk assessment process - Provision of coherent framework to integrate risk information in different subject areas and different sources	Use of logical displays with specific concrete examples to demonstrate concepts. Emphasis on multiple parallel approaches to problem definition and demonstration of their consequences. Employment of dramatic means such as debates in educational channels to develop flexibility and critical approach	Continuous low intensity for routine channels. Intense episodic reinforcement through educational channels followed by low intensity continuous exposure
	General information about subject matter	Public	TV and radio, posters in selected locations	General information	Dramatic displays, high emotional appeal, intuitive level of presentation, short messages. Economy in information	Saturation campaigns, wide distribution
Risk information to trigger action	Specific directives for action	Public	"Implementation point" triggers	Specific directives for actions and warnings	Simple instructions and warning, short messages. Economy in information	High intensity but limited locations
	Action	Decision makers	Special (ad hoc) organizational formal channels reinforced by informal presentations and indirect external channels	as above	Dramatic displays, intuitive level of presentation, short messages, simple instructions. Mobilization of indirect channels (e.g. mass-media reports). Economy in information	High intensity (wide distribution of external forces mobilized to support particular actions)
Crisis management Climate management	General information	Public	- Two-way channels (public meetings, study circles) - Written mass media - Advisory community boards - Use of "third party" high credibility sources as channels for information	Complete and detailed background information with simple instructions for actions and identification of specific, accessible additional channels of information. Emphasis upon controllable aspects of the crisis	Simple displays, concrete examples, intuitive level of presentation with back-up of detailed information (completeness is essential to maintain credibility). Low emotional content. Consistency in presentation (present information within a coherent conceptual model)	Low intensity. High distribution
Alert (fight tendencies for high level of complacency)	General information about hazard and specific information about required control measures	Decision makers	Special formal channels reinforced by informal channels	Emphasis on consequences of hazard, its controllable aspects and vulnerability of the decision maker (or the organization he represents) to the hazard	Dramatic but simple displays. Intuitive level of presentation. Concrete and dramatic scenarios	High intensity. Use all relevant channels to reduce filtering impact of "gate keepers" and avoidance behavior

The choice of message content must satisfy not only what the communicator judges as necessary for the purpose at hand, but must also meet the expectations of the audience. In situations which are characterized by information overload and/or conflict, the assessor must identify and include in the message any "keystone" concepts, facts and problem attributes that the audience uses as checklists in screening information. When an unfamiliar subject must be introduced, the introduction should, when possible, be based upon the familiar and known.

An important criterion for the selection of a communication channel is the exposure of the audience to this channel. The assessor must ensure that his audience is looking for the particular type of information that he intends to communicate through the channels which he has chosen. Evaluation of exposure potential must also consider indirect exposure and its influence (i.e. to what extent the indirect exposure will keep the fidelity of the risk message).

The ability to control the channel is another factor of selection which becomes especially important for crisis management and situations with a great potential for conflict.

The form of the message is an important factor which determines attention and perception. The choice of form must increase attention and minimize biases of interpretation. In particular, it should reduce unintended emotional responses, while improving the quality of problem formulation and decision making.

The choice of intensity of a message should be guided by concern for triggering an action (i.e. focusing attention upon a subject matter) and long term learning and improvements of the cognitive skills of the audience in dealing with risks. These two objectives may lead to contradictory recommendations; long term learning requiring low intensity, but persistent communication, while the need to trigger an action may call for a situation, episodic communication. Wide distribution may improve exposure and induce attention but may cost a loss of control. The choice of intensity and distribution of risk communication must consider the tradeoffs between impact and control and long term and short term objectives of a communication process.

While this paper advocates the use of audience profiles for the design of a more effective risk communication strategy, it also contains a warning. Our knowledge of responses of audiences to risk information is limited. A communication strategy must be flexible and provide for learning. Feedback mechanisms and monitoring should be built in when feasible. The use of stereotypic audience profiles should be treated only as preliminary hypotheses to be tested by experimentation with communication strategies. For example, one can use one's professional and organizational background to form hypotheses about the way certain audiences may behave. It is not unreasonable to assume that lawyers and judges, whose major job experiences take place in an adversarial system, are more capable of entertaining conflicting, extreme positions and deriving from them a balanced opinion. Indeed, their training sharpens their ability to deal with doubt and inconsistencies contained in information. In contrast, most engineers are used to dealing with a well defined system of relationships, and there is some evidence that their training does not equip them to handle internal inconsistencies and doubt. Economists are trained to consider a system holistically and to focus upon tradeoffs. Politicians, who, for their very survival must consider public attitudes and values, can handle value information perhaps more proficiently than scientists. The politician's tolerance for ambiguity of sources and reasoning is high, but he requires clear conclusions. Scientists whose training demands a high level of conclusiveness before assessing the implications from their data bases, tend to be more comfortable with highly qualified information (i.e. with a lot of "ifs" and "buts"). It is also reasonable to assume that those who engage in a particular area would be familiar with that subject matter and thus equipped to understand technical details (e.g. nuclear engineers would be fluent in technical jargon concerning reactors). However, there are always exceptions to general rules and the communicator must guard against errors based on sweeping generalities. The risk-communication environment is changing rapidly. There is continual change in the familiarity and concern of different groups with particular hazards. The group profile of yesterday may be an inadequate description of today's audience. Finally, one must recognize that, in dealing with risk, to a larger extent than in other decision areas, labile individual psychological factors in many cases have a dominant influence on behavior and decision. This introduces another constraint upon the ability of the communicator to fine tune his strategy.

REFERENCES

Allison, G.T. 1971. Essence of decision. Little, Brown, Boston.

Bar-Hillel, M. 1973. On the subjective probability of compound events. Organizational Behavior and Human Performance, Vol. 9, pp. 396-406.

Bar-Hillel, M. 1980. The base-rate fallacy in probability judgements. Acta Psychologica, Vol. 44, pp. 211-233.

Bazelon, D.L. 1980. Science, technology and the court. Science, Vol. 208, pp. 661.

Benbasat, I. and Schroeder, R. 1977. An experimental investigation of some MIS design variables. MIS Quarterly, Vol. 1, pp. 37-49.

Bettman, J.R. and Zins, M.A. 1977. Constructive processes in consumer choice. Journal of Consumer Research, Vol. 4, pp. 75-85.

Borgida, E. and Nisbett, R.E. 1977. The differential impact of abstract vs. concrete information on decisions. Journal of Applied Social Psychology, Vol. 7, pp. 258-271.

Bruner, J.S. and Postman, L.J. 1949. On the perception of incongruity: A paradigm. Journal of Personality, Vol. 18, pp. 206-223.

Campbell, D.T. 1969. Reforms as experiments. American Psychologist, Vol. 24, pp. 409-429.

Cartwright, D. 1971. Risk taking by individuals and groups: An assessment of research employing choice dilemmas. Journal of Personality and Social Psychology, Vol. 20, pp. 361-378.

Chapman, L.J. and Chapman, J.P. 1967. Genesis of popular but erroneous psycho-diagnostic observations. Journal of Abnormal Psychology, Vol. 72, pp. 193-204.

Cohen, J. and Hansel, C.E.M. 1955. The idea of independence. British Journal of Psychology, Vol. 46, pp. 178-190.

Cohen, J. and Hansel, C.E.M. 1959. Preferences for different combination of chance and skill in gambling. Nature, Vol. 183, pp. 841-842.

David, E.E. 1975. One-armed scientists? Science, Vol. 189, p. 891.

Dearborn, D.C. and Simon, H.A. 1958. Selective perception: A note on the departmental identification of executives. Sociometry, Vol. 21, pp. 140-144.

Downs, A. 1967. Inside Bureaucracy. Little, Brown, Boston.

Ducharme, W.M. 1970. A response bias explanation of conservative human inference. Journal of Experimental Psychology, Vol. 85, pp. 67-74.

Edwards, W. 1968. Conservatism in human information processing. In: B. Kleinmuntz (Ed.), Formal Representation of Human Judgement, Wiley, New York, pp. 17-52.

Einhorn, H.J. and Hogarth, R.M. 198 . Uncertainty and causality in practice interfence. Graduate School of Business, University of Chicago, Unpublished Manuscript.

Estes, W.K. 1976. The cognitive side of probability learning. Psychological Review, Vol. 83, pp. 37-64.

Fischhoff, B. and Beyth, R. 1975. "I knew it would happen." Remembered probabilities of once-future things. Organizational Behavior and Human Performance. Vol. 13, pp. 1-16.

Fischhoff, B., Lichtenstein, S., Slovic, P., Keeney, R., and Derby, S. 1980. Approaches to Acceptable Risk: A Critical Guide. Oakridge N.L., Oakridge, Tenn.

Fischhoff, B., Slovic, P., and Lichtenstein, S. 1978. Fault trees: Sensitivity of estimated failure probabilities to problem representation. Journal of Experimental Psychology: Human Perception and Performance, Vol. 4, pp. 330-344.

Gerrity, T.P. 1971. Design of man machine systems: An application to portfolio management. Sloan Management Review, Vol. 12, pp. 59-75.

Hammond, K.R. 1978. Toward increasing competence of thought in public policy formation. In: Hammond, K.R. (Ed.), Judgement and Decision in Public Policy Formation, Westview Press, Boulder, Colo., pp. 11-30.

Harik, I. 1971. Opinion leaders and mass media in rural Egypt: A reconsideration of the two-step flow of communication hypothesis. American Political Science Review, Vol. 65, pp. 731-740.

Hogarth, R.M. 1975. Cognitive processes and the assessment of subjective probability distributions. Journal of American Statistical Association, Vol. 70, pp. 271-289.

Hogarth, R.M. 1980. Judgement and Choice: The Psychology of Decision. Wiley, Chichester, England.

Janis, I. 1972. Victims of Groupthink. Houghton Mifflin, Boston.

Janis, I.L. and Mann, L. 1977. Decision Making. Free Press, New York.

Kahneman, D. and Tversky, A. 1972. A subjective probability: A judgement of representativeness. Cognitive Psychology, Vol. 3, pp. 430-454.

Kahneman, D. and Tversky, A. 1973. On the psychology of prediction. Psychological Review, Vol. 80, pp. 237-251.

Kahneman, D. and Tversky, A. 1979. Prospect theory: An analysis of decision under risk. Econometrica, Vol. 47, pp. 263-291.

Katz, E. 1978. Looking for trouble-social research on broadcasting. Journal of Communication, Vol. 28, pp. 40-45.

Katz, E. and Lazarsfeld, P.F. 1955. Personal Influence: The Part Played by People in the Flow of Mass Communication. Free Press, Glenco, Ill.

Keeney, R. and Raiffa, H. 1976. Decisions with Multiple Objectives Preferences and Value Trade-offs. Wiley, New York.

Langer, E.J. 1975. The illusion of control. Journal of Personality and Social Psychology, Vol. 32, pp. 311-328.

Larsen, O.N. and Medalia, N.Z. 1962. Diffusion and belief in a collective delusion: The Seattle windshield pitting epidemic. In: B.H. Stoodley (Ed.), Society and Self, Free Press, New York.

Laumann, E. and Guttman, L. 1966. The relative association contingtuity of occupations in an urban setting. American Sociological Review, Vol. 36, pp. 169-178.

Lewin, K. 1938. The conceptual representation and measurement of psychological forces. Duke University Press, Durham, N.C.

Lichtenstein, S. and Fischhoff, B. 1977. Do those who know more also know more about how much they know? Organizational Behavior and Human Performance, Vol. 20, pp. 159-183.

Lichtenstein, S. and Newman, J.R. 1967. Empirical scaling of common verbal phases associated with numerical probabilities. Psychonomic Science, Vol. 9, pp. 563-564.

Lichtenstein, S., Slovic, P., Fischhoff, B., Layman, M., and Combs, B. 1978. Judged frequency of lethal events. Journal of Experimental Psychology: Human Learning and Memory, Vol. 4, pp. 551-578.

Lucas, H.C. and Nielsen, N.R. 1980. The impact of the mode of information presentation on learning and performance. Management Science, Vol. 26, pp. 982-993.

Lyon, D. and Slovic, P. 1976. Dominance of accuracy of information and neglect of base rates in probability estimation. Acta Psychologica, Vol. 40, pp. 287-298.

McLuhan, M. 1964. Understanding Media: The Extensions of Man. McGraw-Hill.

Mason, R. and Mitroff, I. 1973. A program for research in management information systems. Management Science, Vol. 19, pp. 475-487.

Mazur, A. 1973. Disputes between experts. Minerva, Vol. 11, pp. 243-262.

Nelkin, R.R. 1977. Technological Decisions and Democratic European Experiments in Public Participation. Sage, Beverly Hill, Cal.

Otway, H.J. and Fishbein, M. 1977. Public Attitudes and Decision Making. International Institute for Applied Systems Analysis, RM-77-54.

Piehler, H.R., Twerski, A.D., Weinstein, A., and Donaher, W.A. 1974. Product liability and the technical report. Science, Vol. 186, pp. 1089-1093.

Pruitt, D.G. 1971. Conclusions: Toward an understanding of choice shifts in group discussion. Journal of Personality and Social Psychology, Vol. 20, pp. 495-510.

Robinson, J.P. 1976. Interpersonal influence in election campaigns: Two step-flow hypotheses. Public Opinion Quarterly, Vol. 40, pp. 305-319.

Ronen, J. 1973. Effects of some probability displays on choices. Organizational Behavior and Human Performance, Vol. 9, pp. 1-15.

Rosenstock, I.M. 1960. What research in motivation suggests for public health. American Journal of Public Health, Vol. 50.

Rowe, W. 1977. An Anatomy of Risk. Wiley, New York.

Sage, A.P. and White, E.B. 1980. Methodologies for risk and hazard assessment - A survey and status report. I.E.E.E. Systems, Man and Cybernetics, Vol. SMC-10, pp. 425-446.

Selvidge, J. A three-step procedure for assigning probabilities to rare events. In: Wendt, D. and Vlek, C. (Eds.), Utility, Subjective Probability, and Human Decision Making, Reidel, Dordrecht, Holland.

Sjoberg, L. 1979. Strength of belief and risk. Policy Sciences, Vol. 11, pp. 39-57.

Slovic, P. 1978. Judgement, choce and societal risk taking. In: Hammond, K.R. (Ed.), Judgement and Decision in Public Policy Formation, Westview Press, Boulder, Colorado.

Slovic, P., Fischhoff, B., and Lichtenstein, S. 1976. Cognitive processes and societal risk taking. In: J.S. Carrol (Ed.), Cognition and Societal Behavior. Erlbaum Press, Hillsdale, N.J., pp. 165-184.

Slovic, P. and Lichtenstein, S. 1971. Comparison of Bayesian and regression approaches to the study of information processing in judgement. Organizational Behavior and Human Performance, Vol. 6, pp. 649-744.

Smart, C. and Vertinsky, I. 1977. Designs for crisis decision units. Administrative Science Quarterly, Vol. 22, pp. 640-657.

Starr, C. 1972. Benefit-cost Studies in Sociotechnical Systems. In: National Academy of Engineering: Perspectives on Benefit-risk Decision Making.

Starr, C., Rudman, R., and Whipple, C. 1976. Philosophical basis for risk analysis. Annual Review of Energy, Vol. 1, pp. 629-661.

Thorndike, E.L. 1914. The Psychology of Learning, New York Teachers College, New York.

Tversky, A. 1974. Assessing uncertainty. Royal Statistical Society Journal, Vol. 368, pp. 148-159.

Tversky, A. and Kahneman, D. 1971. The belief in the law of small numbers. Psychological Bulletin, Vol. 76, pp. 105-110.

Tversky, A. and Kahneman, D. 1973. Availability: A heuristic for judging frequency and probability. Cognitive Psychology, Vol. 5, pp. 207-232.

Tversky, A. and Kahnman, D. 1974. Judgement under certainty: Heuristics and biases. Science, Vol. 185, pp.1124-1131.

Tversky, A. and Kahnman, D. 1981. The framing of decisions and the psychology of choice. Science, Vol. 211, pp.453-458.

Underwood, B.J. 1957. Interference and forgetting. Psychological Review, Vol. 64.

Vertinsky, P. 1979. The use of mass communication strategies to promote life-style change: The case of energy conservation in Canada. In: Nemetz, P.N. (Ed.), Energy Policy: The Global Challenge, Butterworth, Toronto, pp. 383-420.

Vertinsky, P., Vertinsky, I., and Zaltman, G. 1972. Health information diffusion: An integrated model. International Journal of Health Eduction, Vol. 15, pp. 1-24.

Vertinsky, I. and Wong, E. 1975. Eliciting preferences and the construction of indifference maps: A comparative empirical evaluation of two measurement methodologies. Socio. Econ. Planning, Vol. 9, pp. 15-24.

Vlek, C. and Stallen, P.J. 1980. Rational and personal aspects of risk. Acta Psychologica, Vol. 45, pp. 273-300.

Wade, S. and Schramm, W. 1969. The mass media as sources of public affairs, science and health knowledge. Public Opinion Quarterly, Vol. 33, pp. 197-202.

Walesa, C. 1975. Children's approaches to chance- and skill-dependent risk. Polish Psychological Bulletin Vol. 6, pp. 132-138.

Ward, W.C. and Jenkins, H.M. 1965. The display of information and the judgement of contingency. Canadian Journal of Psychology, Vol. 19, pp. 231-241.

Wason, P.C. 1960. On the failure to eliminate hypotheses in a conceptual task. Quarterly Journal of Experimental Psychology, Vol. 12, pp. 231-241.

Whyte, A. and Burton, I. 1981. Perception of risks in Canada. In: Risks in Canada, A report of Risk Assessment Group, University of Toronto, Toronto.

Wilpert, B., Burger, P., Doktor, J., and Doctor, R. 1976. The risky shift in policy decision making: A comparative analysis. Policy Sciences, Vol. 7, pp. 365-370.

THE ROLE OF RISK PERCEPTION IN ESTABLISHING A RATIONAL ENERGY POLICY FOR W. EUROPE

Richard Caputo

Jet Propulsion Laboratory,
Pasadena, California

The perception of risk has played a key role in this attempt to establish a rational energy policy for Western Europe. The approach taken in this study is extremely simple but powerful. Based upon different value systems or paradigms held by the key activists in the energy arena, a path is defined that, in general, tends to minimize the social conflict over energy. It does this by:

- eliminating the blocking role now pursued by some, which interferes in the decisions made by the current coalition of government ministries and the energy industry.
- providing for adequate energy via a combination of multi-supply options and serious conservation (increased energy efficiency) throughout the entire spectrum of energy use.
- encouraging those who achieve their personal social goals by using less energy.
- carefully implementing this strategy so that those playing this blocking role are included in the process of decision making.

The multi-supply side options are not treated indiscriminately in that a kWh of energy produced by one type of system is the same as a kWh from another energy system. Risk perceptions by those involved are used to define a minimum of two categories of these supply side options. These are simply called those with major risk characteristics and those with minor risk features.

The major risk supply options are to be limited in the contribution they each make to the overall supply of primary energy. Also, the total contribution of all major risk sources of energy is limited to less than half the total energy supply. The minor risk supply options are encouraged to play a larger role. Energy options in the major risk category produce difficulties due to their political, environmental, or cultural characteristics.

There is no attempt to quantify the cost of the risk or to translate the magnitude of these costs into some common currency for assessing the total social costs. Rather, the value system of the blocking energy activists is used to determine what is and what is not a major risk due to cultural characteristics. Since these energy activists are also heavily into environmental issues, the candidates for the major risk category due to their environmental impacts are nearly the same as those with adverse cultural characteristics. Finally, political dependency questions dominate consideration of which energy sources are placed on the major risk list due to political factors.

This approach to energy policy is heavily dependent upon risk perceptions which, in turn, are based upon anthropological theories of cultural bias. Establishing the need for these theories, showing how they apply to the energy arena, and translating these theories into government policy is the subject of this paper.

A. INTRODUCTION

The question asked of this study is what is a proper investment strategy for a country in central Europe to take advantage of solar energy. This is to include consideration of European possibilities beyond the borders of the country. In performing this two year study, we were surprised how far afield we were forced to stray from the more or less straightforward program we had originally designed to answer the questions about the solar potential of Western Europe. We found that more than engineering and economics were required. We eventually borrowed from both engineering, economics, and anthropology, and tried to integrate them using the black art of systems analysis.

Early attempts to bound the limits of the technical posibilities stumbled upon differences of technical judgment. Indeed it was impossible to scope the range of possibilities to include these alternative views of energy experts, since they were mutually exclusive. When on-site and near-site solar energy systems were considered, results clustered into extremes which ranged from solar eventually becoming a marginal contributor ("the 5% solution") to solar providing almost all of Western Europe's energy needs ("the 100% solution").

As shown in Figure 1, the lower and higher numbers that resulted from the early attempts at finding the range of these factors were not what they appeared to be. Normally, the higher number is an upper bound and the lower number is a lower bound. Curiously enough, it was found that the opposite was true; the lower number was an upper bound, and the higher number was a lower bound. The range between these numbers was a perceptual void - a perception gap.

These differences were difficult to explain by examining the engineering assumptions that were used. It almost seemed that it was due to differences in conclusions. Conclusions turned out to be the starting place, followed by assumptions, followed by analysis which always reached the same conclusions that were the starting point. One researcher simply believed that decentralized solar energy would not play a significant future role and his calculation "showed" this belief, while the other saw a major role for solar. Both apparently were making social predictions and then used their technical calculation of approximate resource potential to verify their vision of future societies.

With this beginning to the analysis, we found we could not start the task of considering a solar investment strategy for a Central European country in a W. European context. Without some idea of where the investments might lead, that is, the eventual role of solar systems in Europe, it was fruitless to continue.

We stumbled almost randomly into similar problems in several other important areas within this project:

- magnitude of future European energy use of needs (energy demands)
- future economic growth, and
- future energy prices.

The sets of data on either side of these perception gaps are considered anomalous data by the energy experts holding the opposing view. It was difficult, if not impossible, for the holder of one view to seriously consider the other view. The different people involved in this study had very different perceptions about solar technical possibilities, future magnitude of the use of energy (demands), future energy prices and the level of economic activity (growth). These "beyond the pale" possibilities are easily excluded from most energy studies or at least those studies dominated by one set of perceptions.

A key decision, made early in this program, was to keep all these considerations open and not to impose one class of possibilities on the study. This decision is probably the unique characteristic of this study. The usual approach was not taken. This would normally be that the views of a lead scientists, or the concensus position of a review board would be used as the reference position to be applied to all these disparent factors. What this amounted to was a decision not to decide early in the project what was or was not anomalous data.

We proceeded with our attempt to understand why there was such perceptual differences and what to do about it. Without some expose of these underlying and profound differences, it would be impossible to suggest investment strategies for solar use in W. Europe. If the solar possibilities being suggested were viewed as ridiculous, what meaning would investment strategies have? If the future energy use level suggested was viewed as absurd and the role of solar depended on this, what meaning would investment strategies have that were based on this? If the suggested energy prices resulting (or assumed?) from this study were seen as far too high (or low) to be reasonable, what meaning would investment strategies based on this have? Thus, we were forced to take a few steps backward before proceeding.

B. CULTURAL CATEGORIES

Why do people see what they see, and do what they do? Why would one researcher feel: that society would embrace most forms and types of solar energy, especially those used near the end user; and that society would do all the things necessary to take advantage of all these possibilities? Some of these things would be done immediately and some gradually over the decades until we had assembled a solar society in Europe. Why would another researcher feel this was totally beyond credibility? There are many theories which attempt to explain this difference, but we chose one that we feel is adequate and useful. It is borrowed from the social scientists (primarily the anthropologist) and is called the cultural bias theory. Within a society with a given history, politics, similar religious activities, and relative industrial development status, there are a number of cultural sub-groups or social categories. These social categories share a common well-spring of attitudes and views toward themselves and the world around them. This clustering of beliefs are at the operational core of these individuals. This shared belief system is called a paradigm by some(Reuyl, Harman 77) or a world view by others. The resulting cultural categories have very different views about energy related issues such as:

- time frame
- risks
- nature of the "problem" and "solution"
- future energy use
- economic efficiency

1. Dimensions of Cultural Space

Since so much is based on this theory, we attempt to explain the basis for it so that our application will seem less arbitrary. The basis for this culturasl bias (cosmology) theory comes to us through pioneers like Ruth Benedict(Benedict 35) and more recently from Mary Douglas (Douglas 72) and Michael Thompson (Thompson 79, 80A). One of the initial attempts to apply this research looked at the subject of poverty to find out who were the poor and what relationship poverty had to some minimum income. The whole question was explored of how people manage and use their resources and how this relates to their attitudes toward life and their strategy of life.(Thompson 80B) This work identified five very different categories.(Thompson 80C) This amounts to five kinds of social individuals, five cosmologies, five kinds of perceptions of risk, and five risk-handling strategies.(Thompson 80A)

As a way to describe this cultural space, we borrow from these researchers a graphic description in three dimensional space, as well as a word description of these cultural categories. The dimensions of the cultural space which define these categories are:

- group
- grid, and
- manipulation.

The group is the extent to which an individual is involved in, or free from, bounded social groups. So this dimension would go from "individualized" to "collectivized".

The second dimension of this cultural space is grid. This is the extent to which an individual is subject to socially-imposed prescription. So this dimension would go from "egalitarian" to "hierarchal". The third dimension is manipulation. The conjunction of social context and cosmology will generate its own distinctive strategy. This strategy will result either in the individual manipulating others or being himself manipulated.

The cultural bias theory maintains that a person can come to reside in a limited number of stable zones or cultural cateogries in a three dimensional socio-cultural space. The cultural bias theory as developed by Douglas and Thompson have identified five cultural categories or paradigms and explain why only three actively participate in the energy debate. These coincide perfectly with Harman's three energy paradigms. Indeed a number of researchers have found these three views of energy users. Some are: Schanz on oil and gas resource magnitude (Schanz 78); Chapman on future energy use magnitude (Chapman 75); Humphrey and Buette's political science perspective (Humphrey and Butte 80); and Orr's energy perspectives (Orr).

We refer to these as the three energy tribes (Thompson 81) and label them A, B, and C, and call them the entrepreneur, the hierarchist, and the survivalist. They are the active participants in the energy debate, and the remaining two cultural categories do not participate. The life-is-a-lottery person (anomie or D category) is unable to participate no matter how much he may wish to, and the automonous individual (hermit or E category) will not, no matter how capable he is of participating, since he will not become involved in any coercive social situation.

The three active participants each have a distinctive personal strategy. The A person (entreprenuer) has an individual manipulative strategy while the B person (hierarchist) has a collective manipulative strategy and a cast social structure. The C person has a collectivists survival strategy and a sect social structure.

In terms of the three dimensional space described, there are two manipulating cultural categories and two that are manipulated. Each of these two sets has one individual and one group category, and also one with strong prescription (grid) and one without. The combinations are shown below:

Cultural Category	Socio/Cultural Dimension Manipulation	Group	Grid
A	+	-	-
B	+	+	+
C	-	+	-
D	-	-	+
E	0	0	0

The entrepreneur (A) is an individual who manipulates with little imposed prescription (negative grid). The hierarchist is the other manipulator but is a group member and has strong prescriptions imposed (positive grid). The third major actor in the energy arena is the survivalist who is manipulated, is a group member, and has little prescription (negative grid). A graphic representation of this three-dimensional space is shown in Figure 2 (Thompson 80). It tries to illustrate that at the locations where the contour becomes flat (five places), it is possible for individuals to come to rest and there exists a cultural category.

With this graphic description in mind, what are the resulting characteristics of these cultural categories that give life to what have been so far rather abstract concepts of the anthropologist?

2. Social Bases of Perception

With each cultural category, there goes a distinct rationality--a world view and cosmology, a cultural bias, a paradigm. As described by Thompson, this is a particular way of seeing the world and one's place within it. This provides a moral justification for certain kinds of action, and a moral basis for moral disapprobation of other kinds of action.

The idea is that social context and world view will tend to stabilize one another and that, as people in a shared context come to share a particular world view, so they acquire and sustain a particular morality that enables them continually to make judgments on human actions: rewarding some and punishing others. The hypothesis states that such shareability--such stabilization of moral community--can only occur at or near these five equilibrium states and that each requires a distinct personal strategy to maintain its stability.

As explained by Thompson, the result of all this is that individuals in different social contexts will tend to home in on to distinctive strategies that will enable them to act so as to steer some optimal personal course through all these socially-imposed rewards and penalties. And, if you observe an individual as he follows one of these strategies, you will discover whether he ends up manipulating others or being himself manipulated. It is these disjunctions of manipulation--sometimes positive, sometimes negative--sometimes zero--that are responsible for the clear separation of the cosmologies and their associated strategies.

The unique combination of world view and strategy that is appropriate to each social context results in an individual in that context perceiving his external world in a distinctive way. So this hypothesis forms the basis for an anthropological theory of perception--not of how we perceive (physiologically) nor of what we all perceive (psychologically) but of the patternings that, when more than one perception is possible, are socially imposed in order that certain moral commitments may be rendered self-evident.

3. Cultural Categories

The A cultural category has so far been identified as an individual (negative group) who is egalitarian (negative grid) and manipulates (positive manipulation). This seems to result in his being a pragmatic materialist who gets things done and believes in minimum government interference. His view of the short term dominates the long term. He feels that his needs are every growing, and that you can manage your needs and the resources generated to meet these needs. However, he cannot control the overlap between them; that is, he cannot live well within his resources. Thus, his strategy is to maximize his resources to meet these growing needs. He sees nature as cornucopian and tries to manage the horn-of-plenty to point in his direction.

A member of the B cultural category is collectivised (positive group), hierarchical (positive grid) and manipulates (positive manipulation). He has a balanced discrimination between the long and short terms. He feels you can collectively manage your resources but not your needs, and needs are relatively stable. His strategy is to maximize resources collectively. He lives in relatively stable cast-like groups and is fond of rules, regulations, and social prescriptions to manage his world.

The C cultural category is collectivized (positive group), egalitarian (negative grid) and manipulated (negative manipulation). He is a sect member and feels you can collectively manage your needs but not your resources. His strategy is to minimize needs (he is against growth). He sees an accountable nature and would say there is no such thing as a free lunch. He sees the long term dominating the short term. The group is defined by those who do not belong to it.

The D cultural category is an individual (negative group) who lives in a strongly prescribed setting (positive grid) and is manipulated (negative manipulation). He feels he cannot manage his needs or resources, and his strategy is survival. He has short-term interest and sees life as cornucopian but cannot get the horn-of-plenty to point in his direction. Thus, he relies on Lady Luck to help him.

Finally, the E cultural category is at the null point and has low group, grid, and manipulation. He avoids all <u>coercive</u> involvement and neither manipulates nor allows himself to be manipulated. He can manage both his needs and resources, as well as the overlap between them. His strategy is to maximize the overlap by simultaneously managing needs and resources. A thumbnail sketch of these five cultural categories and their personal strategies is shown in Figure 3. (Thompson, 80A)

4. Hypothesis

Based on this cultural bias model, we make the following hypothesis: these cultural categories are pervasive throughout society and at the very heart of the dissonance in the energy "debate." We further propose that we take a few of the key characteristics identified by the anthropologists as a core aspect of the cultural group, and then try to assign the other characteristics and energy-related attitudes of members of each cultural category. We use as subjects the members of our own study team and, where necessary, the attitudes of others well-known in the energy "debate." As described earlier, the existence of persistent gaps in perceptions indicated that members of several cultural categories already exist on our study team. Thus, using this theory and our hypothesis, and very limited field work, we set out to try to understand the basis for the profound differences that surfaced as we initiated our study.

5. Extension of Cultural Bias Theory to the Energy Arena

Examining these five cultural categories, we find that three enter actively into the energy debate: A, B, and C. The D category cannot enter and the E chooses not to. There are two cultural categories that we refer to as limited sighted, and the third we call the bridging or connecting category.

a. Limited Sighted Cultural Categories

The limited sighted categories "see" clearly or are primarily concerned about either the near term or the long term.

Entrepreneur

The near-term sighted group can see near-term opportunities to be taken advantage of, feels the world is cornucopian, and that the greater danger to the social fabric occurs if economic growth falters and social chaos results. This is somewhat like skating on thin ice: if you slow down you will fall through. He is a risk-taker and a doer. He believes that increasing use of energy (along with economic growth) go hand-in-hand, and that the "problem" is artificially contrived shortages due to unnecessary rules and regulations, timid behavior of governments, obstructionism of some irresponsible people, and increasing restrictions due to essentially groundless environmental concerns. He either does not see longer-term physical or environmental consequences of current activities, or he just feels that if these problems actually develop, they can be dealt with in the future through technology and experts most probably at economic advantage. His motto would be, "if I don't do it, someone else would." He is an individual with weak group ties, and is a manipulator. He is a dynamic doer and risk taker who sees near-term opportunities. We call this social category the entrepreneur.

Survivalist

The other cultural category that has limited sights is risk adverse and is relatively indifferent to the near term but has excellent vision of the longer term threats to the society. Although deeply concerned with the human dimension and looking for ways to increase humanism in the world around him, he usually sees these future threats as dangers to the physical environment.

This cultural category sees the world and its avaiable resources as limited (spaceship earth). He feels the best strategy is to decrease needs and stay within these limited resources. Thus, he sees future energy use decreasing usually along with increased energy use efficiency so that there is actually a higher energy activity level with less energy. He sees the "problem" as mindless application of economic optimization where most important things are ignored in this type of decision. This leads to numerous hazards which taken together threaten the very survival of our species. He also feels human institutions have grown increasingly complex and specialized, and are becoming almost devoid of humanness. Thus, he sees that people living more simply in a village-type setting is the key to bringing everything back under control. These individuals press for profound change now as the only way to get to this secure future.

This social category is inhabited by individusls who form strong egalitarian groups (sects). They identify themselves by surrounding themselves by a wall of virtue. This separates all those who are and are not group members. They are not manipulators. We call this social category the survivalists.

b. Bridging Cultural Category

The connecting cultural category is not just a clustering of individuals with a similar world view--they belong to inter-related social groups. They are embedded in hierarchical and bureaucratic organizations with a great abundance of rules and regulations. This category is nestled between the other two in many respects, and it has some interesting and important differences.

They are risk-adverse, but they do not take the approach of the survivalist which is to avoid any activity that does or might contain risk. Nor do they take the approach of the entrepreneur of taking almost any risk to avoid the risk of not growing.

Instead, this connecting cultural category spreads the risk over their own groups and downwards through the hierarchy so that it is not a burden for each individual but shared by all. Because they are concerned with both near- and long-term risks, they fall into some middle ground between the entrepreneurial individuals and the survivalists in the perception of the time frame. They take the approach of setting limits to the activities of individuals via rules and regulations that keep what is allowable within agreeable group bounds. Such groups inhabit most government ministries and other hierarchical institutions. Their attitudes toward needs and resources (energy demands) are that the overall needs that they see are fixed by other forces in society and resources are somewhat limited. However, within this they work diligently to increase their share of the resources and manage their needs upward. Thus, depending on the cultural context, they might be in favor or higher or lower energy use and/or economic growth.

They can and do manipulate, and are in constant conflict with other similar groups for their share of these resources and with the A individuals. Hwever, they are also attracted by the concept of increased energy efficiency as a way to stretch their resources and can consider seriously the decoupling of economic and energy growth. We call this group the hierarchists.

C. Three Views of the Future

When energy use is considered, three very distinctive futures emerge when viewed through the "eyes" of these three energy tribes. As illusatrated in Figure 4, the A group sees a continuation of past trends and has a "growth forever" view of the future. The future is to be like the past, and there is no gap between the present and the future. The C group also sees the future close in upon the present, but there must be a sharp and discontinuous leap to a much lower level of energy use. This is a radical change in the perception of the future and a low growth future. The B group sees a future discontinuous from the present and further away. The B group energy level is somewhere between the A and C group. Some B's can be fairly close to the A view of the magnitude of future energy use, while other B's will be much closer to the C view of magnitude. Thus, the B's occupy a middle road but sees a discontinuous future that requires a balancing of extremes and much planning to achieve this.

d. Cultural Category Dynamics

Other cultural categories exist but do not play a direct role in the swirling energy debate, because they cannot or do not want to. The major power axis today exists between the entrepreneur, which for convenience we call the A's, and the hierarchist which we call the B's. The B's are constantly in struggle with the A's and are trying to minimize and spread the risks of energy activities, while the A individuals are trying to throw off the resulting proliferation of rules and regulations. The balance point is constantly renegotiated as the A's and B's confront each other.

The survivalist, which we call the C's, are moving around the periphery of this main struggle and are usually aghast at the unholy marriage between A and B. (That is, the day-to-day negotiated compromises reached by the A and B people.) The C's cry out at this folly, and the obvious doom and destruction are just around the corner. Since the B's are more or less receptive to suggestions of risk being real, the C's are able to convince the B's of the reality of some of these dangers. The B's then attempt to impose new restraints on what is allowable. This results in new or strengthened rules and regulations. Thus, in a properly functioning social interaction, the C concerns are gradually introduced and institutionalized by the B's in their struggle with the A's. This is illustrated in Figure 5.

What we are suggesting is a kind of Bohr atom model of social interaction. As with this simplistic and primitive model of sub-atom particle behavior, there are two heavy quantities (neutron and proton) existing at the core of the substance which have strong forces between them. Meanwhile, there is a much lighter quantity (electron) orbiting around these two. This lighter quantity influences the core quantities and is influenced by them but never directly enters the core space. It is content to orbit about the outer space and has the opposite polarity of one of the two core substances. Although with closer investigation, it was found that the Bohr atom does not exist as such, it provided a visualization of something intangible. It was the conceptual breakthrough of the relationship among sub-atomic particles that enriched research that followed.

So it is in this spirit that we suggest this relationship among the cultural categories to help visualize things that were unseeable before. It is simplified and even primitive, but we believe very helpful in the initial understanding of social substances that exist, their behavior or characteristics, and the interactions that are likely or possible. From this we hope to give guidance to "reasonable" policy strategies that will lead to an increased ability to understand and, hopefully, to deal with these swirling social forces.

e. Vital Roles

All three types of cultural categories are the key to the proper functioning of society. The ability to see near-term opportunities and vigorously act on them is vital to a society. The capability to see the longer-term dangers that may or will result from our varied and complex technical and social dealings is equally vital to a society. Finally, some way is needed to balance these vital and disparent functions and institutionalize them in some social framework.

6. First Policy Recommendation

This observation of vital roles leads to our first recommendation that no government policy should so constrict one of these three cultural categories, so that it cannot perform its role. The doers should not be prevented from doing. The risk spreaders should not be prevented from making their necessary rules and regulations. Those who see possible longer-range dangers should not be held mute so they cannot call out the danger. Only by allowing all three to function will the balance among these views be established. This is the greatest hope for our continued passage in what we hope is a long-term sharing of the planet.

C. APPROACH TO SENSING "REALISTIC" SOLAR POTENTIAL

Early in the study, we constructed three major physical arrangements of energy technologies which we call scenarios. All are able to sustain W. Europe's energy needs for the indeterminate future. They are based primarily on nuclear, centralized solar (hard), and decentralized solar (softer). Although they each provide the same function to society, they have some vastly different characteristics.

To these scenarios we add two projections of future energy use, a lower and higher case. Comparison can be made by reviewing required capital, land, material, and attempting to catalog environmental insults and human health effects.

However, we place the greatest emphasis on two aspects of these energy systems: the social conflicts resulting from attempts to adopt each scenario, and on the macrosystem characteristics.

1. Macrosystem Characteristics

Macrosystem characteristics are the family of characteristics which have governed past energy substitutions. They include increased streamlining or convenience as persistent growth in global primary energy (2.2% per years since 1800) has pushed us from the use of solids to liquids and now gases and electricity. This growth has also pushed us farther up the energy hierarchy of levels of energy systems from on-site, to district, to national, to continental and, finally, with the arrival of cross-ocean oil transport, to the global level. There also seems to be an improving environmental situation as the overall health and physical impacts improve, since we have been moving from coal to oil and now to natural gas.

Institutionsl behavior plays a role in macrosystem characteristics as the dominant energy source industry gets "old" as it achieves this dominant position. It institutionalizes its success by fixed internal relationships and is dominated by ritual. It no longer can respond flexibly to new opportunities or changing situations. (Marchetti 75 and Caputo 81)

Macrosystem characteristics give us the basic time dynamics of energy substitutions. Stimulated in the most profound manner by human innovation and invention, these energy substitutions are based on the human learning and diffusion process (Marchetti, 80). These depend on a multitude of cultural traits and characteristics, but exhibit themselves by the time constant for market penetration. It has taken W. Europe about 30 to 35 years for the market share of fossil energy sources to go from 1% to 50%. The rate of withdrawal for coal, and the rate of introduction for oil and natural gas are in this range.

Nuclear energy seems to have slower W. European penetration with a time constant of about 70 years. However, this is based on less than 5% total market share and long-term projections have limited reliability based on this low market share.

Thus, the learning system dynamics of W. Europe as a composite group have a time constant of about 30 years for fossil systems and about 70 years for nuclear technology.

The historical data for OECD Europe (Organization for Economic Co-operation and Development, which is very similar to the 19 countries of W. Europe) and a simple future projection is shown in Figure 6. The assumptions made are that coal, oil, gas, and nuclear continue at historic rates. Also, it is assumed that new coal is introduced in 1990 at 1% penetration and new solar (composite of all direct and indirect solar technologies) is introduced at 1% market share in 1995. "New coal" is simply the use of coal in entirely new ways that would bear little resemblance in the traditional coal industry.

New solar is an amount and type of solar energy not existing in 1980. The simple model(Marchetti and Nakicenovic 79) predicts the future market substitution shown in Figure 6. Nuclear peaks at 17% market share of primary energy in 2012; "new coal" at 39% in 2020. Solar reaches 50% market share in 2025 and continues to dominate the energy system, since we do not introduce any post-solar energy option. We apply these historical macrosystem characteristics to our future suggestions as a reasonableness check.

2. Socio/Cultural Conflicts

The social conflicts are sensed by first adding a social context to these physical scenarios and future energy use levels. This is an attempt to take the "indigestible beads" of physical supply scenarios and describe the sequence of social and political events and situations that make the resulting energy system more plausible. If not more plausible, then at least more understandable. These scenarios and future energy use levels are viewed through the "eyes" of the three major cultural categories that are the main actors in society's swirling energy debate.

From these views of the suggested futures we see what is agreeable, and what will result in some of persistent conflict among the cultural categories. With these conflicts in mind, we attempt to define scenario/energy use levels that are more successful; not technically, since all these physical scenarios work at providing all of Europe's future energy eventually (≥2070), but socio/policitcally in that major cultural categories can embrace the suggested scenario.

If such an agreeable modified scenario/energy use level is not apparent, then we put forth a set of recommendationa and policies (investment strategies) that seem warranted.

3. Other

Any comparison of futures should evaluate other important aspects of these scenarios/energy supply levels. Certainly land use, materials use, necessary capital allocation, energy cost, environmental impacts and human health effects are such important aspects. These are reviewed to help sense where difficulties would lie in these futures being reasonable. In addition, storage requirements are examined due to the perception that this is a particular problem for solar systems. Hourly simulation of solar plants and energy use profiles are compared so that required storage can be identified.

Since this is a relatively wide-ranging systems analysis, it is not possible to delve into each of these important areas as deeply as we would wish.

D. KEY FINDINGS

1. The "Problem"

In sitting back and contemplating the meaning of all of this research, it is difficult to sort through the dozens of technologies, hundreds of energy-use and economic assumptions, thousands of references, and millions of numbers used in scenario calculations and arrive at the single most important finding. It probably would be that the current problem with energy in W. Europe is the social difficulty in establishing an energy policy that is broadly supported and seems to meet societal needs. The current A-B coalition that makes decisions normally, is being blocked more or less effectively by a C inspired opposition that occasionally spills into the streets, and occasionally results in violence and injury. The perception of this by the usual decision makers more often than not is that some people are not acting "rationally," have unclear or unreasonable demands, are wild-eyed romantics that should have been born in some preindustrial time where their fantasies of a simple pastoral life could be easily fulfilled.

There seems to be a hardening of views occurring as attempts to be "reasonable" have failed over the last two decades. There is a sense that the increasing resort (in some countries) to overwhelming police presence and occasionally police force to preserve the viability of energy project decisions made by those who normally make decisions, will lead to more of the same. More massive police presence, more frequent application of force, more occasions of injury, more hardening views, and so on.

This is a strategy of desperation born of frustration on all sides. It seems likely to sporn more desperate individuals and small groups convinced that it is truly hopeless to try to deal with "them." This will certainly make more likely the kinds of activism that are clearly outside almost all norms of socially acceptable behavior. This gives rise to criminal behavior and this, in turn, will make it easy to criminalize all or most of the opposition to the decisions of normal decision makers. This seems to be leading to a "solution" that will fill prisons and camps with those who object.

When the A cultural category person is deeply concerned with the social difficulties that result from insufficient economic and energy growth, he is trying to avoid conditions that he feels are unacceptable and to everyone's detriment. He feels that social chaos born of resource limits precipitating economic stagnation will lead to the onerous conditions which existed in Europe in the 30's. He will move mountains to avoid the recurrence of these conditions. One can certainly understand his anxiety and increasing hostility to those who he feels are by their misguided and romantic notions trying to precipitate exactly these conditions.

However, the current situation is leading to a remarkably similar situation, not from economic stagnation, but from the feeling of an increasing number of citizens who want to be involved in decision making, that they are outside the process. In either case, social conditions are being created that lead to "solutions" that are highly undesirable for Europeans. It is difficult to see how these solutions can lead to a whole Europe that not only is meeting its energy needs but meets them in a way that keeps the social fabric from being ripped asunder.

Conditions do not exist as described in each of the 19 countries of W. Europe. The situation is certainly different in each country due to all the differences that make each country unique. Thus, we are addressing what we feel is the most difficult and desperate type of situation that now exists in some countries or could be created by continuation of past activities.

The question becomes how do you establish an energy policy in W. Europe that meets societal needs and is sufficiently broadly supported to diffuse the existing and likely future confrontations in this area.

2. Technical/Economic "Solutions"

Within the scope or our research, we have concluded that a wide variety of technical solutions are possible at a relatively wide range of energy-use levels using for the most part tools developed previously at IIASA. (Hafele 81) These range, in one extreme, from an all-nuclear Europe with at least twice today's per capita energy use, where nuclear exceeds a 50% share of total energy use by 2030. All-solar Europe is possible, based primarily on centralized (hard) schemes such as southern solar thermal plants at per capita energy-use levels of about 1.5 times higher than today. Indeed, all-solar Europe is also possible based on half-decentralized and half-centralized solar energy (softer) at about today's per capita energy-use levels by the end of the next century.

The energy-use levels that go with each physical supply scenario are not really limited by resource constraints. (For example, the softer solar scenario could meet more than today's per capita energy use.) Rather, it is the coalition of cultural categories that fit a given scenario and their social values that would determine the combination of energy supply techniques and the magnitude of energy-use. (Energy-use magnitudes are commonly called energy <u>demands</u> by some cultural categories.)

An example of one of these scenarios is the centralized, hard solar that primarily depends on large plants in southern Europe to provide electricity and hydrogen for use throughout Europe. The penetration of primary energy or oil equivalent is shown in Figure 7 (total) and in Figure 8 (fraction of total market share). About 50% penetration of solar (southern plants, biomass, and some hydroelectric) is achieved by 2030. This is quite close to that predicted in Figure 6 by the macrosystem model. A similar profile can be drawn for nuclear (50% by 2025) and the softer solar (50% by 2015).

These widely ranging technical futures all have relatively similar overall economic characteristics in that the total energy system cost is similar at the same energy-use level. Differences of 30% seem to be the magnitude of the difference between these vastly different approaches at least for the limited time period of greatest difference. The total energy system cost is the sum of all capital, fuel, operation and maintenance, and transmission costs divided by the energy generated that year. This difference is well within the range of economic uncertainty.

This can best be illustrated by reference to Figure 9 which shows the economic results for five European scenarios and four regional scenarios. The results are for a time when each scenario has stabilized (2070 to 2100) and are shown relative to the most economic combination of all technical options. To give somewhat more information, the results are shown versus the share of the sum of indirect solar (wind, biomass, hydroelectric, etc.) and decentralized solar (on-site and neighborhood systems). The more exclusive scenarios are the most expensive; nuclear is about 1.32 times more expensive, hard solar is about 1.28 times more expensive, and the softer solar scenario averged over all of Europe is about 1.22 times more expensive.

It is interesting to note that even the nuclear scenarios use about 8% solar (primarily biomass for chemical feedstocks) and the hard solar scenarios have about 18% indirect solar (a combination of biomass and hydroelectric). The softer solar Europe scenario has about 100% indirect and decentralized solar (primarily wind, on-site heating and photovoltaics, biomass, and hydroelectric). Combinations of these three generic technical approaches all reduce costs below these more exclusive cases.

The combination of nuclear and hard solar reduces energy costs to 1.25 times the all-systems economic scenario. The centralized economic scenario (previous case plus wind, more hydro and wave) achieves a cost of 1.15 times the economic case with a 25% share of indirect snd decentralized solar.

The all-system economic scenario for central Europe (reference system for these economic comparisons) has 59% indirect solar (wind, biomass, and hydro) and decentralized solar. Hard solar systems conribute 13% and nuclear the remaining 28%. When nuclear is removed fom this all-systems economic scenario, the energy cost increases by 10% in the solar economic scenario. Removing decentralized solar from the all-systems economic scenario increased energy even more to 1.15 times (centralized eonomic scenario). Removing decentralized solar and wind systems from the all-systems economic scenario increases the cost by 1.25 times (hard solar and nuclear economic scenarios). Removing decentralized solar, wind and hard solar increases the cost to 1.33 times (nuclear scenario).

Most scenarios have similar results throughout Europe, but the exception is the softer scenario. As a European average, it is 1.22 times the all-systems economic scenario. However, this is the population weighted average of the south (0.9 times the energy cost), the central (1.51 times), and the north of Europe (1.28 times the cost of all the systems economic scenarios). The central European energy costs are reduced from 1.51 times to 1.1 times the all-systems economic scenarios and not insisting on relatively uneconomic amounts of decentralized solar.

If the all-European scenarios are considered, the range of energy costs are actually within 16% of the mean. This is a relatively small band of relative costs among these extreme scenarios, and indicates that economic considerations are of a secondary nature compared to other factors.

All of these scenarios share the trait of being much more capital intensive. They go from the 1 to 10.5 capital to fuel cost ratio of today to about 3 to 1 by 2070. A dramatic change and the eventual (>2050) capital to fuel cost ratio is 2 to 1 for nuclear, 4 to 1 for hard solar, and 1.8 to 1 forsofter solar. These are relatively small differences compared to today's situation. Thus, all three schemes will have an increasingly difficult time raising capital.

However, the "energy cost" (total annual energy system cost divided by the energy generated that year) for all three scenarios go from 22 mills/kWhr today to 40 to 66 mills/kWhr by 2070 (1980 dollars). This range of uncertainty is primarily due to:

- magnitude of "real" inflation for the reference system;
- the fraction of the total capital used in the system that is subjected to financing charges (interest);
- future cost of various technologies.

Within the uncertainty of these factors, it is not possible to say which scenario (nuclear, hard solar, or softer solar) is more or less expensive. If anything, the softer solar at the lower demand level that it is culturally consistent with, has the lowest total energy system cost but at a somewhat higher cost per unit energy.

The capital investment needed in the energy sector is as high as 7% of total GNP (hard solar in about 2023) compared to the 2% to 3% of today's fuel cost dominated system. When imported fuel costs are significantly reduced or eliminated, this percentage capital for the energy sector could reasonably be 4% to 5% without raising serious questions. Note that about 20% to 22% of total GNP is used today for all capital investment. Therefore, the amount required for the most capital intensive of these capital intensive systems is about 1.5 times this estimate, based on no imported fuel. This indicates that changes would have to occur in the structural relationships between the energy sector and the rest of the economy in W. Europe due to energy capital costs having such a large share of total GNP.

Therefore, we have the paradoxical situation where cost per unit energy doubles or triples over the next century while using a smaller share of total GNP at that time than today (energy is cheaper). Yet the share of capital used in the energy sector is about twice to three times today (energy is more expensive). So, at the same time, energy costs are both cheaper and more expensive, and macroeconomic evaluation is more difficult than one would expect.

systems but would have a much more limited political role due to the B's taking over almost all decision-making machinery in this "big brother" future.

The softer solar scenario would fit best with a B-C dominated coalition and result in this half-and-half energy system at about today's per capita energy use. It appears that this is likely if a broad based Ghandi-type passive political movement swept Europe over the next 10 to 20 years and prevented all nuclear and most large conventional energy systems from being created. This would force a political solution that increasingly met the C view of the future with emphsis on energy frugality and more decentralized decision making as well as decentralized energy systems. This would create some, but more limited, economic opportunities for the A's but leave them just as politically estranged as in the previous case.

4. Multi-Path Strategy

None of these three scenarios seem to work well in that at least one cultural category is left with a diminished role which would result in unresolvable social conflict. Based on this integrated view of the system--the energy/people system that is the subject of this study--we suggest the following investment strategy. This strategy has two major and simultaneous elements. The first involves a simple, crude -- but we suspect -- a powerful categorization of opportunities that exist which we recommend be used to meet Europe's energy needs. The second and equally important element is "how to implement" these opportunities.

a. Meeting Energy Needs

We divide the opportunities to meet Europe's energy need into four parts. The first two are supply-side options that are the more or less usual list of major supply opportunities that are all economically attractive in the proper application after successful development and commercialization. However, they are divided into two parts based on an extremely simple characteristic--those that have a major and those that have a minor risk potential. The judgment of major or minor is made based on environmental, political, or cultural risk potential.

This judgment of risk perception is made primarily through the "eyes" of those involved and especially those currently playing the blocking role. There is no attempt to quantify the cost of the risks or to translate the magnitude of these costs into some common currency for assessing the total social costs. Rather, the value system of the blocking cultural category is primarily used to determine what is and what is not a major risk due to cultural characteristics. Since this cultural category (C) is also heavily into environmental issues, the candidates for the major risk category due to their environmental signature is nearly the same as that due to adverse cultural characteristics. Finally, political dependency questions dominate consideration of which energy sources are placed on the major risk list due to political factors.

We recommend that each of the six suggested major risk options be limited to a small (less than 5 to 10%) share of the supply side of total energy. We further recommend that the eight minor risk options be each encouraged to accept a large (up to 30%) share of the total energy. These 14 options are shown in Table 1. Three of the six risky options can, if future events show it is necessary, be eliminated and the less risky supply options increase to make up the difference.

TABLE I: SUPPLY-SIDE OPTIONS IN MULTI-PATH STRATEGY

MAJOR RISK SOURCES:

- o Limit the contribution of each so that any 3 of 6 can be dropped if if future events prove it is necessary
  - nuclear
  - coal
  - imported oil and gas
  - large amounts of Spanish or Turkish solar
  - N. African and Middle East solar
  - Extra-continental energy (SPS, ocean, other)

Total: less than half

MINOR RISK SOURCES:

- o Encourage to play more substantial role
  - domestic oil and gas
  - hydroelectric
  - wind and wave
  - biomass
  - utility STEC (1) AND PV (2)
  - solar district systems
  - on-site solar heat
  - on-site PV (2)

Total: More than half

1. Solar thermal energy systems: electric, hydrogen, and heat
2. PV - photovoltaic

The amount of land used for these three scenarios goes from 6% of Europe's total land for the all-nuclear, 8.5% for the hard solar, and 4% for softer solar. This land use is at the energy-use level thought to be most appropriate for each scenario. This is 2.4 TWyr/yr secondary energy for nuclear, 1.9 TWyr/yr for hard solar, and 1.3 TWyr/yr for softer solar. (A TWyr/yr is about 30 quad/yr or 14 million barrels of oil per day.) If each supply scenario meets the same energy-use level (the higher one), then the hard solar land use becomes 10% and 8% for the softer scenario. As we indicated earlier, the energy-use level does not appear to be an independent variable. It seems to depend strongly on the physical supply scenario and the cultural situation that fits this scenario.

The macroeconomic check of whether the energy cost - energy use combinations are reasonable seems to indicate that the nuclear, hard solar, and soft solar at the higher use level are reasonably well within the uncertainties of real inflation, the degree of financial charges for capital, and future energy costs. These macroeconomic relationships seem not to hold true at the lower energy-use level using the set of assumptions made for the higher energy-use level. Uncertainty about future energy sector productivity could allow even this macroeconomic theory to support the consistency of the energy cost/energy use combination at the lower energy level. The physical supply scenario that goes with this lower energy-use level is the softer solar scenario. This fits best with a cultural category coalition between B's and C's. A future dominated by this coalition would make much stronger attempts to decouple economic growth from energy use by increasing energy-use efficiency among other approaches. This would certainly increase what is called energy productivity and give macroeconomic consistency.

Thus, we found a range of technical/economic solutions that more than anything else seemed to fit certain dominance of cultural categories or paradigms as shown in Figure 10.

3. Paradigm/Scenario Relationship

The present A-B dominated coalition, if continued without modification seems to lead to a nuclear dominated energy future for Europe at energy-use levels of at least twice today's per capita energy-use. We hypothesize that this would be more likely if the potential blocking role of the currently estranged C's would give way. This could happen, for example, if a global depression started in this decade and persisted until the end of the century. This would certinly tend to bring people back to "hard realities" and tend to sweep away "undue concerns" with the environmental "frills" espoused by the C cultural category.

The technical/economic failure of nuclear, including many directly attributable deaths with no other major factors changing, would lead the way to a B dominated situation. With B in control due to nuclear failure, there would likely be a technical switch to hard solar with some energy and economic growth decoupling, resulting in about 1.5 times today's energy use level. The nuclear failure would allow the B's to over-regulate, over-control, and over-plan Europe's future by being given broad public support to a non-nuclear future but within today's centralized type of social situation. C's would still be estranged by this highly centralized world with massive central energy systems. The A's would be heavily involved in creating these energy

The third part of the first element of our suggested strategy is to pursue increased energy efficiency in all energy sectors.

The fourth part is to encourage those individuals who wish to use less energy to meet their own social goals to do so. This simply would allow those who wish to meet their own social goals by using more energy to do so with less of the overall onerous impacts of energy use. This appeals to all the C's and some of the B's and E's. This could mean encouraging village-type communities for those who wish energy frugality and a more decentralized society for themselves. These four parts of the first element of our strategy are listed in Table 2.

D. MAJOR AND MINOR RISK SUPPLY SIDE CATEGORIES

All nuclear systems are in the major risk category due to its cultural difficulties, since there is such a strong response against it from several cultural categories. The probability of great damage from nominal operation, the long-lived nature of some of the waste products, the dependency of specialized knowledge of experts, and the characteristic of nuclear being synonymous with large, centralized systems all contribute to the difficulties of nuclear. Finally, the charge of abuse from sabotage groups as well as the link to weapons production make nuclear a major risk to many people.

The human health impacts of coal to both occupation and public sectors is well documented. Environmental impacts are great at mining and end-use stages of the system from mine drainage, strip mining disruptions, acid rain and air pollution.

Imported oil and gas have the obvious political difficulties of foreign dependency. To a lesser extent, this same problem will exist with imported solar energy from North Africa and the Middle East. Also, if a single country resource such as solar energy from Spain or Turkey is relied upon too extensively, it creates similar political problems.

Extra-continental sources of energy, such as the satellite power system (SPS) and ocean solar system, even if self-owned, have a number of difficulties related to how secure this source really is. Thus, the prudent path is to limit use of these resources. In addition, the SPS has a number of possible environmentl, legal, political, and economic problems which further complicate its use.(Caputo 77)

The minor risk supply options are domestic oil and gas and a wide range of renewable energy sources (both direct and indirect) Their being placed on the minor risk category does not mean that they do not have risks, but that if used in a socially responsible manner and scale, it is likely that they will be widely acceptable.

Thus, we are suggesting a crude but effective ordering of supply-side options that puts the subject of risk in perspective. We basically use the cultural bias of the blocking group to help identify what is or is not likely to be acceptable. Also, political and where separate, environmental factors which could limit acceptance are also introduced.

Our engineering and economic studies show that there is sufficient flexibility to the technical options to order them in a more acceptable manner with little economic impact. Issues related to not only type of energy

TABLE 2. ELEMENTS OF MULTI-PATH STRATEGY

- Limit energy sources with major risk to less than half
- Develop supply options with little or no major risk potential
- Pursue increased energy efficiency in all sectors
- Encourage individuals who wish to use less energy

technology but also to size, scale, and ownership are also sensitive dimensions and could determine whether a particular approach is on the major or minor risk category.

c. How to Implement

Reaching the C's (Survivalists). The second element of this overall strategy is the "how to implement" the four parts designed to meet Europe's energy needs. This, if anything, is the more important aspect of the strategy. You may wish to rearrange the supply-side options, change the percentage contributions, and so on. But whatever a particular country comes up with that seems relevant to them and their particular situation, the "how to implement" element is vital.

It is quite clear from our simplified model of the three cultural categories which are playing the major role in the swirling energy debate in Europe, that the current difficulty is the more or less effective blocking role of the C-type individuals and groups. It is equally clear that the C's are a vital part of cultural dynamic that is our best hope for long-term species survival. Finally, it is clear that the uniqueness of the C's is their uncompromising dedication to the purity of their ideas and their refusal to compromise the issues that they feel rest both with the survival of the planet and the survival of the human spirit. Therefore, we cannot expect them to compromise in the way the A's and B's can and do as part of the usual give-and-take of everyday political and economic life. All the C's will never fully accept any compromise of these vital issues no matter how far we seem to move toward their position.

Therefore, even if the entire strategy identified in the first element is enacted quickly throughout Europe, it is clear then there will be some opposition to what they see as this "halfway step." This reaction would exist even though this is a strategy that some among you will view in complete disbelief as an unwarranted concession to the "worse and least responsible elements" among the B's and C's.

Thus, the key to our second element is not the quick and effective implementing of the strategy, because this in itself may not illuminate the blocking role of the C's. The key is to put a very strong effort into attempting to introduce the C's into the decision-making process.

Even for the 40 to 90 years it will take to fully implement this strategy, each step of the way should appear and indeed be, the result of the attempt not only to reflect C concerns but of the attempt to include them in the process. This should be the most effective way to actually derive the full benefit from each step toward the balancing of the cultural categories' social needs while meeting Europe's energy needs. We are not suggesting a mock display of public relations hoopla at each announcement of A-B group decisions to satisfy the C's. We are suggesting a broadened political process of involvement that more actually reflects the C sentiment that is currently excluded from almost all decisions. This suggestion is irrational behavior within an A or even a C cultural context, and to some degree within the current B cultural context. However, we feel that this strategy is rational based on these theories or cultural value systems.

The all-systems economic scenario we have developed is reasonably close to the multi-path strategy as far as the supply-side elements are concerned. After about 2040, all fossil fuels have less than a 10% share of total energy. Of the six risky energy sources, only nuclear energy and southern hard solar are used in the all-economic scenarios. Nuclear use is 28% of primary energy and/or oil equivalent by 2100. The cost of reducing this to zero is a 10% increase in total energy cost. Reduction to less than 5% to 10% market share should be less than a 5% cost penalty.

The use of hard solar is 13% in the all-systems economic scenario. The upper limit of southern potential for centralized solar using only low conflict land is 0.8 TWyr, if Turkey is limited to a one-third share of this resource. At an energy use level is 1.5 times what it is today, this hard solar resource is 0.09 TWyr/yr or 11% of the total hard solar resources. Thus, there would not be a problem with this type of solar energy becoming a single country dominated source since it could be more evenly spread over the seven countries of southern Europe. Thus, it and would not be in the major risk category. Therefore, all-system economic scenarios with adjustments which limit only the nuclear share to a 5% to 10% role is essentially identical to the multi-path strategy. The use of this amount of nuclear rather than 28% would be distributed over the 8 or 9 minor risk options.

d. Difficulties

Better Class of People

There are major difficulties with this approach. The most obvious is that while we acknowledge that A's will be A's and B's will be B's, and so on, we are expecting them to recognize the vital but limited cultural role they play and try to work within a large cultural context. That is, we are expecting the A's and C's to work in this strategy even though they will have difficulty seeing the sense of this approach. We are personally suspicious of any strategy that depends on a "better class of people" being an important part of the solution. However, we see no other choice at this time.

We are also depending on the C's having a low profile as they did before the mid-50's, as society gradually takes steps toward the kind of society they envision as necessary. This expectation may sound reasonable, but there is the possibility that it will not quite work that way. Again, we see no other choice at this time.

However, there seems to be a range among C-types where a spectrum exists on exactly what constitutes a survival issue. Also, the support the C's obtain from other cultural categories (some B's, some D's, and some E's) vary depending on many factors. The inclusion of C concerns and attempts to include the C's in the decision process should satisfy some C's and many of those in other cultural categories that the C's depend on for political support and indeed achieve the effect we suggest. This erosion of the C political base by moving toward their position is the key to this strategy to remove them from their current blocking position.

Beyond these theoretical difficulties is a very practical difficulty: the C's do not really negotiate. Usually any C who becomes too involved with those outside the wall of purity, are tainted and will sooner or later be rejected. If this rejection does not occur before the latest compromise step is announced, it certainly will after it is announced. Thus, we need to invent a way to include the C's in the process--a process, as far as we can tell, that they will refuse to really become involved in.

Negotiating commission. At this time, we would suggest an institutional framework such as a negotiating commission which addresses these issues and has members from various A and B sources. Also, C should be asked to participate, but surrogate negotiations should be found who, if not C's, will adequately represent C concerns. This can be much like a lawyer representing a client who is unable or unwilling to represent himself in a legal proceeding. If this sounds unwielding, well it is; but again, we see no other choice at this time.

This negotiating commission would have to have strong and direct links to the legislative process where there is a high degree of support for taking this commission recommendations and to enact them into law.

A recent example which is close to what we are suggesting is the Environmental Negotiating Commission, which resulted from the Coal Board Study in the U.S. This commission functions as we are suggesting except that it appears to have little or no C representation. Thus, it would function exactly as we are suggesting, if surrogate or real C's will be included in the process.

The closest example in Europe may be the Enquete Commission which was convened recently in the FRG. This is a commission made up of half parliamentary and half non-parliamentary members. The latter half were drawn for the most part from the ranks of energy experts from various academic and institutional sources. Although it was possible, it is unlikely that any C's were present. At least without this model, we are suggesting there would be no special insight to support C membership.

The compromise reached by this type of negotiating commission should be given strong parliamentary support. Also, similar commissions should exist at lower levels of government to deal with other than national level issues.

Macrosystem Dynamics Stymied. Perhaps the greatest criticism of this multi-path strategy with limits for the risky six and encouragements for the less risky eight, are that it appears that we are making rigid the macrosystem dynamics. This certainly seems true for the risky six. However, two of the six, coal and imported oil, now have descending market shares so there may be nothing that is particularly needed to limit them to a small role within 20 to 40 years, except minimizing current attempts to reverse coal's historically dropping market share. Historic dynamics seem to be taking care of these two.

The other are either ascending or have not yet entered the picture. Imported natural gas and nuclear are ascending. Here it will be necessary to plan limits on these two while encouraging the others to at least start. These are single country resouces like hard solar plants in Spain or Turkey, extra-continental hard solar from N. Africa or the Middle East, and self-owned extra-continental solar like the SPS or ocean systems. These could be introduced but limited by public policy to a small fixed share. Hydroelectric seems to play such a role today.

Within the more than half of the the total supply-side energy that is met with some combination of the eight low risk options, there is no need to arbitrarily limit any one of them to a certain upper limit. Rather, the usual macrosystem dynamics can hold sway within this framework. However, we note that this combination of encouraging and discouraging supply-side options although considered a "normal" thing by most energy decision makers, does involve a tinkering with the historic free flowing energy macrosystem. This is not to say that the past macrosystem dynamics have not had subsidies (some estimates of government subsidies reach about 250 billion dollars for U.S. conventional energy systems alone (1978$). With the exception of nuclear energy, it is not clear that these subsidies have played a key role. The nuclear industry seemed to have been the lone exception where strong governmentintervention in the commercial process paved the way for several U.S. companies to commit to turnkey plants in the early 60's. It is not clear whether this is a harbinger of things to come like some elements of the multi-path strategy, or an indication of the barrenness of such stimulations it depends on your cultural category).

e. Why Now?

As we have tested some of these preliminary theories of cultural categories applied to energy, people keep asking why is this happening now? Some suggest reasons based on a kind of "generation gap" theory. This theory states that the young people (<35 years old) have had it so good due to the post-war boom recovery period that they do not know what life is really like. They seem to feel affluence is a birthright and not something that was created by those who are older by hard work, self-sacrifice, discipline, and so on. Their inordinate preoccupation with frills like environmental purity and unsupportable concentration on the risky aspects of the new solutions to problems that we (the older) have fashioned, is without merit. It will only block precisely the things that we need to continue our necessary and never-ending growth to better tomorrows. They (the younger ones) just do not understand. They have no history. They are creatures of whim and fantasy who somehow have never gone through the events necessary to steal them to the true nature of life and prepare them for the true struggles of life. This generation-gap theory would continue by noting that we have probably overindulged the young and are partially to blame for their lack of maturity. But we must press on with solutions, and, if need be, take a firm hand to make sure their irresponsible behavior does not kill the goose that laid the golden egg. When push-comes-to-shove, they must be prevented from impairing our solutions so we can all go on to live in a better world tomorrow.

The "generation gap" theory or "wayward child" theory of current events in the area of social conflicts over energy is at the heart of the A view of events. It is precisely the paternalistic view of things that angers the C's the most. This coupled with the things that they see the current A-B "solution" doing to the planet physically, and what they are doing to people in the almost inhuman institutions they fashion to carry out this destruction of the planet, are what leads the C's to feel that there is no way to get there from here. They feel that radical change now is the only reasonable way to break out of this deathhold the A-B's have on all of us.

Why is all this happening now? The generation-gap theory is interesting and is certainly comfortable and reasonable to the A's. It has the opposite effect on the C's. Others could and have developed other psychological theories that seem to explain things. Rather, we suggest what we feel is reasonable and a simpler theory based on our observations of current events encouraged by this study.

We have always had the C's with us. They are probably some limited but outstanding examples of individuals who exposed C-type views and have been treated relatively kindly by history and their contemporaries. Thoreau might be one example of a C-type who was so pure that he was a member of sect group with a population of one. The judgment being that they were certainly interesting and different people, but eccentric. They should be tolerated as a mark of our liberal views. But why in the late 50's, 60's, and 70's have there been such a change in the magnitude and scope of the C involvement in society?

We feel it is a combination of three factors occurring almost simultaneosly:

- we become a global animal
- continued urbanization
- nuclear technology started commercial introduction.

Although we have been walking vertically on the planet for several million years, it was during this time (≃1960) that we became a 'global animal." For the first time, the results of human activity were having more than local impacts. It is best seen by noting the combination of population, agricultural, industrial, and war-making capabilities that were having global impacts on the environment.

The long-term trends toward continued urbanization had reached the point where more than half the people in industrialized countries were in urban areas. They found themselves increasingly embedded in large and increasingly dehumanized institutions and physical environments. This was a very different human context than living in small family units or villages much more on a human scale. The worker ant, in an ant-colony-sense-of-things, became a more common feeling for many in stark contrast to their prior living arrangement.

Finally, nuclear techology reached the state of commercial introduction. It has a set of uniue characteristics that presented new human difficulties. The basic workings of the technology seemed beyond understanding for most. It had a zero-infinity aspect that almost defied human comprehension. The almost zero probability of almost infinitely onerous consequences as a feature of the technology does not seem to fit well into human mental computational abilities. Added to this is the very long-term nature of some of the risks and the direct linkage to weapon's systems, which seems to present people with a new technology that was "too much." People were being asked to warmly embrace "solution" that seemed to create more problems than it solved.

We suggest that the concurrence of these three factors is what has given birth to the current magnitude and scope of the C resistance to A-B-type decisions in developed countries. These are exactly the same type of decisions that had such a profound or relatively beneficial effect over the last century or two. However, increased numbers of C-type people emerged from other cultural categories or became activities from a passive role to become a counter force against the continued development of the kind engendered by the A-B coalition.

This theory seems to fit well with our models used to explain differences in perceptions about energy. We offer it as an explanation and hope it is useful and allows more constructive social responses to be formulated.

E. SUMMARY

1. Minor and Major Risk Options

The list which identifies 14 supply-side options and crudely separates them into two categories of major and minor risks has been done by fiat without much justification. This might appear to be strange in light of the pivotal place this has in the multi-path strategy. However, it is clear that certain cultural categories would not recognize some or most of the options in the major risk list as having major risk. Indeed, they would probably state that these are exactly the choices that "realistically" represent our best set of choices for a favorable future. Limiting them would seem foolhardy. Thus, attempts at explanations of why each has a major risk in the envionmental, political, or cultural areas would certainly be futile to these people.

It is equally clear that considering all the options on the major risk category and some of the options on the minor risk category as part of a multi-path strategy would be unaceptable to people from another cultural category. For reasons of purity and species survival, they would cast them off as one would cast off millstones around the neck of a drowning person. Trying to justify the inclusion of these options even in a limited role and designing the strategy so that as future events unfold, future generations could do without at least 3 of the 6 major risk options without serious impact, would be impossible for people in a certain cultural category to understand.

Thus, we are presenting this strategy primarily to the B cultural category, since they are the social glue that can hold this cultural dynamic together. We simply state that the major risk sources of energy are obviously major risks, because one or more culturasl category recognize them as a major risk. All nuclear systems - coal greater than today, fossil imports, single country southern solar, extra-continental solar owned by other, and extra-continental solar owned by Europe - all have characteristics that would evoke a strong concern in the political, envionmental, or cultural areas. That strong response is enough for us to declare they are worthy of the honor of being on the major risk list.

The eight options on the minor risk list are primarily renewable solar options with domestic oil and gas as the sole exception. They all have some characteristics that have environmental and cultural risk, especially when configured as large centralized facilites. However, it is again simply stated that these belong on the minor risk list without any hope of all cultural categories agreeing on this.

2. Implementation

So how could such a strategy be adopted? it rests primarily on the B category responding strongly that this is indeed reasonable and acting day-in-and-day-out to bring this strategy into existence politically. This must be done while depending on the A's and simultaneously keeping them at bay. It also must be done by the almost acrobatic attempts to include the C's in the process each step of the way even though the C's will constantly refuse to be captured by this process.

Thus, it is abundantly clear that we are recommending a difficult strategy, but the one that appears to be the most reasonable we can develop at this time. We would be delighted if out of this attempt to formulate policy, someone would suggest an easier and simpler path that elegantly achieves the goal of meeting Europe's energy needs with the support of all cultural categories so that civic strife is minimized.

So, the A's are risk takers to avoid what for them is the only risk worth talking about--the risk of creating social conditions similar to the 30's in Europe that led to the most humanly destructive series of events ever to occur on the planet. The tens of millions killed, untold injuries physically and psychologically, and the incredible disruption of hundreds of millions of lives surely dwarfs anything that has materialized from disruptive human industrial activities. So, we see that between the A's and C's, we are aware of all risks from human activities. It would be folly to consider one set of risks to the exclusion of the others. So, the trick is to walk the tightrope and balance all of these risks without falling into the swamps of an over-regulated worled of gray hierarchy, where everything is made so safe by having prescriptions and rules for everything where we end up no better than an insect colony.

F. IS THERE ENOUGH TIME?

With all these difficulties, there is one favorable development. The continued low use of energy which may be expected to last until about 2000, gives European nations a reasonable amount of time to assemble the multi-path strategy.

This statement is based primarily on the observation of the variation in primary energy use around the constant rate of exponential growth. Based on the U.S. data, Figure 11 shows that there is a sinusoidal variation in energy use when a constant exponential growth is subtracted from the total. On a global basis, this constant exponential factor is 2.2%/year growth, and it has persisted from 1800 to today (when wood is included). However, this sinusoidal variation about this basic curve has an amplitude of ± 20 % and a period of about 55 years. The last two times that the downward part of the sinusoidal curve has crossed zero (intersecting with the basic exponential growth curve) occurred in 1929 and 1874. The next zero interrupt is scheduled for 1984, and the last peak was reached in the early 70's. Thus, there is nearly 30 years of reduced energy growth from the early 70's until nearly the year 2000. If this pattern holds up for Europe for one more quarter of a cycle, it means that there will be less than 1% primary energy growth during the last 30 years of this century.

Thus, there should be lower pressure on the need for new energy facilities during the next 20 year period of lower energy use. By 2000, when the next greater than average energy use period should start, the multi-path strategy could be in place and ready to meet the needs of this boom period. This should leave a richer heritage for the future generations to choose from.

3. Post-Script

Although these are just the results of a marriage between the "numbers" of engineering and one anthropological theory of cultural paradigm or bias theories, it has given us a "model" that seems to explain the "data" in the energy field. The perception gaps we found early on are now rather obvious in their origins and nature. The physical scenarios have been laid into a social context, and interpretated by noting the cultural categories that seem best to be associated with them. The future level of energy use (demands) is not an indepenent variable, but goes with the various coalition of cultural categories.

We feel that these theories allow us to see the "problem" and to understand the difficulties with various "solutions" that were suggested earlier (nuclear, hard solar, and softer solar scenarios).

But most importantly, we were able to state a goal for policy or an ethic to be used as a measure for recommendations. This ethic is that the greatest good is achieved when all the cultural categories are functioning and the future path minimizes social conflict. The combined insights and skills of the three major cultural paradigms are vital and the best chance of our species has for being able to cope with the future. Using this ethic, we are able to recommend a policy that appears to be in societies' best interest, although we have many reservations that tell us this is not an easy path. So, in the best tradition of IIASA, we conclude it should and might be done.

ACKNOWLEDGMENTS

This paper is based on work done while the author was a member of the staff of the International Institute for Applied Systems Analysis, Laxenburg, Austria; however, the author is solely responsible for how the work is used and interpreted in this paper.

The author acknowledges with gratitude contributions by Sabine Messner, Michael Messenger, Tony Ward, Michael Thompson, Karen Closek, Claire Doblin, Nebosja Nakicenovic, Todor Balabanov, Manfred Strubegger, John Reuyl, and Ingrid Teply-Baubinder; however, all of the interpretations of their contributions are the author's own.

Support is gratefully acknowledged from several sources: the Federal Ministry for Research and Technology of the Federal Republic of Germany, the Austrian Society for Cybernetics Studies, and the Department of Medical Cybernetics of the University of Vienna Medical School.

The scientists participating in the IIASA Energy and Social Science seminar held in September 1980 contributed a number of stimulating ideas to the work.

Ruth Benedict, Patterns of Culture, Routledge, London, 1935.

R. Caputo, "An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems", JPL 900-780, Pasadena, CA, March 1977.

R. Caputo, "Solar Energy for the Next 5 Billion Years", International Institute for Applied Systems Analysis (IIASA), pp 81-9, 1981.

R. Caputo, et al, "A Rational Energy Policy for W. Europe", IIASA, First Draft, June 81.

P. Chapman, "Fuels Paradise", 1975, London, Penguin

M. Douglas, Natural Symbols; Explorations in Cosmology, 1972, Random House.

M. Douglas, "Cultural Bias", Occasional Papers of Royal Anthropological Institute.

W. Hafele, Program Leader, 1981, Energy in a Finite World: A Global Systems Analysis, (simplification for Energy Systems Program Group of International Institute for Applied Systems).

C. R. Humphrey, F. H. Buttel, "The Sociology of the Growth/No Growth Debate", Policy Studies Journal, Winter 1980, pp 336-345

C. Marchetti, "Transport and Storage of Energy", RR-75-38, (IIASA), Laxenburg, Austria.

C. Marchetti, N. Nakicenovic, "The Dynamics of Energy Systems and Logistic Substitution Model", RR 79-13, IIASA, Laxenburg, Austria, 1979.

C. Marchetti, "Society as a Learning System: Discovery, Invention, and Innovation Cycles Revisited", International Institute for Applied Systems Analysis, Lsxenburg, Austria, Oct. 1980.

D. W. Orr, "U. S. Energy Policy and the Political Economy of Participation", The Journal of Politics, Vol. 41 pp 1027-56.

J. Reuyl, W. Harman, et al, "Solar Energy in America's Future", SRI, 1977.

J. J. Schanz, Jr., "Oil and Gas Resources--Welcome to Uncertainty", Resource No. 59, Resources for the Future, Special Issue, March 1978.

M. Thompson, Rubbish Theory: The Creation and Destruction of Value, London and New York, Oxford 1979.

M. Thompson, "Political Culture: An Introduction", IIASA, WP-80-175, 1980A.

M. Thompson, "The Social Landscape of Poverty", IIASA, WP 80-174, October 1980.

M. Thompson, "Among the Energy Tribes: The Anthroplogy of the Current Energy Debate", IIASA, June 1981.

M. Thompson, "An Outline of the Cultural Theory of Risk", IIASA WP-80-177, Dec. 1980.

FIGURE 1 Perception gap toward eventual solar share from decentralized sources (eventual – after all market penetration dynamics have stabilized. In W. Europe, this takes approximately 60 years after 1% penetration is achieved).

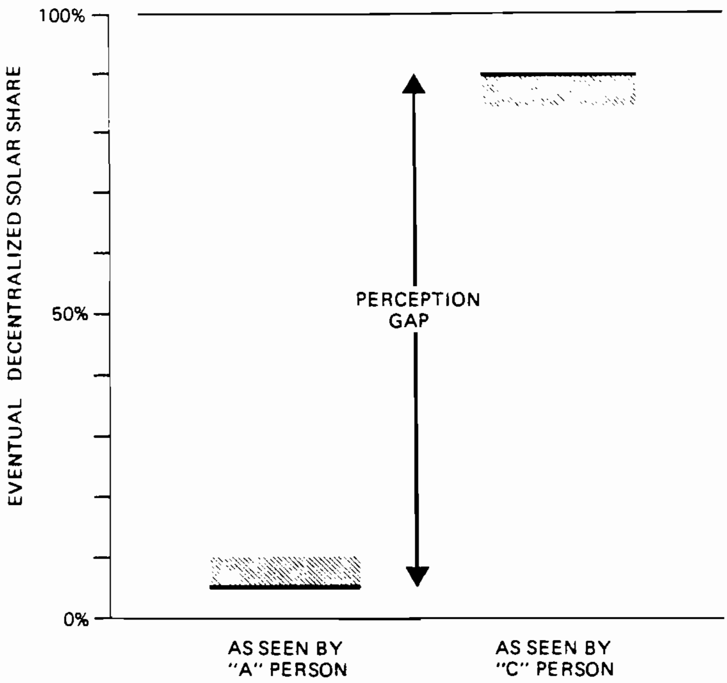


FIGURE 2 Relationship between social context and manipulation (from Michael Thompson, An Outline of the Cultural Theory of Risk, IIASA, WP-80-177, Dec. 1980).

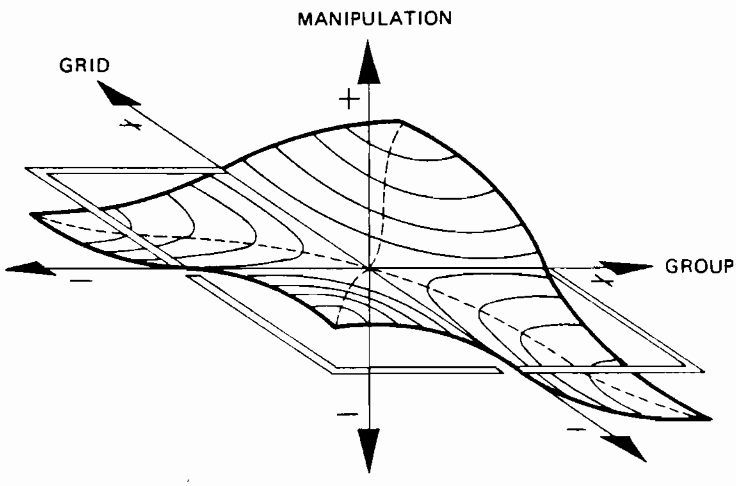


FIGURE 3 Thumbnail sketch of the strategies, the cosmologies and the justifications (from Michael Thompson, An Outline of the Cultural Theory of Risk, IIASA, WP-80-177, Dec. 1980).

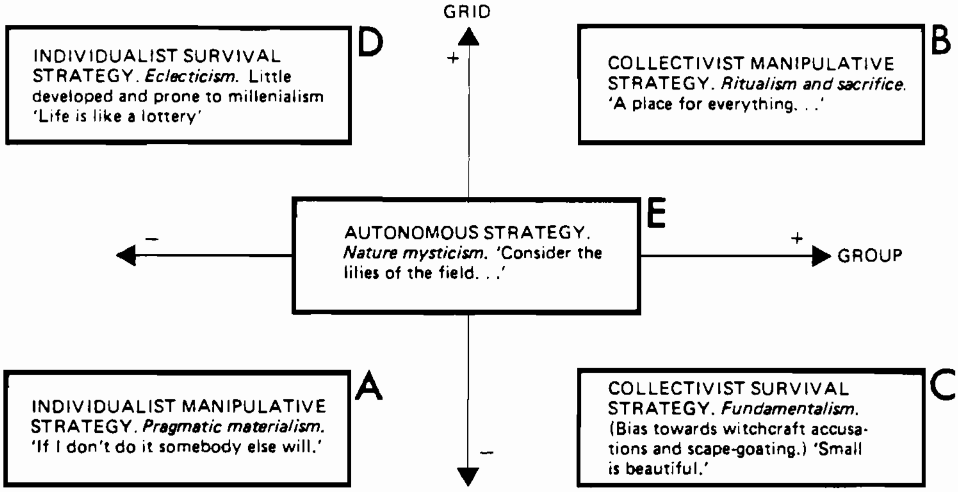


FIGURE 4 Three futures.

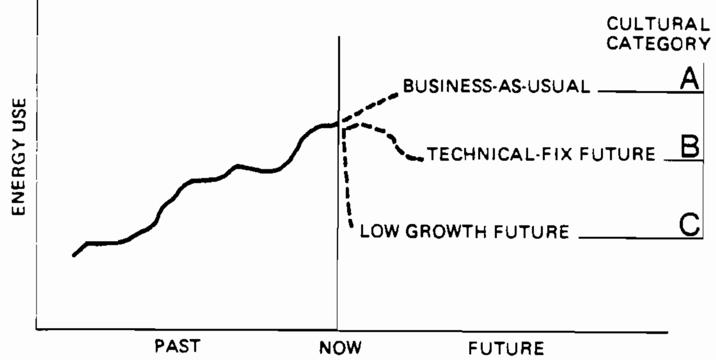


FIGURE 5 Cultural category dynamics.

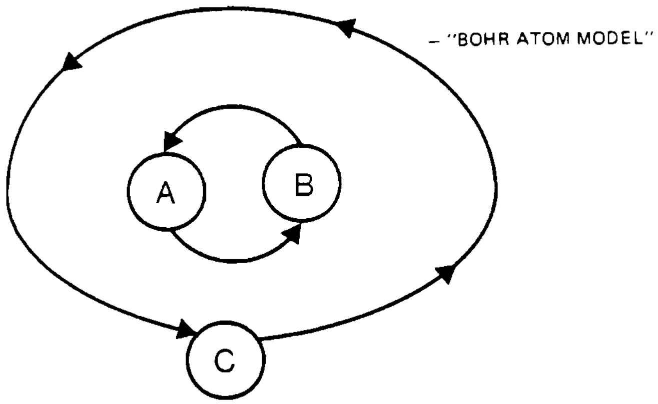


FIGURE 6 Projection of logistic model for OECD Europe (IIASA version 29.12.80 by N. Nakicenovic).

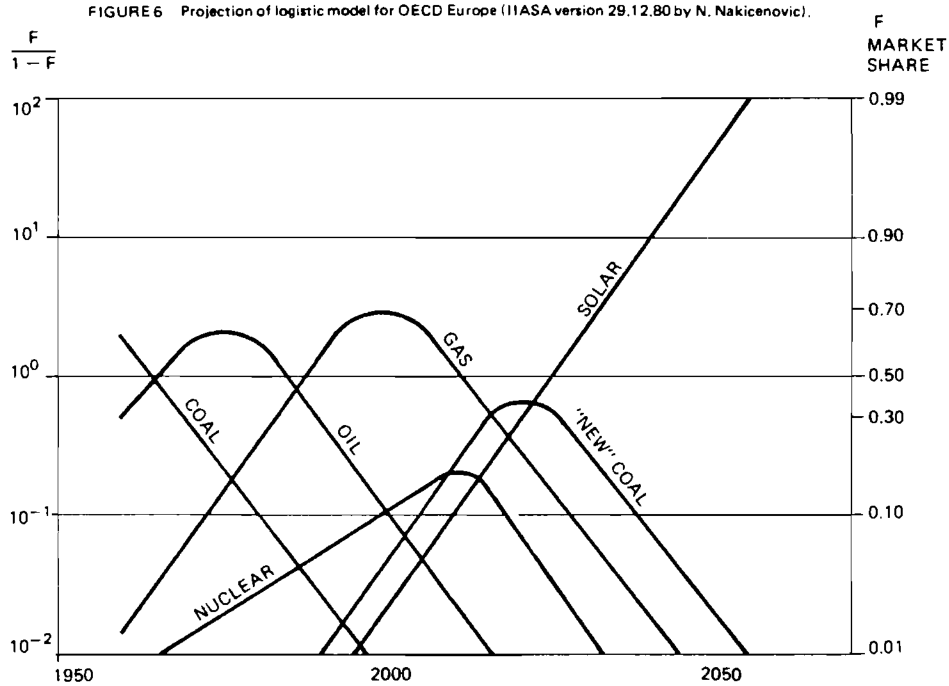


FIGURE 7 Hard solar scenario, primary energy.

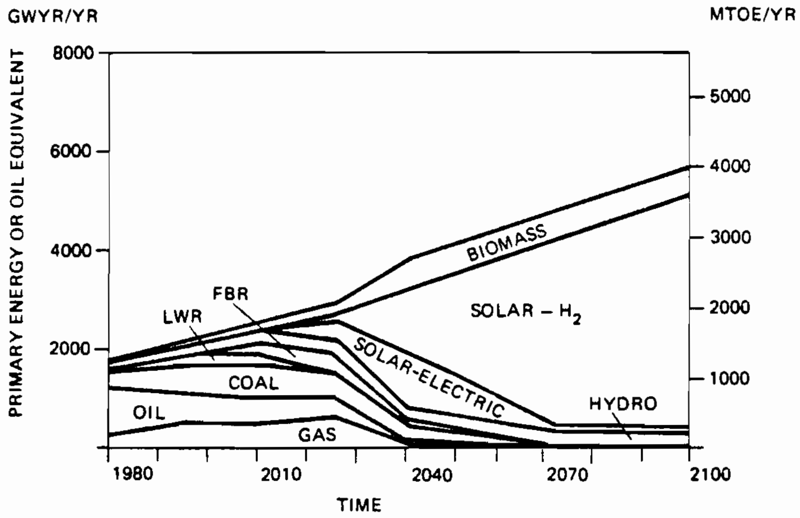


FIGURE 8 Hard solar scenario, share of primary energy.

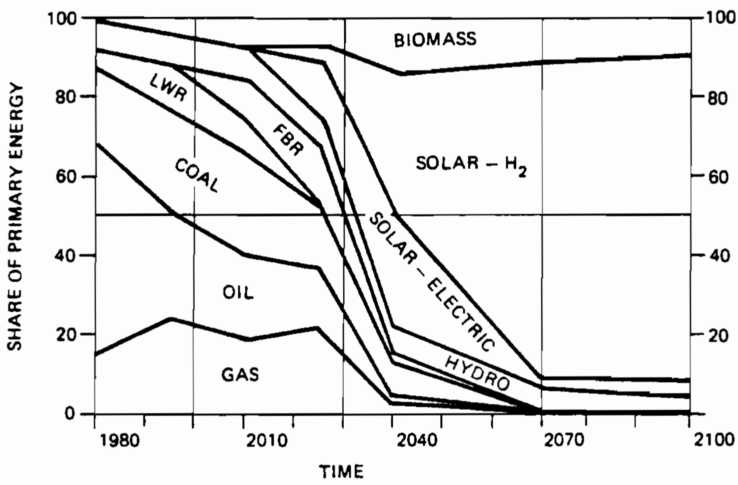


FIGURE 9 Relative total energy cost – reference system is all systems economic scenario for Central Europe.

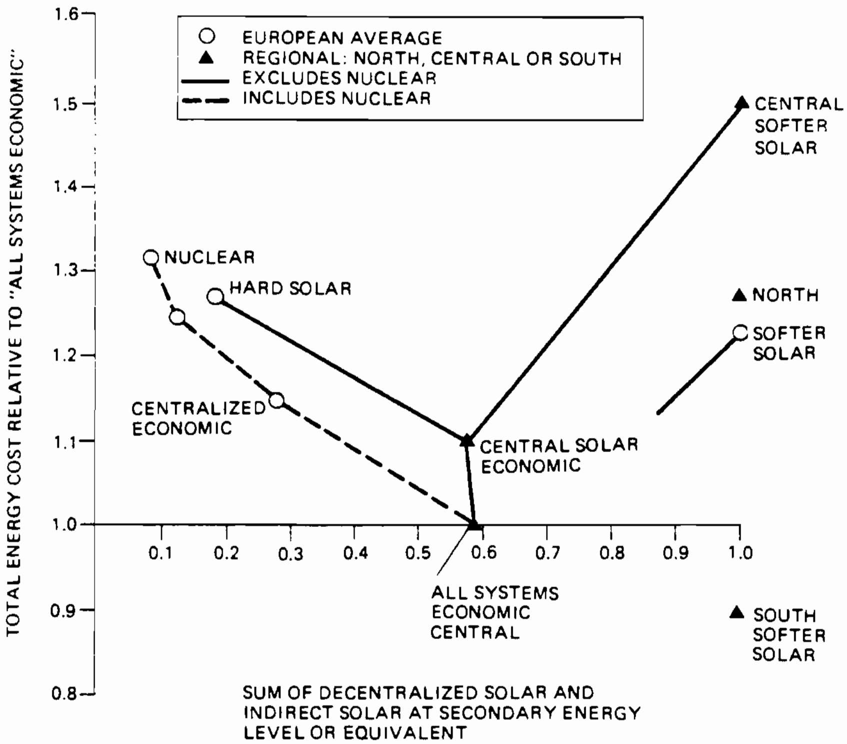


FIGURE 10 Relationship between cultural categories and energy scenarios.

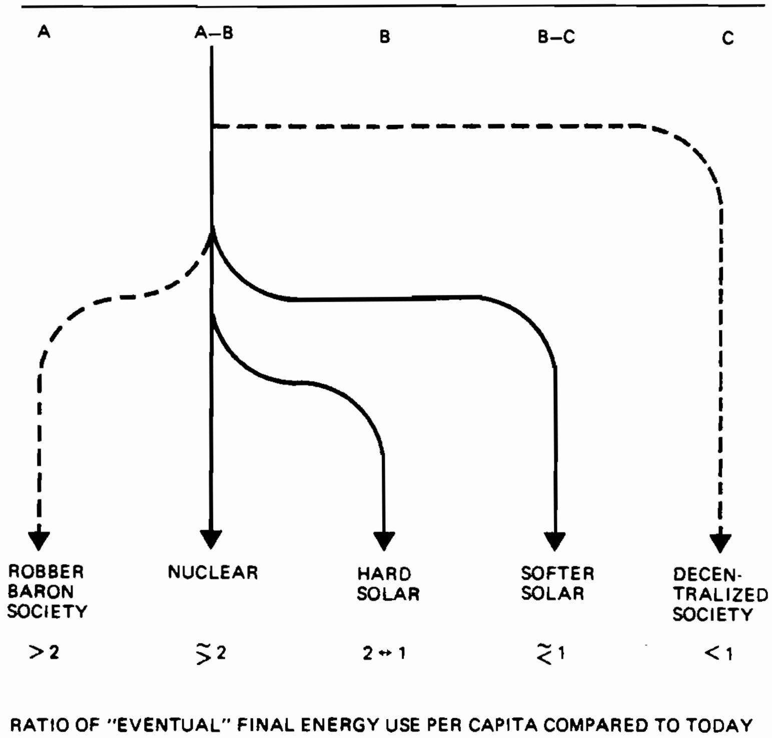
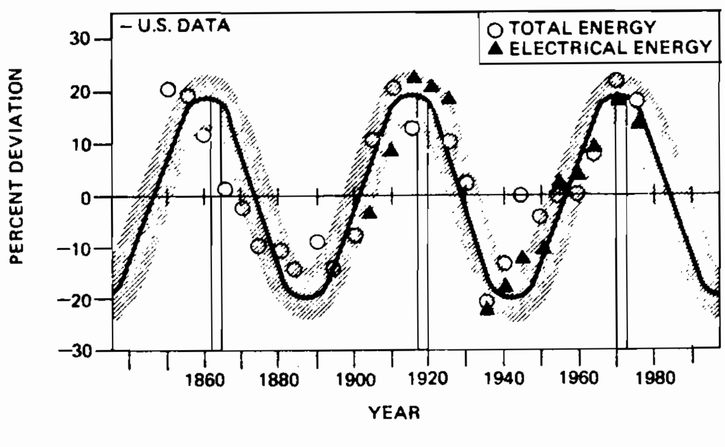


FIGURE 11 Oscillation of primary energy demand wave about the fundamental exponential growth curve (global growth is 2.2% per year since ≈ 1800).



ENERGY, ENGINEERING INSPECTION, AND THE SAFE USE OF NUCLEAR POWER*

Octavius Hunt Critchley

Reardon—Critchley International (Scientific, Safety and Medical Consultancies and Services), Hounslow, Middlesex, England

Nuclear power, though potentially a dangerous technology, has been rendered very safe in use by human ingenuity and good engineering. For nearly twenty years there have been no fatalities and few injuries attributable to nuclear work. This paper describes the system of regulation utilized by the Nuclear Installations Inspectorate in anticipating and preventing the occurrence of serious faults in the design, construction, and operation of nuclear power stations in the United Kingdom.

*An amended and updated version of a paper entitled: "Inspection and its Role in the Case of Nuclear Power", which was presented in September 1980 to a meeting of the Institution of Nuclear Engineers held in Engineering Department of Cambridge University, U.K., with the co-sponsorship of the Science Research Council, to discuss: "Directions in Nuclear Engineering Research".

1. INTRODUCTION

Nuclear power is likely to be of great importance among the more lasting sources of energy upon which the advanced industrial countries of the World must draw to meet the energy crisis which will come as the planet's oil reserves near exhaustion. The utilisation of atomic energy is an extremely dangerous process, but one which has been tamed by human ingenuity. In the quarter century since the first nuclear power stations became operational in Britain and the U.S.A., there have been remarkably few accidents which have involved radiation or their 'nuclear' features. In the case of those which have occurred on plants operated by the utilities, there has not been a fatality, cases of radiation injury to workers have been rare and harm to neither public nor environment has been convincingly established. Inspection in its various forms has played a most important part, not only in achieving, but in maintaining this level of safety and reliability.

Special watchdog bodies

Before nuclear power can make its full, and perhaps vital, contribution to the World's energy balance, the body politic must be convinced that the grave and lethal hazards of the process have been effectively contained so that the perceived threat is small enough to ignore. There must also be assurance that there is a credible organisation which can maintain this state of affairs. In the U.K., the Nuclear Installations Inspectorate (NII) is entrusted with this duty and, in the U.S.A., the Nuclear Regulatory Commission (NRC). One of the consequences of the environmentalist opposition to nuclear power is that their responsibilities, modus operandi and competence have been under almost continuous review for the past decade and a half.

The recommendations of numerous committees of inquiry, sometimes following reports of dangerous occurrences at nuclear power stations or inspired by a general concern for safety in the nuclear industry, have led from time to time to major changes in the allocation of responsibility for the NII and NRC among government departments and agencies and in the organisation and personnel of their top managements. Yet, these alterations appear to have had little effect so far as their modi operandi, notably at the working interfaces where the inspectors from these bodies are in contact with the engineers employed by the utilities. It seems this was particularly the case for the NII as may be judged from reports in the press and technical publications, e.g. Gausden (1979), McGinty (1981) and Judy Redfearn (1981). In engineering history this is not surprising as known practices of established worth are not lightly abandoned. These came through experience, for if the NII inspectors were to develop an effective watchdog function, their methods of working could not be invented and prescribed by administrative fiat. They had to be the result of the evolution of procedures which matched the realities of the technology in the field and incorporated the day-to-day lessons of regulatory surveillance.

Field of responsibility for safety

The purpose of the regulatory duties laid upon the NII by the U.K. Nuclear Installations (Licensing and Insurance) Act 1959 was to anticipate and prevent the occurrence of serious faults in the design, construction and operation of nuclear power stations which could lead to severe accidents affecting the public. For reasons of economy in government expenditure and administrative convenience, it was also charged with certain extra duties, e.g. radiological protection and general plant safety, but the extent and propriety of these never secured full acceptance amongst the inspectors.

Nature of the inspectional task

The basic task of inspection is to ensure compliance with design and to obviate human error in its implementation. Past experience has shown that it can be outstandingly successful in this role. Inspection is not the abstract intellectualisation of quality assurance and safety assessment of design, though these things may give a most valuable, if not essential, background to the work. It is a function which must be carried out to bridge the intentions of the design office and the business of shop floor and site where it must not only see that there is obedience to the instructions of the former, but it must enter and perceive in the interpersonal field of human behaviour, assessing conflicts, aims and weaknesses. It must not supercede the proper functions of line management, as the duty of the inspector is to advise, inform, correct and to chide, identifying error, bad practice, poor workmanship and faulty materials.

In its executive phase when involved with advanced technology projects, it becomes a managerial task. It is then engineering of challenging aspect, requiring high educational and scientific qualifications and relevant experience, backed by appropriate professional attainments. It is not a generalisable administrative exercise resulting in the propounding of policy divorced from continuing job contact. This 'executive' or 'assessment' inspection should be supplementary to the safety and reliability surveillance normally carried on within the plant or installation by its own management. It may either be part of the line management or, better, be carried out by a specially appointed internal body responsible directly to the managing director or chairman of the board. Such health and safety provisions are usually subject to higher tier statutory regulation.

The government inspector on whom the duty falls has to accept an intricate and open ended obligation. On the one hand he must be an independent and disinterested agent. Yet, on the other he is unable to carry out his duties by eschewing responsibility for the consequences of his intervention because his work is innately participative.

His official decisions are normally the result of consultations with engineers employed by nuclear plant licensees or operators.

The topic of safety and quality assurance inspection in the domain of advanced technology has been discussed in detail elsewhere (Critchley 1976, 1980 and 1981) to which works further mention will be made infra.

2. NUCLEAR POWER AND THE ENERGY CRISIS

The looming supply difficulties which face a World already overdependent on oil are focusing attention on the need to secure stable and continuing sources of energy and so to be free from this thraldom. Of the many options other than a greatly intensified exploitation of coal,only atomic energy is readily available and can be a growing rather than a dwindling source. Alternatives like wave and wind power are not feasible before an oil shortage could heighten international tensions to a level where any peril from nuclear power generation shrinks into insignificance when compared with the horror of modern war (Hoyle 1979, Sharfman et al 1980). The health and safety reckoning owing to the prolific production and burning of fossil fuels cannot be ignored, but they have been hallowed by long acceptance, although in the long term the human and environmental detriments attributable to them may well outweigh those of atomic energy. In contrast, the dangers of nuclear power, real and imagined, have effectively frustrated its once happily envisaged function as man's main and inexhaustible future power source. It is appropriate therefore to examine how the vital nuclear option might be freed in time from these present curbs which are holding back its further development and wider use as an alternative to oil.

3. ATOMIC ENERGY AND THE CONTAINMENT OF ITS GRAVE HAZARDS

The hazards to man and his environment that come from the utilisation of atomic energy have the disturbing property of being unknown except by extrapolation from data available on some unfortunate over-exposures of people during medical treatments, on the radiological detriments resulting from the use of atom bombs in 1945, by the unforseen consequences of weapons testing and by speculation about a few well publicised radiation accidents. The measures for accident prevention are thus based in the main on theoretical studies and postulated event sequences leading to severe faults which, though very unlikely, could have very harmful and destructive effects. Scenarios of the worst accident to a power reactor such as the well known U.S. Nuclear Regulatory Commission study of 1957 depict a grim and heavy toll of human deaths and injuries and heavy property damage.

The Windscale incident of 1957

Following the accident to the No.1. Plutonium Pile at Windscale in Cumbria, U.K., on October 10, 1957 (Penny 1957), there were some misgivings about the safety of the industry which led to a reorganisation of the health and safety structure of the U.K. Atomic Energy Authority (UKAEA). However, as things turned out, the burning pile was rapidly brought under control and the emissions of radioactivity to the atmosphere proved not to have any known harmful consequences, except that agricultural and dairy produce in the immediate area of the plant was condemned for a relative short period (Beattie 1981). The two piles in the unit were permanently shut down and written-off .

An unusually safe industry

The facts are that the experience of the nuclear industry since its inception gives the lie to prognostications of disease and disaster by its extreme critics, such as Gofman and Tamplin (1973) and Bacon and Valentine (1981). It has, in fact, been outstandingly safe with an accompanying good record of general industrial safety. There have been a few plant accidents and even the minor ones among these have received more than due publicity. The major incidents, like 'Browns Ferry' and 'Three Mile Island', have been noteworthy for the way in which they have been safely terminated without harm to environment, public or staff on the sites, although the plants themselves have been seriously damaged with heavy financial losses .

It must be accepted that there is no such thing as absolute safety in the case of any potentially dangerous process or plant. These things are not inherently safe, but innately hazardous, and can only be kept safe by continuous and conscientious efforts directed to that end. It is the mechanism that can ensure this maintenance of safety which will be examined in the passages that follow.

4. SPECIAL FEATURES OF NUCLEAR SAFETY

To what then can this 'nuclear' paradox of safety-in-danger be attributed? It is certainly not inherent in the technology as such things as the 'Windscale Plutonium Pile' incident, the 'Enrico Fermi' meltdown, and the SL-1 reactor prompt criticality explosion among a number of other incidents have shown. They are all examples of the occurrence of the unexpected whose causes have been revealed after the event.

Safety through foresight, not hindsight

The answer is that it can be attributed to the novel and innovative approach to health and safety which has characterised the atomic energy industry from its start. The dangers associated with the large scale release of nuclear energy were immediately recognised by Groves who ensured that all possible care was taken to safeguard his employees, in the Manhattan Project and its associated works (Groves 1962). The philosophy of safety by foresight rather than hindsight has continued and been further developed. An important application is the precept of requiring prior safety assessment of design of plant before construction or modification. An underlying principle which is unitary posits that, not only is safety of the plant as a whole dependent on that of its component systems, but that good design must ensure as far as possible that the performance of the parts linked together secures a greater level of safety for the whole entity with overlapping protective zones reinforcing one another. The holistic idea is also expressed in the guardline concept of protective instrumentation in depth.

Integrated safety management

The principle of unitary safety in engineering applies to management systems as well as to hardware, particularly as the former are prone to break into disparate sub-groups to perform technically distinct functions and drift into introversion. Co-operative working is not inherent in human society and identifiable groups in organisations tend towards hierarchial entities rather than to merge as sharing teams. Such behaviour in the management of large, complex and risk prone plants can be inimical to safety and among the special measures taken in nuclear installations to promote functional integration are the practices of maintaining a plant technical safety committee and that of requiring submission of a 'safety report' ensure that the safety of the design of the plant, any modification, change in operation or experiment has been assessed and considered before it is put into effect (Gronow and Gausden 1975, Haire and Shaw 1979).

Correction of schizoid tendencies

While it is the duty of management to evoke unity of function in the organisation it controls, it can itself be afflicted by the same individualistic trends. This foible was identified in the management system of the UKAEA by Sir Alexander Fleck (1957) when he made his searching enquiry into the organisation of that body after occurrence of the Windscale plutonium pile affair in 1957. A similar finding was made in respect of the Three Mile Island accident of April 1979 (Rogovin and Frampton 1980). In both cases restructuring of the management entities exhibiting it was recommended.

The new approach to safety in the UKAEA and origin of the NII

The UKAEA responded to the Fleck Committee's strictures by establishment of a Safeguards Division with responsibility for overall monitoring of safety, but with an advisory rather than an executive role. It had two branches, one devoted to radiation protection and the other of the nature of an inspectorate called the Authority Health and Safety Branch (AHSB) concerned with siting, the overlooking of safety in plant and process design and operation and criticality. The Committee made analogous proposals for the then burgeoning civil sector of the nuclear industry (Fleck 1958) with a recommendation for the formation of an independent licensing and inspecting body which led to the establishment of the Nuclear Installations Inspectorate (NII) under the Nuclear Installations (Licensing and Insurance) Act 1959 (Joslin and Griffiths 1962) .

AHSB and NII - tasks of the new bodies

Much of the attention of the AHSB and NII was directed towards the oversight of the safety aspects of the work in design offices and surveillance of activities arising from the construction, commissioning, operation and maintenance of reactors in power stations and other nuclear facilities operated by the UKAEA, Generating Boards and certain corporate bodies. The NII had no jurisdiction over government and UKAEA installations until after its assimilation into the U.K. Health and Safety Executive (HSE) in 1975 as a result of the commencement of the Health and Safety at Work Act 1974 (Robens 1972) The AHSB ceased to exist some years ago when the main nuclear fuel manufacturing and processing and isotope preparation facilities were divorced from the UKAEA to form commercial companies. The installations involved included a number of reactors (Atomic Energy Authority Act 1971).

Though AHSB was restricted to an advisory role, the Branch was armed with the right to acquire from the design offices and divisional and site constructional and operational managements any information deemed necessary for its work. Its members sat on all plant technical safety committees. However, it had recourse to the Management Board of the Authority when serious differences of opinion arose which could not be resolved in direct debate with the local managers concerned. Similarly, members of the NII lack the power of prosecution normally accorded to government inspectors, for example, to H.M. Inspectors of Factories, but a Nuclear Installations Inspector can invoke more general and very effective sanctions through the licensing regime. When an admonition is without effect, the inspector may threaten revocation of the licence or to attach to it a special condition suspending operation of the plant until his requirement is met or infringement of the rule or regulation has stopped. Conditions may also be attached requiring plant modifications or operating rule changes. Again, an NI Inspector has lawful authority to see any document of a technical nature relating to the plant with which he might be concerned and to acquire such information as he deems necessary for his work, backed by right of entry to the licensee's installation.

Inspection by dialogue and participation

An important aspect of the inspectional function is that legal authority to acquire information does not mean that it is going to be obtained. It is not necessary for the inspector's opposite number to obstruct him by wilfully withholding it. Indeed, the latter may not even be aware of what the inspector wants to know. It is essential that the right questions be put and that, in regard to any scrutiny of the plant and its equipment, the inspector knows where to look and at what. Hence, satisfactory discharge of the function demands a dialogue and empathy between the two parties and these things are not going to be made against a background of legal threats and prosecutions. In this situation a novel kind of participative regulation maintained by a continuing dialogue between licensees and inspectors came into being and, thus, the sustained level of adherence to the required safety procedures which have been described in detail by Haire and Shaw (1979) was evoked rather than imposed. Although this style of supervision might appear to be weak, it has in fact a profound but subtle influence on those who fall under its aegis. These offices by requiring members of the lower tier to report, to explain and to render an account has a most stimulating, powerful and integrative effect (Vickers 1967). It can be one of the most important benefits of an inspectional regime, not least by correcting innate introspective and schizoid trends in management structures and by encouraging conversation among their elements which otherwise drift into isolation.

Four categories of inspection

The work done by the NII falls into the third of four categories of inspectional function identified by Critchley (1981).

(i) Viewing

This is the performance of 'go/no-go' scrutinies of manufactured workpieces, e.g. printed circuit boards for computers, and requires little or no exercise of discretion. It may, however, be a very skilled function when the viewer has to check a complex piece of equipment or one that has been made to a very high standard of precision.

(ii) Examining

The examination of products, structures, equipment and systems to confirm that they meet the intention of the design, going beyond meticulous adherence to its letter. The function is interpretive and considerable exercise of discretion and judgement is needed. Examples are customer acceptance inspection of complicated apparatus and systems and routine inspection of minor industrial premises by statutory safety inspectors.

(iii) Executive Inspection

This is the function carried out by the NII and described briefly above. It may be divided into two sub-classes, namely:

(a) Managerial Inspection - investigation of the manner in which persons, teams and groups discharge their contractual obligations or perform their official duties and includes the inspection of schools, staff inspections in large organisations like public service bodies. It involves the assessment of managerial or professional competence and that of relevance or function of the organisation being scrutinused.

(b) Assessment-inspection - chiefly an engineering activity concerned with the extent to which a design intent is achieved in plans, designs and specifications for a technological system, plant or piece of equipment

It can extend to assessment of the satisfactory attainment of these goals in the manufacture, construction, commissioning and in their use or operation. Its performance involves design office, shop floor and site contacts with designers, managers, engineers and technicians and may involve tests and equipment inspections.

Note - these two sub-classes may be combined in one duty.

(iv) Inquiry - the highest order of inspection is concerned with the examination and assessment of the roles, appropriateness of function, efficacy, integrity and propriety of state, commercial and social institutions, corporate bodies and government functions and programs. For instance, the Hon. Mr. Justice Parker was named as 'The Inspector' and chaired 'The Windscale Inquiry' into the extension of irradiated nuclear fuel processing on the British Nuclear Fuels Limited (BNFL) site in Cumbria (Parker 1978).

Research support for inspection

AHSB had its own research facilities as well as being able to call more widely on Authority resources. These were made available as appropriate to NII who could also require licensees to make specific investigation relating to safety features of their installations, though research of a more general nature was commissioned from universities and commercial services. Of recent years, there has been a substantial increase in the safety research projects commissioned by the HSE in support of the NII (Gausden 1979).

5. THE STRANGE PHENOMENON OF PUBLIC HOSTILITY

In view of the great attention which is being paid to the achievement of safety in nuclear plants and the consequent investment of money and human effort which has been rewarded by an outstandingly good accident record by the industry, the public hostility to atomic power is not easy to understand. As it seems not to be related to any balanced view of risks and benefits, it may be attributed to factors other than the true concern for safety of the plants. Among these may be distinguished:

(i) Lack of understanding of the actual nature of the nuclear hazard;

(ii) Perception of the hazard as totally unacceptable in spite of its presentation as an exceedingly small risk;

(iii) Emotional associations with atomic weapons (Slovik et al. 1979);

(iv) Fears about the safe management and disposal of active nuclear wastes;

(v) Apprehension that the standards of safety will decline as the scale of nuclear operations increases;

(vi) Fears that plutonium and other fissile materials might fall into the hands of terrorists;

(vii) Concerns about the proliferation of nuclear weapons;

(viii) Fear that civil liberties may be eroded by spreading security precautions (Flood and Grove-White 1976);

(ix) Objection to the growth of bureaucratic power in the nuclear corporations (Cotgrove 1978);

(x) Hostility to technological progress (Roszak 1972) in which nuclear energy has led the field (Haefele 1974); and

(xi) The predicted energy crisis is fictitious and there is no need for nuclear power, The rapid rate of increasing energy demands will not be sustained and any shortfall can be made good by conservation, increases in coal mine output and stimulated development of the alternative energy sources. (This theme has wide acceptance, implicit and overt, e.g. Flowers 1976, Ryle 1977 and Bacon and Valentine 1981).

The first seven of the above eleven objections are

tangible, except perhaps for the second and third, and thus there are five which could be overcome in rational debate. The other two are subjective and, while they cannot be refuted by logic, they should be amenable to elucidation and persuasion, being feelings rather than convictions. However, the eighth, ninth and tenth are imponderables in the context of the energy debate which those who espouse them are, in effect, using as a vehicle in which to advance certain concerns about contemporary society. These disquiets have their origin in a dislike of technology generally rooted in a philosophy more akin to that of Descartes than Popper (Ravetz 1971).
The eleventh and last is of different genre and, among other things, may be attributed to the prejudices of particular commercial and occupational groups who feel that their interests might be impaired by an enhanced nuclear power program. They may also be associated with the tendency of governments, and especially democratic ones, to avoid spending public money on any project that is not likely to yield immediate electoral benefit. To justify a course of greater futurity, there must be a clear public demand for such action or a firm conviction amongst the responsible politicians that such an investment is demonstrably necessary in the public interest. Neither of the conditions is met in the case of nuclear power.

6. QUANDARIES IN THE NUCLEAR ENERGY DEBATE

The objections identified in the preceding passage are held in innumerable combinations by the people who comprise the environmentalist movement or belong to the various other groups opposed to the choice of the nuclear option. They are the constituents of a body of opinion to which they give different shades in the measure of their predilections. These objections are, therefore, propositions which cannot be disposed of piecemeal, but must be dealt with from a unitary stance.

The 'nuclear' opposition can be grouped broadly in three areas, emotional, philosophical (and ethical) and economic. The people who profess to such persuasions are unlikely to be swayed by the achievement of greater reliability in the engineering safeguards of nuclear reactors. Nor are they likely to be much concerned about any slight increase in health risks that might be attributed to some tiny rise in background radiation caused by the nuclear industry. It is, therefore, unlikely that they will be impressed by the use of elegant risk mathematics to present the nuclear power hazards as miniscule and insignificant by setting them in mists of vanishing small numbers (Critchley 1976, 1978) . Furthermore, they are unlikely to yield to pleas of a more practical kind from engineers who proffer the high quality and reliability of the technology with its established record of safety. Indeed, the story of engineered safeguards has been that the opponents of nuclear power seem always to be able to find a new conjectured threat or disclose a fresh technical weakness when an earlier one has been remedied (Nelken 1975). Those pragmatists who doubt the need for nuclear power at this stage anyway can see no reason for further investment in what has proved to be a difficult,controversial and costly technology.

Scientific method can contribute little to disputations of this kind. They have been identified as 'trans-scientific' by Weinberg (1972, 1978) involving things which cannot be expressed meaningfully in the language of science. Therefore, the subjective and philosophical areas of the argument are beyond the scope of an engineering paper about the reliability and safety of nuclear power plant and how these desirable technological features can be promoted and assured.

The adverse state of public opinion

Hostility to nuclear power may not be growing, but neither is it going away, In the leading industrial countries of the West, except for France (Papon 1979), it is fostered by well-organised, determined and vocal anti-nuclear groups and lobbies, motivated in a wide range of ways by the eleven factors listed supra. These pressure groups swim in a sea of the amorphous, uncommitted opinions of 'the great silent majority.' Though not won to the anti-nuclear cause, large numbers of people have thus been infected with doubts about the safety of the technology, finding cause for ill-understood worries about such things as reactor pressure vessel integrity, the statistical effects of low level radiation doses, sabotage and the problems of the management of enduring radioactive wastes. The confusion created by this hail of obdurate, often ill-founded, criticisms may, perhaps, lend itself as a convenient cover for official procrastination on nuclear policy decisions which are difficult and technically controversial. Such an issue is the 'gas cooled' (AGR) versus 'pressurised water' (PWR) reactor type choice bedevilling the proximate decision makers in Britain.

The outcome of the brouhaha is a politically expedient status quo in which a modest investment in nuclear power seems to be tolerated, providing as it does, a trial of the technology which can either 'wither on the vine' or at an appropriate time provide a basis for vigorous growth should the need arise.

Some disastrous plant accidents and their political outcomes

The characteristic of all known nuclear power reactor accidents so far, with the exception of the SL-1 incident of February 1962 , is that they have been contained and, other than for the political and social overtones, the damaged plant has been brought quickly under control and the situation made safe. The societal effects have been much less favourable to nuclear engineering and certain reactor faults have had profound political effects. An important consequence of the Windscale plutonium pile fire of 1957 was a major shake up in the U.K. nuclear industry (supra). John Hendrie, then Chairman of the U.S. Regulatory Commission, was dismissed shortly after the Three Mile Island affair and the reverberations of TMI are still felt over the American regulatory scene.

The safety problem of no accident, no fault data

An odd detriment of the safe arresting of power reactor accidents is that valuable design data and experience is not gained because the sequence of unusual systems events and failures that would otherwise take place is aborted. Of course, there is the merciful and proper avoidance of the casualties and environmental and plant damage, but must they be weighed against a problematical gain in design office expertise provided by the information which might have been available had the accident run its dire course? The lacunae handicap safety analysts because recourse must be made to conjecture to make good the lack of certain knowledge about the full run of fault sequences to disaster. The point is a moot one: does the prevention of a small accident at one point in time set the scene for a much more devastating one later? Nevertheless it stresses the importance of imaginative technical design safety assessment in nuclear engineering. The argument is not wholly speculative. The successive, and at the time mysterious, disastrous losses of two British 'Comet' commercial aircraft in the Winter and Spring of 1954 (Cohen 1955) revealed serious areas of ignorance in stress analysis, strength of materials and aircraft structural technology. Had these regrettable accidents not occurred and aeronautical engineering been deprived of essential information, might there not have been a more distressing series of calamitous incidents involving heavily loaded passenger aircraft through otherwise built-in structural weaknesses?

When an accident can halt a technology

Society's reactions to disastrous events are complex. In 1917, a munitions ship in the roads off Halifax, N.S., blew up after a collision with another vessel and demolished most of the town. Casualties ran into thousands with many dead. A disaster of like magnitude occurred in September 1921 at Oppau near Mannheim on the Rhine when 200 tons of ammonium sulphate, held by the Badische Anilin Fabrik in a works store previously assessed as safe, exploded. The factory and a large part of Oppau were destroyed and over 1,000 people killed. Other than for the shock and horror of these events, no momentous decisions followed.

Notwithstanding the less censorious social conscience of over a century ago, the unexpected powder mill explosion at Faversham, Kent, in 1847 so profoundly disturbed the national decision makers that gun cotton production in the U.K. was stopped for two decades . This step was taken in spite of the need for a military propellant with better impulse and chemical properties than black powder. The circumstances in the cases differed in that the operations at Halifax and Oppau were of long standing, the first a well established port and the other the home of a chemical company for several generations. The faulty process at Faversham was a new technology. It is generally held in the nuclear industry that the outcome of a reactor catastrophe with a heavy toll of deaths and injuries and extensive environmental damage would halt nuclear power development for a long time.

<u>The case of the 'Zero-Infinity Dilemma'</u>

The 'nuclear' risk which appears as an exceedingly unlikely accident causing catastrophic damage is by no means unique in modern advanced technology. Noteworthy cases are the hazards of transport and storage of liquid natural gas (LNG) and the side-effects of delayed incidence caused by the introduction and widespread usage of potent new drugs and remedies. The threats to life and property presented by the handling and bulk storage of LNG and other petrochemicals have been the subject of an important and comprehensive safety assessment (Locke et al. 1978). The finding was a vanishingly small chance of a major disaster to the residents of the Canvey/Thurrock area.

Talbot Page (1979) has identified these things with a 'Zero-Infinity Dilemma' presented to politicians, government administrators, industrialists and engineers when a technology is characterised by a very low probability (zero) of a very serious accident with catastrophic costs (infinity). He suggests an 'actuarial solution' to be achieved by drawing on the long established and proved tactics of the insurance industry in managing risks in general and indeterminate, high risks in particular, e.g. a film star's legs, with considerable commercial success. The story of the insurers' management of the 'nuclear' risk was to escape from the peril of the 'infinity', though it seems Page had in mind the action of the nexus between underwriter and client by which the latter would be driven by market forces to improve the safety of his hazardous plant so as to enjoy the differentially lower premiums thereby earned.

Nuclear power and the insurance industry

The insurance underwriters have responded to the 'nuclear' risk by seeking legal relief from the threat of excessive out-payments, restricting their liability to an actuarially tolerable amount, with responsibility to meet claims in excess of a prescribed sum transferred to the State. Restrictions relating to 'nuclear' damage, harm and injury are normally written into all insurance policies. Clauses to achieve this end exist in the American and European atomic energy legislation which regulates the national nuclear power industries, e.g. The Price-Anderson Act in the U.S.A., and the Nuclear Installations (Licensing and Insurance) Act 1959 in Britain. The latter Act originally set the upper limit at £5 million and contained clauses which relieved the licensee of a nuclear power station (or other 'nuclear installation') of liability entirely after ten years from 'termination of his period of responsibility' for the plant, successful claims then being met by the government. This legislation has been amended since its introduction to raise the upper limit to meet inflation and to incorporate obligations accepted by the ratification of certain international conventions and protocols (Street and Frame 1966).

7. ACCEPTANCE OF THE NUCLEAR OPTION

The hostilities, aggressive and faint, to nuclear power and the general aura of doubts about the wider aspects of its safety that have been created are likely to put serious obstacles in the way of a massive expansion of the industry should the need arise. However, it would be a denial of human ingenuity to acknowledge that such obstacles cannot be overcome and unwise to attempt to force a decision in favour of a massive nuclear commitment on a reluctant public. Though nuclear power is a risky technology, a remarkably high standard of safety has been achieved by its engineering. It should be possible to convince public opinion that this is so and that in comparison with any of the other energy options suitable for intensive development, it is not only as safe, but probably much safer when all known detriments are taken into account. Little further progress toward this end is likely to be achieved by the continuing pursuit of esoteric mathematical risk studies or by well publicised expatiations on the comparison of the very low probability threats from nuclear power, among other new technologies, with the constant common dangers of modern civilised living. The same comment may be made about the progressive ratchetting up of investment in engineered safe-guards beyond what is called for by a realistic technical safety assessment of the particular nuclear plant or system and which has been espoused by sound engineering judgement. Safety enhancement by that route may have reached an asymptote of effectiveness as those engineered features which it is feasible to incorporate are already part of the tried and established thermal power reactor systems. Yet, it is a situation which cannot stagnate and new understandings and technical progress must be admitted.

Where adequate safeguarding by technical means is not practicable, then safety must rest on administrative controls and operator competence. Their effectiveness is made by provision and maintenance of an appropriate and well-designed management structure and staffing policy which can create a working system matched to the engineering and human demands put upon it by the plant and the vicissitudes of its behaviour.

The accidents at Browns Ferry and TMI were not due to failure or the overcoming of physically realised safeguarding systems, but to unsound maintenance practices, e.g. the leak tester with a candle, ill-judged operator actions which defeated the protective responses of the plant safety features and the confusion which comes when men are suddenly faced with a series of not well understood events. Those incidents were not due to weakness in the technical constitution of the plant, but to inadequacies and defects in management structures and human capabilities and to the 'human errors' made when they were put to the test. The assurance of safety in this domain must come from independent confirmation of the efficacy and soundness of these offices which is the duty of a disinterested and and effective official examining body, e.g. the NII or NRC.

The conditions for the acceptance of nuclear power, given a confident assurance that the engineering standards which have been attained in the plant and its operation are adequate, if not more than that, then lie in the social realm. The body politic must be persuaded to conviction that this is so and that, though absolute safety cannot be guaranteed by engineers, the industry is safe enough for the purposes of the community and that accountable organisations exist and function efficiently to keep it that way.

Societal risk acceptance criteria

Rowe (1979) has distinguished a number of conditions which make a risk acceptable. Two of them which are relevant to the case of nuclear power and bear on the foregoing premises are that:

(i) The perceived risk is 'so small that it can be ignored', and

(ii) A credible organisation with responsibility for health and safety has established that the risk is acceptable.

Rowe's conditions are particularly onerous in the case of the nuclear industry. In the light of what has been said so far, the perceived risk is certainly not'so small that it can be ignored', nor will it be easy to achieve that state of affairs as the mechanisms of perception are independent of those by which the actual risk is assessed. Acceptability must turn, therefore, by success of the steps taken to meet the second criterion and, thereby, serve as a sufficient condition for attainment of the first.

No commitment without prior public assent

As Flowers (1976) in his brief review of the British energy scene concluded, choice of nuclear power as a major energy source, even in association with a greatly increased contribution from coal, would call for a massive diversion of the nation's capital and engineering resources to that end. It would involve an extensive, large scale reactor building program that would have to continue into the next Century and expansion of ancilliary facilities such as fuel manufacturing, irradiated fuel processing and those for the management of radioactive wastes. In view of the relatively limited quantities of the essential isotope, uranium-235, which can be obtained economically, consideration would have to be given to fissile material breeding through an associated Fast Reactor program. Treatment of thorium by fast particles from accelerators might provide a competitive and less controversial supply in the alternative of uranium-233 (Davies 1978). A decision to assign over a generation or more a conspicuously large portion of a country's wealth and effort to a controversial option like nuclear power could not be prudently undertaken without the support of a political consensus and mandate from its people, these assents having been obtained well in advance of any irrevocable action. The prospect of winning them in Western nations other than France (Papon 1979) in present atmosphere of doubt, fear, hostility and mistrust which characterises the nuclear power debate, and particularly when the issue of Fast Reactor is raised, is not good unless better tactics than those used so far are adopted.

Two prerequisites for acceptance of the nuclear option

The approach suggested by consideration of Rowe's analysis (supra) of the energy risk management dilemmas would seem to be a better path to the attainment of national agreement to the nuclear choice, should that be made. Nevertheless, two prior conditions would have to be met. The first is obvious. The electorate would have to be persuaded that it was right and necessary to commit industry and the exchequer, and thus the taxpayer, to the heavy expenditure and large scale diversion of national resources that would be needed for the creation of such an energy source. This would not be made any easier by the fact that it would have to be done long before any perceptible signs of a serious energy shortage appeared. Groundwork of this kind would be required before a firm decision on any of the options, e.g. wave, wind or solar power, let alone an expansion of nuclear sources, could be taken. The task is clearly political and beyond the scope of this study.

The second prerequisite is to make the prospect of nuclear power on a large scale acceptable to the body politic. Concurrence with Rowe's societal criteria leads to the conclusion that this can be achieved if the 'credible organisation' he envisaged could be created and given the means so that through its own authority and prestige it could show that the grave potential threat from nuclear reactors could be effectively reduced to, and maintained at, a level so small that it could be ignored. The establishment of such a watchdog body is thus central to the task of securing the popular acceptability of a major nuclear program. Its credibility in the eyes of the public as the trusted guardian of nuclear safety would be due to its independence of those political, public corporation, commercial, financial and trades union interests who would seek to influence its decisions. Another important matter would be the eminence, capability, disinterested commitment and 'charisma' of its head, supported by an appropriately qualified staff able to face efficaceously the demands of a duty of likely to be exacting. These things are discussed further elsewhere.

Duties of the guardian

It would not be a duty of the 'credible organisation' to engage in direct surveillance of the day-to-day work of the industry, though it would have to be able to assess and report on its quality. It would engage in a superior style of 'executive inspection' (supra), but its activities could never be 'a source of safety' as that is the duty of the managers, designers, builders and operators of the nuclear plants. It would be charged to confirm that the nuclear power industry was organised and managed in a way likely to assure its safety, to verify the professional and vocational competence and efficiency of its staff in all grades and to report scrupulously and independently on the relevant technical attainments, morale, efficiency and vigilance of the operational managements and personnel. The internal state and efficacy of the body itself would be subject to continuous review at the highest executive levels, e.g. a standing commission, and by legislative inquiries. Though a statutory body of a new kind would have to be created, much of the necessary structure exists and procedures have already been evolved to meet the safety needs of other high risk, high-technology industries and applications. In this respect the NII is its paradigm and its antecedents and methods are discussed in some detail in the Appendix.

Similar guardianship proposals and their fate

The Air Registration Board (ARB), formed in 1936 to overlook commercial aviation in Britain, was the indirect forerunner of the NII and had been suggested as a paradigm for the guardian body needed to give the public a confident assurance about nuclear power station safety. The ARB was a statutory corporation under the general aegis of the Ministry responsible for civil aeronautics, but playing a largely independent hand under a chairman chosen for his eminence in the field of aviation. His management board was representative of all corporate bodies with major interests in the air transport industry, the government being represented by specialist nominees.

It was responsible among many other things for oversight of all aspects of safety, which included air worthiness of machines, professional staff competence attested by licensing of engineers and pilots, approval of designs and modifications and the inspection of aeroplanes and navigational equipment during manufacture and use. A few years ago it was incorporated in the Civil Aviation Authority (CAA), a government agency.

Lord Fleck, then Sir Alexander, during his investigation of the organisation of safety in the UKAEA following the 1957 Windscale plutonium pile fire saw analogies between the tasks of the body which he thought should be set up to overlook the safety in rapidly growing civil side of the nuclear industry and the ARB. Accordingly, he recommended that the former be modelled on the existing aeronautical Board (Fleck 1958). Though the essence of the recommendations was accepted, the government turned down the proposal that the NII take the form of an independent nuclear safety board, arguing that matters of policy should not be delegated to an organisation not answerable to Parliament, that is placed outside direct Civil Service control.

A similar proposal was made by Lord Robens (1972) in his report on the regulation of safety and health at work in the U.K. He recommended a unitary health and safety authority responsible in a clear line management structure to a chairman. Again, the proposals were not accepted and it was decided to follow current civil service practice and make a clear division between policy and its execution. Surveillance of health and safety was thus split between a 'political' Health and Safety Commission (HSC) and an executive agency, the HSE, staffed by civil servants and managed with a further divorce between policy and inspection. This latter principle has been applied to most of the HSE's divisions, e.g. the Factory Inspectorate (HMFI), but the NII retained the unity of inspection and safety assessment in spite of a number of functional reviews of its modus operandi.

8. ENGINEERING INSPECTION IN THE FIELD OF ADVANCED TECHNOLOGY

The 'viewing' (supra) of simple repetition engineering artefacts like printed circuit boards or domestic appliances can proceed on a GO/NO-GO basis. The product, if inspected at all, either passes the guage, comparison trial or completeness and functional test or fails. The use of discretion is minimal, being limited to the acceptance of trivial blemishes and fringe range judgements, However, the need to use it increases rapidly in relation to the technical complexity of the product and the design specification tends to become more of a guide than a prescription. As a case in point, the specification for a modern airliner may include several million separate plans, drawings and assembly instructions. Exact compliance is impossible and proper and safe construction of the machine depends on the engineering skills of craftsmen, technicians and shop engineers. Inspection has become almost wholly interpretive and discretionary, the 'examiner' being concerned more with deviations from specification than enjoining obedience.

In the case of very complicated advanced technology installations which may take years to build, the specification is little more than a message from the designer about the final form of his concept, often to be implemented after he has left the scene. His instructions are seldom complete and often contain major errors. The deficiencies have to be made good by the engineering teams on shop floor and construction site with the participation of the inspecting authority.

'Examining', 'Executive Inspection' and 'Inquiry'

There are no sharp divisions between the four categories of inspection defined in Section 4 above, though they may appear to be very diverse in nature. In spite of the steady change in the mode of working as the strict scrutiny required in 'Viewing' gives way to the increasing exercise of discretion needed in the higher tiers of inspectional activity, the innate purpose of all four is to discern human fallibilities in the performance of tasks and duties , to prevail against the continuance of such error and to seek rectification of that which has occurred.

A very large measure of discretion may be called for in 'Examining' when action to enforce conformity with the detailed stipulations of statutory regulations or of an engineering specification has to be taken and flexibility of interpretation is often required. This was recognised in the shop floor practices of the erstwhile Aeronautical Inspection Directorate (AID) to which reference is made in the Appendix. 'Examiners' were authorised to allow deviations from strict compliance with the minutiae of a technical specification by giving a temporary 'Concession', impression of a personal stamp on the defective item indicating that it had been accepted. A 'Production Permit' gave formal and lasting agreement to relaxation of a more important design requirement. Sections 21 and 22 of the Health and Safety at Work Act 1974 introduced a rather similar arrangement in the practice of factory inspection in Britain. The 'Improvement Notice' procedure enables an inspector to deal with an infringement of a regulation by the issue of a 'Notice' which gives the occupier of the premises concerned time to alter his offending ways or modify his plant or process to bring them into accord with statutory demands. Moreover, use of a dangerous piece of equipment or behaviour judged to be hazardous can be brought to an immediate halt by a 'Prohibition Notice'. In this manner an inspector can avoid prosecution of the offender by the exercise of his discretion and can couple this with advice on how to overcome the failing.

In 'Executive Inspection' the work is largely interpretive and discretionary, though there may be some recourse to 'Viewing' as a means of sampling the standard of performance of a task or duty, of the quality of a process, the appropriateness of the manner in which a design requirement has been implemented or the competence of management and, not least, the standard of engineering achieved in the plant or process. It differs chiefly from 'Examining' in that not only are a greater depth and span of perception and range of discretions called for, but that the inspector often makes a significant contribution to the outcome of his task by participating in the work of solving the engineering problems that inevitably arise. There will invariably be design inadequacies, mistakes both gross and subtle in its interpretation, failures of materials, sub-assemblies and sub-systems to meet necessary specification requirements and the usual run of manufacturing and site construction mistakes. The inspector is involved as an engineer, if not in rendering assistance in overcoming them, then by adjusting his criterion of acceptance to accommodate for the deviation from the specification requirements.

When the objective of the inspection is safety assurance for a nuclear power station, the task is one of great technical complexity. The inspector's main occupation is a study in depth of the design of the system coupled with surveys of the plant and important sub-systems as he proceeds with his safety appraisal. An exhaustive technical assessment of the design and a survey of its realisation in the substance and functioning of the plant as it proceeds through the stages of construction and commissioning to full operation are essential parts of the safety case by which approval for commercial operation can be justified.

At the level of 'Inquiry' inspection has become wholly a matter of interpretation and discretion and is further characterised by an element of authority whereby terms of reference or an established approach may be varied by the 'Inspector'. Lord Flowers (1976) during his term as Chairman of the Royal Commission on Environmental Pollution extended those given to him beyond their previously accepted limits to matters concerning the safety of nuclear power and examined the adequacy of the NII and the appropriateness of its methods.

'Executive Inspection' and the NII

In the safety work of the NII, technical assessment of design takes pride of place in its 'executive inspection' of nuclear power plants. The activity has been described in some detail by Gronow and Gausden (1975) and by Haire and Shaw (1979). It is done by mature professional engineers who can claim to have had long and relevant experience. In addition to being highly qualified academically, they must have an ability to conceive the design of nuclear plant and systems as eventual functioning realities. They are required to see beyond the plans and specifications to the reliability and safety of their embodiment in the future power station, envisaging the consequences of faults, failures and operational mistakes in terms of accident scenarios. On this basis engineered safeguards and accident control measures may be judged for their likely efficacy.

The NII directs much of its professional effort to the direct assessment of design and in the examining of plant in various stages of construction, commissioning and operation (Gronow and Gausden 1975). This provides statutory confirmation that the engineering is of the necessary high standard and that the safety norms have been attained and regulations satisfied. Moreover, the Inspectorate is the upper echelon in the guardianship progression described by Ravetz (1974). As the licensing and approving agency, it is the superior body in the inspectorial guardianship chain, its views inevitably affecting all aspects of nuclear safety policy.

Each nuclear licensee has some form of internal organisation composed of people who have been assigned responsibilities for health and safety together with various safety committees. In the case of the electricity utilities, they are established as formal groups, e.g. the Nuclear Health and Safety Department (NHSD) of the Central Electricity Generating Board (CEGB). They have a clear guardianship role and are subject in varying measure to surveillance by the NII. This structure is a partial answer to the ancient, but still important question, 'Quis custodiet ipsos custodes?' (who guards the guardians? - Ravetz 1974). It is still open-ended unless something akin to the 'credible organisation' suggested by Rowe (1979) and discussed in Section 7 above were to be adopted. The matter is pursued further elsewhere.

9. HOLLAND AND HER TRUSTED GUARDIANS - AN ENCOURAGING EXAMPLE

The posit that public acceptance of nuclear power can be won by the creation of a trustworthy guardian body can claim support from the existence of Holland. The people of that country with eight-tenths of its land area below the maximum spring tide surge put their faith in the integrity of the national engineering system which maintains the elaborate technology of dykes and sluices that keep out the flood waters. These defences can not be absolute and have on rare occasions been overwhelmed by a combination of exceptional tides and storms with heavy loss of life and damage to property. There is no ultimate security because considerations of cost determine the height of the sea walls and there can always be a surge of water driven by the elements which will exceed that economic limit. Yet, the risk is accepted because it is known that all that is reasonably practicable has been done under the circumstances, even though the scale of some of the past disasters when the technology has failed has exceeded that most pessimistically envisaged for the worst reactor accident (Everyman's Encyclopaedia 1968).

The 'credible organisation' proposed by Rowe (1979) supra as the trusted guardian of the safety of nuclear power must of necessity be of the nature of an inspectorate and in practice an engineering one. The duty of the guardian is not the organisation and achievement of safety, but verification through surveillance that these things have been well done and are maintained in that state. The composition, structure and allegiances of the required body have been outlined in Section 7 above and need no reiteration at this point, except to emphasise the need for patent disinterest, independence and competence with the faculty to take a balanced view of matters in dispute.

10. SUMMARY

Countries whose economies are dependent on imported fossil fuels, especially oil, are likely to be very adversely affected if their supplies are cut. Thermal fission nuclear power has reached a stage of technological and commercial development where it can be a major energy source in an advanced industrial country. Moreover, there has, as yet, been no serious attempt to develop any of the alternatives of solar, wind or wave power on a scale that could prove adequate to meet a sudden demand. For even the most promising of them, it would be several decades before a major contribution could be made to the energy balance. Therefore, failure to make an early commitment to nuclear power could set the scene for a severe energy shortage which could destroy a country's standard of life, debase national status, threaten public tranquility and seriously increase international tensions.

Nuclear power, though potentially a very dangerous technology, has been rendered very safe in use by human ingenuity and good engineering. Its new technology emerged in an atmosphere of caution. In addition to the fear of the unknown, the lessons learnt from earlier unhappy experiences with X-rays and radioactivity were heeded. The policy was to achieve safety by foresight rather than hindsight. Steps were taken in the new atomic energy establishments to integrate responsibility for safety into management at all levels. Among these measures was an important requirement that no significant project, experiment, innovation or change to the plant or process could be started unless its safety had been assessed and then justified before a broadly based technical safety committee.

In spite of these precautions and the high standards of safety achieved, there were a few serious accidents in the U.S.A. and the U.K. Notable among them was the fire in 1957 in a plutonium producing pile on the Atomic Energy Authority's site at Windscale in Cumbria. Although it was potentially very serious, the incident was eventually safety contained except for some transient environmental contamination. The Government commissioned an enquiry under an eminent chairman, Sir Alexander Fleck. Weaknesses were found in the Authority's safety organisation and restructuring was recommended. As a consequence, a separate Safeguards Division was created. It was divided into radiological protection and technical safeguards branches. The latter had wide ranging inspectional and advisory duties covering design as well as construction and operation of the UKAEA's plants.

The Fleck committee also recommended that a body analogous to the Authority's new technical safety branch, but on the lines of the independent civil aircraft Air Registration Board, be formed to regulate the commercial side of the nuclear industry which was growing rapidly. A new inspectorate, the NII, was formed, but unlike the ARB which Fleck proposed as the model, it was incorporated into the Civil Service.

In the event, the nuclear power industry has proved itself to be very safe. For nearly twenty years there have been no fatalities and few injuries attributable to nuclear work. Those reactor incidents which have occurred have been satisfactorily contained without harm to the public or environment. In spite of these successes, propaganda from vocal and often intemperate partisan groups claiming to be concerned about the longer term and more general dangers of nuclear energy as well as the threat of uncontained reactor accidents, has disturbed public opinion and encouraged official procrastination over the nuclear energy option. Attempts to assuage this opposition by reasonable scientific argument have had little success. In response to each criticism answered or new technical safety measure introduced, another challenge has soon been found. There is reason to think that the motivation for the protest movement comes more from opposition to technological progress generally than to any special threats from atomic energy. It has been focused on nuclear power as the salient pace setter which, because of its indisputably grave potential hazards, offers a convenient and vulnerable target for attack. If this is so, then continuing substantial investment in the development of ever better engineered safeguards is likely to be unrewarding as the results are asymptotic to the attainment of any absolute assurance of reliability or defence against serious faults. Mathematical studies which attempt to show that risks from nuclear power are negligibly small compared with those endured in the course of normal living have also failed to convince because they do not relate to the way in which people perceive risk. In this climate of hostility and public doubt, government decision makers are naturally reluctant to embark on a massive nuclear power program, at least until a serious energy shortage which can not be met by any other more acceptable means can be indubitably foreseen. Unfortunately, it may then be too late.

The consequences of the recent escalation in the price of petroleum have been vexatious. They have caused steep increases in energy costs together with rising fuel bills and higher transport fares. A result has been serious inflation and unemployment. The relationship between an energy shortage and falling living standards has been made clear. There is now evidence that, apart from committed anti-technology groups, the general public are being persuaded that something must be done to provide sources of energy other than oil.

The suggestion that most people could be won to accept the nuclear option if they could be convinced that a truly 'credible organisation' charged to assure the safety of nuclear power existed has been examined. The technological basis for this approach to public opinion already exists.

Nuclear engineers have been very successful in their attempts to make reactors safe and reliable. Those failures which have occurred have not been caused by intrinsic design defects and constructional and commissioning mistakes have been detected and made good. Nevertheless, there is an element of human fallibility which can affect every aspect of the design process and the construction, operation and maintenance of plants and systems. Hence, it is very much more likely that human error will be the cause of a serious accident than faults in the physical constitution of the plant. Indeed, the incidents which have occurred may, almost without exception, be attributed to it, an omission, error of judgement, misunderstanding, failure to obey instructions and so on. However, such shortcomings can be anticipated and prevented by inspection which is an art that has been devised for the purpose of overcoming human failings of this kind.

Good behaviour and high standards of performance can not be inspected into a system. They must be inherent in it, but the existence of this desirable internal property can be confirmed by examination from without. A scheme of regulation by progressive attachment of safety conditions to a nuclear power station site licence has been used by the NII for the purpose over the past two decades. This regulatory activity is in no way intended to supplant the essential task of self-inspection, both implicit and explicit, which is necessary to ensure the orderly and disciplined existence of a nuclear installation. On the contrary, they exist to reinforce it. Finally, the responsibility for safety and reliability and for the supervision of those internal processes needed to secure them must remain firmly with the management of the plant and can in no way be diluted.

The work of the NII has been reviewed in the light of the foregoing philosophy. Its practise of the art has been identified as 'Executive Inspection', the third in a sequential classification which embraces 'Viewing' with little or no exercise of discretions, 'Examining' which is largely interpretive and discretionary and 'Inquiry' being the conduct of august official investigations.

It is not claimed that the NII is the embryo of the 'credible organisation' in which public trust can be happily placed so that the body politic can accept the nuclear power risk as 'so small that it can be ignored.' The Inspectorate could readily provide a basis on which the 'credible organisation' might be built, but with the NII alone at the top of the inspectional structure, the situation would be open-ended. An inspectorate can be shown to be fallible and itself to need scrutiny as the fate of the U.S. NRC in the Three Mile Island affair disclosed. There must be an effective superior level of surveillance to which the inspectional hierarchy is accountable, an entity to 'guard the guardians'. This is the role in which the 'credible organisation' would be cast, itself being accountable to the higher authority of Parliament.

To earn the necessary public trust, the 'credible organisation' would not only have to fulfil its function but would have to be seen to be capable of doing so. It would need to show an impressive and authoritative presence. To achieve such a status, a very eminent, charismatic and clearly disinterested person would have to be appointed as its head. Further, the organisation itself would have to be clearly independent of the normal political interplay of sectional, party, industrial and institutional interests and not afraid of incurring temporary disfavour.

That public faith and trust can be won for a safe-guarding system is confirmed by the existence of Holland. That country depends absolutely on the efficiency and integrity of the engineering system which maintains its sea defences. They are occasionally overwhelmed with disastrous consequences, yet the Dutch keep faith in their dykes.

11. ACKNOWLEDGEMENTS

The opinions expressed, some of which may be controversial, are entirely those of the author for which he takes full responsibility. They are in no way attributable to any former colleague or associate nor is it suggested that they are supported in any way by any previous employer or principal. Nevertheless, this disclaimer must not exclude the influence of many discussions and debates with these people and the generous encouragement, not without some criticism, which they so often gave. It is also appropriate to recall the assistance given by the academics of the Department of Liberal Studies in Science of Manchester University during the author's sojourn there during tenure of a Simon Fellowship.

In particular, mention must be made of Messrs T.Griffiths, E.C. Williams (deceased) and R. Gausden, all erstwhile Chief Inspectors of Nuclear Installations, of Mr. S.G. Luxon, a former Deputy Chief Inspector of Hazardous Substance in the Health and Safety Executive and of Professor Brian Harvey who was at one time HM Chief Inspector of Factories and latterly and until retirement one of the three senior Members of that Executive. Last but by no means least, the assistance given by Dr. John Shaw of the Department of Nuclear Engineering in Queen Mary College of London University, is gratefully acknowledged.

REFERENCES

Bacon, H. and J. Valentine. 1981. Power Corrupts: The arguments against nuclear power. London, Photo Press.

Beattie, J.R. 1981. 'The assessment of environmental consequences of nuclear reactor accidents.' Proc.Conf. on Environmental Impact of Nuclear Power. Brit.Nucl.Energy Soc. London. 215-235.

Cohen, Lord. 1955. Report of the Court of Inquiry into the Accidents to COMET G-ALYP on 10 January 1954 and COMET G-ALYY on 8 April 1954. London, HMSO.

Cotgrove, S.F. 1978. 'Nuclear Power safer than Windmills?' (Letter) London, The Times, Monday, 27 November, 13.

Critchley, O.H. 1976. 'Risk prediction, safety analysis and quantitative probability methods - a caveat.' J.Brit.Nucl.Energy Soc. 15 18-20.

Critchley, O.H. 1978. 'Aspects of the historical, philosophical background to the statutory management of nuclear plant risks in the United Kingdom.' Proc. Conf. on Radiation Protection in nuclear power plants and the fuel cycle. Brit.Nucl. Energy Soc. 11-18.

Critchley, O.H. 1980. 'Inspection and its role in the case for nuclear power.' Proc.Conf. on Directions in Nuclear Engineering Research. Brit.Nucl. Energy Soc. Paper No. 201.

Critchley, O.H. 1981. 'Technological progress, safety and the guardian role of inspection.' Science and Public Policy. 8. 291-307.

Davies, J. 1977. 'Conserving uranium without the fast breeder.' Nature 270. 375-377.

Everyman's Encyclopaedia. 1968. Floods and Inundations. London, Dent. 331.

Farmer, F.R. et al. 1970. 'Quantitative Safety Analysis.' Nucl. Engineering and Design. 13. 183-244.

Fleck, A. 1957. Report of Committee to examine the organisation of the United Kingdom Atomic Energy Authority. London, HMSO. Cmnd 338.

Fleck, A. 1958. Report of Committee of Inquiry into the organisation of the control of Health and Safety in the United Kingdom Atomic Energy Authority. London, HMSO Cmnd 342. S.25-S.37.

Flood, M. and R. Grove-White. 1976. Nuclear Prospects. London, Friends of the Earth.

Flowers, B. 1976. 'Nuclear Power and the Environment.' In: Reactor Safety and Siting. Chap.VI. Sixth Report of the Royal Commission on Environmental Pollution. London, HMSO Cmnd 6618.

Gausden, R. 1979. Health and Safety: Nuclear Establishments - 1977-78. London, HMSO.

Gofman, J.W. and A.R. Tamplin. 1973. Poisoned Power. London, Chatto and Windus.

Gronow, W.S. and R. Gausden. 1975. 'Licensing and regulatory control of Thermal Power Reactors in the United Kingdom.' Proc. Symp. on Licensing and Control of Nuclear Installations, Vienna. I.A.E.A.

Groves, L.R. 1962. Now it can be told: the story of the Manhattan Project. New York, Harper.

Haefele, W. 1974. 'Hypotheticality and the new challenges. Minerva 12. 303-322.

Haire, T.P. and J. Shaw. 1979. 'Nuclear power plant licensing procedures in the United Kingdom.' Progress in Nuclear Energy 4. S.8, S.9 and S.11.5, 161-182.

Haire, T.P. and J. Shaw. 1979. 'Nuclear power plant licensing procedures in the United Kingdom. Progress in Nuclear Energy. S.5-S.12 and S.14.

Hoyle, F. 1979. Energy or Extinction? London, Heineman.

Joslin, S.W. and T. Griffiths. 1962. 'The Nuclear Installations Act 1959 and its application.' Proc. Congress of the Royal Society of Health on the Design and operation of Nuclear Power Stations: Section L. Radiation. Scarborough, England. 104-109.

Locke, J., J. Dunster and A. Pittom. 1978. Canvey: an investigation of the potential hazards from operations in the Canvey Island/ Thurrock area. London HMSO.

McGinty, L. 1981. 'Select Committee has doubts about nuclear plans.' New Scientist 91. 461.

Nelken, D. 1975. 'The political impact of technical expertise.' Social Studies in Science 5 35-54.

Page, T. 1979, 'Keeping Score: an actuarial approach to Zero-Infinity Dilemmas.' In: Energy Risk Management. Ed.Goodman and Rowe. New York, Academic Press 177-186.

Papon, P. 1979. 'Why France has had no nuclear debate.' Nature 281 94-95.

Parker, Mr. Justice. 1978. The Windscale Enquiry. Vol.1. (3 Vols). London, HMSO. 11-24.

Penny, W. 1957. The Windscale Pile No.1. Accident of 10 October 1957. London, HMSO. Cmnd 302.

Rasmussen, N.C. et al. 1975. The Reactor Safety Study: WASH-1400. Washington, D.C. N.R.C. NUREG-75/014.

Ravetz, J.R. 1971. Scientific Knowledge and its Social Problems: 12 Technical Problems. Harmondsworth, Penguin Books 321-338.

Redfearn, J. 1981. 'Committee douches nuclear energy'. Nature 289 620-621.

Robens, Lord. 1972. Safety and Health at Work: Report of the Committee 1970-1972. London, HMSO Cmnd 5034, S.206-S.216.

Robens, Lord. 1972. Safety and Health at Work: Report of the Committee 1970-1972. London, HMSO Cmnd 5034, S.226 and S.227

Rogovin, M and T. Frampton. 1980. Three Mile Island: Vol.1-A- Report on the Commissioner and the Nuclear Regulatory Commission, Washington, D.C. N.C.R. Division of Technical Information and Document Control.

Roszak, T. 1972. Where the wasteland ends. London, Faber and Faber.

Rowe, W.D. 1979. 'What is an acceptable risk and how is it determined?' In: Energy Risk Management. Ed. Goodman and Rowe. New York, Academic Press. 327-344.

Ryle, M. 1977. 'Economics of alternative energy sources'. Nature 267. 111-117, 374.

Sharfman, P. et al. 1980. The Effects of Nuclear War. (Office of Technology Assessment). London, Croom Helm.

Slovik, P. et al. 1979. 'Images of disaster - perception and acceptance of risks from nuclear power.' In: Energy Risk Management. Ed. Goodman and Rowe. New York, Academic Press. 225-245.

Street, H. and F.R. Frame. 1966. The Law Relating to Atomic Energy. London, Butterworth.

Vickers, C.G. 1967. Towards a Sociology of Manágement. London, Chapman and Hall. 86.

Weinberg, A.M. 1972. 'Science and Trans-Science.' Science 177 211.

Weinberg, A.M. 1978. 'Trans-Science.' Nature 93 273.

COMPETITION, OWNERSHIP AND CONTROL IN MARKETS WITH IMPERFECT INFORMATION:
The Case of the German Liability and Life Insurance Markets

Jörg Finsinger

International Institute of Managers, West Berlin, FRG

The recent literature on the economics of information suggests that markets with incomplete and asymmetric distribution of information may fail to allocate resources efficiently. This is why such markets tend to be heavily regulated. Insurance markets are generally believed to fall into this category. This paper suggests that regulation may cause lack of market transparency and thereby decrease competitive pressure on firms. Significant differences in firm performance can be observed. In such markets public enterprises as well as mutual companies seem to outperform stock companies.

1. The German Insurance Industry

The private insurance industry is the fastest growing branch of the German industry. Its relative share in gross value added has doubled in the period between 1960 and 1976. In 1977, the average household spent 2358 DM on insurance, adding up to 4.7% of GNP.

It is generally held that competition in this market allocates resources efficiently and that market performance is acceptable. Also, it is generally accepted that the regulatory agency serves an important role in making competition viable, where many real and imaginary market failures may hurt consumers. We present some institutional details, some simple theory of firm behavior and finally some casual evidence and we conclude that certain regulatory policies create market intransparency and thereby, cause market failure.

2. Institutional Constraints on Competition in German Liability and Life Insurance Markets

Since 1901, when the Law for Insurance Regulation was passed, the most prominent argument for regulation has been consumer protection. "The social and ethical role of insurance has to be protected, because even the diligent and careful consumer is unable to evaluate insurance institutions".[1] This is why a regulatory agency was established and given control over all competitive parameters of the industry.

Entry

Insurance companies must first obtain a license by submitting a proposal for the planned business operations. Minimum capital requirements have to be met, the proposed premiums have to guarantee the firm's long run viability, the proposed insurance contract conditions have to conform to regulatory standards, careful estimates of adminstrative costs, marketing costs and of the required reinsurance have to be given. This plan of business operations has to be updated at regular intervals. The agency has the necessary rights to enforce compliance with the plan.

In order to prevent cross-subsidization each firm can only be licensed for certain lines of insurance. Licenses for life, liability, health, credit, legal suit insurance are deemed to be incompatible.

---

1) c.f. Prölss, E.R., R. Schmidt and J. Sasse (1978), p.11.

Premiums

In general, premium calculation must reflect all costs such that the long run viability of the firm is insured. Within the boundaries given by this precaution the firms can freely set premiums. More stringent standards apply to the main lines of insurance - automobile, life and health insurance - where premiums must be approved of by the agency. There the level of premiums is determined by rate of return on premiums or capital considerations.

Profit Regulation

a) Automobile Insurance

Automobile Insurance Tariffs are determined as the sum of the risk premium, administrative costs and commissions to agents, a safety margin plus a 3% rate of return on total premiums written. The risk premium is taken to be the same for all firms and is equal to the average industry loss experience unless a firm can prove to have a lower loss experience for at least five consecutive years or shows a significantly higher loss experience. Projected administrative costs are based on last years experience. Commissions cannot exceed 11% of premiums. Ex ante, a profit margin of 3% return on total premiums written is conceded. Thus, premium regulation establishes a conservative lower bound on automobile insurance tariffs. Insolvency is effectively prevented, but ex post profits may be large.[1)]

This is why ex post profit regulation requires firms to return excess profits to the insured. The exact rate of return regulations are given in Table 1.

---

1) Average rate of return on "visible" assets of liability insurance companies were 42.8% in the period from 1974-1979.

Table 1: Ex Post Profit Regulation

Surplus in % of Premiums	Allowed Surplus Share	Minimum Ex Post Rebate
up to 3%	1	0
3% - 6%	0	1
6%- 15%	1/3	2/3
above 15%	0	1

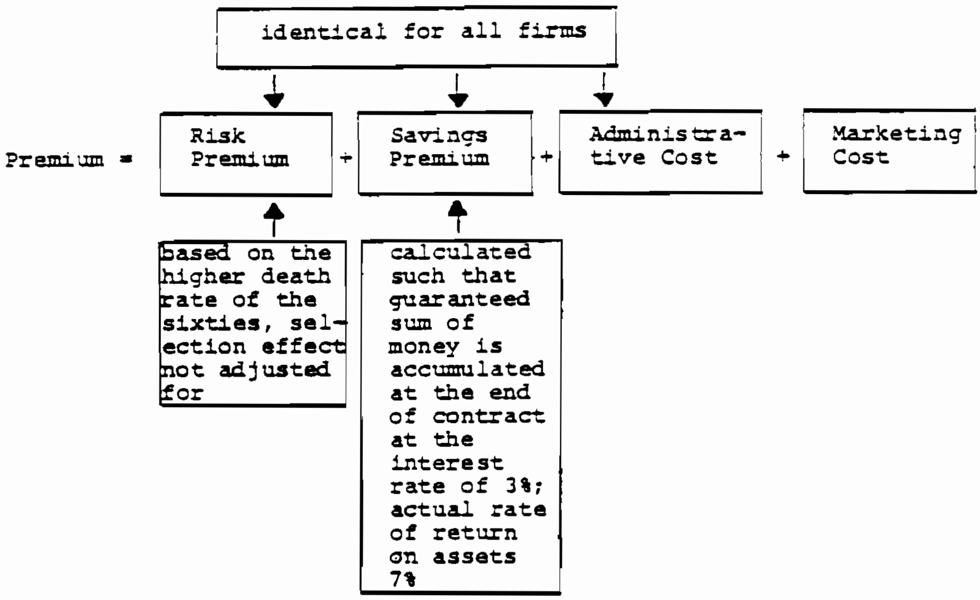
Take for instance a company whose pretax surplus amounts to 12% of premiums. It can retain 3% + 1/3 (12%-6%) = 5% and has to return 1 (6%-3%) + 2/3 (12%-6%) = 7% to its customers.

b) Life Insurance

Government promotes life insurance by exempting the returns to the insured or the beneficiaries from taxation. Also, depending on income, the premiums can be fully or partly deducted from the income tax paid. This is why most life insurance contracts are composed of a risk and a savings component. The contract stipulates the amount of money a policy holder or the beneficiary is entitled to

- in case of death
- at the end of the contract period

The mean length of currently written contracts is 28 years. Irrespective of the rate of return on the invested capital or of the interest rate, premiums are required to be fixed for the whole contract length. They must be calculated according to the death statistics of 1960/1962 plus a safety margin. In those days life expectancy was significantly lower than today. The projected (nominal) rate of return is taken to be 3% when the average (nominal) return is about 7%. Thus, the risk and the savings premiums are higher than necessary. In particular, these two components of the total premium as well as the administrative cost component are the same for all firms irrespective of their individual performance.



The only firm specific premium component is the marketing cost. The agency has always attempted to contain in particular the substantial marketing cost share by setting a low upper bound on these costs. With very few exceptions the bound is exceeded and thus, must be used as the basis for the premium calculation procedure. As a consequence, premiums are almost identical for all companies. Note how the attempt of the agency to contain marketing costs eliminates price competition, thereby shifting the competitive effort to marketing and ultimately increasing marketing costs.

Given these conditions it is not surprising that the average surplus in the German life insurance industry amounted to 33% of premiums in 1978. The regulatory agency therefore requires the life insurance companies to return at least 90% of these surpluses to the insured. In fact, all insurance companies return more than this minimum. However, only very few companies return the surpluses immediately to the insured. Most of them keep these surpluses in special accounts until the end of the contract and make another handsome profit on their customers' capital.

Uniformity of Contracts

As stated by regulatory law the main objective of insurance regulation is the protection of consumers. In the eyes of the regulators the most prominent means to this end is a restriction on the variety of contracts. Contract clauses must be standardized within each line of insurance. This aim has been attained in the automobile insurance, where all companies offer identical contracts for all risk classes. The risk classes are specified by the agency in terms of objectively given characteristics of the car and its owner. However, such contract uniformity could not be achieved in the life insurance industry, ultimately due to the elimination of price competition. Virtually all life insurance companies have chosen different schemes for the distribution of the regulation induced surpluses. There are numerous schemes for apportioning the surpluses to the individual contracts, to the risk component (paid out in case of death) or to the savings component (paid out at the end of the contract). In this line of insurance price uniformity was obtained at the cost of complete lack of transparency for the distribution of excess surplus. Even many life insurance salesmen do not seem to know or understand their companies complicated schemes.

The regulatory impact of interest in the context of this paper is easily summarized:

- In the automobile insurance market contracts are uniform, but net premiums, ex ante premium minus ex post rebate, are uncertain.

- In the life insurance market premiums are almost uniform, but contracts are highly differentiated. Complicated profit sharing schemes with large discretionary powers of the firm managers cloud the real value of contracts.

3. Property Rights and Market Behavior

The debate on ownership and control is ultimately a debate on management behavior. Does management maximize profits, sales or managerial utility or does it satisfice - i.e. does it satisfy minimal levels with respect to several objectives? To answer this question the relationship between management compensation and firm variables have been investigated. It could be shown that management compensation is increasing with firm size, but after controlling for this effect management compensation is positively associated with profits.[1)] Then there is the Marris and Manne theory, that managerial discretion is limited by takeover bids. Finally, we have the Darwinian argument that profit maximization is forced upon firms in the competitive process, that management slack leads to bankruptcy.

This latter argument does not hold for insurance markets. Bankruptcy is prevented by regulation. Also, regulation reduces price competition by making real prices uncertain. Therefore, competitive pressure may be weaker than in other markets and consequently discretionary behavior of management is more likely.[2)] In particular, we expect to observe systematic differences of management decisions between firms of different ownership structure.

Three different types of firms supply insurance: stock companies, mutual companies and public enterprises. The profit motive is plausible only for stock companies provided it is not enforced by competitive pressure. Mutual companies do not make profits by their very constitution. All surplus is

---

1) For details c.f. Scherer, F.M. (1980), p.29

2) Since 1960, only three firms entered the market for automobile insurance, twelve life insurance firms are less than ten years old. Today we find approximately a hundred firms in each market.

ultimately returned to the insured. The same is true for public enterprises.[1] Nonetheless, neither of the two firm types are run by the insured. In fact, the management is not even elected by the insured, management is replaced by co-optation. In this respect mutual companies differ from public enterprises only when they are constituted. The insured only meet once as members to elect the first group of managers. Thereafter, the management is on its own.

Historically, the members of mutual companies wielded some power. However, as the companies grew the members became less involved in decision processes. Even their liability to pay for company losses have been shifted to reinsurance companies. In this sense the status of the members has become identical to the status of the stock company clients. This fact leads to the widely held view that there are no systematic management related differences between firms of different ownership structure.[2] Later on, the fallacy of this argument will be shown.

Before turning to empirical evidence for regulation induced market failure simple models of management decisions are presented. The decisions of a rate of return regulated profit motivated management are compared to the decisions of a sales maximizing management.

---

1) Note, neither mutual companies nor public enterprises enjoy tax privileges.

2) c.f. Prölss, E.R., R. Schmidt, J. Sasse (1978), p.289.

4. Price and Quality Decisions Under Various Management Objectives in Automobile Insurance Markets

4.1 Regulated Profit Maximizing Behavior

4.1.1 The Price and Quality Choice

As explained in Section 2, the profits from automobile insurance are restricted to a fair rate of return on premiums. The impact of such a regulatory constraint will now be analysed in simple theoretical models. Consider a firm offering automobile insurance at price p and quality q. Let x(p, q) denote the demand or sales function. Since consumers do not have complete information, the firm has a certain amount of market power. Thus, for given q_o $x(p, q_o)$ is downward sloping or in terms of the inverse demand function p (x, q) we have $\frac{\partial p}{\partial x} < o$.

The cost of producing x insurance policies of quality q is given by c x q, c > o. Constant returns to scale with respect to output may be justified for liability insurance by the findings of P. Joskow (1973). Constant returns with respect to the quality index q is less restrictive than it seems, for the quality index is defined up to an arbitrary monotonic transformation.

The profit of the firm can now be written as

$$\pi = px - cqx.$$

Since profit π is restricted to a fair return on premiums

$$\pi < \alpha \, px \qquad o < \alpha < 1.$$

If this constraint is binding the following optimality conditions can be derived, the subscript$_p$ denoting the profit maximizing firm's decision variables:

P 1 $$p_p = \frac{cq_p}{1-\alpha}$$

P 2 $$\frac{\partial p_p}{\partial q} = \frac{c(1-\frac{1}{e_p})}{1-\alpha}$$

where $e_p = -\frac{\partial x_p}{\partial p}\frac{p_p}{x_p}$

is the price elasticity of demand. The price rule P 1 means an increase of price p_p above marginal cost cq_p by the factor $\frac{1}{1-\alpha} > 1$. The quality choice rule P 2 will be analysed in the following section.

4.1.2 The Rate of Return and the Quality Choice

The fair rate of return on premiums α is set by the regulatory agency. Therefore, it should be of interest that in general the quality of service q_p declines as α is increased. Substitute $t = \frac{1}{1-\alpha}$ into P1 and P2 and do the comparative statics.

$$\frac{dq}{dt} = c\frac{\Gamma}{\Delta}$$

where

$$\Gamma = (x\frac{\partial^2 p}{\partial x^2} + 2\frac{\partial p}{\partial x} - \frac{\partial^2 p}{\partial x \partial q}q)$$

$$\Delta = \frac{\partial p}{\partial x}\left[\frac{\partial p^2}{\partial q^2} - tc\frac{x}{p}\left(\frac{\partial^2 p}{\partial x \partial q} - \frac{\partial p}{\partial x}\frac{\partial p}{\partial q}\frac{1}{p}\right)\right] +$$

$$+ \frac{\partial p}{\partial x}\frac{x}{p}\left[\frac{tc}{p}\left(x\frac{\partial^2 p}{\partial x^2} + (1+\frac{1}{e})\frac{\partial p}{\partial x}\right) - \frac{\partial^2 p}{\partial x \partial q}\right]$$

Note that $\frac{\partial p}{\partial x}$ in general increases with q, i.e. $\frac{\partial p}{\partial x \partial q} \geq 0$. Consider $\frac{\partial x(p,q)}{\partial p}$ at a given price level p.

At a low quality level q_L a slight price decrease $\Delta p < 0$ leads to a smaller sales increase Δx_L than at a higher quality level q_H, $\Delta x_H > \Delta x_L > 0$[1]. Hence, we expect

$$\frac{\partial x}{\partial p}(p, q_H) < \frac{\partial x}{\partial p}(p, q_L)$$

or

$$\frac{\partial p}{\partial x \partial q} \geq 0 \ .$$

provided $\frac{\partial p^2}{\partial x^2} \leq 0$. But then $\Gamma \leq 0$ and $\Delta \geq 0$ follow. Hence, we have $\frac{\partial q}{\partial t} < 0$ or quality decreases as α increases.

4.1.3 Variable Cost Distortion

Before comparing p 1 and p 2 to the decision rules under other forms of management objectives, reconsider the assumption of minimum cost production. We now show that the regulatory constraint may well raise variable cost above the minimum cost level. Suppose for any given amount of (security) capital K the minimum variable cost of producing output x of quality q is given by $v(q, x, K)$. Also, assume decreasing marginal variable cost savings with increasing capital intensity, i.e. $v_{KK} > 0$ and obviously $v_K < 0$. Thus, we allow short run marginal cost to deviate from long run marginal cost, for equality we must have

$$\frac{\partial v}{\partial K} + r = 0 \ .$$

Under these assumptions the regulatory constraint can be written as

$$px - v \leq \alpha px \ .$$

---

1) Note, x(p,q) denotes the sales function of an individual firm in an industry with many firms. In an industry with one firm, a monopoly, this argument does not hold.

For the regulatory agency measures profit or rather surplus as revenues minus variable cost. The allowed costs do not include a fair return on capital. It can now easily be shown that the regulated profit maximizing firm does not choose cost minimizing factor inputs. It produces at higher variable costs than is efficient. It chooses K, x and q such that

$$\frac{\partial v}{\partial K} + r = \lambda\frac{\partial v}{\partial K} < 0,$$

where $\lambda > 0$ is the Lagrangian multiplier corresponding to the rate of return constraint.

But another theoretical argument for inflated variable costs can be given. Consumer search for low priced offers is discouraged by the uncertainty about the yearly rebate. Ex ante price may be high, but the rebate may be high or low. Also, the eligibility for rebates varies from company to company and from year to year. In general, drivers with low loss experience ratings are favoured. But this knowledge is harly sufficient as a guide for price comparisons. Consequently, buyers are insensitive at least to small price differences. Hence, in the neighbourhood of the mean price and most certainly below the mean price, the price elasticity of demand may be below 1 for a given level of quality. Now, P 1 and P 2 imply that the monopolist will not set prices in this range. He will increase price until the elasticity equals or exceeds 1. This price increase raises revenues without additional cost. Profits go up and may exceed the allowed return on revenues px:

$$px - c \leq \alpha px.$$

There is only one way to avoid excess returns, the inflation of cost. Cost can be inflated by marketing efforts and by investing in quality or simply by inefficient production. Also, there is an incentive to deceive the regulators by manipulating cost figures in the balance sheets. This incentive is most serious when the returns to marketing and quality increases are low.

4.2 The Sales Maximizing Firm

A sales maximizing firm must solve the following problem:

$$\max_{x,q} \quad p(x,q)x$$

$$\text{s.t.} \quad p(x,q)x - cqx \geq 0$$

Note, the regulatory constraint is not binding. There is only the viability constraint that revenues exceed cost. The decision rules corresponding to P 1 and P 2 are

$$\text{S 1} \quad p_s = cq_s$$

$$\text{S 2} \quad \frac{\partial p_s}{\partial q} = c\left(1 - \frac{1}{e_s}\right)$$

Recall the comparative status result in section 4.1.2. P 1 and P 2 are transformed into S 1 and S 2 as $t = \frac{1}{1-\alpha}$ approaches 1 or as α approaches 0. We conclude that the sales maximizing firm chooses higher quality than the profit maximizer. Also, we see that the current rate of return regulation modifies profit maximizing behavior towards sales maximizing behavior.

4.3 Summary

We compared price and quality decision rules for the profit and the sales maximizing firm. Our findings are summarized in Table 2. They also hold for a Cournot-Nash type of market equilibrium with many firms when each firm faces the same demand function $x(p,q)$ i.e. when consumers only form expectations about price and quality variables and when their decision is not influenced by any other considerations.

Table 2

Objective / Choice	Sales	Profits
Price rule	$p_s = \alpha q_s$	$p_p = \frac{\alpha q_p}{1-\alpha}$
Product quality	q_s >	q_p

In Section 4.1.3 it was shown that the currently used form of rate of return regulation induces the profit motivated monopolist to produce at inflated cost. In Section 5.2 we present empirical evidence for this induced inefficiency.

In Section 4.1.2 it was shown that the quality of service of the rate of return regulated monopolist declines as the rate of return is increased.

5. Some Empirical Evidence from the Automobile Insurance Market

5.1 Ownership, Marketing and the Price-Quality Relationship

Data was collected on 72 insurance companies constituting 91.2% of the market. Only the smallest firms were excluded from the sample. Most companies use exclusive agents for the sales of contracts. Some stock companies and the majority of the mutual companies use direct marketing; they sell insurance mostly in exclusive bureaus. Thus, five categories of firms can be distinguished (cf. Table 3).

Table 3: Market Share and Number of Firms

	Stock Companies	Mutual Companies	Public Enterprises	
Exclusive Agents	69.0% 48	5.4% 6	4.6% 5	79.0% 59
Direct Marketing	1.1% 6	11.1% 7	0% 0	12.2% 13
	70.1% 54	16.5% 13	4.6% 5	91.2% 72

The regulatory agency supplied the number of complaints about individual firms by dissatisfied customers for the first six months of 1980. For each firm this number was divided by the market share and taken as an index of the quality of service.[1] An analysis of variance revealed that ownership structure has an effect on this quality index (significant at the 5% level). The deviations from the mean are given in Table 4.

Similarly, premium levels were related to firm type as well as to marketing policy. Ownership structure as well as the marketing policy have a significant impact (at the 1% level) on premium level. The cell means deviations are given in Table 4. Also, the deviations of premiums adjusted for the mean rebate of stock and mutual companies as well as of public enterprises were calculated.

1) Some objections have been raised against the use of this index. First, it is argued that the propensity of customers to complain could be systematically related to the choice of firm type. Second, it is unclear which aspects of quality the complaints refer to. In J. Finsinger and E.J. Flöthmann (Feb. 1981) we analyse the subset of complaints, which were classified as justified by the regulatory agency. The pattern shown in Table 4 only becomes more pronounced. We also analyse subsets of firms with different specialization and obtain similar results.

Table 4: Index of Complaints and Premium Levels (% deviations from the mean)

		Stock Companies	Mutual Companies	Public Enterprises
Exclusive Agents	Index of Complaints	+ 1 %	- 2%	- 54 %
	Premium Levels (Ex Ante)	+ 1 %	- 1%	- 2 %
	Premium Levels (adjusted for rebates)	+ 0.6%	- 5%	- 3.3%
Direct Marketing	Index of Complaints	+63 %	-27%	
	Premium Levels (Ex Ante)	- 4 %	- 4%	
	Premium Levels (adjusted for rebates)	- 4.5%	- 9%	

Table 4 suggests that consumers should prefer mutual companies to stock companies. For both types of marketing policy mutual companies show a superior price quality relationship. But then, how is it that stock companies survive in the market? The answer is obvious. First, consumers only slowly learn about differences in the quality of service. Second, the regulated ex ante premiums differ less than the ex post premiums adjusted for rebates. Consumers cannot form realistic expectations about future rebates.

Public enterprises seem to provide higher quality of service, but show somewhat higher premium levels than mutual companies. Comparing Tables 4 and 2 one is tempted to classify the public enterprises as sales maximizers, whereas stock company performance more closely resembles the profit maximizing choice rules. Mutual company decisions seem to come closest to a welfare maximizing pattern. However, it should be noted that the analysis of variance results only prove that ownership structure has a significant impact on premium level and on the quality index. The analysis of variance does not provide a rigorous test for the models developed in Section 4. In fact, such a test was never intended. For it seems obvious that the pure management strategies, profit, sales and welfare maximization will not adequately describe actual firm behavior. Observable firm behavior will rather be a "mix" of these ideal types.

5.2 Regulation Induced Inefficiency

Even though observable firm behavior may not be "idealtypisch" in the Weberian sense, it is clear that the regulatory rate of return constraint can only be binding for stock companies. For all other companies profits are excluded by their very constitution. As shown in Section 4.1.3 the rate of return constraint may lead to inflated costs. This is why we calculated the administrative costs as well as the marketing costs (commissions) as a fraction of premiums. Note, since the stock companies generally charge higher premiums their cost ratios are underestimated in terms of real output.[1] Table 5 gives the cost ratios for the different types of firms.

Table 5: Cost as Percentage of Premiums

Year	1975	1977
Stock Companies		
Commissions	10.2	10.9
Administration	9.8	9.7
Total Cost	20.0	20.6
Mutual Companies		
Commissions	5.6	5.9
Administration	7.6	7.1
Total Cost	13.2	13.0
Public Enterprises		
Commissions	8.6	9.8
Administration	8.7	9.1
Total Cost	17.3	18.9

Source: Veröffentlichungen des Bundesaufsichtsamtes für Versicherungswesen, Vol 27 and 28, 1978, 1979.

1) It is generally acknowledged that the output per premium is largest for mutual companies who show a slightly higher loss record.

It is not surprising that the commission costs of stock companies by far exceed those of mutual companies, because these costs reflect the use of agents for marketing. However, it is surprising to find a 2.5% difference in administrative costs between stock companies and mutual companies. This difference suggests that the rate of return constraint on stock companies either induces cost inefficiency or leads to a misrepresentation of actual costs.

In addition to these marked cost differences, there is evidence for substitution of reinsurance for capital. Stock companies rely more heavily on reinsurance and show a lower visible capital/gross premiums ratio than public enterprises or mutual companies. [1]

Table 6: Reinsurance Activity and Capital

	Stock Companies	Mutual Companies	Public Enterprises
Fraction of Gross Premiums Retained	61%	75%	87%
Visible Capital in percent of Gross Premiums	19%	20%	26%

1) This effect is consistent with the results in Section 4.1.3.

6. Some Empirical Evidence of Market Failure in German Life Insurance Markets

6.1 Market Transparency and Performance Indicators

There is no price competition in the German life insurance market. Regulation imposes almost uniform premiums on all companies in spite of large differences in performance (cf. Section 2). These differences may persist over long periods of time for consumers lack the relevant information. In fact, some of the accessible information is misleading. Only partial performance indicators are published, some of which play a central role in signaling consumers firm performance. Companies make an effort to improve such partial indicators without improving overall performance thereby hurting customer interests in the long run.

In 1975 the yearly report of the regulatory agency stated that some companies return much less surplus to the accounts of the insured than others. For the comparison a partial indicator of performance, the RE-Quota (Rückerstattungsquote) was used. The RE-Quota is basically the fraction of surplus put into the special accounts of the insured to be paid out at the end of the contract period. The RE-Quota is indeed a very partial indicator of performance. Even if the surplus is small due to inefficient operations the firm may still transfer a large fraction of surplus to the return accounts. In spite of this fact the RE-Quota became a widely used indicator. It was estimated[1)] by business magazines such as "Capital" and the consumer magazine "Test". Firms began to manipulate the RE-Quota wasting resources rather than improving performance.

---

1) In fact, very few interesting performance indicators can be exactly determined from publicly available data. Only the regulatory agency knows the relevant data, but it does not publish material pertaining to individual firms. Only aggregate data is reported, which is of little interest for consumers. Business magazines have to estimate most indicators.

Another indicator, the UE-Quota is still reported.[1] It gives the fraction of surplus which is retained in the company. A third indicator of performance, the current return on invested assets, is similarly misleading. It does not reflect realized capital gains such as the sale of property or other assets with low book value. Fortunately, the business magazine "Capital" has recently begun to report more relevant performance indicators reflecting cost efficiency, marketing expenses, early cancellation of contracts etc. Thus, consumers now have access to more complete information on performance variables. It is, however, doubtful whether they are able to interpret the multitude of indicators correctly. In particular, it is still impossible to rank firms according to overall performance. Nonetheless, this lack of market transparency seems less harmful than the misleading transparency of those days when only the RE-Quota was available. Firms now have less incentive to manipulate partial indicators of performance.

---

1) c.f. Capital 10, 1980, p. 117

6.2 Performance Indicators and Firm Ownership

Data on the following performance indicators were collected from "Capital" as well as from the regulatory agency:

K79	total cost in % of total premium revenues for 1979
BK75/79	operating cost in % of premium, total cost minus marketing cost for 1975-1979
S79	number of early cancellations of contracts in % of total number of contracts in 1979
GR79	rate of return on mean invested capital for 1979
BEGM	number of complaints divided by market share, counting only complaints which were classified as justified by the regulatory agency
UE79	UE-Quota, fraction of surplus retained in the company for 1979

These performance indicators were related to the relevant firm characteristics. As firm dummies all those variables were included which are assumed to have an impact on operations.

OSHIP	ownership: public enterprise, stock company, mutual company[1]

1) Stock companies which are daughters of mutual companies are classified as mutual.

M marketing:
direct marketing,
use of agents

A age of company:
established if older than 10 years,
young if younger than 10 years

B client specialization:
customers only amongst civil servants (Beamte)
and employees of state enterprises

KMIX client specialization:
Kleinleben if firm sells a disproportionate
amount of small "Kleinleben" contracts which
are considered to cause higher cost than
other contracts, Normix otherwise

In the following we present the analysis of variance results.

Table 7: Sample Description

	Stock Companies	Mutual Companies	Public Enterprises	Total
Market Share	67.6%	23.4%	9%	100%
Number of Firms	52	36	12	100
Average Market Share per Firm	1..30%	0.65%	0.75%	

Analysis of Variance

X79 by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	3705	6	617	15.0	.001
OSHIP	488	2	244	5.9	.004
M	470	1	470	11.4	.001
A	1505	1	1505	36.6	.001
B	65	1	65	1.5	.211
KMIX	630	1	630	15.3	.001
2-Way Interactions	152	4	38	.9	.453
OSHIP A	44	1	44	1.0	.302
OSHIP B	120	2	60	1.4	.238
OSHIP KMIX	4	1	4	.1	.749
Explained	3858	10	385	9.3	.001
Residual	3619	88	41		
Total	7477	98	76		

Multiple Classification Analysis

X79 by OSHIP M, A, B, KMIX

Grand Mean = 28.92

Variable + Category	Unadjusted Deviation	ETA	Adjusted for Independents Deviation	BETA
OSHIP				
PUBLIC	- 7.8		- 5.3	
STOCK	2.3		1.7	
MUTUAL	- .7		- .7	
		.37		.26
M				
DIRECT	- 18.8		- 15.6	
AGENTS	.4		.3	
		.31		.26
A				
ESTABLISHED	- 1.5		- 1.5	
YOUNG	10.9		10.9	
		.47		.46
B				
ALL	.3		.2	
BEAMTE	- 7.6		- 4.0	
		.18		.09
KMIX				
KLEINLEBEN	5.5		6.0	
NORMIX	- 1.1		- 1.2	
		.28		.30
Multiple R Squared				.50
Multiple R				.70

Analysis of Variance

BK75/79 by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	1425	6	237	9.9	.001
OSHIP	490	2	220	9.1	.001
M	163	1	163	6.8	.011
A	15	1	15	.6	.435
B	38	1	38	1.6	.214
KMIX	472	1	472	19.6	.001
2-Way Interactions	116	4	29	1.2	.315
OSHIP A	12	1	12	.5	.481
OSHIP B	106	2	53	2.2	.116
OSHIP KMIX	0	1	0	.0	.889
Explained	1541	10	154	6.4	.001
Residual	2119	88	24		
Total	3660	98	37		

Multiple Classification Analysis

BK 75/79 by OSHIP M, A, B, KMix

Grand Mean = 15.78

Variable + Category	Unadjusted Deviation	ETA	Adjusted for Independents Deviation	BETA
OSHIP				
PUBLIC	- 6.62		- 5.52	
STOCK	1.62		1.37	
MUTUAL	- .08		- .10	
		.42		.35
M				
DIRECT	- 10.32		- 9.20	
AGENTS	.21		.19	
		.24		.22
A				
ESTABLISHED	- .16		- .15	
YOUNG	1.15		1.08	
		.07		.07
B				
ALL	.22		.13	
BEAMTE	- 5.11		- 3.06	
		.17		.10
KMIX				
KLEINLEBEN	6.01		5.21	
NORMIX	- 1.16		- 1.00	
		.43		.38
Multiple R Squared				.389
Multiple R				.624

Analysis of Variance

S79 by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	326	6	54	11.7	.001
OSHIP	62	2	31	6.6	.002
M	13	1	13	2.7	.103
A	196	1	196	42.2	.001
B	0	1	0	.0	.852
KMIX	28	1	28	6.0	.016
2-Way Interactions	64	4	16	3.4	.012
OSHIP A	44	1	44	9.5	.003
OSHIP B	9	2	4	1.0	.390
OSHIP KMIX	26	1	26	5.6	.020
Explained	390	10	39	8.4	.001
Residual	409	88	5		
Total	798	98	8		

Multiple Classification Analysis

S79 by OSHIP M, A, B, KMIX

Grand Mean = 5.26 Variable + Category	Unadjusted Deviation	ETA	Adjusted for Independents	BETA
OSHIP				
PUBLIC	- 1.96		- 1.24	
STOCK	.87		.76	
MUTUAL	- .58		- .67	
		.35		.28
M				
DIRECT	- 4.01		- 2.55	
AGENTS	.08		.05	
		.20		.13
A				
ESTABLISHED	- .54		- .54	
YOUNG	3.89		3.93	
		.51		.51
B				
ALL	.04		- .01	
BEAMTE	- .98		.20	
		.07		.01
KMIX				
KLEINLEBEN	.82		1.27	
NORMIX	- .16		- .25	
		.13		.20
Multiple R Squared				.408
Multiple R.				.639

Analysis of Variance

GR79 by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	22	6	4	5.9	.001
OSHIP	2	2	1	1.6	.203
M	0	1	0	.1	.778
A	15	1	15	24.3	.001
B	0	1	0	.3	.602
KMIX	2	1	2	3.4	.070
2-Way Interactions	3	4	1	1.3	.262
OSHIP A	0	1	0	.6	.433
OSHIP B	1	2	0	.7	.509
KMIX	2	1	2	2.5	.120
Explained	25	10	3	4.1	.001
Residual	55	89	1		
Total	81	99	1		

Multiple Classification Analysis

GR79 by OSHIP M, A, B, KMIX

Grand Mean = 6.73

Variable + Category	Unadjusted Deviation	ETA	Adjusted for Independents Deviation	BETA
OSHIP				
PUBLIC	- .30		- .39	
STOCK	.04		.07	
MUTUAL	.04		.03	
		.12		.16
M				
DIRECT	.26		.16	
AGENTS	- .01		- .00	
		.04		.03
A				
ESTABLISHED	.15		.15	
YOUNG	- 1.12		- 1.09	
		.46		.45
B				
ALL	- .01		- .01	
BRANCE	.22		.21	
		.05		.05
KMIX				
KLEINLEBEN	.33		.35	
NORMIX	- .10		- .07	
		.26		.17
Multiple R Squared				.273
Multiple R				.522

Analysis of Variance
BEGM by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	1177	6	196	.4	.873
OSHIP	405	2	202	.4	.659
M	37	1	37	.1	.782
A	661	1	661	1.4	.246
B	54	1	54	.1	.739
KMIX	6	1	6	.0	.914
2-Way Interactions	262	4	66	.1	.969
OSHIP A	73	1	73	.2	.698
OSHIP B	82	2	41	.1	.918
OSHIP KMIX	159	1	159	.3	.568
Explained	1440	10	144	.3	.980
Residual	40614	84	483		
Total	42053	94	447		

Analysis of Variance
UE79 by OSHIP M, A, B, KMIX

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	80	6	13	1.6	.171
OSHIP	15	2	8	.9	.418
M	3	1	3	.4	.545
A	44	1	44	5.1	.027
B	0	1	0	.0	.848
KMIX	12	1	12	1.5	.230
2-Way Interactions	49	4	12	1.4	.230
OSHIP A	19	1	19	2.2	.140
OSHIP B	31	2	16	1.8	.165
OSHIP KMIX	0	1	0	.0	.940
Explained	129	10	13	1.5	.152
Residual	655	77	9		
Total	784	87	9		

In this paper we interpret only the results pertaining to ownership. Whenever ownership makes a significant difference, public enterprises outperform mutual companies,[1] which in turn outperform stock companies. Take for example total cost as a fraction of premium revenues: on the average 28.9% of all premiums are eaten up by the cost of operation.[2] However, public enterprises only spend 21% of premium revenues on administration and marketing as compared to 28.2% for mutual companies and 31.2% for stock companies. There is no significant difference between the respective returns on invested capital. Now, recall that public enterprises as well as mutual companies ultimately return all profits to the insured. Consequently, consumers do better when buying from these two firm types than from stock companies. The two reported quality indicators only strengthen this conclusion. The fraction of early cancellations S79 measures the quality and the amount of information provided to the insured before purchase. If insufficient or misleading information is provided by agents, then early contract cancellation may be necessary, usually with substantial losses to the insured. Thus, the significantly higher S79 value for stock companies is an indication of bad service.[3] The complaint index shows no significant difference with respect to ownership, even though the mean complaint index BEGM of public enterprises is 1.3 as compared to 8.6

---

1) Daughters of mutual companies were classified as mutual companies even though they are set up as stock companies.

2) Those who wonder why a life insurance contact may still be a profitable investment should recall that the returns are exempted from taxation.

3) Note, the cash value of contracts with stock companies is lower than the cash value of contracts with public enterprises or mutual firms for the entire period of the contraction particular at early cancellation.

for stock companies and 6.3 for mutual companies.

With respect to other firm variables one further result deserves mentioning. Civil servants seem to have the same propensity to complain when compared to the remainder of the population. The four companies exclusively insuring civil servants do not deviate from average performance as measured by the reported indicators. In particular, the quality of service indicator, number of complaints per market share, is not significantly different for these firms.

Finally, we controlled for market share which has an insignificant impact on cost (at the 7% level of significance). Hence, economies of scale cannot be substantial over the range of observed firm sizes. All the above relationships continued to hold when market share was controlled for.

7. Conclusion

The main purpose of the government intervention in insurance markets has been to prevent bankruptcy and to establish market transparency. Bankruptcy has been prevented, but market transparency is low. Even worse, certain regulatory policies ultimately cause intransparency. Into this category falls the ex ante-ex post profit regulation in the automobile insurance market and the strangulation of price competition in the life insurance market.[1)]

The lack of market transparency reduces competitive pressure. This is why significant differences between the performance of stock companies, mutual companies and public enterprises may persist. Public enterprises and mutual companies seem to outperform stock companies. For example, public life insurance companies produce at 24% less cost than stock companies. Since they do not enjoy any tax preferences, it has been argued that their mostly regional structure may account for this cost advantage. If this were true, from a normative viewpoint all companies should stop their nationwide service and concentrate their operations regionally. If there was effective competition in this market other firms, in particular firms with expense ratios typical for the current market, would not survive.

1) Not all regulatory policies decrease market transparency. Many regulations of contractual clauses seem to be beneficial.

Acknowledgments

I am grateful for helpful comments from D. Bös, D. Farny, P. Kleindorfer, J. Müller, S. Peltzman, F. Schneider, C.C. v. Weizsäcker and from the regulation group at the Sonderforschungsbereich 21 of Bonn University.

References

FINSINGER, J., "Wettbewerb im Versicherungswesen - Die Kraftverkehrsversicherung", Wirtschaft und Wettbewerb (Journal of Competition and Trade Regulation), April 1981, pp.251-263.

FINSINGER, J. and E-J. FLÖTEMANN, "Prämien und Versicherungsleistung der HUK- und Sachversicherer in Abhängigkeit von der Rechtsform", IIM-IP, Research Report, February 1981.

JOSKOW, P.L., "Cartels, Competition and Regulation in the Property-Liability Insurance Industry", Bell Journal of Economics, Vol 4, No 2, 1973, pp.375-428.

PRÖLSS, E.R.; SCHMIDT, R. and J. SASSE, "Versicherungsaufsichtsgesetz", Kommentar, 8. Auflage, München, 1978.

SCHERER, F.M., Industrial Market Structure and Economic Performance, Chicago, 1980.

LIST OF CONTRIBUTORS

Professor David E. Bell
307 Morgan Hall
Harvard Business School
Boston, MA 02163
USA

Dr. Richard Caputo
c/o Mr. Roger Bourke
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91103
USA

Dr. Jobst Conrad
Battelle e.V.
Am Roemerhof 35
D-6000 Frankfurt 90
Federal Republic of Germany

Mr. Octavius H. Critchley
c/o Reardon-Critchley Int.
9 Sutton Lane
Hounslow
Middlesex TW3 3BB
United Kingdom

Dr. Joerg Finsinger
International Institute of
Management
Platz der Luftbruecke 1–3
D-1000 Berlin (West) 42

Dr. Baruch Fischhoff
MRC/APU
15 Chaucer Road
Cambridge CB2 2EF
United Kingdom

Dr. Patrick Humphreys
Decision Analysis Unit
Brunel Institute of Organization
and Social Science
Brunel University
Uxbridge
Middlesex
United Kingdom

Dr. H. Inhaber
Atomic Energy Commission
Ottawa
Canada

Dr. John Lathrop
Woodward-Clyde Consultants
3 Embarcadero Center, Suite 700
San Francisco, CA 94111
USA

Dr. Lester Lave
Brookings Institute
1775 Massachusetts Ave., N.W.
Washington, DC 20036
USA

Dr. Sarah Lichtenstein
Decision Research
1201 Oak Street
Eugene, OR 97401
USA

Dr. Frederich Niehaus
IAEA
VIC – P.O. Box 100
A-1400 Vienna
Austria

Dr. Harry Otway
Joint Research Centre
Commission of the European
Communities
Ispra (Varese)
Italy

Professor Howard Raiffa
Graduate School of Business
Administration
Harvard University
Soldiers Field Road
Boston, MA 02163
USA

Dr. Paul Slovic
Decision Research
1201 Oak Street
Eugene, OR 97401
USA

Dr. P.J.M. Stallen
TNO
Postbus 542
7300 AM Apeldoorn
The Netherlands

Dr. Chauncey Starr
Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304
USA

Ms. Elisabeth Swaton
IAEA
VIC – P.O. Box 100
A-1400 Vienna
Austria

Professor Richard Thaler
Cornell University
Graduate School of Business
and Public Administration
Malott Hall
Ithaca, N.Y. 14853
USA

Dr. A. Tomas
University of Nijmegen
Erasmuslaan 4
Nijmegen
The Netherlands

Professor Barry Turner
Professor of Sociology
3 Taddyforde Court
New North Road
University of Exeter
Exeter EX4 4AR
United Kingdom

Professor Ilan and Patricia Vertinsky
Faculty of Commerce
University of British Columbia
Vancouver, B.C. V6W 3S1
Canada

Dr. S.R. Watson
Emmanuel College
University of Cambridge
Cambridge
United Kingdom

Dr. Alvin Weinberg
Director, Institute for Energy
Analysis
Oak Ridge Associated Universities
P.O. Box 117
Oak Ridge, TN 37830
USA

Dr. Christopher Whipple
Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304
USA

Professor Robert Winkler
University of Indiana
Bloomington,
Indiana 47401
USA

Professor Detlof von Winterfeldt
Social Science Institute
University Park
Los Angeles, CA 90007
USA

IIASA Contributors:
Howard Kunreuther
Michael Thompson