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CONCEPTUAL TRENDS AND IMPLICATIONS FOR RISK RESEARCH

Report of the Task Force Meeting:
Risk and Policy Analysis Under
Conditions of Uncertainty
November 25–27,1985

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PREFACE

Risk has been studied at IIASA for many years. The work has been substantial, covering both technological and acceptability questions. Some of the case studies examined include:

- Nuclear accident preparedness and management
- Two blowouts in the North Sea
- Siting of liquefied energy gas facilities
- Regulating industrial risks
- Risk management of hazardous waste sites
- Transport of dangerous goods
- Insuring and managing hazardous risks

During the course of these studies, a large international network of collaborators has been built up.

In the late spring of 1985, the question arose, "What should IIASA do next in the study of risk?". At that time, the IIASA agenda was rather full, planning for a summer meeting on the role of insurance in managing risks, and preparing a final report to Transport Canada on the transport of hazardous substances. Nevertheless, it was felt appropriate to look ahead to the next generation of issues.

Our proposal to hold a Task Force Meeting in November 1985 to discuss "Risk and Policy Analysis Under Conditions of Uncertainty" proved to be a winner, certainly with respect to the several agencies (UNESCO/MAB; US EPA; Canada FEARO; Canada Health and Welfare) who cosponsored the meeting.

The IIASA research activities are undertaken within an international East-West framework and are policy-driven. The Task Force Meeting was therefore asked to identify the main risk-related policy issues that needed to be addressed in an international context, and to determine the associated long-term research needs.

Thanks to the hard-working participants and to financial support from the sponsoring agencies, the Task Force meeting lived up to expectations, providing IIASA with a very full menu indeed for future activities in the risk area. Special credit should be given here to Dr. Carol Miller, coordinator of the meeting, who prepared this report.

Currently the IIASA Directorate is seriously reconsidering the question: "What should IIASA do next in the study of risk?" The report of the Task Force Meeting will help tremendously in answering this question.

P. Kleindorfer and *R.E. Munn*

ABSTRACT

The Task Force focused on the uncertainties in decision systems for choosing or modifying technologies intended to improve human well-being. The challenge was to delineate an international research agenda to assist communities to venture into the future with greater confidence in technological innovation*.

The Task Force recommended research in three interrelated areas:

- *Protocols*. Development of procedural advice for the integrated assessment of the contribution of technologies to environmental and economic achievements, and the associated uncertainties.
- *Case Studies*. Integrated assessments involving local or regional clusters of technologies and decision-making bodies, and investigation of ecosystem effects, economic effects, and effects on human well-being, as well as the structure and performance of institutions.
- *Educational Materials*. Development of educational materials to support integrated assessments.

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*The World Bank, 1984.

> "The Bank — will not finance projects that cause severe or irreversible environmental deterioration —".

WHO. Targets for Health for All. (HFA2000)1984. Target 18. Multisectoral Policies:

> "By 1990, Member States should have multisectoral policies that effectively protect the human environment for health hazards, ensure community awareness and involvement, and effectively support international efforts to curb such hazards affecting more than one country."

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* This paper was submitted after the Task Force Meeting.

UNCERTAINTY AND INSTITUTIONAL ARRANGEMENTS

Task Force Meeting: Risk and Policy Analysis Under Conditions of Uncertainty

25–27 November, 1985

International Institute for Applied Systems Analysis

Conceptual Trends and Implications for Risk Research

1. INTRODUCTION

1.1. Purpose of the Task Force

The IIASA Task Force Meeting on Risk and Policy Analysis under Conditions of Uncertainty had as its primary objective the delineation of research opportunities in an international context. This objective was an outgrowth of the previous decade of research at IIASA on technological and environmental risks. The Task Force Meeting was planned to take stock of where IIASA had been and where it might devote its research efforts on risk issues in the future. The meeting was also directed toward determining potential areas for collaborative research among interested countries and international agencies. This introduction will concentrate primarily on IIASA's research interests, pointing out a few of the main strands of IIASA's past and present risk research.

1.2. IIASA's Contributions to Risk Research

Over the past decade IIASA has supported risk research within complementary programs in Environment and Systems and Decision Science, and now new initiatives in Technology, Economy, and Society are being developed. The Systems and Decision Sciences Program has conducted research into the basic foundations of robust mathematical and statistical methods to support decision making. In addition to quantitative methods, the research has included studies of interactive decision processes and pioneering work on the linkage between computer data manipulation systems and group procedures for soliciting the perspectives of stakeholders and structuring the problem to be addressed.

A parallel thrust has been the policy-oriented research of the Environment Program. Together, these Programs have established IIASA as a center for a growing network of scientists concerned with environmental and technological risks. A major strength of the research at IIASA has been its continuing focus on substantive problem areas with evolving and often seminal conceptual approaches. Mention of a few of the environmental projects at IIASA over the past decade will indicate the breadth of IIASA's commitment.

Oil Drilling in the North Sea: This early IIASA research project applied decision analytic tools developed at IIASA and elsewhere and served as an important introduction to the unique policy concerns created by the low probability but potentially catastrophic impact of a systems failure in large-scale technologies.

Nuclear Power: This collaborative project with the International Atomic Energy Agency on the risks from nuclear power generation gave IIASA wide recognition for its contribution to the psychological foundations of risk perception.

Liquid Energy Gas: This IIASA project on the siting of liquid natural and petroleum gas terminals in four different countries articulated the issue of disagreement among expert advisors and consultants.

Hazardous Materials: Several projects at IIASA have examined the problems of regulating both hazardous wastes and dangerous goods. These projects have explored both the environmental impacts of hazardous materials as well as appropriate institutional mechanisms for controlling the risks associated with hazardous materials.

Acid Deposition: This ongoing project has evaluated and extended descriptive models for the processes and consequences of acid deposition and the policy options for international coordination and control of the associated technologies.

Sustainable Development of the Biosphere: This collaborative project engages an international and interdisciplinary team in questions of the long-term consequences of man's use of the biosphere. This project is closely related to other past and ongoing work on climate and forestry.

Environmental Monitoring: Ongoing work at IIASA has supported diverse projects on environmental monitoring and the assessment of man—environment interactions.

1.3. Conceptual Trends in Risk Research

Risk: Constraint or Opportunity? Managers in industry, government and research are beginning to look at risk in new ways. Central to this conceptual shift is the separation of the notion of uncertainty from the judgment of the "badness" of the consequences. Both positive and negative consequences are equally subject to uncertainty. Quite apart from adverse effects, uncertainty is itself discomforting even when associated with some positive consequences. People like to know where they stand. At the same time, the willingness to take a chance and act in spite of uncertainty is inherent in the entrepreneurial spirit. This psychological tension between security and opportunity can either drive or inhibit innovation and forward progress. How people think about risk is important.

In the past, "risk" has been regarded as a negative thing, forcing a wedge between long-term social and environmental interests and the more immediate economic ones. There has even been an implicit assumption that these interests are mutually exclusive. Now, the interconnections between these interests are increasingly recognized. Most human activities have some potential for both positive and negative consequences, and uncertainty is a property of both. Uncertainty is thus neutralized. It stands as a property of the future, separate from the judgment of what is good or bad. From this perspective, uncertainty can be assessed more objectively and more positively. The challenge is to venture into the future with a clearer understanding of what the opportunities really are. Knowledge of the pitfalls is not an impediment to progress, but rather a guide to success. Recent trends in the approach to risk research will demonstrate this conceptual reversal.

The Risk Perspective. (Figure 1) IIASA's first risk research was on risk perception. Generally, it was human health and safety that was at risk. The main insight of this research was that perceptions of "risk" have several dimensions which can be factored out, and that the risk generators (natural hazards and technologies) have multiple attributes whose relative significance is variably perceived and evaluated. This was pioneering work, and gave IIASA a justified standing in the whole field. (See Annex 2 for authors and titles.)

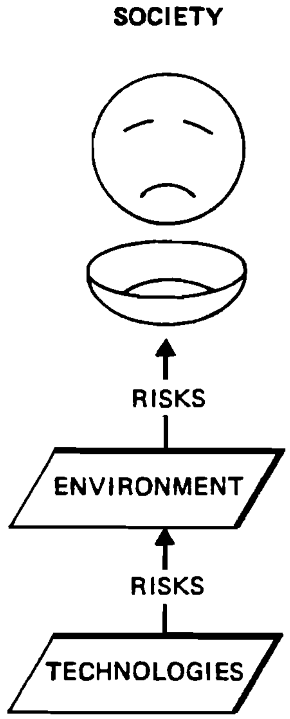

Figure 1: The "Risk" Perspective

Internationally, a significant cleavage was developing, though not really articulated, through the late 1970s and beyond. On the one hand "risk research" took RISKS as the origin, and black-boxed the technologies which are their source. As a result, some analysts tended to regard the technologies as fixed, and did not adequately consider potential technological innovations. This view isolated the negative aspects of risk from the broader context of forward progress. On the other hand, a smaller thread in the field kept trying to root risks in TECHNOLOGIES, and to analyze the attributes of the technologies which gave rise to risks and risk perceptions, rather than to analyze risks detached from their source.

The next phase of IIASA's work examined risk analysis for one general category of risk (and technology), the low probability, high consequence kind. That is, relatively compact, well-defined, single plant failures – oil well blowouts, nuclear reactor accidents, and liquid energy gas (LEG) accidents. The LEG siting study, comparing four countries, was useful mainly for its analysis of the divergence of different risk analyses commissioned by different stakeholders. Often, science was used as a means of political advocacy, rather than as an aid to policy synthesis. Disagreement among experts was by then (and remains) a central problem for policymakers.

The Environmental Perspective. Work in the environmental area also began with the evaluation of low probability systems failures, for example the collapse of a dam. However, interest quickly shifted to the risks associated with the routine operation of new technologies, especially those releasing chemicals to the environment. In the early days, pollution and its effects were immediately apparent. As each round of remedial measures was implemented, however, the residual problems became more subtle and more uncertain, involving trace contamination, long latent periods, and complex causal pathways, but nonetheless with highly significant consequences. In response to these circumstances, the quantitative estimation of probabilities began to take its place in environmental impact assessment.

However, with this insertion of concern over the probability of uncertain future events, the focus on technologies was lost. Analyses centered around a specific chemical agent and the probability of its effects on human health. This discrete part of the risk analysis field, dealing with chemical agents and health effects, became known, at least in the USA, as "risk assessment". Simultaneously, health effects began to drop out of technology-focused environmental impact assessments (EIA), and EIA became more the domain of ecologists than toxicologists. Steps are now being taken to restore the balance of ecological and health considerations, and it is hoped that the swing of the pendulum will not now impede the ecosystem approach.

Most environmental impact assessments focused on a single, new, site-specific project – the building of a factory, power plant or waste facility. This narrow focus entrenched the notion that technologies can be compartmentalized – each being treated as if the others did not exist. Now analysts are recognizing the important interconnections. For example, extensive use of fossil fuels, agricultural use of nitrogen fertilizers, climate warming, acid deposition, and stratospheric ozone depletion are all interrelated through the biogeochemical cycling of chemicals.

In response to this integrated perspective, the field is adjusting itself in two ways. Assessments such as IIASA's Doon Valley (India) project which examines man–environment interactions at a geographical location, are beginning to involve an interacting network of technologies. Also, in thinking about risk-generating systems, consideration is given not just to NEW technologies, but to the spectrum of "baseline" activities and natural phenomena as well.

This is not to suggest that the boundaries of the system can be moved out to infinity. Rather, the rationale for the inclusion/exclusion of valued attributes and the phenomena relating them has become more explicit.

This broadly based approach to the understanding of society's impact on the present and future condition of the environment has led to one more important conceptual shift. Since benefits to some people are risks to others, and improvements for one attribute (food productivity through monoculture crops) are risks for another (ecosystem resilience) we are forced to question any absolute distinction between risks and benefits. If the probability of good health is accounted as a benefit, then increased cancer risk simply lowers the probability of good health. There is no need, in fact it is downright deceiving, to engage in double accounting. There is now a (healthy) trend toward concentrating on the aggregate of incremental benefits. Assessments shed light not so much on priorities for risk reduction, but rather on priorities for positive innovation and improvement (see Figure 2).

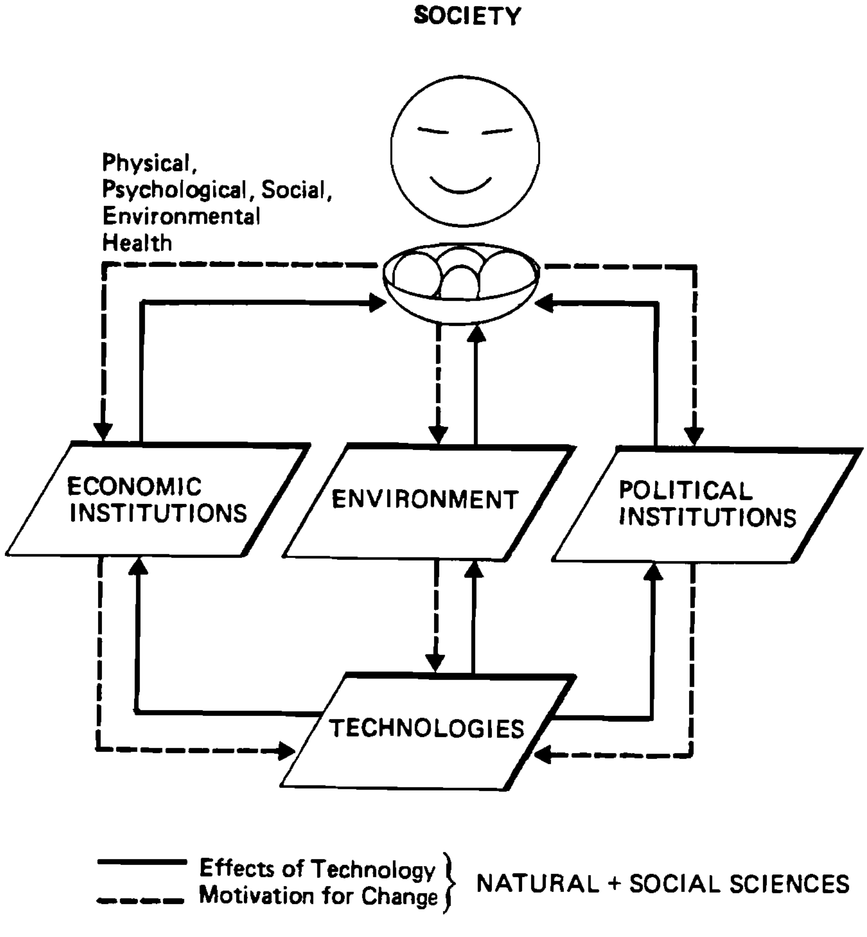

Figure 2: Integrated Risk Analysis

1.4. Implications for Risk Research

Institutional Arrangements: One important implication of this conceptual shift is that, in future, new initiatives for optimizing benefits will less frequently take the form of government interventions and will more frequently take the form of local technological innovation. The responsibility for initiating action will reside less with regulators, and more with technology managers and communities themselves. The responsibilities of the public and private sectors are shifting as are the roles of scientists and citizens. New institutional arrangements for linking responsibility and accountability will be important.

IIASA could play an important role in smoothing the way for this change. With new players and new roles there will be a need for new institutional arrangements, new avenues of communication and education, and new approaches to the effective use of both natural and social sciences in the synthesis of public policies.

Environmental Characterization of Technologies: An effort is needed to look into the chaotic phase of the many competing embryonic technologies. IIASA's new Technology, Economy, and Society Program proposes to characterize technologies in terms of the life cycle of their market penetration. It may be possible to characterize technologies not only in terms of their economic performance, but also in terms of descriptors for their environmental consequences. Already, many front-end innovation processes are being pressed to internalize downstream environmental risks as costs and reactions escalate. Thus, potential environmental consequences have a place in the characterization of technologies. This may assist preferential selection of the "winners" with respect to subsequent market penetration. In addition, the approach could be used to determine which technological adaptations the host society would specially value and welcome. However, it will be necessary to synthesize a better understanding of the uncertainties inherent in the relationship between technologies and natural phenomena.

This "hard" science cannot stand alone. Development policies must look to the shifting goals of societies, and understand the objectives that motivate change. In the risk perception area, a start has been made to identify the factors that influence the willingness of people to accept risk and to take risks. However, the interaction between social and natural scientists has not been sufficient. Toxicologists, for example, do not always address the questions of most significance to policy development. Not having made their needs clear, policymakers then become frustrated and regard science as useless. It is essential that social and natural scientists be persuaded to become collectively engaged in the elaboration of alternative development pathways.

Communication: In the selective elaboration of technological development (and in securing a legacy for the future), communication plays a strategic role. The speed and penetration of modern communication technologies has created a "New World" in which plants, factories, and firms become public territory. It is no longer possible (let alone acceptable) to conceal information about either routine operation or system failure, or to report it in an anaesthetized way. There is no private sector.

There is an urgent need for new technical and institutional structures that can cope adequately with the "New World" of communication. Nowhere is the communications issue more apparent than in the field of toxicology. For 20–30 years, industries and governments have wrestled internally with the uncertainties of evaluating the effects on human health of such essential technologies as food preservation, pest management, and pharmaceuticals. Now, in addition to these deliberate chemical applications, consideration must be given to the many inadvertent chemical intrusions into the environment. While controlled consultation with selected "publics" has been a component of past evaluations, it was generally only the overall conclusion and not the supporting rationale that reached the public at large. Rarely were the assumptions and uncertainties made explicit. Now, with the "New World" of communication, these uncertainties are bursting out, and people, having been allowed to believe that safety was absolute, feel betrayed – outraged.

The current "toxic chemical" issue may well be as much an issue of how information is communicated, both to and from the public, as an issue of health effects or technological management. In the characterization and preferential selection of new technologies, two-way communication is a strategic imperative.

1.5. IIASA's Future Role

Against this background, it seemed to be important to clarify where IIASA might best place its emphasis in the risk area, with an eye on IIASA's key position in the international research community as a nonpolitical East–West research institute with a broad basis of support in its National Member Organizations.

Today the trend is more and more toward research directed specifically at the needs of identifiable clients, and IIASA is firmly committed to this approach. Thus, one of the main purposes of this workshop has been to explore priorities that are shared between IIASA and potential sponsoring agencies or institutions. Intensive consultation with IIASA's National Member Organizations is much needed.

The handling of problems involving high degrees of risk and uncertainty seems to have been characterized in the past by a lack of communication, not only between technical experts and the decision makers they seek to advise, but also between the technical experts themselves, working too often in isolation from each other and thus failing to best use their collective expertise. If societies are to manage new technologies effectively, new decision processes and new institutional arrangements must be developed by which an integrated, systematic analysis of policy options can be carried out. IIASA provides a rare opportunity for this kind of interdisciplinary synthesis. The difficulties are serious; but the need is pressing.

Among the general areas of concern are a better understanding (by all parties) and communication of (1) the interrelationships between technologies and natural phenomena; (2) the origins of uncertainty in scientific assessments; (3) the social values and risk perceptions that motivate public policy; and (4) institutional arrangements to unite government, industry, science and citizens in a manner that links ability, responsibility and accountability. However, the political sensitivity of the issue makes it difficult for national organizations (public or private sector) to undertake this critical analysis on their own. IIASA, on the other hand, is in a good position to undertake an objective, cross-cultural analysis. The integration of disciplines, the synthesis of cultural perspectives and an objective, positive approach to uncertainty are of vital importance to the future. IIASA could contribute through the analysis of systems for the synthesis of decisions for ecologically sustainable technological development.

2. OVERVIEW OF PAPERS

This section will present a few selected themes from the presentations contributed by Task Force participants. The intention is to show how the presentations fit into the conceptual evolution described in Section 1 and direct the reader to specific papers for more detailed treatment.

The sponsors of the meeting contributed their views on the main policy issues requiring new approaches. The overview begins with highlights from this policy perspective. The scientific papers have been grouped on the basis of their dominant orientation: the scientific assessment of risk; applications to technological management; perceptions and communication; and institutional arrangements. It is recognized that most of the presentations span several of these areas. Indeed, the deliberate bridging of disciplines and traditional practices may be a major contribution of the papers, which are reproduced in their entirety following this report.

2.1. From the Sponsors: Main Policy Issues

A shift of concern from obvious detrimental pollution to the subtle human health impacts of trace amounts of toxic chemicals and the diminishing returns of future regulations are prompting a revolution in the principles guiding environmental protection decisions in the USA. In Canada, public Environmental Impact Assessment Panels are seeking guidance on risk assessment. Simultaneously, the rapid transplant of technologies into a cultural setting very different from that which spawned the technology and the associated urbanization are bringing the need for integrated risk analysis into sharp focus.

In the USA "risk assessment", the determination of the nature and magnitude of existing and reducible risks, is now the cornerstone of environmental policy. The earlier criterion of total protection with an ample margin of safety was simply not realistic. The insights of natural science are now used to find out what the problems are, and prevailing environmental, social, economic and political values are used in conjunction with legal precedent to decide what to do about those problems. The myth that science alone could provide defensible policies is being dispelled, and the rest of the components of the decision system are being slowly identified.

Analysis of both the scientific and political elements of this decision system has identified some opportunities for improvement:

1. ***Integrated assessment.*** There is a need for new methods to evaluate all of the risks at a location in an integrated way. Centralized federal decision-making cannot take into account the specific circumstances of communities. Local authorities need integrative methods to support risk management decisions under the more general umbrella of national and international guidance. Inventive, local solutions could then take into account the specific properties of the particular mix of technologies, the receiving environment and local social, economic and cultural factors. In addition, guidelines may be developed whereby regional authorities can handle different problems and clients at the same time, using a multiactor decision-making framework.

2. ***Priority Setting.*** Legitimate procedures are needed to set priorities for regulatory attention. Such procedures must accommodate explicit analysis and display inherent uncertainties. Without this, regulatory agencies are set up for failure and loss of credibility. People must be brought into the process. Rules that automatically spit out decisions are not acceptable.

3. ***Risk Assessment Rules.*** In the analysis of selected cases, to assure that factual information is not being warped and manipulated to serve particular interests, EPA endorses the use of formal, public rules that guide the conduct of scientific risk assessment. The Guidelines prepared by EPA deal with the conduct of toxicological studies of chemicals and mixtures in appropriate animal species and test systems. Flexibility and agency discretion are restricted to the political risk-management stage.

Hopefully, any scientific assessment rules will achieve a high degree of scientific consensus and be subjected to ongoing and rigorous scrutiny of their theoretical foundations, presuppositions and uncertainties.

4. ***EIA Protocols.*** There is an urgent need for risk assessment protocols to provide substantive direction to those responsible for preparing EIA guidelines and reviewing the resulting studies. In particular procedures are needed to define the risk event and the vulnerable resources more clearly at the beginning of an EIA. New procedures are needed to ensure that the analysis reflects the risks as perceived by the public.

5. ***Ecosystem Effects.*** There is a need to assess the probability of effects at the ecosystem level. How much pollution is how likely to cause how much ecological damage? The presence of traces of exotic chemicals is not necessarily harmful.

6. ***Analysis of the Total Decision System.*** The tools of systems analysis have been most extensively applied to the natural science component of public policy decision-making. As the myth of entirely science-based policies fades, it becomes increasingly urgent to explore in an equally systematic way the political elements of the decision system, the principles that drive it, the institutions that harbor it, and the mechanisms used to interpret social, economic and environmental

outcomes.

2.2. Uncertainty in the Scientific Assessment of Risk

Andrews traced the independent origins of "risk assessment" (RA) and "environmental impact assessment" (EIA). RA emerged in the scientific community in response to the need to advise regulators about uncertain health hazards, most often associated with chemical agents. EIA, on the other hand, evolved as a tool used by proponents to assess qualitatively the biogeophysical impact of technological projects. Long-term effects on human health received relatively little attention.

These two processes – risk assessment and environmental impact assessment – were built on different kinds of expertise, served different clients, and addressed different issues. Each has its advantages, and future decision strategies could constructively blend community involvement and practicality arising from the specific context of an EIA with the greater rigor and long-term foresight of RA.

In his report of a "Workshop on the Application of Risk Assessment Principles to Environmental Impact Assessment in Canada", Grima agreed that RA and EIA can be mutually supportive; the fields have much in common and have evolved to the point where their different pathways toward an appropriate mix of scientific rigor, social concern and political judgment are converging.

One beneficial effect of the application of RA concepts to EIA would be to infuse the whole process with the risk philosophy. That is, to reject the dichotomy of **safe** and **unsafe** with its implied certainties, and explicitly recognize a range of risks. While it is true that a combination of scientific and societal judgments may lead to a level of "acceptable" risk, this level is based on some range of probability and consensus and not on iron-clad certainty or universal acceptability. Grima's report discussed the implications of this risk philosophy for techniques of risk analysis, public involvement and institutional arrangements.

Suter described applications of "formal" risk assessment. Data are manipulated to provide quantitative estimates of the probability (and uncertainty) of selected outcomes. The paper contributed a useful analysis of the different origins of uncertainty, and showed that different approaches are needed to address, display and reduce each type of uncertainty.

In those situations where a mathematical model of the dynamic cause–effect relationship can be described, error analysis can be applied to express the results as probability distributions. Errors in predictions generated by models result from faults in the model structure, inaccurate estimation of the parameters, and the natural variability of the environment.

Examples of the application of quantitative RA to waste effluents, acid deposition and genetically engineered organisms were described. Results were directed toward decisions such as whether to act now or do more research; how to allocate research funds; whether to proceed further in a tiered hazard assessment; and whether a certain scenario is in compliance with regulatory standards.

Habegger contrasted three different contexts where RA may be useful. The first used relatively simple physical, chemical and biological data to provide an initial ranking of the hazards associated with chemical substances. This ranking was independent of the realities of any particular technological, environmental or social setting.

A second application was the more detailed evaluation of risks associated with a single pollutant or activity. Each such specific RA could become a component to support the third category of broader technology assessment. As an example, an analysis of energy alternatives was described as one input to decisions to continue or redirect research and development of alternative technologies.

Variations in the semantics for the sequence of steps involved in risk assessment and management as applied to the health effects of specific agents were outlined by Krewski and Birkwood. While all of the selected schemes recognized both scientific and extra-scientific components, the extent to which these do or should operate in isolation from each other was debatable.

Fowle focused on problems associated with the information base. The introduction discussed the kinds of information needed and the problems of uncertainty. As various scientific inquiries and interpretations converge, confidence in the resulting decisions increases. However, information and understanding are never complete. In many cases, the largely subjective judgment of experienced administrators and politicians plays the paramount role in decision making.

Subsequent sections of the paper dealt with the uses of information in risk analysis and management and, finally, the problems of securing adequate information. These ranged from a simple lack of information, lack of standardization, and faulty methodologies, to complex processing and transfer of information in hierarchical organizations, and failures in intersectoral and interagency communication.

It is inevitable that decisions will have to be made under uncertainty. Fowle concluded that the central problem in risk management is coping with uncertainty.

2.3. Uncertainty and Technological Management

Pegov reports* several definitions of "systems analysis". Systems analysis may be regarded as "quantitative common sense". This view is reflected in the thinking of practitioners of RA. From the operations research perspective, systems analysis is "a tool for improving an organization by marshalling its structure and function, and orienting it toward problem solving for the accomplishment of its goals at earlier dates and lower costs". This view will be familiar to those most concerned with the institutional aspects of EIA. Both of these concepts – a rational way of thinking, and organizations directed toward problem solving – are central to the analysis of man–nature interactions.

Pegov describes an approach based on the premise that ecological stability is fundamental to acceptable man–nature interactions. For each development alternative, expert judgments (combining formal and heuristic knowledge) are used to characterize the risk level (probability) of changes in environmental state and population health for selected indicator species that inhabit the area in question. These risk levels may be expressed on ordinate scales with verbal descriptions of quality easily interpreted by economists and decision makers. In this approach, "risk" (the probability of severe ecosystem damage) is used to characterize development alternatives. Social and economic properties are assessed independently prior to an overall appraisal.

Pegov's approach to the characterization of technologies looks outward to the environment for guidance. It stands in contrast to many other schemes, which focus on neither the technology nor the receiving environment, but on the

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* This paper was submitted after the Task Force Meeting.

properties of the agent mediating between them. Examples of systems that focus on the chemical intermediary include the OECD minimum premarket data (MPD) scheme; the US–EPA pre-manufacture notification (PMN) scheme; WHO's "Rapid Assessment" for air, water and land pollution, and most hazard ranking schemes.

A model system known as RAINS (Regional Acidification Information and Simulation) is being developed at IIASA to support integrated assessments of the complex problem of acid deposition in Europe. The credibility and usefulness of such models depends on sound estimates of uncertainty – the departure of model calculations from current or future "true values".

Hordijk described a step-wise approach to the evaluation of uncertainty:

1. *Inventory of Uncertainty Sources.* The purpose is to identify and classify sources of uncertainty. These include model structure, parameters and forcing functions.
2. *Screening and Ranking of Uncertainty.* The goal here is to reduce the number of sources of uncertainty that need to be quantitatively evaluated. Conventional sensitivity analysis or qualitative judgment is used.
3. *Evaluation of Uncertainty.* Depending on the source, techniques may include model comparisons, Monte Carlo analysis, matrix analysis, statistical analysis and historical data correlation.
4. *Application to Decision Making.* The model user (decision maker) assesses the outcome for various scenarios. For example, even with a constant confidence interval in forecast sulfur deposition, the importance of uncertainty varies spatially and temporally. Therefore, depending on the location of sensitive targets, expenditures to reduce uncertainty may or may not be warranted.

Pitovranov compared two approaches to the synthesis of advice with respect to the allocation of lands to specific agricultural crops. The first used complex historical climatic data to direct land allocation while the second used relatively simple measurements of springtime water storage in topsoil. In both cases data were used describing yields for specific crops in the Marx district of the Saratov Region of the USSR.

Three decision philosophies were considered: "maximin" in which the decision maker wishes to obtain the maximum benefit for the worst possible case; a less conservative philosophy which attempts to achieve the maximum benefit for average conditions; and a third strategy which attempts to minimize the maximum deviation from average. Springtime water turned out to be a better indicator of what and where to plant than the weatherman.

Kaczmarek discusses* the treatment of uncertainty in the planning and operation of water resource systems with specific reference to the Vistula and Tisza River Basins. He describes in practical terms the range of sources of uncertainty recognized earlier by Suter, and shows that dealing with individual risk estimates (probabilities) for each (or just a few) of these is not adequate to describe the higher order overall uncertainty associated with the project. This need for higher order estimates was also recognized by Clark in the context of climate warming.

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* This paper was submitted after the Task Force Meeting.

Kaczmarek reconfirms the need for an interdisciplinary approach combining the social and natural sciences. The need for better understanding of the hydrologic system is no more or less important than understanding the social and economic processes that contribute to the dynamics of demand and the synthesis of criteria to govern decisions. Kaczmarek recommends a scenario approach for the study of alternative futures, the explicit description of all sources of uncertainty, and sensitivity analysis of management alternatives.

2.4. Uncertainty, Perceptions and Communication

Renn provided a conceptual framework of the interdependencies between beliefs, concerns, values and attitudes. Perception of an object naturally includes perception of its hazardous consequences, their mental assimilation and general mechanisms to cope with uncertain situations. The separate measurement of object perception and risk perception can answer the question whether there are typical patterns in the intuitive perception of risk sources which can assist in predicting how people will react. Such insights are of prime importance in the characterization of new technologies that are likely to be economically successful and socially acceptable.

Major results of risk perception studies with immediate impact on the process of risk management and policymaking included:

- the strength of the belief that a catastrophe can happen is more important than the expected losses over time;
- risks that are perceived as dreadful, involuntary, unaccustomed and personally uncontrollable receive special attention, regardless of the probability of occurance or the expected number of victims;
- there is no universal threshold for risk acceptance – risks differ;
- judgments on risky activities depend on a whole range of interrelated factors including reference group judgments, previous loyalties, and rationalizations of unconscious feelings and social constraints that are very difficult to elucidate.

Renn concluded that both scientific risk analysis and analysis of lay perceptions are essential for the synthesis of public policies. "The values of each citizen should have the same impact on policy as those of experts or policymakers." Innovative survey methods combining attitude measurements, information and participation have to be developed to resolve the concerns that underlie the overt resistance against modern technologies that impose public risks.

Clark vividly displayed the reality of Renn's conclusions for the carbon dioxide and climate warming issue. To the extent that one believes the available risk figures, the chance that the world of 2100AD will have witnessed a major nuclear power catastrophe is probably 10 and perhaps 100 times **less** than the chance of drastic climate warming (e.g., a "Cretaceous earth" with ice-free Arctic Oceans and profound changes in agriculture). Yet, the public and political attention given to these two issues is not at all proportional to these probabilities. For the carbon dioxide greenhouse issue, the policy analysis community has, almost without exception, ignored the uncertainties and their implications.

Clark's presentation of relative probabilities in nuclear and climate warming issues became a topic of hot debate within the Task Force. Clark was accused of "taking us back to the Cretaceous era of risk analysis" by dealing only in probabilities and ignoring important perceptions of the nature of the consequences involved. Clark challenged the methodological pundits to show *how* they were going to improve the analysis by including perceptions of the relative seriousness of two conditions people cannot even imagine. The stumbling block was clearly located in the area of communication and education.

There was general agreement that closer integration of political and environmental perspectives is required. The paper provided an authoritative review of techniques used to assess and display the uncertainties of extreme events.

Lagadec's essay on strategies for communication in crisis situations showed how a slip in communication becomes a skid into a swamp. Two fundamental and profoundly wrong assumptions were identified. "The assumption that equipment and experts are infallible is the mark of a society with too many milk teeth." In response to system failure this expectation leads to reticence, silence and even relentless denial with a regularity that borders on the caricature.

Second, "the assumption that economic enterprise is private and preserved from outside interference is patently false." The formidable power of the media, ingenious lines of access to information and the lightning speed of modern communication destroy all possibility of a private sector.

Tactical materials and even fundamental strategic abilities often reveal their limitation only when an actual crisis has to be met head on. There is a need for practical drills, which test not only the competences of individual participants, but also the ability of the combined team in dealing together with delicate situations. However, such preparedness is cumbersome and, perhaps more significant, inglorious, especially if it is successful in avoiding any maelstrom of public profile.

Lagadec provided a framework for developing competence in crisis communication, and called for new initiatives in the sharing of "expert" scientific interpretations.

2.5. Uncertainty and Institutional Arrangements

Linnerooth returned to the kind of risk assessment and management models discussed by Krewski, and made the case that despite all the models in print, the process does not, in fact, take place in anything like the linear flow described. Examples were given where risk assessments, rather than becoming a part of the policy synthesis, were used to defend the positions and biases of particular stakeholders. A shift was recommended away from closed decision processes dependent on an ever-increasing demand for more and better science, to new institutional arrangements in support of open, multiparty negotiation.

Kleindorfer reported on an earlier Task Force which met in July, 1985, to set a 5 to 10 year research agenda in the area of hazardous materials management. Detailed research recommendations were developed for each of the following themes:

1. ***Problem Context.*** There is a need to increase our understanding of the problems and opportunities facing firms which manufacture products that create toxic waste, the alternatives open to transporters of hazardous materials, and the challenges facing those involved in the siting of storage and disposal facilities.

2. ***Risk Analysis.*** There is a need to document the potential benefits and inherent limitations of risk analysis, both at the assessment level and at the level of communication to different parties. In particular, we need to understand how bargaining and negotiation can facilitate the decision process.

3. Risk Management and Insurance. There is a need to understand the role that legal institutions and regulation can play in facilitating the production, transport and storage of hazardous materials. What is the appropriate role of insurance in dealing with these problems?

Krishna Murti contributed sensitive insights into the problems of the cultural transplant of technologies from industrialized countries into developing ones. First, there is a real tendency for the specific transplant of hazard-prone technologies. Further, change is very fast. None of the natural forces of moderation that governed the original evolution of the technology are operative in the new setting. On the technical side, the development has already taken place. The new community has little opportunity to adapt itself, or adjust the technology. New technologies are often greeted with fatalistic attitudes: tragedy must be both anticipated and accepted.

Sometimes, rather than an improvement in the basic quality of life, the result is a double burden. The familiar stresses of food supply, infectious disease and sanitation are compounded with threats of chronic pollution, environmental degradation, and catastrophic systems failure.

The level of public education often leads, of necessity, to "elitist" decision processes. The lack of proper attention to the cultural result of invasive technology transfer is fostered by the absence of organized pressure groups and political lobbies. Krishna Murti concluded that the need for better institutional arrangements for the pragmatic consideration of simple, local, social, economic, health and environmental factors far outweighs the need for sophisticated probabilistic analysis.

Consensus: One recommendation was uniformly endorsed by all participants from cultures as diverse as the USA, India, USSR, Canada, Poland, France and Germany. Conscientious management of technology development will require an interdisciplinary approach that unites social, political and natural science more effectively than has been the case in the past. For IIASA, a significant issue will be to find appropriate structures within its own operation to achieve this disciplinary synthesis. IIASA was designed as an integrating institution to bridge the cultures of East and West through collaborative scientific research. What institution is better suited to take up the challenge of disciplinary synthesis in risk and policy analysis?

3. RECOMMENDATIONS

The Task Force identified three approaches to improving the validity and credibility of risk and policy analysis under conditions of uncertainty:

- protocol development,
- case study analysis,
- preparation of educational materials.

3.1. Protocols

Recommendation 1: Procedural advice should be developed for the integrated assessment of the contribution of technologies to environmental and economic achievements and the associated uncertainties.

It would not be enough for experts to know how to conduct risk analyses – however perfect their expertise might become. It is essential that the expertise be transferred to those who have the opportunity to use it.

There is a pressing need for specialists and users to communicate more effectively and together develop understandable guidance on how to conduct risk and policy analyses. The various stakeholders involved in the analyses have different backgrounds, interests and roles, and the protocols should use a common language.

The protocols should capture the principles underlying key components of the risk and policy analysis process (e.g., understanding the institutional setting, structuring the issue, displaying the conclusions and uncertainties of science, and evaluating the importance of the consequences of alternative courses of action). They should provide an overview of the roles and responsibilities of participants, what the available practices and procedures are, and what pitfalls are currently recognized.

The protocols would serve several purposes: provide practical guidance to users; promote the application of systematic policy analysis techniques, and provide a framework to integrate subsequent research efforts. Users might include government officials at municipal, regional, national, and international levels and the stakeholders (including the public) that they serve.

Analytical Procedures: Fundamental to the process of risk and policy analysis is the application of a wide range of scientific expertise (natural and social) in order to understand cause and effect relationships. The list of analytical procedures in Table 1 makes no attempt to be comprehensive, but selects particularly thorny areas which the protocols could address.

The Task Force Meeting suggested areas for initial attention. The need for procedures to integrate all risks at a location arose repeatedly in several different settings. Integrative methods for the analysis of multiple risks are needed as an aid to priority setting within regulatory agencies, to planning for environmental protection in a community, and especially to strategic planning to guide urbanization in developing countries.

The Importance of Context: At the Task Force Meeting it was apparent that the limitations of risk and policy analysis did not arise solely from analytical techniques. Rather, improvements to the practice of risk and policy analysis require greater attention to the constraints imposed by the *context* in which the analysis is set. It is the context of the issue that determines the people most involved, the information available, the range of options to be considered, the analytical procedures to be used, the institutional arrangements available for decision analysis, and the cultural norms of responsible conduct.

Important dimensions of issue context include the purpose of the analysis, the institutional setting, and the scope of the issue to be analyzed. To the extent that they are known, the constraints and opportunities arising from the context in which an issue occurs should be spelled out in the protocol.

3.2. Case Studies

Recommendation 2: Comparative international case studies should be conducted involving local or regional clusters of technologies and decision-making bodies, ecosystem effects, economic effects, and effects on human well-being, as well as the structure and performance of institutions.

Comparative study of international and cross-sectoral cases provides insight into effective methodologies for risk and policy analysis based on practical experience. In the previous consideration of protocols, problems were identified arising from both the analytical techniques and the context in which they must be applied. These same concerns provide the focus for comparative case studies. Case analyses should emphasize problem structuring, the institutional setting,

Table 1. Risk and Policy Analysis: Areas for Protocol Development.

Social Sciences

- strategies for problem structuring by drawing out relevant causal events, activities, or phenomena and the full range of interests and objectives at stake;
- strategies for defining legitimate distributions of risk and benefit;
- strategies for information sharing, education, and training.
- strategies for facilitating the construction of viable compromises.

Natural Sciences

- methods to integrate all risks at a location;
- methods to monitor the environment, with emphasis on efficient and effective sampling design; with special attention to the transport and transformation of chemicals in tropical and arctic environments;
- methods to estimate ecosystem effects (indicators and criteria for assimilative capacity, instability thresholds, and recovery time);
- methods to estimate noncancer risks to health; with special attention to mechanistic models reflecting biological heterogeneity, adaptive responses, explicit presuppositions.
- methods to organize scientific expertise.

Economics

- strategies to generate incentives for voluntary, responsible stewardship;
- strategies for benefit distribution: insurance, payments in cash or kind, tax relief, community services and facilities.

Mathematics and Statistics

- study of the sources of uncertainty in cumulative, low risk scenarios;
- methods to estimate and express uncertainty;
- methods for dealing with incomplete data;
- appropriate reporting formats;
- methods for dealing with the time dimension: cumulative effects; adaptive response; economic discounting.

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monitoring systems for problem identification, priority setting and program evaluation, as well as methods for estimating and displaying uncertainty.

Several major issues (Table 2) were identified for which there has been significant experience with respect to the nature of the risk, the policy analyses conducted, the impact that the analysis did or did not have on subsequent actions, and the consequences for the human condition. This body of experience should be exploited to prepare prescriptive advice, for application in the management of new technologies (e.g., biotechnologies) or newly recognized consequences (e.g., global environmental changes).

Table 2. Issues for Retrospective and Prospective Case Study of Risk and Policy Analysis.

Retrospective

Natural Resource Management
- International Rivers
- Agriculture, Fisheries, Forestry

Acid Deposition

Urbanization

Urban Risk Management (steady state)

Hazardous Materials
- Cradle to grave management
- Transportation
- Waste Disposal Siting
- Hazardous Facility Management

Pesticides, Food Additives and Contaminants

Energy Sources

Prospective

Biotechnology

Global Environmental Change
- Climate warming
- Stratospheric ozone depletion

Trace Contamination of Drinking Water

The institutional setting of an issue significantly influences the procedures needed to support efficiency, effectiveness and equity in decision making. New insights are needed as to how to set the stage for constructive international collaboration. Processes are needed to share knowledge, perceptions, and uncertainties and ensure that participants truly represent the constituencies who will be expected to implement the agreements. Such insights could be derived from study of the histories of commissions dealing with international rivers, the history of the law of the sea, Admiralty law, and other international agreements with global influence.

A recurring theme in the Task Force discussions was the need for improved communication of science. Better approaches are needed to make both the knowledge and the uncertainty arising from scientific studies understandable to all of the people involved in the issue, as major stakeholders, authorities and citizens.

A different kind of communication challenge is apparent within the scientific community. While quantitative procedures and the formal logic of mathematics can be effectively used to manipulate and interpret complex data bases, the structuring of the problem in terms of the perceived stresses and social values at risk requires the application of social sciences. In order to pose appropriate questions, these often isolated disciplines must work together. The mathematician must provide guidance on the kind of structure and information needed for meaningful analysis. Equally, the social scientist must make the structure of the real situation and the purpose of the analysis clear to the quantitative specialist. Only then will the talents on both sides become useful in the solution of socially relevant problems.

The analysis of cases must provide insight into the principles underlying prescriptive advice. Case **descriptions** are not enough. Case comparisons should be carefully directed toward the elucidation of principles and, further, to dissemination of these principles to those who can apply them.

3.3. Educational Materials

Recommendation 3: Educational materials to support the integrated case studies should be prepared.

Educational materials are needed to familiarize those engaged in public policy decision processes (e.g., environmental risk assessment, municipal planning) with the nature of the process and their roles. Equally important is the need to motivate and inform employees involved in safety procedures, as well as the general public.

It is recommended that interactive microcomputer learning systems be prepared. Careful attention must be paid to the level and nature of understanding of the user. A range of decision models could be incorporated into the system along with the capacity for users to input their own information, or access available data bases. Users would then have the ability to ask "what if" questions, and gain valuable insights into the significance of various assumptions and uncertainties.

3.4. Conclusion

These approaches to improving the practice of risk and policy analysis – development of protocols, case studies and educational materials – are interrelated. Protocol development has been deliberately placed first in the list to emphasize the need for "best available" advice – however tentative. Policy analysts should not fall into the trap of refusing to give advice because their art is not perfect! It is through the testing of even tentative procedures that progress is made. This progress will be slow if the rationale underlying policy decisions remains covert and is not subjected to thoughtful, constructive analysis.

The variations in the scope of the cases that might be analyzed is infinite, considering combinations with respect to person, place, time, causes, effects, frequency and magnitude of risks. The Task Force recognized the need for international collaboration in the design and conduct of a program of research into risk and policy analysis. The many centers of interest and expertise need to coordinate their efforts to ensure maximum benefit from the individual contributions.

International Collaboration. The Task Force agreed that international bodies have special roles to play in helping to carry out the recommendations given above. There is clearly a need for:

- international exchange of information on current and proposed research, and the availability of expertise in risk and policy analysis. This exchange would lead to the identification of common needs for protocols, as well as shared interests in particular issues. A coordinated international program, directed toward defined achievements, is needed;
- internationally accepted protocols that capture the principles underlying key components of the consensus-building process (e.g., understanding the institutional setting, structuring the issue, and displaying the conclusions and uncertainties of science);
- collaborative investigation of cases in which those technologies common to many nations interact at a geographic location with the potential for international impact;
- preparation of educational materials to transfer the lessons learned.

In the health risk field, the recent proposal of IAEA/ILO/UNEP/WHO on "Assessing and Managing Health and Environmental Risks from Energy and Other Complex Industrial Systems" is to be commended.

With respect to risks to ecological and natural resource systems, intergovernmental bodies such as UNESCO/MAB, UNEP and WMO have important roles.

Amongst nongovernmental organizations, IIASA should be especially mentioned for the following reasons:

- IIASA has long been involved in risk research;
- IIASA is nongovernmental and nonpolitical; it is supported by 16 countries, and thus has a large number of national organizations to turn to when networking seems appropriate;
- IIASA is particularly effective in contributing to the East–West dialogue, because of its member organizations;
- IIASA provides a place where research scientists from different countries and different disciplines can join together for sustained periods of time to work on common problems.

Overall the Task Force Meeting provided lively debate and a constructive synthesis of perspectives. The task now is to find the intersection between the priorities of nations and international agencies, and the international research capacity in terms of both money and expertise.

National Member Organizations, Research Agencies and Industrial Organizations are invited to express their interests in participating in such projects through the contribution of expertise, collaborative research or project funding.

Increased public confidence in the security of the future is a worthy goal and a major challenge. The Task Force Meeting indicated that IIASA could play a significant role in the strategic analysis of technological change.

SUMMARY

Background

The Task Force focused on the uncertainties in decision systems for choosing technologies intended to improve human well-being. The challenge was to delineate an international research agenda to assist communities to venture into the future with greater confidence in technological innovation.

A holistic model of decision systems for choosing technologies was inherent in the Task Force discussions. In this model the effects of technologies were seen as mediated by (1) the biogeochemical environment; (2) the economy; and (3) the political institutions of the community in question (Figure 2). Understanding the impacts of technology on society requires consideration of the structures and forces operating in each of these three subsystems. The resulting knowledge and perceptions about the well-being of man and the environment are then processed back through scientific institutions, economic institutions, and political institutions. The products of this information processing become the forces that motivate the selection of new or modified technologies. Clearly the three lines of reasoning are not in fact so simple, and many interactions occur.

Among these contributing elements, only the biogeophysical environment and the tangible effects mediated by it are subject to the immutable laws of nature. All the rest are products of man's ingenuity, and are subject to human intervention. It seemed reasonable, then, to concentrate on understanding those natural structures and forces that we must learn to live with, in conjunction with opportunities for directed change in the man–made elements.

Issues

The Task Force identified a set of issues – points of debate, controversy and uncertainty – in this decision system. In each case the need for *integrated* procedures was at the root of the problem.

RA and EIA. Risk Assessment (RA) has dealt with the probability and effects of a chemical, physical or biological agent or process, usually on the physical health of man. Environmental impact assessment (EIA) has looked at the probability and effects of proposed new technologies or projects, usually on the biogeochemical environment. There have been too many battles over who owns the turf at the interface. There is a need to develop integrated procedural advice ("protocols") combining RA and EIA.

Integrated Geographic Assessment. In the past, assessments have focused on a single technology or development project. However, the effects of technologies are not independent. Procedures for the integrated assessment of all technologies at a location are needed. Opportunity for a first level of integration is provided by study of the technology–environment interaction (EIA), since all technologies act on the same environment. A higher order of integration may be achieved by considering the ultimate effects on human well-being, where not only the effects mediated by the environment, but also effects mediated by economic and political structures come into play.

Priority Setting and Risks Without Precedent. The scope and scale of modern technology are creating risks for which there are no precedents. Society has not had (and hopefully never will have) experience of a Nuclear Winter. While geological history records wide shifts in climate, changes as great as those which appear possible due to anthropogenic greenhouse gases have not been experienced within the history of civilization. Therefore, society has no precedent for judging the importance of such events relative to competing demands for research and policy development. Priority setting will require not only new approaches for the integrated assessment of relatively familiar risks, but also methods for dealing with entirely new kinds of risk.

Ecosystem Effects. It is not realistic to consider effects on components of the environment in isolation, since, again, the components interact. Indicators to characterize the impact of technologies on important properties of ecosystems need to be applied and validated.

Health Risk Assessment. RA is generally based on estimates of exposure, the physicochemical properties of the agent, and laboratory tests in selected species, supported by any available epidemiological evidence. RA has become a cornerstone of environmental policy, and certain RA methodologies are becoming fixed in law. However, analysis of the presuppositions underlying current methodologies reveals some highly debatable assumptions. Examples include the assumption that not only individuals but also species are identical, and that organisms including man cannot adapt to low level stress.

Further, studies of the factors that most influence the willingness to take risks indicate that things like opportunity for personal intervention and the dreadedness of the outcome are more important to decision making than the probability of occurrence of the event. Yet, many toxicological evaluations focus more on tenuous quantitative measures of probability (dose–response in test animals) than on these other factors. There is a need to develop alternative toxicological models based on more relevant assumptions and to use more of the available insights into the causal chain of events linking technologies and human health.

Objectives of Technological Development. The success of technological development can only be evaluated (and appreciated) if the objectives are understood (and accepted). There is a general consensus that the long-term integrity of the environment and the physical, psychological and social well-being of people, are "good" things. However, methods need to be developed for displaying, even qualitatively, the probabilities and degrees of achievement within each of these general areas. Rarely are the objectives sufficiently clear even to allow constructive debate.

Societal goals change and normative solutions to risk management may be dangerous. Dynamic ways to identify the objectives "at risk" for each group of people and then to evaluate and compare achievements are urgently needed. Further, rather than attempting to assign shadow prices to human values, it would allow a more fundamental level of understanding to search for ways to express economic values in human terms.

Equity and Discounting. The effects (positive and negative) of technological development do not distribute themselves uniformly across society. A major challenge to economic and political institutions is to seek better methods for equitable distribution, and to accommodate long time scales.

Communication and Institutional Arrangements. Four broad classes of institutions are identified in Figure 2: technological (e.g., firms, multinationals); economics (e.g., banks, insurance companies, stock markets); scientific (e.g., professional societies, research institutions), and political (e.g., governments, communication media, interest groups). Each of these exists on international, national and a range of subnational levels. Each has information processing and communication (receiving and sending) roles. Each contributes to the motivation of technological development. Integration of these motivating forces *does* occur, and new or improved technologies *are* chosen, one way or another. However, confidence in the choices would be strengthened if the contributions of major institutions and the mechanisms of integration could be made more explicit.

The Task Force recognized the dynamic state of institutional roles. Multinational corporations seem to have increasing control over technology development relative to national governments. In the scientific community, national institutions are deferring to international organizations (UNEP, ICSU, SCOPE, OECD, etc.) for standards and guidelines. On the other hand, responsibility for the choice of specific interventions may be shifting from the national to the local arena, to facilitate inventiveness based on knowledge of the specific mix of technologies in specific environmental and cultural settings. National governments seem to be left more and more with the responsibility for softening the impact of change and achieving some degree of equity. With such a dynamic decision system it is increasingly important to explore and make explicit the roles of the various institutions and to seek new ways to link responsibility and accountability.

Recommendations

The Task Force recommended three interrelated approaches to addressing these issues:

- *Protocols.* Development of procedural advice for the integrated assessment of the contribution of technologies to environmental and economic achievements, and associated uncertainties.
- *Case Studies.* Integrated assessments involving local or regional clusters of technologies and decision-making bodies, and investigation of ecosystem effects, economic effects, and effects on human well-being, as well as the structure and performance of institutions.
- *Educational Materials.* Development of educational materials to support integrated assessment.

This comparative analysis of cases would serve both corporate and public clients. Industrial corporations would gain insights into the potential outcomes of development scenarios, drawing on international scientific expertise. Such insights would complement their own perspective of development priorities. Public authorities would receive insights into how best to influence the directions and outcomes of technology development. Comparison of similar geographic and technological scenarios in different cultural settings in East and West would assist in the transfer of insights gained from specific cases to strategic planning more generally.

By undertaking such studies, IIASA would provide a forum for the *integration* that was identified as the crucial gap underlying current issues in risk and policy analysis.

ANNEX 1

LIST OF PARTICIPANTS

Task Force Meeting on
RISK AND POLICY ANALYSIS UNDER CONDITIONS OF UNCERTAINTY

November 25–27, 1985 IIASA, Laxenburg

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ANNEX 2

IIASA PUBLICATIONS IN RISK RESEARCH

IIASA PUBLICATIONS IN RISK RESEARCH

The Economics of Risks to Life. *W.B. Arthur*, RR-79-16, IIASA, Laxenburg, Austria.

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Considerations on the Large Scale Deployment of Nuclear Fuel Cycles. *R. Avenhaus, W. Haefele, P.E. McGrath*, RR-75-36, IIASA, Laxenburg, Austria.

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The Prediction of Voting Behaviour in a Nuclear Energy Referendum. *C.H. Bowman, M. Fishbein, H.J. Otway, K. Thomas*, RM-78-8, IIASA, Laxenburg, Austria.

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ANNEX 3

RESOLUTION OF THE IIASA COUNCIL

PAPERS PRESENTED

Task Force Meeting: Risk and Policy Analysis Under Conditions of Uncertainty

International Institute for Applied Systems Analysis
25–27 November, 1985

The policy perspectives and scientific papers presented at the Task Force Meeting are reproduced here in their entirety.

Resolution of the IIASA Council (13 June 1986): IIASA Task Force on Technological Risks

IIASA/COUN-XXVI/Reslu 178

13 June, 1986

Whereas IIASA has since its inception compiled an internationally recognized research record of high quality in the fields of risk analysis, risk management, risk perception, and the management of technological emergencies,

whereas IIASA has cooperated closely with the IAEA in earlier years along such lines,

whereas IIASA has a well-established series of accomplishments in stochastic analysis and probability theory, and addresing issues of hypotheticality,

whereas IIASA also conducts substantial international programs on the environment and population analysis,

whereas there exists a very valuable resource in the international networks of IIASA alumni and the Institute's former and current collaborators in the above research fields,

whereas recent accidents in the technological domain have prompted statements from many national leaders seeking better ways to handle international issues of safety, risk, health, standards, monitoring, information exchange, emergency crises management, and public understanding,

whereas it is a prime objective of IIASA to seek to improve "methods of investigation and analysis ... to make them more adequate to predict, evaluate and manage the social and other repercusions of scientific and technological development" (IIASA Charter),

whereas IIASA as a nongovernmental international institution would bring, by providing a comprehensive approach, particular advantages to a joint involvement with organizations such as the IAEA, WHO and/or UNEP, which have a direct, immediate interest in the above mentioned accidents,

the Council therefore moves

1. to create a task force consisting of a standing group at the Institute and scientists in the NMO countries that are able and willing to actively contribute to the work of that task force;

2. to ask that task force to consider

   - the international management of perceived risks
   - the societal issues in perceiving technology risks including the notion of probability
   - the design of an international monitoring and warning system;

3. to approach the IAEA and to look for ways and means to associate the activities of IIASA as closely as possible to that Agency, in particular by considering the institutional mechanism that would result in international reactor safety measures and standards;

4. to invite the NMOs for further specific suggestions of the role the Institute might play;

5. to ask the Director of IIASA to propose to the Council a scheme for implementing the above ideas including the aspect of financing.

RISK ASSESSMENT AND RISK MANAGEMENT: TOOLS FOR ENVIRONMENTAL POLICY ANALYSIS

Dan Beardsley
Director, Regulatory Integration Division
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Since the U.S. Environmental Protection Agency was founded in 1970, much has changed in how we view the use of science in making environmental protection decisions. That we are here in Vienna to discuss managing risk rather than eliminating it underlines the movement toward a scientific way of thinking -- and greater realism about the absurdity of the notion that we could or should eliminate risk in industrial and technological society.

Much has changed in the way EPA approaches problems because, in part, the problems themselves have changed. Fifteen years ago, we in America were concerned with obvious problems in the environment: we were looking at dead fish, closed beaches, dying lakes and fire in our rivers with smog-born tears in our eyes. Early solutions to pollution were to establish rigid safety standards and impose mechanical and technological fixes -- and to a large extent, they worked. Because of these quick, enforceable controls we could, by the mid-70's, begin to see again the streetlamps of Pittsburgh, and fish were returning to rivers we had believed to be hopelessly fouled.

But the focus of our environmental policy has now shifted to subtler hazards to health and our biosphere. By 1980, refined measurement technology showed that air and water that seemed pure 10 years ago were in fact harboring toxics. Dramatic early victories against obvious pollution targets have given way to a campaign of attrition against literally thousands of potential enemies to human health.

We are also becoming more conscious of what the economists call the "knee" of the cost-effectiveness curve. Ten years ago, the job seemed easy: huge pollution reductions could be achieved for relatively little cost. Now, however, the costs are potentially much more painful to us, and the environmental benefits much more difficult to demonstrate.

These two considerations -- a shift of concern to the subtle human health impacts of toxics pollution and the potentially diminishing returns, in economic terms, of future regulation -- are prompting an intellectual revolution in what should be the proper basis for making environmental protection decisions.

"Risk" is the key concept in what has occurred. In the early years of EPA, we were concerned with "safety", which was usually defined as total protection. The Clean Air Act demands that we set standards that will protect public health with "an ample margin of safety." Risk is not mentioned. What focused public attention wonderfully were hazards flowing from two carcinogenic substances ubiquitous in the American environment -- PCBs and asbestos; a realization that exposure to a very large number of unfamiliar, largely untested chemicals was widespread; laboratory and studies that associated certain widespread pollutants with cancer; and finally, the consuming public issue of abandoned toxic-chemical dumps. All these events created a notable shift in the way EPA approaches its mission.

First, subtler problems have changed the way in which science is applied to practical questions of protection and environmental regulations. Second, it has raised difficult questions of how to manage chronic risks within the context of democratic institutions. These developments urged us to adopt a new approach to assessing and managing risk.

Major impetus for EPA in this came from a 1983 report by the National Academy of Sciences, <u>Risk Assessment in the Federal Government</u>. The report made a critical distinction between <u>risk assessment</u> and risk management, insisting that the two activities should be insulated from each other in agency decision-making. Scientists assess a risk to find what the problems are -- using information about likely human exposure and generating, through plausible assumptions, an estimate of human health risk. The process of deciding what to do about those problems is <u>risk management</u>. Ideally, the action decided upon is based on factors such as the goals of health and environmental protection, relevant legislation, legal precedent and prevailing social, economic and political values.

Risk assessment -- the determination of the nature and magnitude of existing and reducible risks -- is the cornerstone of accomplishing our mission. Our decisions, the result of our risk management process, flow from the information about risk reduction potential and all of the other things which we must take into account. Risk assessment is the basis from which our priorities, our choices as to what risks to attack first, flow. It is also the basis for determining how strictly pollutants should be controlled to provide for the total welfare of the people we serve. Yet, we are constrained in our use of risk management and risk assessment for these purposes in a number of ways.

In performing our risk-reduction mission EPA acts under nine principal, and various other, minor statutes. They help define how risk assessments can be used in decision making. These statutes were passed by Congress at different times, under different circumstances, with different motivations, and with different ends in view. Some of those statutes are risk-balancing statutes, such as the Toxic Substances Control Act and FIFRA -- the act under which we regulate pesticides. These Acts specifically tell us to take into account the broad costs and benefits of regulating toxics and pesticides and come up with a reasoned decision that will protect the American public appropriately.

On their face, however, other statutes give us little opportunity for risk-balancing in the decisions we make, and relatively less flexibility in making reasoned judgments based on risk assessments. For example, the Clean Air Act tells us to set standards for emission of hazardous air pollutants to provide

"... an ample margin of safety to protect the public health ..." Consider the implications. There are emissions of products that have been judged to be carcinogenic and the science says that we must conclude there are no thresholds. Thus, on its face, the statute suggests zero emissions be allowed for these substances.

I believe that as public servants we need constraints. The law should not simply say "do good." But, we also need flexibility if we are to use EPA's and society's limited resources for maximum environmental results. The law recognizes that need for flexibility when it gives us the responsibility to administer the laws -- to decide how they are to be applied and implemented. For example, under the Clean Air Act as noted above, our choice is either to interpret the law as not saying zero emissions, or else to deny use of certain products, some of which are effectively essential to a modern economy, because zero emissions in their output is impossible. We conclude that the latter is not intended. Congress also implicitly recognizes the need for flexibility when it establishes our budget: it is impossible for us to do everything with a limited sum of money. So, one of our major tasks under these laws is to set some priorities and determine which things we're going to do first.

Implicitly there is flexibility. But there is also a mood in the Congress to restrict that flexibility, sometimes with deleterious consequences to health and the environment. Here is one example. In our statutes, we face well over 400 specific statutory deadlines, written into separate statutes by separate committees, at different times, which precluded joint consideration of the effects of the total set of deadlines on the Agency's workload. Everything is important, but in the nature of things, Congress cannot meaningfully decide which things are more important. The consequence is that we are told to do everything, now. We can't meet a large proportion of these directives on time. The problem is not that we are inactive or not trying. In some cases it isn't a matter of resources either; in some situations it simply takes more time than is available to do the science, write the regulations, and fulfill the requirements of the Administrative Procedures Act (and of good government) in getting comments and information from knowledgeable and affected parties. As a result, we find ourselves frequently in violation of these statutory deadlines.

What does this mean in terms of our mission? One thing it means is that we are mostly working on someone else's agenda, since every time one of these deadlines is missed we are technically violating the statute. Anybody who wants to sue us can, and any judge can find for that plaintiff and set us on a court-ordered schedule, enforceable with contempt sanctions. So, at any given time, we find ourselves directing our resources to the most Draconian court-ordered deadline that happens to come next.

That is all right if meeting the next court-ordered deadline happens to make a major contribution to reducing risks. Sometimes that is the case. But often it is not, for an understandable reason. The suits are brought by people acting with a specific environmental media agenda, which does not take into account the alternative risks that we could be reducing if we were acting on some other issue rather than that one. Thus a skein of impossible deadlines sets us up for failure and loss of credibility, and causes us to be untrue to our ultimate mission to protect the American people to the maximum extent we can.

There is another constraint on our use of risk assessment to inform our risk reduction mission -- the public -- which also, again properly, helps to set our agenda. When the public worries, it is our responsibility to worry. This is clearly true because in a democratic society we are the creatures of the people. In a deeper sense, too, removing anxiety is also a public health good. We must be mindful of the need to address the specific fears people have about the food they eat, the water they drink or the air they breathe. We would not succeed in our broader public health mission if we simply used risk assessments to rank risks and then in some mechanistic, calculating way sought to maximize changes in the mortality and morbidity tables for the American people.

Instead, we must welcome and facilitate the participation of the public in our decision processes, not only in choosing our priorities but also in determining the nature and strictness of the controls we put in place. In contrast to the risk assessments, risk management decisions are value-laden choices about which everyone has the right to an opinion. This means bringing people into the process -- politics, with the small "p."

In order to facilitate participation, we try to let people know -- in quantitative terms to the extent that we can, in non-quantitative terms when that's impossible -- what the scientific bases of our decisions are. We also seek to expose the implications of these decisions in terms of economic, social and other impacts. In doing so, we open the decision-making process so that people can see both the values and the science that go into our decisions. Then they can judge -- and influence -- those decisions, and possibly conclude that their statutory predicates should be changed.

Another constraint on use of risk assessments to drive decisions is that the scientific basis for estimating risks is incomplete and uncertain. The hazard of some chemicals is poorly defined, and the dose-response relationship for most substances is subject to substantial uncertainty because of the necessary extrapolation from high to low doses and from animals to man. Perhaps even more subject to error is the exposure assessments that trace emissions through the routes by which they reach man and the environment. Research is continuously improving the quality of the estimates, but uncertainty will always be present. This does not mean that risk assessments can not provide the basic information on which decisions can be made; comparative estimates of risk, based on consistent application of risk assessment principles, are particularly helpful. It does mean, however, that risk assessments provide the anchor for decisions, not a set of numbers that will automatically spit out a decision. Judgment is always necessary.

An example of this can be found in our recent decision regarding ethylene dibromide or EDB. For some time we had been examining the potential health effects from fumigants and other pesticides, including EDB, used to protect food supplies from destruction in the field and deterioration in storage. In the fall of 1983 EPA suspended the use of EDB as a soil fumigant because groundwater monitoring data showed contamination. Based on what was known then, we also put in motion a process to cancel the grain and fruit fumigant uses of EDB that most likely would have resulted in elimination of its use in 1986. Despite its health risks, we did not suspend its grain and fruit fumigant use immediately. One factor that went into this decision was the possible health effects of substitutes about which relatively little was known, though studies were underway.

Subsequently, more information about EDB exposures came to light. Specifically, food residues of EDB were found which, while substantially smaller than we had estimated in our conservative exposure assessment, were also more widely found in grain and fruit products than expected.

Of ultimately greater significance, EDB became a matter of intense public anxiety, leading to demands for Federal action and to local and state initiatives. State after state began adopting "nondetect" levels, or one part per billion levels, for food supplies. Not only did the prospect of different standards in different areas create the potential for serious disruption of food distribution, but standards at these levels created the potential for destruction or diversion of as much as a quarter of our raw and intermediate grain products -- without anything near commensurate benefits in terms of public health gains. Under those circumstances we would have been derelict if we had said, "we do not know enough to act, because we have insufficient information to know whether, considering substitutes and food loss, removing EDB will do more harm than good." Although there were great uncertainties about the risk of the leading substitute, methyl bromide, informed opinion held that it was probably not more potent than EDB and would almost certainly leave fewer residues. As a public health (in the broadest sense) agency, we were forced to act.

What we did was to immediately suspend almost all uses of EDB so that it would ultimately be removed from the food chain. Further, we established "levels of concern" for EDB such that people could know what food was "acceptable" and what should be destroyed. And, working with sister Federal agencies, the states, and the food industry, we established an inspection system to get contaminated food off the market. The result was a diminution of public concern, a reduction of one risk from our food supply, and an orderly response that prevented the losses to welfare (from diminished diet, price increases and income loss) that would have resulted had massive amounts of food been destroyed.

Now if we are going to be basing decisions, to at least some extent, on risk calculations, it becomes essential to reach an internal consensus on what the risks posed by particular chemicals actually are. As I noted, this is hard to do within the normal rules of science. But if we can't achieve certainty in scientific findings, we can achieve consistency in the way science is used. If we cannot have perfect certitude, we can at least apply science in the same fashion in different risk assessments. This not only builds a set of precedents to guide future agency activities, but also serves to assure the public that risk assessment is not being warped by policy considerations that properly belong in the realm of risk management. To these ends, we are formulating official EPA guidelines for assessing risks to human health in five major areas of risk assessment: cancer, reproductive risk, mutagenicity, complex chemical mixtures, and exposure assessment.

The Guidelines are formal, public rules that guide the necessary issues and assumptions to be examined in each case, reducing the possibility of manipulating findings. Explicit, open codification discloses to the scientific community and the public, too, what is going on. It also offers the hopeful --

if distant possibility -- that one day all the government's protective agencies might speak with one consistent voice when they address risks, so that the public can at least make a sound comparison of the management decisions of various agencies. It may not be too much to hope that, in the future, these measures to achieve consistency in using science may also help our countries to approach international consistency in assessing the environmental problems that spill across our boundaries. The unity of nature, demonstrated once again by its contempt for nationalisms, may urge us toward treating our environmental interdependence as carefully as we treat our economic interdependence.

EPA has also set up a Forum on Risk Assessment that includes our most senior scientists. Meeting regularly to discuss assessments in progress, the Forum identifies areas where we need new guidance as well as discussing new developments in toxicology and other disciplines.

Another essential part of the risk management approach is bringing in the public. I've suggested how clear guidelines for how we make assessments, clearly disclosed, is one part of this. Burying estimates within some procedural framework or abstract scoring system is no solution. Further, effective risk management depends in the end on many hundreds, if not thousands, of people co-operating; early knowledge encourages psychic investment in finding solutions that work. Also, in the atmosphere of mistrust that has characterized relations between the U.S. public and its government since Vietnam and Watergate, it is vital to be forthcoming with all the information involved in decisions. Without advance information, the public also fails to understand genuine risks; then, as Senator Moynihan of New York has written, "When things don't work out as promised it is all too easy to suspect that someone intended they should not."

So we at EPA are more active in public education and information than we used to be. Bringing policy to the people also involves us in stressing the local aspect of problems -- indeed, this is scientifically sound in view of the eccentric distribution of many pollutants, and the multiple risks to which some communities, and even special sections within those communities, are exposed.

Local emphasis is an inevitable part of our program of risk assessment and risk management for other very good reasons. Everyone is in favor of safe disposal, but not in their backyards, so many debates about appropriate risk management end up in the high school auditorium. A system of cooperative state-local-federal action based on local risk management decisions under the umbrella of consistent federal guidelines, may characterize the most effective control programs. Many local communities actually contribute inventive answers and help find solutions that people can live with, too.

A typical example of the localization of risk is where an industrial plant imposes some local risks despite the installation of advanced pollution controls. Local economic interests then confront local health interests in reducing risk. A paradigm of such a case was the situation in Tacoma, Washington, where until recently a copper smelter processed arsenic-rich ore and released quantities of this suspected carcinogen to the ambient air. Even after the plant was heavily controlled, it appeared impossible to eliminate the carcinogenic risk from this release, that is, eliminating the risk meant eliminating the plant. EPA's Administrator believed EPA had a responsibility to explain to the people who would be most directly affected by the decision what we knew about the risks from the smelter. True public involvement meant forcing the public to confront the trade-offs involved in this risk management decision. When we began to examine the Tacoma situation in detail, we discovered that most of the local people were willing to view the problem in terms of a risk management choice, although their positions on the arsenic risk depended, understandably, on where they lived in relation to the distribution pattern of the emissions, and on whether they had a personal economic stake in the plant remaining open. As the public discussions continued and we refined our data on both the risk and the means of reducing it the citizens of Tacoma began to come up with helpful ideas about how we could minimize the acutal impact of the arsenic emissions and keep the smelter open.

Although the plant's owners eventually decided to close it (for reasons not directly connected with the pollution issue) we learned something valuable from the experience. Despite initial fears, it is possible for people subject to toxic risk to think rationally about it. It is possible for them to confront the hard truth that solutions to such problems necessarily involve an uneven distribution of risks and benefits. This rational thinking involves plunging into the uncertainties involved in the analyzes we use to define the issues. How sure are we about exposure? How sure are we about the effect of the substance? How certain are the economic impacts? It requires a kind of democratic citizenship that is willing to dig deeper than the glib headlines and the usual invitations to panic. It also requires much more from the regulatory agency providing the facts: a willingness to explain, an ability to communicate, and, most of all, it requires the agency to admit the uncertainties buried in its calculations. Only then can the appropriate balancing decisions take place. Our environmental laws recognize that there is a perpetual tension between the need for nationwide uniformity and the necessity for local variations, particularly in a nation as large and as diverse at the United States. Risk management is really a new way of working within this tradition.

One way in which we at EPA "get down to cases" at the local level is through a successful workshop we have taken on the road across the United States. In it, a risk assessment game is played by legislators, citizens, members of the press -- a genuine, factual risk assessment/risk management situation of the kind we face is resolved by group decision at the end of the day. Everyone comes away from the exercise more conscious of the uncertainty, delicacy, and trade-offs inherent in any environmental decision.

In sum then, we are starting to see a new kind of environmental protection taking shape, forced on us by the existence of exotic toxics, and made possible by our growing ability to handle complex messes of data. In this new situation we will first continue to stress the fundamental science that can refine our risk assessments, clarifying risks and their dimensions. Second, we will do better at considering the effects of our actions across the environmental media, so we don't just shuttle pollutants around the environment, perhaps reducing one risk while perversely imposing another risk elsewhere.

Third, instead of galloping after any and all risks, we'll attempt to pick our targets, aiming to cut the largest risks first. Practically, this will mean less focus on extremely trivial risks, often from industrial point sources, and greater attention to area sources of air and water pollution, as well as to regions where multiple risks aggravate the impacts of toxics.

Fourth, our attention will broaden. Moving beyond assessing cancer risks, which have dominated our recent actions, we're going to attack reproductive, systemic and other health hazards. Fifth, maintaining our concern with ecological damage to the natural systems that sustain our lives and our landscape, we need more clearly to quantify and place values upon the ecological impacts that we can show. How much pollution insult causes how much ecological damage? Because we are more than a public health agency, we'll continue to make the natural environment a major part of our mission.

In its broadest sense, environmental protection means looking at <u>all</u> effects of pollution and toxics from the perspective of balancing some definable improvement against our always finite resources -- whether in dollar costs or public policy attention. The early EPA fought a conventional war where heavy equipment rolled out and vanquished very visible, entrenched foes. Now we face, in a military analogy that's hard to avoid, a situation more nearly resembling guerrilla warfare, with many of the tactical and psychological problems that make such fighting a nightmare. Targets are elusive, and no traditional weapon seems to work very well. Commanding generals and the public often bitterly disagree about how to proceed. The population is not only terrified about its own safety -- it's deeply divided about appropriate means and ends.

We hope that wisely deploying risk assessment and risk management will at least bringus to the negotiating table to minimize the harm done by this long-term conflict. Just as all of us hope for an overarching peace agreement that might limit the spread of real military conflicts in the years ahead, so we may be permitted to hope for not only national, but international, progress in finding the most effective ways to assess and manage the environmental risks that threaten all our countries.

Some years ago, when pollution control seemed an overwhelming task, Rene Dubos said that the way to cope with such massive problems was to "think globally and act locally." To me, it still seems excellent advice about managing technological risks in democratic societies.

Risk in EIA: The Perspective of the Canadian Federal Environmental Assessment Review Office

presentation by
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at the
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Analysis Under Conditions of Uncertainty

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Introduction

The Federal Environmental Assessment and Review Process (EARP) in Canada is now over 12 years old. In the early days of its implementation the concept and application of risk were not explicitly included in environmental impact assessment. Since about 1978, however, risk analysis has been included in EIA guidelines for certain classes of projects, particularly frontier oil and gas exploration, LNG developments and nuclear power plants.

The Federal Environmental Assessment Review Office (FEARO), the agency administering EARP, now has a number of years experience with risk assessment and has identified some main issues and problems in its application in EIA. This experience is particularly relevant to the objectives of this workshop since it reflects the perspective of an agency in "the front lines" of environmental assessment and management.

Although EARP also includes screening of smaller projects for potential environmental effects, this presentation focusses on the use of risk in environmental assessments of major projects and the difficulties encountered by the independent panels established to conduct public reviews of such undertakings.

The Qualitative Aspects of Risk

In most of the Environmental Impact Statements (EIS) reviewed under EARP which have included a risk analysis, there has been confusion over the exact nature of the event at issue.

For example, in the EIS for the offshore oil and gas development in the Beaufort Sea in northern Canada (Dome Petroleum Lttd., *et al*., 1982), the "event," at various times during the hearings, was interpreted to be:

a) a blowout

b) a "major" blowout

c) a blowout involving oil

d) a blowout releasing more than 5,000 barrels of oil

e) a release of more than 5,000 barrels of oil near the end of the open-water drilling season.

Of course, there was a wide range in probabilities associated with each of these interpretations. There was so much professional disagreement that eventually the review panel had to ask the experts with government and the proponent to join forces and produce a report summarizeing the basic risk issues involved including areas of agreement and disagreement.

The problem may be further confounded when there is no agreement on the *resources* at risk. For example, guidelines may call for a risk analysis on the effects of an oil blowout on marine organisms. If it subsequently becomes apparent, as it did in the Beaufort Sea case, that marine mammals are the most vulnerable, the analysis may be deficient due to a lack of consideration of the avoidance behavior of the species involved and the time during which they frequent the development area.

This question of more tightly defining risk poses two major problems in an EIA. First, it is difficult to determine the events which have the greatest potential for environmental damage until the full range of activities has been reviewed, i.e., the EIS has been completed. Second, the more precisely the event of concern is defined, the less likelihood of data from previous experience being available for analysis.

All of this poses a serious problem for the review panel since definitions may change during the course of the hearings leading to confusion and argument among all parties involved. It might be worthwhile to attempt to get some agreement on the definition of the "risky" events before the EIS is prepared by bringing experts from both sides together in a technical discussion. This approach is being tried by FEARO for scientific topics in general and may have application for risk analysis as well.

The Quantitative Aspects of Risk

A particular problem facing EARP panels dealing with developments in northern frontier areas is the lack of relevant data for analysis. Again, using offshore oil and gas exploration as the example, most of the data from world-wide experience has to be modified to account for the extreme conditions in the arctic. These conditions may drastically alter the results of the analysis based on the three major contributors to risk - environmental conditions, human error and equipment failure.

The lack of data often results in a professional disagreement over probabilities - whether the true chance is one in one million or one in two million. The irony is that a review of EARP panel reports suggests that their advice to decision-makers is more influenced by their perception of the consequences of the event rather than the probability of occurence. Therefore, beyond some level of probability (which is difficult to determine precisely) the arguments over probability are mainly academic. This suggests the need for the development of some general guidelines which could guide reviewers on the "acceptability" of probability estimates for various classes of events.

Paradoxically, the more rigorous and quantifiable approach to risk assessment has resulted in problems in the public arena. When the analysis produces a numerical risk estimate, regardless of how small the risk the public focusses its attention on the number itself as representing a measurable risk. Under such circumstances they cannot be placated by comparing the risk figure with other risks that are taken for granted in daily living.

Some Major Problems

There are a number of more general problems faced by those involved in the application of risk in EIA beyond the quantitative and qualitative aspects discussed above. They are summarized below.

(1) Those faced with incorporating risk analysis into EIA and interpreting and evaluating the results need to have access to commonly accepted protocols to guide their efforts. These protocols need to be generic enough to be applicable to a range of projects and specific enough to provide substantive guidance. Currently panel members may have little exposure to the topic beyond some general understanding or basic texts.

(2) There is a major problem in finding ways to ensure that the risks as perceived by the public are incorporated into the risk analysis. Risk analysis quickly becomes a topic for discussion among experts at public hearings with little or no input from those who must live under the potential risk. This is particularly true when there is lack of agreement on numerical estimates. The technical complexity of the topic poses serious challenges

for public participation; a challenge which must be met since risk is becoming a major feature of EIA.

(3) From the experience of EARP so far, there is a need to design risk anlaysis in a manner which allows panels to evaluate alternative mitigation measures, i.e., the costs and benefits of risk reduction. This basically requires a comparative risk analysis involving options for project design and operations as opposed to a single estimate of risk.

(4) Much of the information available on risk is couched in conceptual or theoretical frameworks. There is a need to use actual environmental assessments as case studies in which various approaches to risk assessment could be evaluated and further modified. Such collective practical experience could provide the basis for the development of the protocols mentioned above.

Current Initiatives

FEARO has taken a number of initiatives which will hopefully lead to substantive improvements in the application of risk analysis to the decision-making process through environmental impact assessment.

In 1984, the federal Minister of Environment, upon advice from FEARO, established the Canadian Environmental Assessment Research Council (CEARC). The 12-member Council was formed to advise on ways to improve the scientific, technical and procedural bases for EIA in Canada. It advises FEARO on the expenditure of a $500,000 annual reseach budget which is seen primarily as seed money to influence developments in the field.

Risk assessment has been identified by the Council as one of its major areas of research interest and it has supported a number of activities leading towards the development of a research prospectus on the topic.

Dr. Grima will be presenting a summary of one aspect of this work later in this workshop.

FEARO is currently designing a training session which will be available to EARP panel members before a public hearing is undertaken. The objective is to familiarize the members with the various aspects involved in the environmental assessment of major projects and to acquaint them with basic approaches and alternatives which have been developed through the experience of previous panels. Consideration is being given to including risk assessment as one of the topics in the training session.

Finally, there is a growing interest in Canada in post-devleopment reviews of EIAs. A number of project-specific reviews have already been completed and FEARO is also looking at the overall effectiveness of the public hearing process in EIA. The role of risk assessment in the decision-making process will undoubtedly be an integral part of such post-development audits.

Conclusions

(1) Risk assessment is now recognized as an important component of EARP and will likely see even greater application in future environmental impact assessments.

(2) In general, in low-probability-high risk situations, the panels have been influenced more by the potential consequence of the event than the associated probability of occurrence.

(3) There is a need for the risk event and the vulnerable resources to be more clearly defined at the beginning of an EIA.

(4) One of the major challenges facing those directly involved in risk assessment is to ensure that the analysis reflects the risks as perceived by the public.

(5) The application of risk analysis in EIA needs to take more account of the interest in evaluating the costs and benefits of risk reduction through mitigation.

(6) There is an urgent need for a set of risk assessment protocols to provide substantive directives to those responsible for preparing EIA guidelines and reviewing the resulting studies.

(7) People given responsibility for interpreting the results of risk studies and providing advice to decision-makers need to be informed of the strength and limitations of the approach.

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ENVIRONMENTAL IMPACT AND RISK ASSESSMENT:

LEARNING FROM EACH OTHER?

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The purpose of this task force meeting is to identify research needs for risk analysis under conditions of uncertainty. To that end, this paper explores the potential for fuller integration between risk analysis and environmental impact assessment, a closely related form of applied policy analysis which is already required by statute or regulation in a large number of nations, subnational jurisdictions, and even transnational institutions such as the European Economic Community (EEC) and World Bank.

In concept, environmental impact and risk assessment have evolved as parallel and sometimes overlapping procedures for rationalist reform of policymaking. With each other and with other forms of policy analysis (such as applied systems analysis, and cost-benefit and cost-effectiveness analysis), they share a common presumption that policy decisions can be improved by the application of explicit analysis and documentation. Both are intended to provide reasoned predictions of the possible consequences of policy decisions, and thus to permit wiser choices among alternative courses of action.

In practice, however, these two forms have been nurtured by different disciplinary and professional communities in largely separate policy contexts. As a result, they have evolved differences of emphasis, both in substance and in process, that merit notice and reflection. Some of these differences may be appropriate to differing purposes or uses of the analyses, but others suggest opportunities to improve each of the analytical forms by borrowing features of the other.

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Many of the policy decisions that most need either of these forms of analysis in fact need some combination of both: a systematic identification of possible environmental impacts, and a rigorous analysis of their magnitudes and probabilities. Examples include offshore hydrocarbon developments, environmental applications of pesticides as well as new biotechnologies, siting of potentially hazardous industrial facilities, and a wide range of others. Exactly what the combination should be, and how breadth of impact identification should be traded off against depth of predictive analysis for key impacts, is an important question for study.

Both environmental impact assessment and risk assessment could probably benefit, therefore, by learning from each other and by consolidation in many cases into a unified process. The purpose of such a process is not, however, merely to produce the most quantitatively sophisticated estimate of particular risks, nor the most comprehensive list of possible environmental impacts. It is rather to produce a rationale for making public policy decisions that is both well reasoned, and recognized as legitimate and acceptable by the public.

This paper recommends two particular topics for research. The first is to develop protocols for unified environmental impact and risk assessment of proposed government actions, beginning with actions for which there is already a recognized need for both forms of analysis (as examples, siting of hazardous technologies and environmental dispersion of potentially hazardous substances). Such protocols should address not only the substance of such assessments, but the accountability of the process by which they are framed, executed, and legitimized for use in public decisions.

The second research need is to attempt unified assessments of existing complexes of hazards to human health and ecological systems. Both environmental impact and risk assessments now are applied primarily to new action proposals, such as government projects and regulations. Many of the most serious hazards, however, arise from existing conditions and cumulative patterns of urban and industrial development rather than from new government actions. A prudent approach to setting priorities for environmental protection and risk management should therefore address existing risk patterns as well as new action proposals.

PROFESSIONAL COMMUNITIES

Both environmental impact and risk assessments are forms of applied policy analysis, as opposed to scientific studies. That is, their purpose is to provide an acceptable basis for making public decisions, rather than to produce new scientific knowledge; and their results are acknowledged to be judgments within constraints of time, money, and existing knowledge. These judgments in turn are made by professional practitioners of particular forms of analysis, whose approaches are shaped both by their experience and by the norms and paradigms of their disciplines.

Environmental impact assessment has developed a large but loose community of professional practitioners, whose academic backgrounds are drawn primarily from ecology, natural resources, environmental sciences and engineering, and some from anthropology and sociology. The most sophisticated environmental impact assessments, such as the Trans-Alaska Pipeline System EIA, represent the results of extensive studies and interdisciplinary collaboration by teams of highly qualified experts. Most EIAs, however, are prepared by small staffs of masters-level professionals representing a few key disciplines.

Risk assessment is a similarly loose label, but appears to represent some half-dozen discrete disciplinary subgroups rather than a single interdisciplinary approach. These subgroups include toxicologists, epidemiologists, and biostatisticians, all focussing on health risks (mainly cancer mortality); engineers and statistical decision analysts, both focussing on technological catastrophes; economists, interested in risk/benefit analyses; actuaries; and cognitive psychologists exploring aspects of human perception and behavior towards risk. More than environmental impact assessments, risk assessments to date appear to reflect choices of one or another of these disciplinary approaches by their authors, rather than an eclectic or interdisciplinary synthesis of several of them.

Both these professional communities would benefit from greater interaction with each other, and from certain strengths and experiences that each has had but the other has not. As yet few papers have been written on the relationships between EIA and RA (O'Riordan, 1979; Dooley, 1983; Beanlands, 1984a, b; Giroult, 1984; Vlachos, forthcoming), and only one of these has been published. An overview of five years' issues of <u>Risk Analysis</u> turned up less than half a dozen mentions of environmental impact assessment, and no articles in which it was a central topic. Journals on EIA have perhaps paid more attention to risk assessment as an emergent form of analysis, but have done no more to develop substantive integration.

SUBSTANCE

As policy analyses, environmental impact and risk assessments should be compared in two ways. One is substantive: what do such analyses include in their content, including what actions or conditions they assess, what alternative actions they consider, what consequences they look for, what basis they use for predicting those consequences and attributing them to the action, and how they treat uncertainty and subjective judgments. The second characterization is procedural: how do such assessments function as administrative processes, including legal basis and purpose, openness and accountability, and role in ensuing decisions. This section explores substantive characteristics; the following section discusses issues of process.

Target Actions

Environmental impact assessments are required for all major governmental actions that might "significantly affect the quality of the human environment." In practice, the majority are prepared for public works proposals such as highway segments, water resource and energy production projects, and public land management activities. In United States practice EIA requirements do not apply to most environmental health regulatory actions, which were exempted by statute. Nor does it include many major nongovernmental actions, such as hazardous industrial facilities, for which the only government action involved is a permit under such regulations; and it is not enforced for legislative proposals and other broad policy actions. In other nations such as Canada, the United Kingdom, and emerging European practice, industrial development projects generally are more consistently included under EIA requirements.

Risk assessment, in contrast, is practiced (albeit selectively) in both public and private sector decision processes. It is increasingly routine, for instance, in both the insurance and the chemicals industries, and is frequently used in energy production and electric utility firms. Within the public sector, risk assessments have been prepared primarily in conjunction with proposals to regulate particular substances as health hazards, and with some proposals to site energy production and industrial chemical facilities that pose risks of catastrophic accidents.

Unlike EIAs, risk assessments are not generically required by statute, and have not therefore been produced under any common set of protocols or administrative guidelines. The primary demands for risk assessments in public decisions have arisen from several particular laws requiring risk-benefit balancing in environmental health regulations, from "commission of inquiry" proceedings into proposals for hazardous facilities in some countries, and from more general administrative pressures for justification of proposed regulations.

Both environmental impact and risk assessments have been applied by and large only to discrete proposals for future action (or discrete hazards for which government controls might be warranted), as part of the administrative process by which proposed decisions are rationalized and justified. They have only rarely been applied to existing complexes or cumulative patterns of risk to health and environment, such as an urbanized area, even though such an area might provide a more realistic unit of analysis for assessing relative risks and setting priorities for management response. One recent exception is the Philadelphia study conducted under the U.S. EPA's Integrated Environmental Management Division (Haemisegger et al., 1985).

Alternatives

The treatment of alternatives is a central issue for any form of policy analysis, for it not only affects the scope and emphasis of the analysis itself but also determines the relationship of the analysis to the ensuing decision process. If the assessment considers only the consequences of a single action proposal, it can perhaps produce more detailed quantitative estimates of possible consequences; but it will also be fundamentally limited to justifying that proposal, or at most identifying marginal changes in it that could mitigate some undesireable effects. If the assessment is designed to compare alternative courses of action, in contrast, it becomes in effect a framework for decision rather than merely justification; but to serve this purpose, its design must focus on comparing differences among the consequences of alternative courses of action, rather than on systematic tracing of the consequences of a single course of action.

Environmental impact assessments are required to discuss alternatives to a proposed action, including the alternative of taking no action, so that the user can compare the full consequences of alternative courses of action. In practice, EIAs are often criticized for failure to seriously consider options preferred by some readers, but the requirement does allow them - for instance, in a recent EIA on alternative management plans for the Nantahala National Forest - to introduce new and sometimes superior alternatives after reviewing those proposed by the agency. More than this, it creates a healthy pressure on the analysts themselves to focus on differences among real choices, and thus makes the analysis more likely to provide a basis for the ultimate decision.

Risk assessments are more heterogeneous in their treatment of alternatives, probably because of the absence of any generic guidance on the subject. Risk assessments for health regulations, for instance, often include estimates of risk under alternative standards, and this is now required in U.S. practice for regulations that may have significant economic consequences. Risk assessments for technologies systematically identify alternative cause and effect sequences by which hazards could arise; they also have sometimes led to the identification of alternative measures to reduce risks, especially in cases such as Canvey Island where reasonable design or operational changes could significantly mitigate risk factors (Cohen and Davies, 1981). But many risk assessments so far are designed more to provide quantitative estimates of the risk of a single proposed action than to compare differences in consequences among alternatives.

One promising target for future research, therefore, might be the design of comparative risk assessments to show tradeoffs among alternative courses of action, including evaluation of how such designs would need to differ from other approaches to risk assessment.

Target Effects

The selection of target effects for analysis, along with the selection of target actions and alternatives as discussed above, determines the overall scope of analytical effort in both environmental impact and risk assessment. Environmental impact assessment in principle can include virtually any categories of impacts that are of interest. As Professor Munn has defined it (1979), it is

> . . . an activity designed to identify and predict the impact on the biogeophysical environment and on man's health and well being of legislative proposals, policies, programmes, projects, and operational procedures, and to interpret and communicate information about the impacts.

In practice, however, environmental impact assessments have emphasized possible impacts on natural ecosystems and (to some extent) human communities, and have paid little attention to health effects and some other risks (Clark, 1985; Beanlands, 1984a; Giroult, 1984). More precisely, even for impacts whose ultimate significance might involve health (for instance, air or water pollution), EIA studies typically predict only the environmental fate of contaminants rather than effects on health end-points.

Conversely, risk assessments have emphasized human health effects, especially potential mortality due to cancer or technological catastrophies; only a few studies, for instance on offshore oil rigs, have attempted to assess other environmental hazards (see e.g. Covello, 1985; National Research Council, 1983; Cohen and Davies, 1981). One important exception is a recent study by the U.S. National Science Foundation on environmental applications of biotechnology, which recommends use of risk assessment methods to assess potential environmental effects of biotechnology applications (Covello and Fiksel, 1985).

These differences in target effects have no intrinsic basis in the nature of the two analytical forms; they appear to have arisen simply as artifacts of the administrative contexts and professional communities associated with each. Both environmental impact and risk assessment would be improved by eliminating such differences, incorporating health effects into environmental impact assessment and conversely applying risk assessment to potential environmental consequences other than simply human mortality.

Prediction

Both environmental impact and risk assessments are forms of applied predictive analysis. In practice, however, environmental impact assessment has much to learn from the more sophisticated approaches to prediction that have been developed in the risk assessment literature.

Environmental impact assessments exhibit generally crude and simplistic estimates of the magnitude, likelihood, and time distribution of impacts. Prediction is typically limited to stated judgments that particular consequences are "likely" or "unlikely" (Beanlands and Duinker, 1983; Paradine, 1984). Exceptions exist in which (for instance) quantitative modelling of pollution dispersion is included, but for most impacts EIAs include few rigorous predictions. A study of the scientific quality of 75 U.S. EIAs, for instance, found that over 82% never used well-developed notions of probability to estimate consequences, and that none did so systematically (Caldwell et al., 1982).

Risk assessment, in contrast, stresses formal quantification of probability and uncertainty. By definition, a risk assessment is a study that provides ". . . quantitative measures of risk levels, where risk refers to the possibility of uncertain, adverse consequences . . . most fundamentally estimates of possible health and other consequences . . . and the uncertainty in those consequences" (Covello, 1985). A risk assessment typically includes a determination of the types of hazard posed, an estimate of the probability of the hazard(s), and estimates of the populations at risk of exposure and of ensuing adverse consequences (Conservation Foundation, 1984); and considerable scholarship has been devoted to developing and refining methodologies for producing such estimates.

Risk assessments may, of course, be based on quite tenuous or debatable assumptions, and in such cases their predictions may ultimately be no more reliable despite their apparent quantitative rigor. Hattis and Smith (1985), for instance, warn that current risk assessment practice relies on unduly narrow statistical methods for quantifying risk, at the expense of other lines of reasoning that may be more valid. Whatever its imperfections in practice, however, a basic virtue of risk assessment is its normative commitment to improving the methodologies of predictive estimation. Environmental impact assessment may have devoted similar attention to procedures for identifying categories of possible consequences, but by and large it has lacked this commitment to improving methods for prediction.

Uncertainty

C. S. Holling once asserted that the core issue of environmental impact assessment is how to cope with decisionmaking under uncertainty (Holling, 1978). The same is true of risk assessment: both are intended to reduce the uncertainties associated with public policy decisions. By the same token, however, both must confront powerful temptations - common to all policy analyses - to discount issues that remain uncertain or disputed, in order to build a confident justification for a decision. The appearance of certainty and consensus is welcome to politicians, but where it is not well founded it tends not to reduce opposition to the outcome but simply to promote cynicism about analysis.

Even after the most thorough assessment, all public decisions ultimately must be made in the face of uncertainty: uncertainty about the future, about human behavior, about stochastic events, about our own ignorance or imperfections in analysis. It is important to judge any policy analysis, therefore, not only by how much it reduces uncertainty but also by how explicitly it acknowledges important sources of uncertainty that remain.

In environmental impact assessment, acknowledgement of uncertainty is required but is rarely evident in practice. Caldwell et al. (1982), for instance, found that over 22% of the impact statements they reviewed never acknowledged uncertainty, and that none of them did so systematically or even more than just occasionally. Reeve (1984) similarly reports that a study of 242 draft EIAs led the U.S. Council on Environmental Quality to conclude that EIAs rarely address the question of incomplete and unavailable information as required by its regulations.

In risk assessment, acknowledgement of uncertainty is similarly expected, but in practice it is often buried in arbitrary assumptions or ignored if it cannot be quantified. Despite its apparent rigor, it is ultimately, like EIA, a very "soft" process of "artful theorizing to construct an appropriate picture of the world for informing specific choices" (Hattis and Smith, 1984).

An important topic of future research for both forms of analysis, therefore, is the refinement of methods for providing explicit and systematic treatment of uncertainty.

Subjective Information

Subjective information refers to statements of concern, value preference, or judgment, coming from either experts or laymen, that cannot be objectively validated. Such information is unavoidably present in both forms of analysis, wherever uncertainty or disagreement exists (Otway and Thomas, 1982); and it is therefore important to identify how each treats such information.

Environmental impact assessment requires at least three specific procedures designed to assure explicit identification of subjective concerns and disputes. These include a requirement for identification of "controversial" impacts, whether or not the agency considers them significant on objective grounds; a process of "scoping," in which all concerned parties may formally participate at the preliminary feasibility study stage in defining the terms of reference for the assessment; and a formal review of the draft analysis by all relevant agencies and interested citizens, comments resulting from which must be made public and explicitly answered by the initiating agency.

Risk assessment does not incorporate any formal requirement for identifying subjective information or divergence among judgments, and in practice it frequently fails both to acknowledge such information and to treat its presence as a legitimate issue. Many risk assessments, for instance, display a strong normative commitment to the concept of expected value, and a corresponding disdain for fears that exceed those values. Such fears are regarded not simply as differences in judgment to be acknowledged and discussed, but as groundless and therefore illegitimate - even though the expected value criterion is neither widely accepted by the general public nor legislatively approved as the basis for decisions (see e.g. Popper, 1983). The U.S. National Research Council also has identified a lengthy list of study design points in risk assessments at which assumptions must be made; but there is no routine procedure for assuring explicit debate of such judgments (National Research Council, 1982).

Risk assessment could probably be improved, therefore, by the development of explicit protocols for the treatment of subjective and disputed information. The procedures used for this purpose in environmental impact assessment may provide one set of useful models.

Summary

As substantive forms of analysis, environmental impact and risk assessments have differed in practice but are intrinsically similar in concept. An ideal example of either could in principle provide the same information as the other: it would clarify a decisionmaker's understanding of the alternative courses of action that could be chosen, and it would provide the best possible predictions of the differences in significant consequences that would be likely to result. The differences between their contents in current practice represent differences in focus and emphasis, some of which are strengths and some weaknesses on each side.

Each form of analysis could therefore benefit substantively from the adoption of some aspects of the other, and both would probably be improved by the development of a unified form of applied analysis that would combine the strengths of both.

PROCESS

The most important differences between environmental impact and risk assessment, however, are not differences of substance but of process. The two forms in practice have functioned not only separately but differently as administrative procedures. These differences are perhaps most pronounced in the U.S. setting, where they have developed in distinctly separate legal contexts, but they appear elsewhere as well. While substantive content is important, therefore, no less important is how well each functions as a process for framing and legitimizing public decisions.

Purpose

Environmental impact assessment originated from a generic statutory requirement, enforceable by citizens in the courts and binding on all government administrative decisions (except environmental health regulations). Its intent was not simply better analysis, but administrative reform: it was to be an "action-forcing procedure," to compel agencies to pay attention to the law's substantive purposes (Andrews, 1976).

The National Environmental Policy Act directed all Federal agencies to prepare a "detailed statement" of environmental impacts, adverse effects, alternatives, and other matters to accompany every recommendation, report on legislative proposal, or other major Federal action that might significantly affect the quality of the human environment. (National Environmental Policy Act of 1969, 42 USC 4321 et seq.). The statement must also be circulated for comment to all other agencies having relevant jurisdiction or special expertise, and be made available (with all comments) to the public. Similar requirements have since been adopted by over half the U.S. state governments, by some local authorities, and by many other nations and some transnational organizations.

EIA was explicitly conceived as an administrative reform to force greater public accountability on government agencies. Its authors perceived agencies not as systematic rational decisionmakers, but as narrow advocates of particular missions at the expense of other values and consequences. While some of its authors believed that more complete information alone would lead to better decisions, in practice it has drawn its primary effectiveness from the threat of public embarrassment and judicial challenge (Andrews, 1976).

Like EIA, risk assessment grew out of a broad movement toward expanded use of rational techniques for analyzing and justifying government decisions. Unlike EIA, however, it developed first as a management technique in the hands of experts, used in part to improve decisionmaking about engineering technologies and in part to justify those decisions - as in the case of the well-known Rasmussen report on nuclear reactor safety - against public fears and opposition.

Risk assessment emerged as an administrative requirement in the mid to late 1970s, in the form of both statutes and Executive orders requiring more extensive documentation to justify proposed risk regulations, and requiring "balancing" of risks against economic costs and benefits (Atkissen et al., 1985). Its practice in the U.S. has therefore been limited largely to the environmental health regulatory agencies, and to the environmental health risks (in practice even more narrowly, to the cancer mortality risks) of those agencies' decisions.

While risk assessment's substantive purpose is not unlike EIA, therefore, its political uses (at least in the U.S.) have been rather different. Where EIA was adopted to increase accountability to citizen groups, RA was adopted to increase internal management control, to foster consistency across actions and programs (U.S. EPA, 1984); and on the part of some advocates, to increase accountability to oversight agencies and business lobbyists seeking to limit risk regulation.

Administrative Process

To be useful in decisions an assessment must be not only accurate but legitimate: it must deal with the full range of decision issues, in a process that is open to public scrutiny and debate as well as well reasoned, even-handed, and candid about unresolved uncertainties. Numerous studies have shown, for instance, that stakeholders in the outcomes of public decisions may hold quite different views regarding any or all terms of reference for the analysis: problem definition, objectives and goal hierarchies, environmental conditions and expected consequences, and alternatives (e.g. Vari et al., 1985; Mason and Mitroff, 1981; Kleindorfer and Yoon, 1984). Susskind (1985) summarizes a substantial body of research showing that joint factfinding, including negotiation both of the scope and methods of analysis and even of the group of experts who will conduct it, is therefore a crucial step in producing legitimate analyses of controversial decision issues. Not only EIA but the recent literatures on strategic planning and facility siting provide valuable insights here that might enrich the practice of risk assessment.

Environmental impact assessment functions as an explicitly open analytical process, with enforceable opportunities for public involvement both in designing and critiquing the analysis, and guarantees that conflicting views must be considered on the record. The scoping process, the requirement that controversial impacts be explicitly discussed, and the review and comment procedure all contribute to this openness, and serve to make the resulting analysis a reasonably thorough and publicly tested record of the issues involved in the proposed decision.

Risk assessment, in contrast, frequently functions as a more arcane expert process, couched in terms that have little meaning to most laymen (risk probability, dose-response curve, expected value), and often lacks formal procedures for public involvement in design and critique of the analysis.

A common response to this observation is that risk information is simply too technical to be understood by laymen, and that such decisions therefore are best left to agency experts. It has been shown that laymen do perceive risks differently from "experts," overestimating some and underestimating others (see e.g. Fischhoff et al., 1981). But "experts" are also prone to certain types of misjudgments, and such decisions in any event are not merely technical choices, but matters of public governance that happen to be framed by technical assumptions. O'Riordan (1979) warns, for instance, that in many risk assessments "scientific rationality is overwhelming political rationality;" and Chauncey Starr (1985) has more recently argued that public acceptance of proposed actions depends more on public confidence in risk management than on any quantitative estimate of risk consequence, probability, or magnitude.

Given the uncertainty of many of the assumptions involved, therefore, and the fact that the public does not necessarily accept the expected value concept as a basis for risk decisions, it is probably wiser to make risk decisions more understandable than more quantitatively sophisticated, and to focus debate on options for risk minimization rather than on the refinement of risk estimates.

Influence on decisions

Despite their differences in substance and process, environmental impact and risk assessment appear to have had similarly modest but beneficial effects on public decisions. Both have produced far more extensive documentation related to proposed decisions than was previously available. Both have served to deter "extreme" proposals, in the senses both of high risk and of high cost for the amount of risk avoided; and both have also created incentives to identify mitigative measures to reduce the risks of actions that are to be taken. Both have given birth to communities of professional practitioners, and the gradual entry of these communities into hitherto narrower, mission-oriented administrative agencies has probably served to broaden perspectives and moderate biases.

As with substance, so with process, therefore, both environmental impact and risk assessment would probably benefit from the development of a unified form of analysis that incorporates the best of both forms. Such a unified analysis must incorporate not only substantive elements, however, but also explicit procedural mechanisms for negotiating the terms of reference of the assessment, for openly debating its assumptions and judgments where uncertainty exists, and for developing and legitimizing a consensus on its conclusions.

PROSPECTS FOR UNIFIED ANALYSIS

Only in a few instances, all recent, has risk assessment actually been incorporated into environmental impact assessment studies. Beanlands (1984b) reports that risk assessment is now stated as an EIA requirement in Canada, and was conducted most recently as part of a 1983 assessment of Beaufort Sea oil and gas development. Paradine (1984) identifies Canadian applications to hydrocarbon projects, nuclear power plants, forestry projects, and a few others such as hazardous train derailment.

In the U.S. a risk assessment of a sort, referred to as a "worst case analysis," is required within the context of an environmental impact statement by U.S. administrative regulations in cases where information about possible impacts is necessary to an informed decision, is not available, and would be too costly or impossible to obtain. To date only a few such analyses have been prepared, but three of them have been contested in the courts, and the U.S. Council on Environmental Quality has recently proposed - amid substantial controversy - to drop the requirement (Reeve, 1984; U.S. Council on Environmental Quality, 1985).

The controversy over worst-case analysis illustrates well the conflict between substance and process in evaluating policy analyses. As substance, worst-case analysis is not the favored approach of the professional risk assessment community, in that it emphasizes speculation about the worst conceivable outcomes rather than precise estimation of the most probable ones. As process, however, it is one of the few available "action-forcing" mechanisms - like the EIA itself - by which an unwilling agency can be compelled to acknowledge risks and uncertainties that it would rather ignore.

In the cases at issue, for instance - concerning proposals for aerial spraying of chemical pesticides by the Bureau of Land Management for forest insect control - the intervenors cite published scientific studies, not mere speculation, as evidence for possible adverse effects, and they point out that the agency simply had no expertise on such health effects and had made no attempt to acquire it.

If CEQ rescinds the requirement, therefore, and leaves the analysis to the agency's discretionary judgment, the result may not be better risk assessment but no risk assessment, since the basis for legal challenge to its absence will be removed (Northwest Coalition for Alternatives to Pesticides, 1985).

If not worst-case analysis, therefore, some alternative "action-forcing" mechanism is necessary to provide an open and legitimate forum for debate, and to compel the acknowledgement of risk and uncertainty by unwilling agencies. One mechanism might be to keep the worst-case analysis requirement in place, but to use the scoping process to define what reasonable range of worst-case scenarios should be considered. Alternatively, one could require some preferable procedure for risk assessment within EIA, but in sufficiently explicit terms to keep open the opportunity for external legal pressure to demand it.

Benefits

On intellectual grounds, environmental impact and risk assessment would both be improved by combining them into a unified analytical process.

Substantively, environmental impact assessment would benefit from the greater sophistication of risk assessment in the treatment of predictive analysis and probability, and should in any event incorporate more explicit consideration of health effects. Risk assessment in turn should be applied to a broader range of risks than just mortality from cancer and catastrophic accidents.

As a process, risk assessment has much to learn from experience with environmental impact assessment in such areas as scoping, comparative analysis of alternatives, formal procedures for incorporating subjective values, and integration into non-regulatory decision processes.

Practically speaking, moreover, many actions in fact need both environmental impact and risk assessment, and one would get more useful analyses by combining the two. Among the most obvious examples of such actions are decisions to site energy production hazardous waste treatment and disposal, and other industrial facilities; environmental applications of biotechnology; and even more mundane programs such as pesticide application for agricultural and forest management. While U.S. federal guidelines may be slow to merge them, Canadian and European practice are already beginning to do so, as are some state and local governments in the U.S. (for instance, in assessing the possible impacts of waste incinerators).

Substance, Process, and Outcomes

There is good reason for optimism, therefore, about the prospects for integrating environmental impact and risk assessments into a unified analytical process. Research and experimental applications will be needed to develop such a process, but the idea is both feasible and timely. All that is really needed is a few good cases to work out the issues in concrete settings, and the institutional sponsorship - either by governments, or by a respected institution of applied research such as IIASA - to work out protocols for unified analysis.

One subtler but fundamental issue remains unresolved by this recommendation, however, namely the domain of situations that warrant such analysis. Some promising target actions have been suggested, but in a broader sense the most important causes of hazards - both to human health and environmental processes - often lie in situations where there is not yet a specific proposal for government action that would trigger such an assessment. Examples include urban encroachment in flood plains, in other areas of natural hazard, and around hazardous industrial plants; and some business uses of toxic chemicals, both in industry and agriculture, whose effects on groundwater, human health, and other outcomes are now attracting increasing concern.

In addition to developing unified analyses for proposed actions, therefore, an important subject for research is the application of similar analyses to existing complexes of hazards that threaten human populations and ecosystems. The purpose of this sort of analysis is not simply to evaluate a single proposed action, but to set priorities for hazard management. Given a highly urbanized area or an ecological region, for instance, what are the important hazards that warrant management response, and how might one set priorities and develop alternative management strategies to mitigate them? This task will require development of a somewhat different approach to assessment, but such an effort would have substantial payoffs both for advancing the methods of risk assessment and for improving the effectiveness of risk management.

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RISK IN EIA: TOWARDS A RESEARCH AGENDA*

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Environmental Impact Assessment (EIA) as we know it to-day originated in 1969 with the National Environmental Policy Act (NEPA), in the United States. The formalization of the process in Canada took place in 1973 with the initiation of the Environmental Assessment Review Process (EARP) and the establishment of the Federal Environmental Assessment Review Office (FEARO). Provincial governments soon followed with their own legislation and procedures for EIA beginning in 1973 (Couch _et al_. 1983). Since then the literature on and the volume of environmental impact statements in Canada have grown rapidly (Munn 1975; Beanlands and Duinker 1983; Whitney and Maclaren 1985).

During the same period interest in risk concepts also grew apace. The substantial work on technical risk analysis that was characteristic of the period up to the 1970s began to be coupled with epidemiological and natural hazards research, and also with the more general recognition that the risk analyses of the potential failure of complex technical facilities should be expanded to cope with the consequences of those failures - that is, a "risk context" was now needed in addition to risk quantification. Important stimuli came from the writings of Starr (1972), Tversky and Kahneman (1974), Rowe (1977), Lawless (1977), Lowrance (1976) as well as the literature on natural hazards (Burton, Kates and White 1978), risks to health and safety, and risks to ecosystem structure and function (Burton, Fowle and McCullough 1982). More recently, interdisciplinary symposia have reflected the growing recognition of the potential for cross-sectoral application of risk concepts, and also of the many factors which frustrate our attempts to cope with risks (Warner 1982; Rogers and Bates 1983).

Even more than these theoretical and scholarly papers however, the main driving force behind the increasing interest in "risk" has been the growing social and political concern over the management and mismanagement of a bewildering array of potentially hazardous systems, products, projects and technologies. Many of these "hazards" are already subject to risk analyses e.g. tests on new drugs, fault-tree analyses for nuclear reactors - and the extension of risk analysis methodologies to more general "risk assessments" is a natural development in the application of risk theory.

Given these circumstances, it is perhaps timely to inquire whether or not the fields of "risk assessment" and "environmental impact assessment" can be mutually supportive; both fields have much in common and have evolved to the point where their different pathways towards an appropriate mix of scientific rigour, social concern and political judgement may be converging.

In Section 1 we outline the background activities and publications that complement this paper. In Section 2 we argue the advantages and limitations of risk assessment applications in EIA. We define some risk concepts in Section 3 before we provide the underlying rationale for the application of risk assessment in EIA (Section 4) and these definitions are adapted as a framework for identifying the research needs in risk analysis (Section 5), public involvement (Section 6), risk assessment and the concept of "acceptable risk" (Section 7) and managing the process (Section 8). In Section 9 we suggest some research priorities.

1. BACKGROUND ACTIVITIES

In late 1984 a risk assessment (RA) project was started at the Institute for Environmental Studies (IES), University of Toronto, under the leadership of Ted Munn, now at IIASA. The RA project is supported by the University of Toronto, Health and Welfare Canada, Environment Canada, Ontario Hydro, the National Research Council/SCOPE and the Federal Environmental Assessment Review Office (FEARO). A workshop on Risk Assessment in EIA was convened in April 1985 at Seneca College, King City, Ontario. The workshop program is in the Appendix to this paper. A second workshop on Information Needs for Risk Assessment was convened at the Guild Inn, Scarborough, Ontario in September 1985. A summary paper based on the second workshop has been prepared for this volume by Professor C. David Fowle. About 50 academics, consultants and government scientists attended each workshop to review invited papers which are being revised for publication.

In early 1985, the Canadian Environmental Assessment Research Council (CEARC) asked IES to prepare a report that would identify the research needs and opportunities relevant to the application of risk management concepts in EIA. In March 1985 a preliminary meeting was held at IES at which a dozen experts discussed research needs and priorities. A draft report was presented to CEARC in early October; a final draft on which this paper is based was submitted in January 1986. We have benefited from all these presentations, discussions and reviews.

2. RISK AND EIA

As Paradine (1985) notes, risk assessment has been used extensively in Canadian EIAs of hydrocarbon exploration in the Arctic and off-shore, and in EIAs of nuclear power plants and related technology (e.g. uranium mining). The role of risk assessment in EIA is likely to increase in part because of a growing concern on the part of the public, the media and the politicians about the failures of complex technologies. Bhopal, Seveso, Three Mile Island, to mention but a few celebrated examples, have left a deep impression on the public, especially the public most exposed to the consequences of technological failure. The assessors of EIA may also be expected to make more use of risk assessments, because risk assessment provides a suitable formal framework for recommending mitigation measures that could reduce the chances of technological failure and mitigate their consequences of failure. The application of risk assessment principles in EIA may, therefore, lead to better and also more widely understood - and therefore more widely accepted - decisions in EIA.

Whether the application of risk principles in EIA would result in better decisions would depend in part on the technical adequacy of the analysis and in part on the degree to which the decision itself is amenable to technical analysis. This qualification is particularly relevant to our study because it applies to EIA too. We view risk assessment and EIA as primarily planning tools or techniques for sorting out data and information. The decisions that follow would depend primarily on both the political context (i.e. which interests wield more power) and on the societal commitment to such considerations as environmental quality, distributional ethics, cultural integrity and inter-generational equity. In this regard risk assessment and management could be useful in EIA by emphasizing the inextricably risk-laden lives we lead with or without formal assessment!

In brief, the risk concept is useful in pointing out both the limits of science (scientific uncertainty) and the limits of public consensus. However, we do **not** subscribe to the view that risk assessment - or EIA - is designed to force a shift in public attitudes towards the environment or necessarily towards more equitable allocations of resources. Like other techniques of policy analysis in the past (e.g. EIA, benefit-cost analysis, location-allocation analysis), risk assessment is an analytical tool and could be used by different interests to further their purposes. Risk assessment is not expected to resolve "value" questions but to clarify the implications of alternative decisions for value-groups. To us, that is a powerful argument for the more specific treatment of risk. We should add that no analytical tool is entirely value-neutral: another reason to insist on the **explicit** treatment of risk in EIA.

3. WORKING DEFINITIONS

We argued above that the explicit treatment of "risk" concepts in EIAs could help to clarify and codify some of the existing aspects of the process and could also point the way to new developments in the existing process. As a preliminary step, it is necessary to explain what we mean by risk assessment and management and how they relate to EIA. The definitions in the literature vary considerably; however, we assume that as long as we are reasonably clear about what we mean, and the definitions we offer are relatively free from ambiguity, we need not become involved in a debate about semantics.

We define **risk**, after Lowrance (1976:8) as [a judgement about the] measure of probability and severity of harm to human health [and the health of human ecosystems, broadly defined]. Most of the risk literature deals with risks to people, and risk impacts are generally measured in terms of mortality, premature death and morbidity. We have, however, also included environmental risks such as impacts on ecosystem structure and function, on amenity and heritage values and on economic well-being.

Risk analysis, is the measurement of the likelihood and severity of harm. Risk analysis is usually made up of <u>risk identification</u> and <u>risk estimation</u>; the latter is the attempt to estimate scientifically, mathematically, statistically, or by some other rigorous procedure the <u>probabilities</u> of an event and the <u>consequences</u> associated with it. Generally, risk analysis is the most time-consuming, costly and technically difficult part of risk assessment, requiring data collection and analysis, in areas where needed data often do not exist and where analysis of these data can be more of an art than a science. Because risk analysis often involves probabilities, statistics and epidemiological data, it may be difficult to convey the results of an analysis to the public and to non-specialists.

Next comes **risk evaluation.** In this volume we use **risk assessment** interchangeably with the term risk evaluation. It is at this stage that values and judgements enter the process explicitly or implicitly by the inclusion of consideration of the importance of the assessed risks and the associated social, environmental and economic consequences in order to identify a range of alternatives for managing the risks, and to consider whether or not the proposed change as a whole is acceptable. Evaluation requires the determination of the tradeoffs between the various beneficial and adverse impacts and for this reason, the views of various interest or value groups need to be solicited and considered.

We use **risk management** as the overall term to include the identification and quantification of risks associated with a proposal/action, the evaluation of alternative strategies and designs that mitigate these risks or their consequences, and the decision and implementation of a preferred course of action. Risk management includes the entire range of methods of coping with risk rationally and systematically.

Next we discuss our underlying rationale for the use of "risk" in EIA: the use of risk focusses attention on one of the fundamental issues of making predictions - the question of uncertainty, scientific and societal.

4. UNDERLYING RATIONALE: THE QUESTION OF UNCERTAINTY

We believe that the first beneficial effect of the application of risk to EIA would be to infuse the whole process with the risk philosophy. That is to say, we would reject the dichotomy of safe and unsafe with its implied certainties, and explicitly recognise that we are always dealing with a range of risks, and that while it is true that by a combination of scientific and societal judgments we may arrive at a level of "acceptable risk", we are constantly dealing with some range of probability and consensus and not ironclad certainty or universal acceptability. In this section we focus on uncertainty; the societal judgements and range of consensus (or conflict) are discussed in a later section.

Scientific Uncertainty

Practitioners of EIA have constantly to deal with two perspectives on scientific uncertainty relative to impacts: uncertainty as perceived by scientists, and uncertainty as perceived by laymen (i.e. non-specialists and the public and sometimes by scientists who do not share the same mindset). Uncertainty is a fundamental component of the scientific method; questioning, doubt, criticism and clarification are basic functions of good science. The progress of their discipline depends upon scientists constantly attempting to undermine - and go beyond - their most cherished laws and paradigms. However, this intrinsic uncertainty often comes across to the public as a lack of control, or a lack of understanding.

This presents the authors of EIAs with a familiar dilemma. If they make categorical statements or make definitive pronouncements without qualification, they are open to criticism by their peers. If they make qualified interpretations, they are open to attack as being "wishy-washy", "noncommittal", or "buck-passing" since all the pressure is on making the "right" decision free from uncertainty as to the consequences.

In an EIA context those predictions about which there is general agreement do not require extensive risk analysis before mitigative measures are considered; of course, there may or may not be as much general agreement about which mitigative measures are best (e.g. building a dam to reduce floods versus land use zoning). Those predictions about which there are no robust hypotheses or data would benefit from risk assessment only to the extent that risk analysis would provide an organizing framework for looking for data and testable relationships. Meanwhile only subjective analysis is possible.

There are events of low probability and high consequences (LOPHIC) such as Seveso, Bhopal. Mitigative measures for LOPHIC risks tend to be very costly as in the case of nuclear plants and hazardous waste disposal facilities while the data are limited and subject to various interpretations. In these cases risk assessment, even in the absence of historical data provides a useful organizing framework for conducting rational discourse and for improving the information base.

Uncertainty about Societal Futures

Tomorrow's society is shaped by today's decisions. For example, EIAs are a device for ensuring that the future will not be catastrophically surprising as a result of some new endeavour. Although an EIA is specifically related to some particular project or area, it is also worth keeping in mind that an EIA is a lightning rod for a whole range of social concerns, simply by virtue of its attempting to discuss the future systematically. Similarly, "risk" is a polarising word, since, like a strong magnet, it sets up fields of concern within which people orient themselves to protest against or firmly espouse the kind of future that is perceived to follow a decision. Part of the answer is to understand better societal uncertainty i.e. the degree of consensus regarding societal futures - including the kind of economy and institutions we want or are likely to have in the future (e.g. a centrally planned economy versus a more loosely knit market economy). For example, some of the controversy in EIAs revolves around whether certain technologies favour the evolution of more centralized, larger institutions and whether such institutions are desirable. We would like to make it clear that the issue is a political one and is more amenable to dialogue among value-groups than to technical information exchanges (cf. public hearings). However, the implications of project development on institutional structures should be part of EIA. In addition some of the potential mitigative measures may be changes in institutional structures (e.g. compulsory, non-subsidized insurance for automobiles).

One way of coping with this situation, as we have said, is to take both public concerns about societal uncertainty and scientific uncertainty into account, and subject them to equivalent seriousness in terms of future research on how to improve EIAs. In terms of social impacts, we are not just referring to alterations in the perception of various risks, but also referring to such issues as: given the range of risks that people already face, are additional risks worth taking on?; how will they fit into the overall spectrum of risk?; the question of equity: who is to be saddled with what risks, for how long, and for what benefits?; and the question of acceptability: what is an acceptable risk, and what is an acceptable process for coming to that determination? The use of risk assessment in EIA would clarify the need to solicit a range of societal judgements so as to arrive at a pragmatic consensus among conflicting values and interests.

In the following sections, we look at the research that may assist in answering these and other questions we have raised in our introduction. We adopt a variation of the conceptual models that are reviewed by Krewski and Birkwood in this volume because

> "These models are of great value in clarifying the main elements of risk assessment and management, and have served to establish a well defined framework within which research may be addressed."

These models distinguish among the risk concepts that we defined above: risk analysis, risk evaluation and assessment, and risk management. These stages of risk assessment and management parallel the well-known steps of rational decision-making (McAllister 1980) and serve as useful check points in the identification and clarification of many important considerations in the complex process of risk management.

5. TECHNICAL RISK ANALYSIS

One of the criteria for judging the quality of a risk analysis is the extent to which existing information has been utilized. Because of the continuing problem of using information gathered for one purpose in order to perform risk analyses for another purpose, the establishment of "translation criteria" and standards is crucial in ensuring the viability of risk assessment. Among the first of these criteria would be an explicit understanding about the confidence bars to be assigned to analyses. Another criterion would help define those cases where a risk analysis would perhaps be ruled out, since the information available was of insufficient quality or quantity to make an analysis worthwhile. Can we devise criteria for what would constitute sufficient information of appropriate quality?

The best known problem related to uncertainty in risk estimation and interpretation is that of low probability high consequence (LOPHIC) risk. "Low probability" is often a euphemism for no known probability: the lack of a track record makes the prediction of the event and the consequences unreliable. Another difficulty is that in order to paint a realistic "risk picture" we often have to undertake cumulative and combined risk analyses. Both of these may be susceptible to serious error through additive or multiplicative effects.

Reliability in estimates depends not only on the quality of information available, but also on catching the ways in which errors creep into risk estimations, either by the additive and multiplicative process, or by heroic assumptions about such problems as human error. How reliable do estimates need to be in order to be useful for risk assessment and management?

One method of reducing technical and interpretative uncertainty to a minimum is "worst-case" analysis. This kind of analysis while exhaustive - and exhausting - may not illuminate the real situation as regards risk. Rather than spending time on examining highly implausible risks, it might be worth analysing "worst plausible cases", i.e. those scenarios which are built up by technical experts, panel members, and the public in order to sketch out acceptable pictures of what the future might hold. Public input into developing guidelines (as in Lepreau II) could include the building of plausible scenarios. Research in this area might address the strengths and weaknesses of worst-case analysis and worst-plausible-case analysis in terms of the minimum necessary technical information, the appropriate levels of understanding by non-specialists and acceptability by interested publics.

The presentation of technical information is a great potential stumbling block in the application of risk analysis to EIA. The uncertain and probabilistic nature of much of the information provided, as well as the mathematical language often used in risk calculations, can make risk assessment threatening rather than enlightening to the layman. This is a central issue, not just for the assessors and decision-makers who must make the final assessments, but also in order to make public participation meaningful and relevant. We need to know whether non-specialists find mathematical risk analysis useful. If not, what else could one use?

The manner of presentation should ideally convey both what is known and what is not known about the risk in question. is needed into the development of an appropriate language for presenting risk analyses. We need to develop aids (e.g. maps, tables, computer simulation games) to convey the nature of different types of risks. How can we best translate technical risk analyses into laymen's language? How do we best convey the reliability of risk estimates? We need to clarify without oversimplifying. We believe that the major responsibility for improving technical presentation - i.e. translating the results and implications of analyses - lies with the technical analysts themselves.

6. PUBLIC INVOLVEMENT

The integration of the concerns of the public in risk assessment is a clear priority area. The difficulty, as we have noted elsewhere (e.g. Grima 1985; Timmerman 1984), is to make those concerns felt in a timely, equitable, efficient and useful fashion. One vital part of making any form of risk acceptable is that the process by which the decision to assume (or impose) a burden of new risk is made should itself be acceptable. This process is a very important research area.

The Perception of Risk

The term "perception of risk" carries with it the slightly pejorative connotation that the public has "perceptions" which are mostly illusory and emotionally based, while scientists and other experts have a monopoly on objective reality. It would perhaps be better if we spoke about different "conceptions of risk" held by different stakeholders, which would remind us that people's perceptions of risk are often a function of their experiences and conceptions of life.

In recent years, differences between what is considered expert opinion and the views of the public on matters of risk (e.g. the nuclear power debate) have created a substantial literature, much of which is referred to as "the perception of risk" (Tversky and Kahneman 1973; Otway and Pahner 1976; Kahneman et al 1982; Timmerman 1985). Controversial issues, especially ones which pose potential threats to human health and well-being, tend to polarise the various players in the evaluative process, and bring to the surface many different views, not just on the specific risks being evaluated, but also on the implications of those risks, on the levels of responsibility and accountability of elected and non-elected public representatives, and sometimes on the whole future of society and institutions (cf. some of the presentations to the Porter Commission on Electrical Power Planning in Ontario).

Human beings have, over millenia, learnt to use "judgement" in dealing with risk. They have developed largely intuitive methods of scanning and simplifying the vast array of incoming stimuli and information in order to concentrate on those phenomena which are adaptively significant; methods which can sometimes be systematically misleading. This human conservatism in the face of uncertainty used to be referred to as "wisdom", and since wisdom is not a quality much in abundance these days, we should be careful about dismissing it out of hand.

In a broader perspective, the public mistrust of expert assessments of risk has to do with, among other things, people's loss of a sense of stability or control over their own lives. In addition there have been occasions when science and expertise have increased, rather than decreased, the risks with which some sectors of society have to live (e.g. Love Canal residents and Bhopal victims). Finally, a large segment of the public do not find quantitative analyses persuasive when the issues are essentially qualitative e.g. the overriding priority that personal health and the care of children have in both household and government budget-making in spite of constraints and multiple objectives.

Public Participation

The acceptability of the process itself is an integral part of the acceptability of the results of the process. The "due process" of EIA is one of the best ways of ensuring that uncertainties about future consequences are not ignored, but are specifically considered, clarified and communicated to the stakeholders. Presentation of data in compelling and clear forms is a fundamental research priority if the complex terminology of much of risk analysis is to be easily and correctly translated, rather than simply adding another layer of frustration to the public participation process.

Research is needed into when, during the process, explicit public focus on risk should take place. The practice of having public input before the guidelines for the EIS are promulgated is to be encouraged. This helps to ensure that some parts of the public concern are potentially resolvable without having to undertake new studies in mid-process. FEARO is currently evaluating this practice in the Lepreau II case; this type of research is essential if we are to learn from experience.

Participation must be handled so that differences of opinion over the competence of technical analyses are clearly identified. The crucial importance of this is that failure to provide adequate or compelling rationales for certain aspects of risk analysis suggests that predictive competence over what will happen in the future is less than adequate, and this very rapidly translates into a loss of confidence in the overall status of the EIA process.

7. RISK EVALUATION AND ASSESSMENT

The evaluation and assessment of risk in an EIA comes at that point in the process when conflicting interests and values begin to be explicity factored into the "risk equation". For any evaluation or assessment to work smoothly there must be confidence on the part of all stakeholders that "all bases have been covered", and that the array of evidence before the decisionmaker is adequate for some decision to be made. It is here that we need research into developing the best and most manageable guidelines for identifying the full range of possible risks and benefits, and then evaluating and assessing their significance. And it is here that we need to learn from past experience, particularly good experience.

There are several assessment methodologies (benefit-cost analysis, risk-benefit analysis, multi-objective analysis, multi-attribute utility analysis) that attempt to clarify the trade-offs between risks and costs and to organize information and gaps in information. Should the guidelines for EIA ask that the proponent and assessors attempt to generate and present data on "willingness to pay" or "willingness to receive compensation" in order to exemplify the necessary trade-offs? This type of analytical approach is particularly important when community compensation, guarantees about liability and risk mitigation are considered as part of the recommended course of action. How does one obtain accurate but quick estimates of public acceptability and guarantees? The information is required not only as part of public participation but, more importantly, as part of evaluation and assessment.

The decision-makers have eventually to balance off the various concerns and presented information and decide if the risks associated with going ahead on a project are acceptable, given everything else. "Given everything else" is a way of saying that some form of weighting is eventually carried out, however much one may dislike comparing apples and oranges. An additional complication is that the distribution of the burden of risks, and of the benefits accruing from those risks is, in part, an ethical concern (Schultze and Kneese 1981).

> An **acceptable risk** is a risk whose probability of occurrence is so small, whose consequences are so slight, or whose benefits (perceived or real) are so great that a person, group, or society is willing to take that risk (Munn, pers. comm.).

The difficulty, of course, is that the combination of elements outlined above rarely occurs. Much more usual are those risks where some combinations are positive, and some are negative: for example, the probability may be low, the consequences high, and the benefits high. Even more complex are those often recurring situations where the persons put at risk are likely to receive some level of benefits, but the bulk of the benefits are to go to a larger group of others, or to some specific beneficiary. Peculiarly intractable are those cases where there is an arbitrary assumed increase in risk to one group, even though the benefits are universal and substantial (e.g. hazardous waste facility siting) (Timmerman 1984; Singer 1979; Hare 1981). One solution for this type of problem is to engage the public in forms of scenario construction, with various compensatory strategies attached to surprises and failures that might ensue. Another is to conduct much more focussed research into the way that the public values and evaluates its own concerns, lifestyles, and other elements of its "well-being".

8. MANAGING THE PROCESS

In this section we look at the EIA process in its own right as a significant institutional arrangement for monitoring, reducing or containing risk. We examine a few issues that have very broad implications for the content and scope of EIA.

Experts as Hired Guns

Scientists, lawyers, engineers, sociologists, economists and other experts play a major role in EIA and risk management. The NRC (1982:34) Committee on Risk and Decision Making pointed out that "While it may baffle lay people, assessors often clash on facts". They give a long list on what experts disagree about: they may disagree on the reliability of data, their import, their interpretation, and their synthesis. Whether the issue is the biological effects of low-level radiation, the safety of food additives, the likelihood what chlorofluoromethanes diminish ozone in the stratosphere, or the health effects of different components of automobile exhaust, the process of reaching a consensus on what is known and is useful for the evaluation component of decision-making is invariably difficult and often contentious (NRC 1982:34). What ought to be done about it?

Including articulate and competent laymen on panels, stating conflicts of interest and biases, setting up "science courts", etc. are only some of the suggestions for increasing the orderliness and clarity of the scientific input. It is therefore important to consider other alternatives such as advisory panels and scientific reviews (e.g. those conducted for the U.S. Academy of Sciences and the Royal Society of Canada). It would be useful to do research into the relative merits of these experiences in order to learn how to deal better with the issue of managing expertise.

Alternative Institutional Instruments for Mitigating Risks

Adjustments and adaptations to risk include insurance (compulsory or voluntary, subsidized or not subsidized), medical care services, emergency services, educational campaigns, scientific research (e.g. epidemiological and toxicological research), policy research, and engineering and economic analyses. However, the administrative response to acceptable-risk questions is typically much narrower. The two most common responses are legislation about liability (e.g. compulsory liability insurance for cars) and regulation (e.g. occupational health and safety regulations, compulsory car belts, emission standards, compulsory product labelling). Some policy choices about acceptable risks are not mutually exclusive: compulsory insurance and health regulations complement each other (cf. workmen's compensation insurance and safety regulations).

In risk management, experimenting with innovative institutional techniques offers management the opportunity to learn from experience. However, we can benefit from this learning process only if regular assessments are made of the institutional mechanisms currently in use. It would be useful: (a) to compare institutional contexts and mechanisms that are already in use in Canada, U.S. and Europe; and (b) to discuss other potentially useful legal-economic mechanisms that would more effectively manage the risks associated with the hazardous facilities, hydrocarbon energy development, phases of the nuclear power cycle, etc.

Assessing Economic Risk

Beanlands (this volume) notes that:

> "The application of risk in EIA needs to take more account of the interest in evaluating the costs and benefits of risk reduction through mitigation."

One needs to assess the effects of mandated changes on the performance of firms and market shares; the effects of regulatory uncertainty on site selection and investment decisions; the effects (positive or negative) of mandated measures on economic performance (e.g. productivity, employment, profitability, investment). We agree with the NRC (1982:60) Committee on Risk and Decision-making that "reliable economic research does not currently exist to refute or establish [various] claims". For example, Stafford (1985) argues from empirical evidence that environmental quality regulations do not rank among leading location factors of industry and are far less important than labour and market access. A literature search and brief review would provide the research community with an initial understanding of research findings and opportunities in this somewhat neglected field and it could be a first step for a working group and workshop to assess what is known and what needs to be known in assessing the economic component of risk.

9. RESEARCH PRIORITIES

In this section we select some of the research needs and opportunities that we think ought to be given priority. Most of these priorities are based on the arguments of the previous sections, but we have also kept in mind other considerations: what we believe would produce useful results in the short-term; what needs to be carried out urgently; and what would be particularly important in improving EIA:

1. **Research is needed into the presentation of technical information on risks to non-experts** (Section 5).

2. The next full-scale EIA should have associated with it a social science research component which would trace and track the various expressions of "risk strategies" on the part of the scientists, experts, project proponents, and the public (Sections 5, 6, 7, 8).

3. We need to investigate the appropriateness of including economic risk into a risk assessment (Section 8).

4. We need to explore various methodologies for making "trade-offs" so as to achieve acceptable levels of risk (Section 7).

5. Scenario building (particularly worst-case analysis) as a method of prediction needs to be examined further (Section 3).

6. Guidelines calling for risk analyses and evaluations in an EIA need to include criteria on when the data and the scientific understanding are deemed adequate (Section 5).

7. Guidelines for carrying risk assessments should be developed (Sections 4, 5, 6, 7).

8. Existing uses of risk assessment in EIA should be codified and systematised. Some environmental sectors would immediately benefit from the systematic application of risk assessment. We recommend that these be identified, and used as potential "initial experiments" for the further implementation of risk assessment in EIA.

9. Retrospective and comparative case studies of previous Canadian and international EIAs should be undertaken.

Our last two, more general recommendations reflect our conviction that there is much to be learned about risk from current and past experience with EIA. One way to take advantage of opportunities for improving the use of risk assessment in EIA would be to examine and codify current applications of what are "risk concepts" in everything but name only (Recommendation 8). The interim evidence collected by Paradine (1985) suggests that risk concepts have already been applied in a limited fashion in EIAs. Research would focus on when risk analysis is useful, whether its utility has been recognised, and whether or not more explicit use of risk concepts would make EIAs more comprehensive and relevant.

Comparative evaluations of past analyses are probably the most cost-effective way of learning how to do better in the future (Recommendation 9). Case studies from a variety of jurisdictions in Canada, the U.S. and other countries would be particularly illuminating, since they could suggest why some risks are tolerated in some countries, cultures, and politico-economic systems rather than in others and whether different countries, cultures, or politico-economic systems have devised different mechanisms are for coping with risk. Critiques could point out omissions and inapropriate methodologies; but perhaps more importantly, they could identify "good" studies, and the features that made them stand out as successes.

In order for these to be more than just interesting stories, retrospective "debriefings" should be carried out by senior scientists, experienced panel members, and other experts working as an interdisciplinary team. We view retrospective, comparative case studies as a way to put into effect the iterative and potentially open-ended nature of the EIA process.

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APPENDIX

Institute for Environmental Studies, University of Toronto

WORKSHOP ON THE APPLICATION OF RISK ASSESSMENT PRINCIPLES TO ENVIRONMENTAL IMPACT ASSESSMENT IN CANADA

Eaton Hall, Seneca College, King City, Ontario 17-18 April 1985

Sponsors

SCOPE Canadian National Committee; National Health and Welfare; Ontario Hydro; Environment Canada; Federal Envrionmental Assessment Review Office

Steering Committee

Ted Munn, IES/IIASA, Chairman; **Phil Paradine**, FEARO; **Bob Malvern**, Ontario Hydro; **Lino Grima**, IES, Co-Chairman; **Dan Krewski**, NH&W; **Carol Miller**, Environment Canada; **Don Miller**, NRC; **Jim Dooley**, IES; **Dave Fowle**, York University.

Administration Gail Rania, IES

PROGRAM
DAY 1, 17 APRIL 1985

SESSION 1

Opening Remarks: Ted Munn on behalf of IES;
Phil Paradine on behalf of the sponsoring agencies

Plenary Session: Scope and process of Workshop, Ted Munn, IES/IIASA

Keynote addesses:

1. Current attempts to introduce risk assessment into the EIA process in Canada: Phil Paradine, FEARO.

2. Current attempts to introduce risk assessment into the EIA process in the U.S.: William Dickerson, US EPA.

SESSION 2

Brief presentation of papers, clarifications, brief comments:

1. The technological treatment of risk: Jim Dooley, IES.

2. The technological treatment of benefits: Ron Pushchak, IES.

3. The social treatment of risk: the public perception challenge: Peter Timmerman, IES.

SESSION 3

4. The incorporation of risk assessment into EIA: Jim Dooley, IES.

5. Modifying the EIA process to provide a better framework for including risk assessment: community impact mitigation: Lino Grima, IES.

6. Information needs of the proponent: Bob Malvern, Ontario Hydro.

7. Information needs of regulators: Peter Duinker, Univ. New Brunswick.

SESSION 4

Three concurrent discussion groups: Detailed review of chapters.

SESSION 5

Two concurrent discussion groups: Authors' response to comments

DAY 2, 18 April 1985

SESSION 6

Plenary Session: Research needs and opportunities, Draft paper, Lino Grima, Peter Timmerman and Dave Fowle

SESSION 7

Three concurrent discussion groups on research needs and opportunities

SESSION 8

Plenary session: Research needs and opportunities.

SESSION 9

Three concurrent discussion groups to draft conclusions and recommendations.

SESSION 10

Plenary session on conclusions and recommendations.

TREATMENT OF RISK IN ENVIRONMENTAL IMPACT ASSESSMENT[1,2]

Glenn W. Suter II, Lawrence W. Barnthouse, and Robert V. O'Neill

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TREATMENT OF RISK IN ENVIRONMENTAL IMPACT ASSESSMENT

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1. INTRODUCTION

The purpose of this paper is to distinguish risk assessment from other environmental assessment activities, define the role of uncertainty in risk assessment, explain and illustrate the utility of environmental risk assessment, and present research recommendations.

Environmental impact assessment is a broad field that includes all activities involved in analyzing and evaluating the effects of man's activities on natural and anthropogenic environments. As indicated in a number of reviews (Munn 1975; Beanlands and Duinker 1983; Westman 1985), impact assessment can conceivably consider the full range of man's activities; it includes identification and prioritization of issues, prediction and comparison of effects, consideration of acceptability, and translation of conclusions into policy recommendations.

Risk analysis is a much narrower field that deals with the quantification of risks. Risk is generally defined as the uncertainty concerning an undesired event, where uncertainty is expressed as probability of occurrence (Rowe 1977; ASTM 1985;, Whyte and Burton 1980). Therefore, risk analysis is applied when there is a quantitatively definable end point about which there is some uncertainty as to whether (or how often) it will occur. The percent reduction in forest production due to a new air pollution source is a suitable topic for risk analysis because there is uncertainty concerning the relationship between pollutant emissions and forest productivity. However, if the action being assessed involves clearing the forest to make way for a new shopping mall, then there is no uncertainty concerning the loss of forest productivity and the concept of risk is irrelevant. However, the effect of the shopping mall on forest productivity is a suitable topic for environmental impact assessment because the significance of the effects and a comparison with effects of alternative actions must be considered. Thus, environmental risk analysis is a subset of environmental impact assessment.

In the following sections we discuss the role of risk analysis in environmental impact assessment in terms of the nature and sources of uncertainty. We then present examples of the treatment of uncertainty in environmental assessments, show how the probabilistic results of risk analyses can be interpreted and used, and suggest areas needing further research.

2. TYPES OF UNCERTAINTY

Primary uncertainty is uncertainty about the state of the world, whereas secondary uncertainty is uncertainty about our actual level of ignorance (Fig. 1). Secondary uncertainty is inherently unknowable and cannot be explicitly incorporated in a risk assessment, but an awareness of its existence contributes a wholesome humility.

The two fundamentally different types of primary uncertainty that can contribute to risk are identity uncertainty and analytical

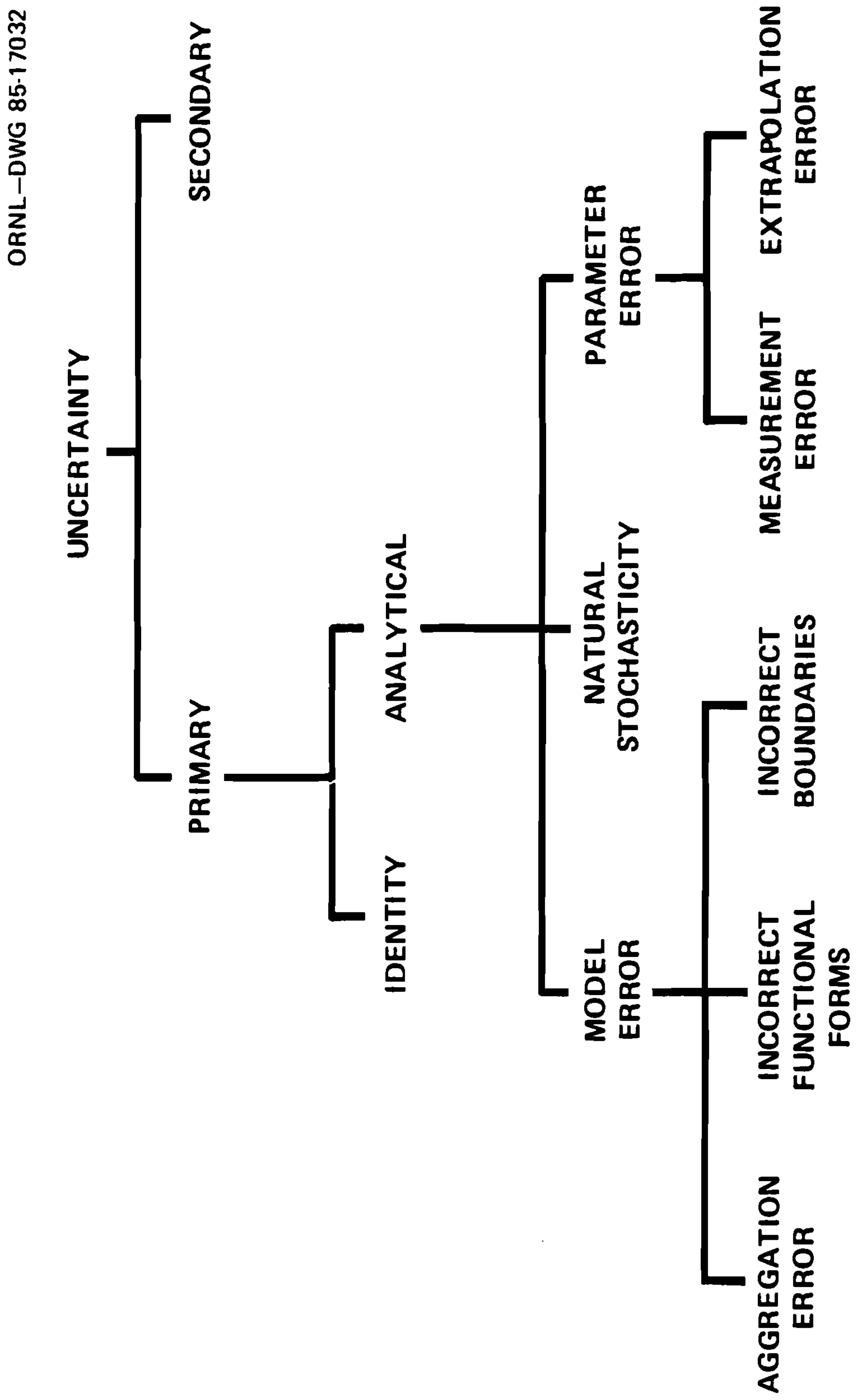

Figure 1 A taxonomy of uncertainty

uncertainty. Identity uncertainty, the uncertainty concerning the identity of future victims, is the fundamental unknown in studies of human risks. An insurance actuary may know rather exactly the probability of death of a particular class of people, but a new insurance company could be bankrupt by the untimely death of its first client, hence the identity risk. Similarly, a person living adjacent to a facility that will cause cancer in 0.01% of the community may agree that the facility is acceptable to the society as a whole and yet move his family to another location. In contrast, the identity of the victim is not of concern in ecological risk analysis. Therefore, the statement that a particular facility will kill 30% of the fish in a receiving river is a deterministic statement of hazard or impact and does not constitute a statement of risk.

The other potential type of primary uncertainty is analytical uncertainty. Because of the uncertainty in the analysis (i.e., in estimating the level or frequency of effects) there is a risk that the effect will exceed some predefined threshold of acceptability. The probability density function for the predicted level of effect can be used to calculate the probability (i.e., risk) that a certain level of effect will occur, given the total uncertainty in the analysis. For example, due to the uncertainty in ecological risk analysis, a pollutant may pose a risk of 0.2 of a 30% reduction in game-fish biomass (an effect that may be both measurable and significant) even though the expected reduction in game-fish biomass is only 10% (an unmeasurable and probably insignificant effect).

While the availability of actuarial and epidemiological data makes analytical uncertainty a minor component of some human risk analysis, such uncertainty is invariably large in ecological analyses. There are no coroner's records for fish or birds. In addition, millions of species of nonhuman biota exist in a web of food-chain and competitive relationships that determine population sizes and effect toxic responses in ways that are largely unknown. Absolute predictions of the future state of ecological systems are not credible (Goldstein and Ricci 1981). The consideration of analytical uncertainty, which has been treated as an option in analyses of risks to humans (e.g., Hamilton 1980; Feagans and Biller 1981), is a necessity in ecological risk analysis.

3. SOURCES OF UNCERTAINTY

The analytical uncertainty associated with predicting environmental effects of stress has independent components that affect the calculation of risk in qualitatively different ways and that vary in the extent to which they can be reduced by additional information. We distinguish three sources of uncertainty: errors resulting from our conceptualizations (models) of the world, stochasticity in the natural world, and uncertainties associated with measuring model parameters. Model error corresponds to Rowe's (1977) descriptive uncertainty, and natural stochasticity and parameter uncertainty correspond to Rowe's measurement uncertainty, although our definitions are broader.

3.1. Model Error

Computing a risk estimate necessarily involves some sort of mathematical or statistical model. A reducible source of uncertainty is the lack of correspondence between model and reality. Major types of model error that have been studied are (a) using a small number of variables to represent a large number of complex phenomena [defined as aggregation error (O'Neill 1973)], (b) choosing incorrect functional forms for interactions among variables, and (c) setting inappropriate boundaries for the components of the world to be included in the model. Because the complexity of the natural world greatly exceeds our ability to model it, model errors can never be completely eliminated. The most serious problem associated with model error is that the errors frequently involve biases whose magnitudes and directions may be difficult to determine.

3.2. Natural Stochasticity

Although philosophers may argue whether the natural world is ultimately deterministic or stochastic, the question is of little practical interest. At all scales of resolution, spatial heterogeneity and temporal variability are characteristic of natural systems. For example, the concentration of a contaminant in air or water varies unpredictably in space and time because of essentially unpredictable variations in meteorological parameters such as precipitation and wind direction. The spatial and temporal distributions and sensitivities to stress of organisms in nature are similarly variable. Limits on the precision with which variable properties of the environment can be quantified define the upper limit of the precision with which it is possible to predict the ecological effects of a stressor. Out of the universe of similar environmental systems, a given percentage would be expected to show an effect. This percentage translates directly into an estimate of risk.

3.3. Parameter Uncertainty

Errors in parameter estimates introduce additional uncertainties into ecological risk estimates. Laboratory measurements of both the chemical and biological properties of hazardous chemicals are subject to (frequently unreported) errors. Many ecological variables are extraordinarily difficult to measure and can be estimated to only order-of-magnitude precision. Parameter values of interest often have not been measured and have to be estimated from structure-activity relationships (e.g., Kenaga and Goring 1980; Veith et al. 1983) or taxonomic correlations (e.g., Suter et al. 1983; Suter et al., in press; Calabrese 1984).

4. QUANTIFYING UNCERTAINTY

To varying degrees, it is possible to quantify all three types of uncertainty.

Stochasticity can be quantified for many characteristics of the physical environment. Long-term meteorological and hydrological records can be used to estimate probability distributions of wind speeds, streamflow rates, etc. Other variable aspects of the environment, including distributions, abundances, and sensitivities of organisms, are in principle quantifiable, although the necessary data are difficult and expensive to collect. As in all aspects of risk analysis, expert opinion can be employed when data are not sufficient.

Parameter uncertainties are also relatively easy to address. Parameter errors usually take the form of statistical distributions rather than biases. The parameters of these distributions can frequently be either calculated directly or realistically bounded, if proper data collection and reporting procedures have been followed. For experimentally measured parameters, such as LC_{50}'s and partition coefficients, a complete accounting of measurement error would include the variance between replications of an experiment within a laboratory, between laboratories using the same protocol, and, if appropriate, between protocols. More information concerning the magnitudes of these variances is becoming available from the protocol development and evaluation activities of the U.S. Environmental Protection Agency, the Organization of Economic Cooperation and Development, and the American Society for Testing and Materials (e.g., Lemke 1981), and has been incorporated in risk analysis methods (Suter et al., in press).

Parameter uncertainty also results from the use of regressions to extrapolate between available data and needed parameter values. Suter et al. (1983, in press) used a regression analysis to estimate the errors associated with extrapolation of acute LC_{50} values between species of fish and invertebrates and extrapolation of chronic toxic effects thresholds from LC_{50}'s. Similar analyses are possible for extrapolations among chemicals based on structure-activity relationships.

Model errors constitute the least tractable source of uncertainty in risk analysis. The most straightforward method is to test the model against independent field data (Miller and Little 1982). However, the data necessary to perform such tests are exceedingly difficult to collect and, when collected, are difficult to interpret. No matter how well a model performs for one set of environmental conditions, it is never possible to determine with certainty its applicability to a new set of conditions. Empirical testing, although crucial for improving the models used in risk analysis (Mankin et al. 1975; NRC 1981), is clearly unsuitable as a routine method of assessing model errors. However, it is still possible to evaluate model assumptions by comparisons of different models (Gardner et al. 1980). By comparing models that use different sets of assumptions, it is possible to assess how assumptions alter model output. Although this procedure does not ensure that model results will correspond to effects in the field, it can be used to distinguish between predictions that are robust to model assumptions and those that are highly sensitive to assumptions and hence susceptible to serious model errors (Gardner et al. 1980; Levins 1966).

5. IMPLICATIONS OF UNCERTAINTY

Relationships among the components of risk are illustrated in Fig. 2. Suppose we are interested in estimating the risk that the environmental concentration of a toxic contaminant will cause a valued species to fall below a specified threshold abundance. The dashed curve (Fig. 2a) is the "true" density function, determined by the intrinsic hazard of the contaminant and the stochasticity of the environment. The solid curve is the density function estimated using a risk model. The curve is shifted because of model error; its variance is increased because of parameter error.

Figure 2(b) presents the cumulative risk distributions for the density functions in Fig. 2(a). When the model distribution is shifted to the left, as shown in the figure, the model is conservative, predicting higher probabilities of risk than the "true" density

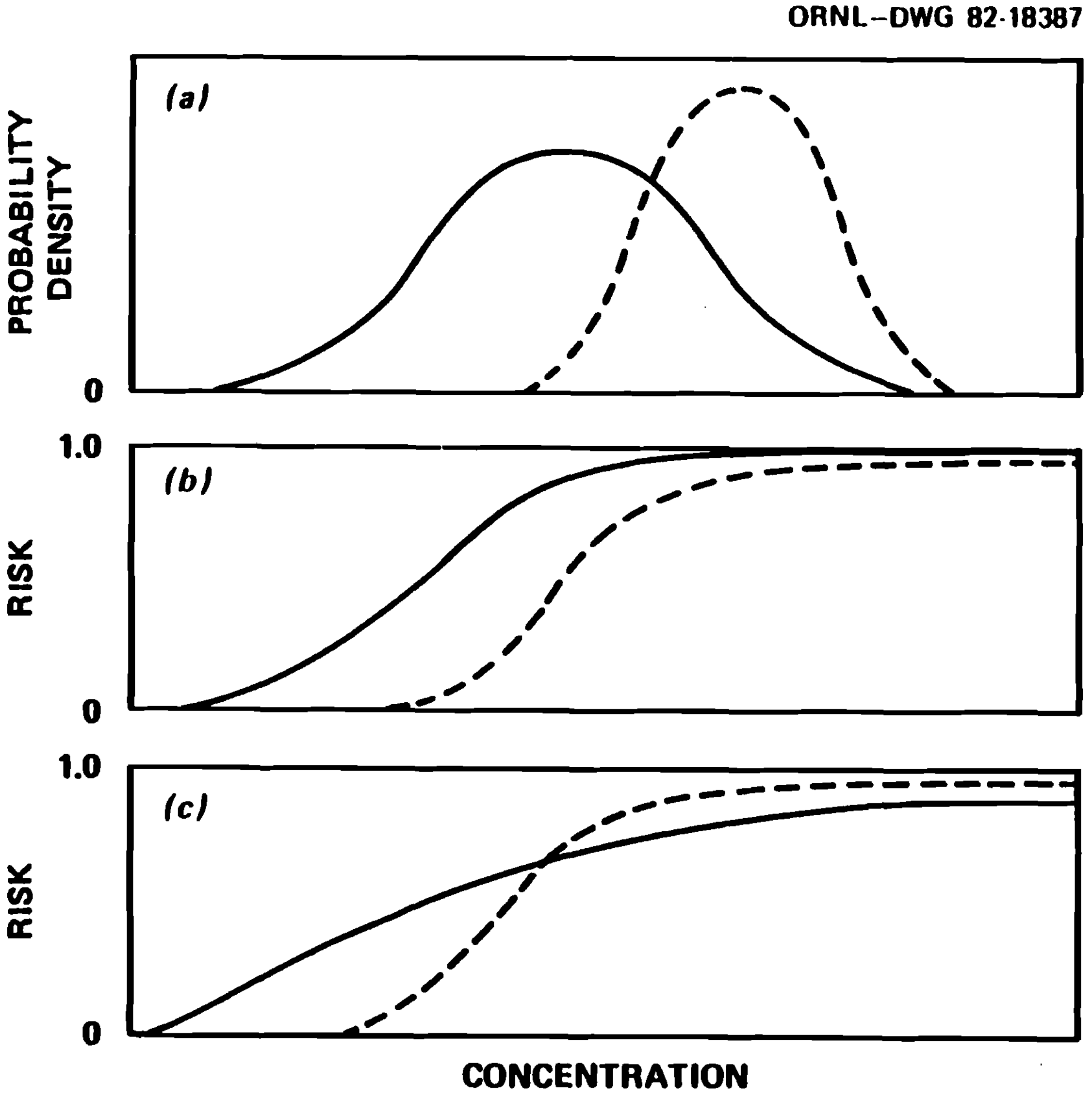

Figure 2 Relationships between true risk (dashed line) and estimated risk (solid line) as functions of concentration for a hypothetical environmental contaminant. Relative to true risk, the estimated risk density function (a) is shifted and its variance is increased because of model biases and parameter errors. Depending on the relative magnitudes of biases and errors, the cumulative estimated risk function corresponding to the density function in (a) may either overestimate true risk at all concentrations (b) or may overestimate true risk at low concentrations and underestimate it at high concentrations (c).

function. Unfortunately, it is often difficult or impossible to guarantee that the model distribution will be shifted to the left rather than to the right. In Fig. 2(c) we show the cumulative risk distributions when the risk model is conservative but the parameter error is very large. In this case, the risk model overestimates risk at low concentrations and underestimates risk at high concentrations. This result has real practical importance because increasing the complexity of a model is often viewed as a desirable goal. However, both disaggregating the variables and increasing the complexity of process functions increase the number of model parameters and the potential for parameter error. Therefore, increasing model complexity may increase the chance the model will underestimate the risk associated with high contaminant concentrations.

The relationship between model complexity and uncertainty is referred to by Rowe (1977) as the "information paradox." The more complex the model becomes (i.e., the more one knows about the structure of the world), the greater the uncertainty because of the greater number of parameters to be estimated, the greater number of stochastic processes that must be included, and the greater number of model functions. In general, the number of model parameters will increase exponentially with the number of environmental components explicitly included in the model; therefore, as model complexity increases, either the costs of testing and parameter measurement or the total uncertainty will quickly become excessive (Suter et al. 1985).

One conclusion that can be drawn from this is that assessment models should be as simple as possible while at the same time including the critical components and processes (Barnthouse et al. 1984). In many cases, simpler models will tend to be conservative. A complete model of effects of toxic chemicals on game-fish biomass would include ecosystem-level effects caused by food-chain interactions and population processes such as density-dependent mortality. Alternatively, one could perform the assessment at the individual level of organization, protecting game-fish biomass by estimating (using taxonomic distributions of sensitivity) a toxicant concentration that would be nontoxic to all of the organisms in the system. The individual-level assessment would have less uncertainty because interactions do not have to be modeled, but it would be conservative because population and ecosystem processes, such as prey switching and compensatory mortality, can compensate for toxic effects. However, this reduced uncertainty is obtained by changing the assessment to a less ambitious form--the prevention of direct toxic effects rather than the prevention of a particular level of combined direct and indirect effects. Similarly, most simplifications of chemical fate models are conservative because they ignore removal processes such as biodegradation or photodegradation for which rates are typically unknown. However, it is not always possible to simplify assessment models in such a way as to be conservative. For example, models of acid rain effects on fish cannot ignore cation leaching from watersheds.

6. USES OF RISK ANALYSIS

It is not usually possible to accurately predict the levels of environmental effects caused by man's activities. However, without prediction of absolute magnitudes of effects, application of the concept of risk can lead to substantial improvements in environmental assessment and protection. By (1) emphasizing probabilities and frequencies of events and (2) explicitly quantifying uncertainty, risk analysis can provide a more rational basis for decisions that may otherwise be highly subjective.

Risk analyses can be applied to evaluating compliance with environmental standards. Frequency distributions of ambient contaminant concentrations can, for example, be used to forecast water quality impacts. For any given benchmark concentration (e.g., an ambient air or water quality criterion), the probability of exceeding the benchmark can be read from the cumulative distribution function in Fig. 3(a). The presentation of such functions would enhance the quality of environmental impact assessments, which frequently are based on worst-case analyses in which the probability of occurrence of the worst case is not considered. Alternatively, the benchmark concentration might be the level above which contaminant discharge would not be permitted. In this case, a curve similar to that in Fig. 3(a) might be used to estimate the frequency of days on which action would have to be taken. Probabilistic models (e.g., Parkhurst et al. 1981; Barnthouse, in press) would be used to generate the curves. The models should include estimates of both variability in relevant environmental parameters and uncertainty in contaminant-specific parameters such as partition coefficients and degradation rates.

Risk analysis can also be used to set standards based on probabilities of exceeding effects thresholds. Suter et al. (1983, in press) described a method for calculating probability distributions for toxicological benchmarks such as LC_{50}'s and chronic-effects thresholds. Such a distribution, plotted as a cumulative probability function, is

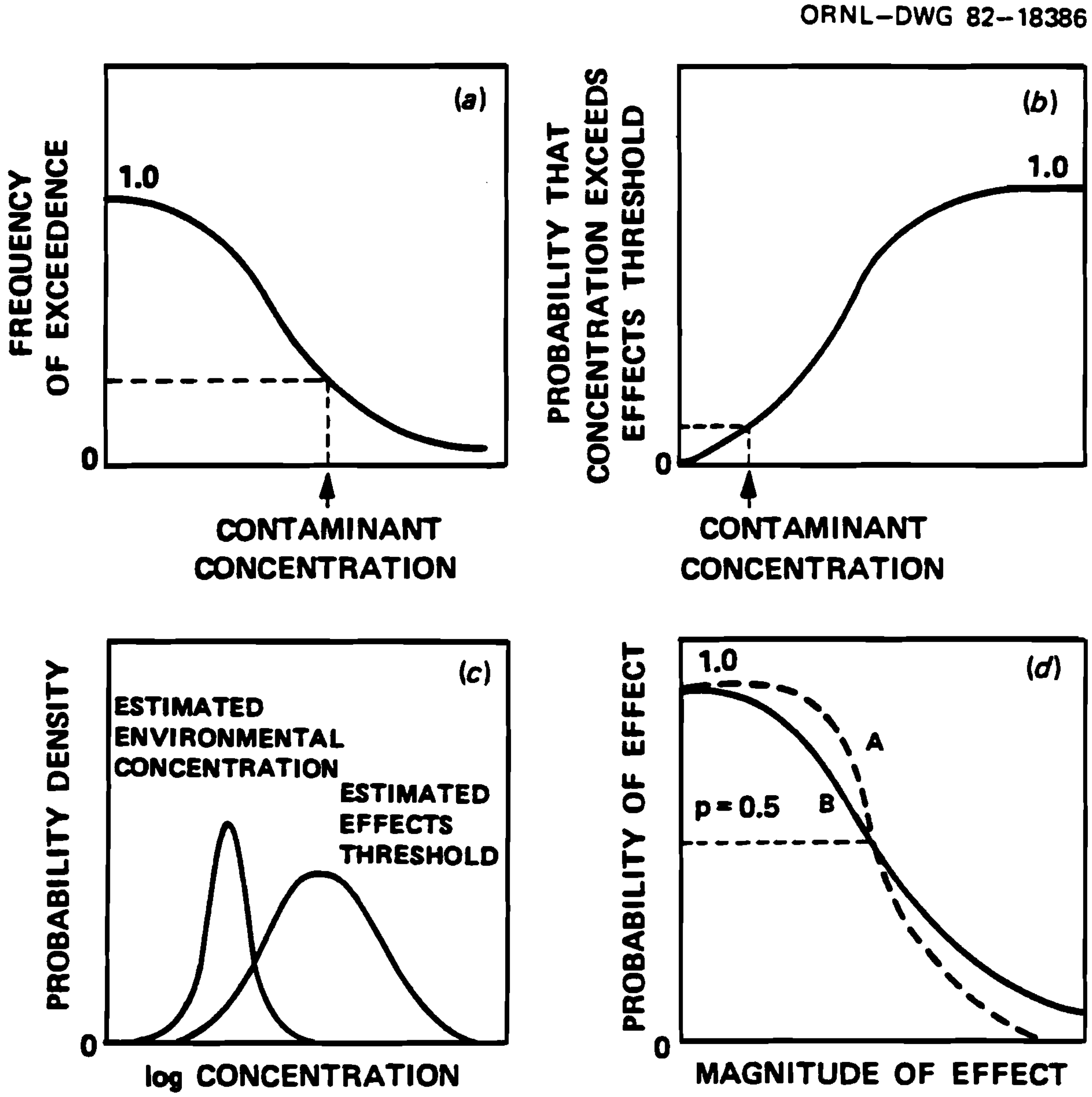

Figure 3 Four applications of ecological risk functions. In (a), a cumulative frequency function is used to estimate the frequency with which the environmental concentration of a contaminant will exceed an "action" concentration. In (b), a cumulative probability function for the effects threshold concentration of a hypotehtical organism is used to select an action concentration of a hypotehtical organism is used to select an action concentration with an X% chance of exceeding the true effects threshold. In (c), probability density functions for two components of a risk estimate are compared to identify the component with the greater uncertainty. In (d), the risks of adverse effects of different magnitudes are compared for two alternative facility designs (A and B). The expected effects of the two alternatives are the same, but alternative B presents greater risks of severe adverse effects.

presented in Fig. 3(b). Using this curve, the allowable ambient concentration might be set so that the risk of exceeding the threshold level is 5%. Figure 3(b) could also be used to define the decision points in tiered hazard assessment schemes.

Another major application of risk analysis is in allocating research effort to maximize the uncertainty reduction per dollar invested in research related to ecological hazards. If the contributions to total uncertainty of several different components of a risk estimate can be compared, then research effort can be concentrated on the component(s) contributing the greatest uncertainty. For example, in Fig. 3(c), uncertainty about the environmental concentration of a toxic contaminant is compared to uncertainty concerning its effects threshold. The relative variances of the two distributions correspond roughly to those estimated by Suter et al. (1983) for largemouth bass exposed to mercury released from a hypothetical indirect coal liquefaction plant. Additional relevant data would decrease the spread of these curves. The predicted reduction in overlap between the curves could be used as a measure of the value of the data.

Decisions concerning alternative plant sites and mitigating technologies can also be facilitated by using risk curves such as those shown in Fig. 3(d). Such curves provide information about both the expected effects of an action (e.g., building a plant or licensing a chemical) and the risk of extremely large effects.

More sophisticated applications of risk analysis to environmental decision making are also possible. For example, Fig. 4 presents a decision tree comparing two alternate courses of action for a decision

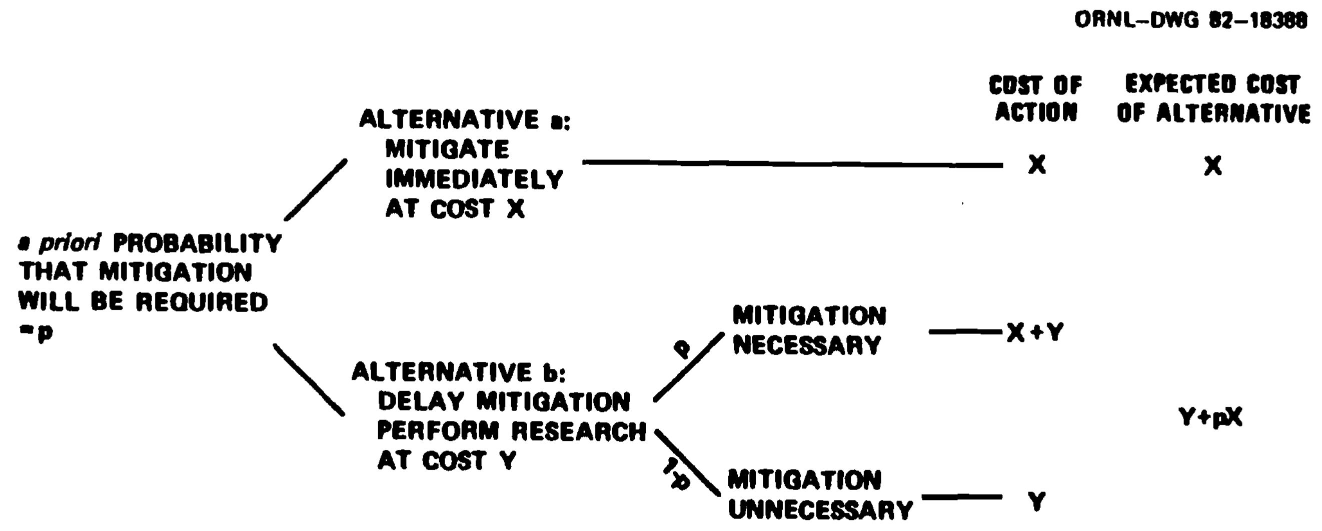

Figure 4 A risk estimate used as a component of a decision analysis regarding a potential environmental impact. Whether it is economical to delay mitigation while performing research concerning the potential impact depends on the *a priori* probability (p), estimated using a risk model, that research will show mitigation to be necessary.

maker confronted with a potential environmental problem. It has been estimated, using a risk model, that the probability is p that the environmental impact of some industrial facility is serious enough to require mitigation. The decision maker has a choice of ordering immediate mitigation, at cost X, or of delaying mitigation while a research program, at cost Y, is performed to eliminate the uncertainty about whether mitigation is necessary. Whether it would be economical to delay mitigation depends on the cost of the research relative to the cost of mitigating and on the a priori probability (p) that, following research, mitigation will still be necessary.

7. EXAMPLES

7.1. Industrial Effluents

The effluents from the proposed synfuels industry present a particular challenge to environmental assessment because their composition is only roughly predictable and is expected to be highly complex. The U.S. Environmental Protection Agency's Synfuels Risk Analysis Program developed risk assessment methods and applied them to the problem of research prioritization for the anticipated industry (Barnthouse et al. 1985; Suter et al. 1984). Effluent streams and components were identified as being in need of additional research if they appeared to pose a significant hazard and their environmental behavior was in some way poorly specified. Risk assessment provided a means of simultaneously identifying the relative hazard and the uncertainty associated with the effluent components.

Effluent compositions were defined in terms of chemical classes to minimize the effluent characterization problem and to reduce the assessment task to a manageable scale. The need for consideration of the effluent toxicities was established by using an additivity model to estimate the acute toxicity of the whole effluents from the toxicities of their component chemical classes. Only one of the effluents was predicted to be acutely toxic, but all effluents had sufficiently high toxicity and uncertainty concerning their actual effects to justify additional research. Some specific research needs were immediately identifiable because certain categories of chemicals for which no environmental toxicity data were available (such as nitroaromatics) were expected to occur in the effluents. Some categories, such as ammonia and cadmium, contributed significantly to aquatic toxicity but, because they are well studied and narrowly defined, the uncertainty concerning their effects is relatively small. Of the chemical classes that have some aquatic toxicity data, only the phenolics had both the high apparent hazard and the high uncertainty that would justify additional research.

7.2. Acid Deposition

The issue of acid deposition involves a variety of complex processes operating at scales ranging from the organismal to the continental. The following two examples show how the issue can be made more manageable by broadly defining the problems and emphasizing uncertainty.

Morgan et al. (1985) considered the problem of health effects of sulfate aerosols. They independently elicited models and judgments concerning parameterization and uncertainty from experts on atmospheric processes and health effects. These were used to generate probability density functions on estimated sulfate exposure and effects. They found that the uncertainty concerning exposure was relatively small because atmospheric scientists have relatively well-developed models which were well supported. In contrast, there was little agreement about models or assumptions among the health effects experts. The results of this exercise provide estimates of effects from a single coal-fired plant that range from 0 to a few thousand excess deaths per year. More clearly, they indicate that further research in atmospheric science would contribute little to improving the estimates of health effects.

The hypothesized effects of acid deposition on forests have raised considerable controversy because effects mechanisms are not understood and because field studies at different sites provide apparently conflicting evidence. Dale and Gardner (submitted) used a forest stand model to examine the implications for forest production of different assumptions about the level and distribution of effects. Uncertainty analysis of the model showed that a given level of direct effects on growth rates of individual trees could cause widely varying decrements in stand productivity, depending on the initial size distributions of the species. Their results suggest that standard regional forestry statistics may not reveal effects on growth and that attention must be directed to critical size classes and species.

7.3. Engineered Organisms

Engineered organisms potentially constitute the most difficult problem facing environmental assessment. Although some of the techniques developed for assessment of toxic chemicals are also applicable to novel organisms, the fact that organisms reproduce, evolve, and have specific habitat requirements complicates the problem of predicting their fate and effects. Because the field is new and the number of organisms to be assessed is small, assessments have not used risk analysis. Rather they have relied on the informal judgments of expert panels. However, because of the overconfidence of experts (Fischoff et al. 1981), the inconsistency of ad hoc procedures, and the eventual need to assess hundreds or thousands of new organisms per year, formal assessment procedures must eventually be developed. Because of the less predictable behavior of organisms and the fact that their reproductive capability allows them to persist indefinitely, it is particularly important that assessment of organisms include explicit treatment of uncertainty.

Suter (in press) presented a conceptual framework for environmental risk analysis of engineered organisms. Major sources of uncertainty include the probabilities of movement between habitats, colonization of new habitat, pathogenicity by a nominally free-living organism, extension of a pathogen's host range to non target species, disruption of ecosystem processes, exchange of genetic material between organisms, and evolution that reduces constraints on the organisms behavior. Because of the specificity of habitat requirements, it is difficult to generalize from tests of the persistence or effects of an organism in a particular system. A bacterium that goes extinct in one soil may proliferate in a soil one meter away. Therefore, it would be naive to accept test results as predictors of the environmental behavior of organisms as is usually done for chemicals. Only a risk-based assessment strategy will be capable of dealing with this problem in an appropriate manner.

8. CONCLUSIONS AND RECOMMENDATIONS

Risk analysis, because of its explicit treatment of uncertainty, provides two significant benefits for environmental impact assessment. The first is that it eliminates the need for worst-case scenarios and analyses by providing probability densities on the expected effect that can be used to estimate the probability of any worse effect. Worst-case analyses are often unrealistic and, because there is no absolute worst case and no scale of badness, they should not be used to compare alternative actions. The second advantage is that it provides an objective means of deciding, based on reduction in uncertainty, what research would most improve the assessment.

Regardless of its intellectual appeal, environmental risk analysis will soon be forgotten unless the concepts can be translated into operational techniques. Steps in this direction have already been taken (Barnthouse and Suter, in press). Most of the necessary components of operational risk analysis methodologies (e.g., air and water quality models, ecological effects models, and toxicological data bases) already exist. The only constraints on the usefulness of existing models and data are that (1) the models must be modified so that output can be expressed in probabilistic terms, and (2) error variances in experimental studies and in data extrapolations must be reported so that parameter uncertainties can be quantified.

As in other types of risk analyses, the most difficult problem facing the environmental risk analyst is that of demonstrating that his risk model provides reasonable estimates of ecological risks in the real world. At least for environmental contaminants, many of the same physical, chemical, and biological processes underly both ecological and human health risks. Thus, progress made in one field can directly benefit the other.

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RISK ASSESSMENTS FOR ENERGY SYSTEMS AND ROLE OF PRELIMINARY DEGREE-OF-HAZARD EVALUATIONS

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1 INTRODUCTION

Risk assessment can be defined broadly as the process of developing qualitative and quantitative information on the health, safety, and environmental risks of technological systems, which can then be weighed against the perceived benefits of the systems. Through a variety of direct and indirect legal, institutional, and economic mechanisms, societies use these assessments to accept or reject deployment of these systems or to place constraints on their operation. Many examples exist of the constraints societies have placed on technologies, based on evaluations of associated risks. These examples range from limits on the speed at which automobiles are driven and constraints on the use of pesticides, to requirements for elaborate safety devices for nuclear power plants.

Three conceptually different, but interrelated, processes of risk assessment and their contribution to public decision making are discussed in this paper. These processes and their interrelationships are illustrated using applications to the risk assessment of energy systems.

At the most comprehensive level of technology assessment, illustrated in Sec. 2, the cumulative risks associated with a range of energy technology alternatives are estimated. These assessments provide input to decisions to continue or redirect research and development of these technologies.

Another major focus of risk assessment is the detailed evaluation of more narrowly defined risks, such as those associated with a single pollutant or activity that is part of the overall technology. These component risk assessments, illustrated in Sec. 3, support the broader technology assessments and also provide input to decisions on the need to prescribe specific controls on the source of the risk under consideration.

As the level of scientific and public awareness of the range of hazards presented by an increasingly technological society continues to expand rapidly, the ability to accurately quantify all identified potential risks decreases. Thus, the need is growing for procedures to set priorities in choosing to conduct certain resource-extensive technology assessments or component risk assessments. Section 4 discusses a priority-setting, or degree-of-hazard, screening procedure being used at Argonne National Laboratory to support more quantitative risk assessments.

2 COMPARATIVE ASSESSMENTS OF ENERGY TECHNOLOGIES

As an example of the application of risk assessment at the broadest level used for decision making on major technology alternatives, an overview is provided of a study conducted at Argonne National Laboratory to evaluate the health and safety risks of seven electrical generation systems having potential for deployment after the year 2000.[1] The systems were compared on the basis of expected public and occupational deaths and lost workdays associated with average generation of 1000 MW(e) per year. Risks and associated uncertainties were estimated for all phases of the energy production cycle, including the risks of direct and indirect component manufacture and materials production and energy inputs, all of which are major contributors to the risks of the more capital intensive solar technologies. The potential significance of the major health and safety issues that remain largely unquantifiable is also considered.

The technologies assessed included (1) a light-water fission reactor system without fuel reprocessing (LWR), (2) a low-Btu coal gasification system with an open-cycle gas turbine combined with a steam topping cycle (CG/CC), (3) a liquid-metal fast breeder fission reactor system (LMFBR), (4) a central-station terrestrial photovoltaic system (CTPV), (5) a decentralized "roof-top" photovoltaic system with a 6 kW(e) peak capacity and battery storage (DTPV), (6) a satellite power system (SPS) having a large array of photovoltaic collectors in earth orbit and using a microwave beam to direct electrical energy to a terrestrial antenna, and (7) a first-generation fusion system (Fusion) with magnetic confinement. Table 1 gives the basic design parameters for the seven systems.

Detailed descriptions of the alternative generation systems were compiled on a consistent basis for comparison.[2,3] The design of the coal system with low-Btu gasification was based on an SO_2 emission factor of 86 kg $SO_2/10^{12}$ J for gas or 140 kg $SO_2/10^{12}$ J for coal. The light-water reactor considered was typical of U.S. commercial designs using enriched uranium without reprocessing. The fusion system was based on a preliminary design using a tokamak reactor with a deuterium/tritium fuel cycle. Silicon photovoltaic cells, at an array cost of $\$35/m^2$, were assigned to each of the solar energy systems. The design of the decentralized solar energy system included 20 kWh(e) of storage capacity and advanced lead-acid batteries with a 10-year lifetime. System storage and utility system backup were not included for any of the other systems.

From the technology characterizations and other related information, all major known and potential health and safety issues that could be unambiguously defined and discussed were identified. Each segment of the energy cycle was considered, including component fabrication, plant construction, fuel extraction and processing, operation and maintenance, and waste disposal. Table 2 summarizes estimated fatalities per year per 1000 MW(e) of average generation.

A range of estimated impacts was included in each quantification, reflecting the uncertainty associated with the magnitude of impact. For some potential health and safety issues, it was not possible to provide any quantification. Estimation of risk magnitudes for these issues was limited to qualitative discussion of potential severity or possible mechanisms for occurrence of the risk because of a lack of information in such areas as dose-response relationships at low-dose levels, siting patterns, populations exposed, uncertainties regarding probability of event occurrence, and characterizations of advanced technologies.

Compared to the more conventional coal and fission technologies, the advanced solar and fusion technologies present a tradeoff between reduced fuel requirements and

TABLE 1 Major Characteristics of the Seven Electrical Generation Technologies

Characteristic	LWR	CG/CC	LMFBR	CTPV	DTPV	SPS	Fusion
Unit capacity (MWe)	1250	1250	1250	200	0.0006	5000	1320
Total direct commodity cost per unit ($\$10^6$)[a]	333.7	356.2	535.2	90.1	0.00717	13,421	1253.8
Average annual load factor (%)	70	70	70	25.8	12.2	90	70
Indirect capital cost per unit ($\$10^6$)[b]	197.1	132.7	262.6	20.0	-	-	628.6
On-site construction labor per unit (10^6 person-hr)	13.1	15.2	14.5	1.7	0.6×10^{-6}	c	22.1

[a] Delivered costs for components, structures, and materials. Land and labor costs excluded. Values are given in 1978 dollars.

[b] Temporary site construction facilities, payroll insurance and taxes, and other construction services such as home and field office expenses, field job supervision, and engineering services. Specifically excluded are fees for permits, taxes, interest on capital, and price escalation. Values are given in 1978 dollars.

[c] Receiving antenna -- 15.0; construction in orbit -- 0.7; launch-area maintenance -- 4.2; and launch-area operations -- 2.8.

TABLE 2 Summary of Quantified Average Fatalities per Year per 1000-MW(e) Generation, 30-Year Plant Lifetime

Characteristic	LWR	Coal (CG/CC)	LMFBR	CTPV	DTPV	SPS	Fusion
Total	0.26-1.4	6.6-79	0.24-1.1	0.43-0.73	1.92-4.4	0.26-0.67	0.22-0.44
Population affected							
Public	0.03-0.18	5.4-76	0.03-0.18	U[a]	U	U	0.0001
Occupational	0.24-1.2	1.3-3.1	0.21-0.94	0.43-0.73	1.92-4.39	0.26-0.67	0.22-0.44
Impact period							
Manufacture and construction[b]	0.10-0.16	0.11-0.18	0.12-0.20	0.31-0.55	1.04-1.94	0.19-0.55	0.16-0.38
Operation and maintenance	0.16-1.2	6.5-79	0.12-0.92	0.12-0.18	0.88-2.45	0.07-0.12	0.03-0.06
Impact cause							
Accidents and nonradiation disease	0.21-0.67	6.6-79	0.17-0.51	0.43-0.73	1.9-4.4	0.26-0.67	0.22-0.44
Radiation	0.05-0.70	0.0023	0.07-0.61	U	U	U	U

[a] U -- Unknown or negligible.

[b] Total impacts averaged over 30-year plant lifetime.

higher initial capital and construction requirements. Furthermore, the industries producing the energy system components in turn require certain commodity inputs (e.g., copper for electrical equipment), and the risks associated with the production of these indirect requirements must be considered in the overall risk analysis.

The analysis indicated that for every $\$10^6$ of direct industrial output required to supply system components to each of the energy systems considered, a combined indirect output of $\$0.5-0.9 \times 10^6$ is required from other industries.

The procedure for estimating direct and indirect occupational risks of commodity production contains various uncertainties, including use of U.S. Bureau of Labor Statistics data for occupational injury and illness.[4] Although these data are considered the best available for these factors, they reflect large error bounds because of underreporting and misdiagnosis. In particular, these statistics do not adequately reflect chronic disease. Other areas where large uncertainties may exist include the use of the historic input-output structure of the economy to estimate indirect requirements for facilities to be constructed after 2000, plant construction requirements, potential changes in employee productivity, and potential changes in risk levels per worker.

Table 2 does not include the risk from production of energy used in component manufacturing. The electrical energy requirement for direct and indirect component manufacture for the coal and nuclear systems is equivalent to a small fraction of the equivalent energy produced in one year of operation of those systems. On the other hand, the input energy for component manufacture for the centralized and decentralized photovoltaic systems is equivalent to 2.8 years and 6.5 years of output, respectively, from these systems. These large "energy-payback-time" estimates can in large part be attributed to the electrical energy requirements for production of silicon photovoltaic cells.[5] The risks associated with production of this quantity of electrical energy are highly dependent on the generation technology assumed.

Of the various systems considered, the coal technology has the largest overall quantified risk, primarily due to coal extraction, processing and transport, and air-pollutant emissions, although large uncertainties remain in the actual effect of the air pollution, as is discussed in the following section. The decentralized photovoltaic system has large associated risks because of the large labor and material requirements of small, dispersed units. The quantified risks from the remaining technologies (fission, fusion, satellite, and centralized terrestrial photovoltaic) are comparable, within the range of quantified uncertainty. The occupational risks for component production, both direct and indirect, are a substantial fraction of the total risks, but particularly for the advanced, capital-intensive solar and fusion technologies. The energy requirements for component production can also be associated with substantial risks, depending on the source of energy.

Table 3 lists the potentially major issues not quantified in this study. Of potential significance as far as public acceptance of new energy systems, but not included in the quantification, is the possibility of catastrophic incidents associated with the fission and fusion systems. Unique unquantified issues of concern also exist for the satellite system related to the use of microwave transmission of energy and extensive

TABLE 3 Potentially Major Unquantified Issues

Solar technologies (CTPV, DTPV, SPS)	Nuclear technologies (LWR, LMFBR, fusion)
Exposure to emissions associated with the production of photovoltaic cells	Major public radiation exposure related to system failure
Exposure to hazardous wastes from the disposal or recycling of photovoltaic cell materials	Occupational exposure to chemically toxic materials that are part of the fuel cycle
Chronic low-level exposure of large populations to microwaves (SPS only)	Diversion of fuel or by-products for military or subversive uses (LWR and LMFBR only)
Crash of space vehicle into an urban area (SPS only)	Liquid-metal fire (LMFBR and fusion only)
Exposure to emissions from launch vehicles (SPS only)	
	Coal technologies
	Long-term effects of CO_2 emissions
	All technologies
	Long-term effects of by-product solid wastes

space travel. For each of the energy technologies, the long-term impact of by-product waste disposal remains largely unquantified.

In general, the more defined technologies (e.g., CG/CC and LWR) have more quantifiable risks and fewer unquantifiable risks. The opposite is true for the less-defined technologies (e.g., fusion and SPS). Table 3 does not rank the unquantified issues; however, the potential for radiation release from fission is probably greater than that from fusion, for example.

3 RISK ASSESSMENTS OF TECHNOLOGY SYSTEM COMPONENTS

An objective of the overall technology assessments of the sort illustrated in Sec. 2 is identification of the system components that contribute significantly to total risk. A frequent sequel to this type of assessment is the more detailed evaluation of major risk components, including the development of a more complete understanding of the uncertainties. Depending on the setting for the analysis, this more detailed component risk assessment can be used, for example, to develop regulatory guidelines, to obtain a better understanding of the source of risks, or to establish the need to consider other overall technology systems.

Detailed assessments of narrowly defined components of technology risk (e.g., from a single pollutant or waste stream) are also frequently called for in the face of large cumulative risk from many sources. However, a potential problem with isolated component risk assessments within an overall system is that reduction of one risk (e.g., air pollutants) may exacerbate other risks (e.g., solid waste disposal). It is frequently the case, therefore, that regulatory mechanisms require individual consideration of many potential risk components.

This section illustrates a risk assessment constrained to consider a narrow component of the overall risks of a nuclear-fueled electrical generation system. The risks evaluated were those associated with the atmospheric release of coal-combustion particulates from a power plant supplying the electrical energy required to produce the annual average nuclear fuel requirements of a 1000-MW(e) light-water reactor.[6] This case study is a clear example of the utility of risk assessments in regulatory proceedings. The results of the analysis, which were in response to a legal ruling, were presented as part of the public testimony regarding the licensing of the Harris nuclear power plant in the U.S.

The exposure analysis conducted in this risk assessment included characterizing the particulate emissions from three existing coal-fired power plants generating electricity for use in uranium gaseous diffusion plants. A dispersion model was used to estimate resulting ambient concentrations of particulates within an 80-km radius of the emission source. Population exposures from these concentrations were based on the surrounding population distributions obtained through the U.S. Bureau of the Census. The ambient concentrations of those particulates associated with production of fuel for the reference power plant were estimated to be less than 0.015 $\mu m/m^3$ for the annual average and less than 0.75 $\mu g/m^3$ for the 24-hour maximum.

Various morbidity and mortality health outcomes from the population exposure were considered, including both chronic and acute effects.* Data from respiratory disease incidents and hospital respiratory disease emergency admissions[7,8] were the basis for morbidity health effects analysis. For chronic morbidity, data on chronic respiratory disease prevalence were considered,[9,10] but were determined not to be applicable to the conditions present in this case study.

To quantify the acute and chronic exposure mortality effects of airborne particles, mortality coefficients derived from time-series and cross-sectional analysis reported by Harvard University[11,12] and Mathtech, Inc.,[13] were chosen. In addition, upgraded cross-sectional mortality analysis was analyzed using the 1980 census and vital statistics data in conjunction with data for the same period on fine particles with aerodynamic diameters smaller than 2.5 μm.

Table 4 gives the range of estimated cumulative health effects within the 80-km radius. Both in terms of absolute numbers and in terms of relative proportions compared to baseline health impacts in the areas analyzed, the projected impacts are very small. Furthermore, the concentrations and health impacts are so small that they could not even be detected with state-of-the-art monitoring, survey-design, and analysis techniques.

Although the assessment was limited to a very narrow issue, it illustrates a direct application of risk assessment in formal regulatory proceedings. In this and other similar applications, careful analysis and clear interpretation of levels of uncertainty are needed to avoid misuse of the results.

4 PRELIMINARY DEGREE-OF-HAZARD EVALUATIONS

Ideally, detailed risk assessments that include quantitative evaluation of uncertainty levels should be performed for each risk component of any energy (or other technological) system being considered as an alternative for introduction or increased deployment. Section 4 discusses a proposed procedure for preliminary hazard evaluation for use in situations where more detailed and quantitative evaluations of risk components are not feasible for various reasons.

Such comprehensive risk assessments are not feasible, for example, when many potential risk components have been identified and the requisite resources and data are not available to evaluate each one in detail within the required time limit. This situation clearly exists with regard to the chemical by-products produced in modern technical societies. The number of such by-products is rapidly increasing, and the growing awareness of the potential risks at chronic low levels of exposure requires evaluation of pollutants formerly thought to be of little concern.

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*Acute (respiratory) morbidity indicates short-term illnesses such as pneumonia, influenza, and common coughs, while chronic (respiratory) morbidity indicates persistent long-term illnesses such as chronic bronchitis, bronchial asthma, or other obstructive lung disease.

TABLE 4 Uncertainty Limits (95% confidence) for the Projected Health Effects from Combustion Particulates from a Coal-Fired Power Plant Providing the Electrical Energy Required to Produce Fuel for a 1000-MW(e) Nuclear Power Plant

Acute Morbidity Effects		Mortality Effects	
Annual Number Emergency Room Visits for Respiratory Disease	Annual Number Acute Respiratory Disease Incidents	Daily Mortality[a]	Annual Mortality
0-1.0	0-17	0.4×10^{-5} -2.5×10^{-5}	0-0.05

[a] The possibility of zero as a lower limit is included when nonsampling errors are included, that is, errors caused by confounding factors and collinearities with other pollutants.

With respect to energy systems, a new class of trace organic and inorganic pollutants, as well as their transport in air, surface waters, groundwaters, and soil media, has been the subject of intense investigation. Because of the large number of these potentially harmful pollutants, a procedure was needed for initial ranking of substances on the basis of limited, but readily accessible, information. With such a procedure, resources for detailed studies could be allocated to the substances that are most likely to pose the greatest health impact. These substances will have the greatest probability of future requirements for regulation or testing.

To meet this need, the Multi-Attribute Hazard Assessment System (MAHAS) was developed by Argonne National Laboratory. It assigns the degree of hazard associated with multi-constituent waste streams produced by various energy technologies. The waste stream degree of hazard (DOH) is based on the toxicological and physiochemical properties of each stream's constituents.[14] MAHAS first calculates the DOH of constituents using a scoring procedure that considers available information on the following six factors: oncogenicity, mutagenicity, reproductive and developmental toxicity, acute lethality, effects other than acute lethality, and bioaccumulation.

MAHAS then develops scores for each of these factors based on 5 to 13 criteria selected on the basis of judgments from experts in relevant disciplines. The criteria for oncogenicity are given, as an example, in Table 5. An artifact of this system is that chemicals about which little is known will have low DOH values. To compensate for this, the "no data" entries for each chemical are flagged. The number of flagged entries is then used as a measure of the uncertainty of the DOH for a given constituent.

MAHAS then calculates the DOH of a constituent by proceeding through three levels, beginning with the most detailed level and aggregating at successive levels to provide a final score for each substance. The most detailed level scores substances on each of the six factors. At the second level, the scores of closely related factors are combined into group scores. For example, oncogenicity and mutagenicity are combined to form the Carcinogenicity Group, while acute lethality and effects other than acute lethality are combined to form the Toxicity Group. Finally, the group scores are combined to give the overall DOH of the constituent.

The final step in a MAHAS analysis is to determine the DOH for a mixture of waste-stream constituents. However, few data exist on the toxicity of various waste streams or chemical mixtures. Furthermore, little quantitative information is available on the potential interactions among waste-stream components. For these reasons, the effects of such waste-stream constituents are assumed to be additive, with a weighting based on the mass fraction of each constituent.

An inherent aspect of any risk or DOH assessment is the need to use large amounts of data. The information necessary to complete a MAHAS analysis can be gathered from seven basic references. Toxicological information and some physical and structural properties are obtained from the Toxicological Data Bank.[15] The status of compounds within the National Toxicological Program (NTP) is available from the NTP Carcinogenesis Testing Program list of chemicals on standard protocol[16] or NTP's annual plan.[17] The state of the matter (solid, liquid, or gas) and its vapor pressure are obtained either from the *Merck Index*[18] or the *CRC Handbook of Chemistry and Physics*,[19] while

TABLE 5 Criteria for Oncogenicity[a]

Index	Criteria
1	Evidence of oncogenicity in humans by oral or inhalation route
2	Evidence of oncogenicity in humans by other than oral or inhalation route
3	Evidence of oncogenicity in two or more animal species by any route of administration[b]
4	Evidence on oncogenicity in one animal species by any route of administration[b]
5	Compound scheduled for or currently undergoing oncogenicity testing
6	Negative or equivocal results from oncogenicity testing
8	No data

[a] Most of the available data will relate to carcinogenicity.

[b] If the data satisfy the criteria for index 3, index 4 should not be considered.

octanol/water partition coefficients are from Leo et al.[20] Waste-stream data can be obtained from many sources; however, much of this information is from the U.S. Environmental Protection Agency's waste-stream data base.[21]

Currently, information is available on more than 200 waste steams; physiochemical and toxicological data are available on over 100 chemical constituents. These data have been computerized to facilitate rapid analysis of a given waste stream.

Table 6 illustrates DOH scores obtained using the MAHAS procedure for selected waste streams, including several related to energy technologies. Such results have been used at Argonne National Laboratory to provide direction concerning development of detailed risk assessments for a much narrower range of waste streams. Also, an earlier version of MAHAS dealing with inhalation routes only[25] has been used by the U.S. Environmental Protection Agency to identify toxic air pollutants for further review as a possible prelude to regulatory actions.

However, results such as those illustrated in Table 6 have limited usefulness in public debates on the need for regulatory action or the selection of alternative technologies on the basis of risk. The level of uncertainty associated with relative rankings provided by the MAHAS procedure can only be discussed qualitatively. MAHAS is best applied in support of the detailed assessments discussed in Secs. 2 and 3.

5 SUMMARY AND CONCLUSIONS

The appropriate approach to risk or hazard assessment can vary considerably, depending on various factors, including the intended application of the results and the time and other resources available to conduct the assessment. This paper illustrates three types of interrelated assessments. Although they can be mutually supportive, they have fundamentally different objectives, which require major differences in approach. The example of the overall risk assessment of alternative major energy technologies illustrates the compilation of a wide range of available risk data applicable to these systems. However, major uncertainties exist in the assessments, and public perception of their importance could play an important role in final system evaluations.

A more narrowly defined risk assessment, often focusing on an individual component of a larger system, is the most commonly used approach in regulatory applications. The narrow scope allows in-depth analysis of risks and associated uncertainties, but it may also contribute to a loss of perspective on the magnitude of the assessed risk relative to that of the unassessed risks.

In some applications, it is useful to conduct semiquantitative degree-of-hazard evaluations as a means of setting priorities for detailed risk assessment. The MAHAS procedure described in this paper provides a means of rapidly ranking relative hazards from various sources using easily accessible data. However, these rankings should not be used as definitive input for selecting technology alternatives or developing regulations.

TABLE 6 Selected MAHAS Degree-of-Hazard Rankings for Selected Waste Streams

Waste Stream	DOH Range	DOH Median
Energy production waste streams[a]		
Geothermal brine	0-19	6
Wet flue gas desulfurization sludge	0-43	5
Coal combustion ash (all types and geographic regions)	0-96	21
Eastern coal ash (all types)	4-88	25
Midwestern coal ash	7-82	32
Western coal ash (all types)	1-58	25
Bottom ash (all regions)	0-59	13
Mechanical hopper ash (all regions)		
Fly ash (all regions)	1-96	23
Oil combustion bottom ash	3-6,200	-
Oil combustion fly ash	497	-
Oil rerefining industry waste streams[b]		
Used oil[c]	-	290
Waste bio-sludge	-	0
API separator sludge	-	4
Spent clay	-	5,500
Acid tar	-	3,900
Caustic sludge	-	9,100
Spent solvent and still bottoms from solvent recovery[b]		
Dichloromethane spent solvent	-	150,000
Dichloromethane spill bottoms	-	37,000
1,1,1-Trichloroethane spent solvents	-	120,000
1,1,1-Trichloroethane still bottoms	-	30,000
Soil	1-300	11

[a] Data are from Ref. 22.

[b] Except where noted, all data are from Ref. 21.

[c] Data are from Ref. 23.

[d] Data are from Ref. 24.

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STRUCTURED APPROACHES TO RISK ASSESSMENT AND RISK MANAGEMENT

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The rational management of health and environmental risks ideally requires a well defined structured approach in order that risk may be dealt with in a complete and equitable fashion. In this paper, formal models of the process of risk assessment and risk management which have been proposed in the literature in recent years are reviewed. Common elements amongst these models are identified, and the potential impact of these approaches on practical decision making is examined.

1. INTRODUCTION

The selection of environmental hazards for government attention has often been handled in an ad hoc fashion in the past, usually in a reactive manner rather than as part of a carefully planned strategy. Issues which attract the public's interest have often been the focus of societal resources at the expense of more serious but less popular problems.

Despite the pressures on regulatory agencies to respond to external initiatives and shifting priorities, several factors indicate the need for a more pragmatic approach to the management of health risks. These include the desirability of balancing risks and benefits across society in an acceptable way, and the trend towards more openness in decision making using consistent and explicit decision criteria. The need for an orderly and systematic approach to risk assessment and risk management is further supported by the existence of resource constraints, which prevent maximum control of all risks. Such an approach can lead to greater objectivity and completeness, consistency of decisions, and public accountability.

A number of formal models for risk assessment and risk management have been proposed in recent years. These models are of great value in clarifying the main elements of risk assessment and risk management, and have served to establish a well defined framework within which risk may be addressed.

In section 2 of this article, we discuss the different models which have been proposed in the literature. These models are then compared and a number of common elements identified (section 3). We conclude with a brief discussion of the key components of the models and their role in understanding and improving the overall process of risk assessment and risk management (section 4).

2. RISK ASSESSMENT AND RISK MANAGEMENT

The risk posed by a particular agent depends on both the nature of the hazard presented and the probability of its occurrence. Health hazards may be characterized in terms of the health consequences or adverse effects induced. These effects may be more or less serious depending on factors such as their nature, severity, and degree of reversibility. The probability or chance of a given effect occurring depends on the potency of the agent, the susceptibility of the host, and the level of exposure (Krewski & Somers, 1984).

Scientific Committee on Problems of the Environment (SCOPE). The first formal model of the risk assessment and management process appears to have been formulated by SCOPE (Kates, 1978; White & Burton, 1980). A three stage risk assessment process consisting of risk identification, risk estimation and risk evaluation was proposed. The first step involves simply recognizing that a hazard exists. A quantitative estimate of the magnitude of the associated risk is then prepared by scientifically determining its characteristics. This is followed by judgements about the significance and acceptability of risk probabilities and consequences. Following risk assessment, some decision regarding whether or not to intervene takes place. This last stage may be termed risk management.

National Research Council (1983). The NRC (1983) model consists of two stages: risk assessment and risk management. Risk assessment refers to the use of a factual base to define the health effects of exposure of individuals or populations to hazardous materials or situations. Risk management is the process of evaluating regulatory options and selecting among them.

Risk assessment is subdivided into four components: hazard identification, dose response assessment, exposure assessment, and risk characterization. Hazard identification is the determination of a cause-effect relationship between a particular chemical and a decline in health status using epidemiological studies of human populations, animal bioassay data, mutagenicity tests, and examination of molecular structure. Dose response assessment involves examination of the relation of magnitude of exposure and probability of occurrence of the health effects in question. Exposure assessment is the study of the extent of human exposure before or after application of regulatory controls. Risk characterization includes hazard identification, dose response assessment and exposure assessment, and involves a description of the nature and magnitude of human risk, including attendant uncertainty.

At the risk management stage, alternative regulatory options are developed and evaluated. Selection of a particular regulatory option involves consideration of the public health, economic, social, and political consequences of implementation. Other factors of significance include the technical feasibility of the proposed solution, desired level of control, ability to enforce regulations, uncertainty in scientific data and the corresponding inferential bridges used to fill gaps in knowledge, and the public's perception and level of information.

The implementation of a specific course of action should be accompanied by the communication of information concerning the basis of the decision to affected parties.

The NRC model was subsequently adopted by the United States Environmental Protection Agency (1984) with no significant structural or definitional changes. The Department of Health and Human Services (DHHS) (DHSS, 1985) has expanded the NRC model to include consideration of nonregulatory options for risk management. These include advisory options as well as risk reduction through technological means. DHHS also recommends expansion of research so as to reduce the uncertainties associated with scientific knowledge.

The Royal Society. The Royal Society model (Royal Society Study Group, 1983) is also composed of two stages: risk assessment and risk management. The former is further subdivided into risk estimation and risk evaluation.

Risk assessment is the general term used by the Royal Society to describe the study of decisions having uncertain consequences. Risk estimation refers to identification and estimation of the probability and magnitude of the consequences of a hazardous event. Risk evaluation is the complex process of determining the significance or value of the identified hazards and estimated risks to those concerned with or affected by the decision. Embedded within this stage are the interrelated processes of developing alternative courses of action and decision analysis. These components take into consideration public awareness and perception, acceptability of risk, and the analysis of risks, costs, and benefits. These latter factors include consideration of the level of justifiable risk, economic and technical feasibility, and resource requirements.

Based on the evaluation of risk, risk management refers to the making of decisions concerning risks and their subsequent implementation. Decision making itself involves consultations between industry, government, the public, and other special interest groups affected by the decision. Implementation of a decision, along with its monitoring, evaluation and revision are considered an integral part of the process.

Interdepartmental Committee on Toxic Chemicals (ICTC). The ICTC model developed by the Interdepartmental Working Group on Toxic Chemicals (1984) represents an elaboration of the SCOPE model. The first step in the process is hazard identification which is based on case reports, epidemiological studies of human populations, and toxicological experiments conducted in the laboratory. Another possible approach for the identification of chemical risks is to compare the molecular structure and biological activity of the substance under study with that of known toxicants.

The next step is to obtain an estimate of the magnitude of the risk in question. This involves the statistical analysis of epidemiological and toxicological data to determine the level of risk associated with specific hazards and to establish acceptable criteria for exposure to environmental hazards. This process is subject to considerable uncertainty and may require strong assumptions, as in the conversion of animal results to the human situation.

The first step towards selecting a strategy for dealing with a given environmental risk is the development of a number of alternative courses of action. Available options can range from advisory to economic to strict regulatory control. In order to ensure a consistent approach to risk management, the set of options selected for further evaluation should be compatible with existing environmental health program objectives and remain cognizant of any overall risk management policy guidelines.

The decision as to the most appropriate course of action depends on a host of factors, including a balancing of health risks against health benefits in some cases. Consideration may also be given to the public's perception of risk, which may not always correspond to the actual risk determined by objective analysis. The technical feasibility of each proposed course of action should be demonstrated, including the ability to enforce any proposed regulations. Economic effects are often important in evaluating alternatives, both in terms of program-related costs and the impact on productive output. Socio-political factors involving equity considerations and repercussions at the international level should not be overlooked.

Implementation of the selected risk management strategy will usually require some commitment of resources and should be accompanied by attempts to communicate the nature of the chosen control mechanism to all affected parties. Once the control mechanism is in place, continued monitoring is recommended. Continual evaluation and review of new health risk information may suggest modification to the risk management strategy currently in place.

Leiss (1985) has modified the original ICTC model in two ways. First, Leiss introduces a separate pathway for consideration of benefits (benefit identification and net benefit assessment) parallel to hazard identification and risk assessment. Second, Leiss recommends incorporation of new consultative and communicative procedures in the risk management process. Specifically, it is suggested that risk and benefit assessments be available as public documents for examination by all interested parties; that standard procedures be developed to notify interested parties about the availability of public documents and about the results of decision making; and that regulatory decisions be accompanied by an explanation of their inherent reasoning.

World Health Organization (WHO). The WHO (1985) model is a four stage process consisting of hazard identification, risk estimation, risk evaluation, and risk management. The process as a whole is influenced by a number of participating bodies including scientists, industry, special interest groups, public, the media, and politicians.

Hazard identification requires the collection of chemical, toxicological, ecotoxicological, clinical and epidemiological data. Toxicity and exposure information are obtained at this first stage.

Risk estimation characterizes the extent of harm and the probability of its occurrence. This stage utilizes the information gained in hazard identification to predict the severity, extent, and distribution of the increased incidence of disease, disability, or defects caused by exposure to a given hazard.

The risk evaluation stage involves comparative analysis between the risk in question and accepted risks, voluntary risks, and other risks. Consideration is also given to political factors, public perception, and industrial and public liability.

The risk management stage consists of decision making with the aim of reducing or eliminating the risk in question. Decision making must take into account cultural, socio-economic, and political factors, and the type and nature of the risk in question. The possibility of reducing or eliminating the risk through control measures, technology changes, prevention or reduction of exposure, and product substitution must be considered in terms of feasibility, costs/benefit and magnitude and distribution. The decisions resulting from such an analysis form the basis for regulatory action.

Other Models. Various individuals have also proposed models for risk assessment and risk management. Baram's (1981) framework consists of six steps: hazard identification, risk measurement, risk management options selection, economic and technical feasibility analysis, ordering of risk management initiatives, and deployment of risk management options.

Lave's (1982) model contains eight stages: hazard identification, risk assessment, identification of regulatory alternatives, decision analysis, regulatory decision, legal or political challenge, implementation, and monitoring. This model closely resembles that adopted by the ICTC.

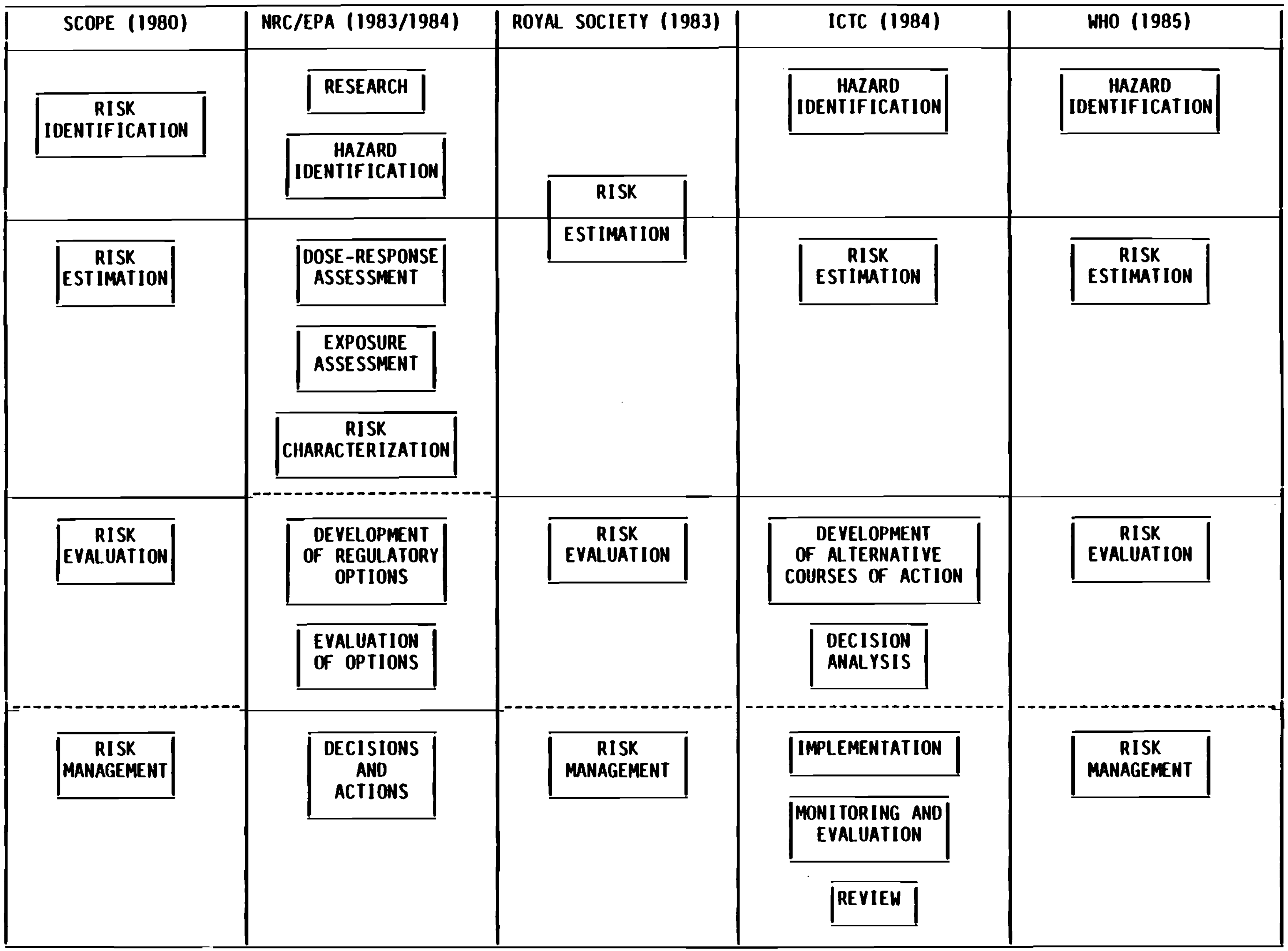
Rodricks & Tardiff (1984) consider only two broad stages: risk assessment and risk management. The former is subdivided into three phases: hazard identification and evaluation, dose response evaluation, and identification of conditions of exposure. The latter stage also consists of three phases: examination of alternative courses of action, decision analysis, and implementation.

Shrader-Frechette's (1985) framework includes three stages: risk identification, risk estimation, and risk evaluation, which closely parallel those in the SCOPE Model.

3. COMPARISON OF MODELS

The models for risk assessment and risk management presented in section 2 follow the general framework devised by SCOPE (1978, 1980), although the degree of similarity and level of detail presented in each of the models varies (Figure 1). In addition to delineating the steps comprising the risk assessment and risk management process, each model distinguishes between the scientific and extra-scientific components of the overall process.

With the exception of the Royal Society model, each of these models explicitly designates hazard identification as the initial step. The NRC/EPA model emphasizes the use of scientific research as the basic tool for identifying risks. Several models more correctly refer to the initial phase as hazard identification rather than risk identification



SCOPE (1980)	NRC/EPA (1983/1984)	ROYAL SOCIETY (1983)	ICTC (1984)	WHO (1985)
RISK IDENTIFICATION	RESEARCH HAZARD IDENTIFICATION	RISK ESTIMATION	HAZARD IDENTIFICATION	HAZARD IDENTIFICATION
RISK ESTIMATION	DOSE-RESPONSE ASSESSMENT EXPOSURE ASSESSMENT RISK CHARACTERIZATION		RISK ESTIMATION	RISK ESTIMATION
RISK EVALUATION	DEVELOPMENT OF REGULATORY OPTIONS EVALUATION OF OPTIONS	RISK EVALUATION	DEVELOPMENT OF ALTERNATIVE COURSES OF ACTION DECISION ANALYSIS	RISK EVALUATION
RISK MANAGEMENT	DECISIONS AND ACTIONS	RISK MANAGEMENT	IMPLEMENTATION MONITORING AND EVALUATION REVIEW	RISK MANAGEMENT

Figure 1. A Comparison of Models for Risk Assessment and Risk Management (dotted line indicates division between risk assessment and risk management)

since the probability of the occurrence of an adverse effect is generally not calculated at this stage. In current usage, the term hazard is used to describe the nature of the adverse effect, whereas risk involves both the hazard and the probability of its occurrence (Kaplan & Garrick, 1981; Krewski et al., 1982).

With the exception of the Royal Society model, there also appears to be general agreement that hazard identification should be followed by risk estimation. (The Royal Society includes both hazard identification and risk estimation in their definition of risk estimation, but does not clearly identify these as distinct sequential steps.) In the NRC/EPA framework, the term risk characterization is effectively equivalent to risk estimation.

All models cite the use of toxicological and epidemiological data as the primary sources of information for health hazard identification and risk estimation. In the case of chemical hazards, structure/activity analysis may also be used.

As with the original SCOPE model, all models then proceed to some form of risk evaluation. At this stage, scientific method is subsumed by public policy considerations. The subsequent models are generally described in more detail than is the SCOPE model, and, with the exception of the Royal Society model, differentiate between alternative courses of action and the decision analysis tools used to choose amongst them. Alternative options may be of an advisory, economic or regulatory nature, and many factors need to be considered in selecting a preferred management strategy. These include the use of formal economic tools for program evaluation (Torrance & Krewski, 1985), tempered by the public's perception of the risk involved as well as prevailing socio-political factors. Although not highlighted as distinct components, similar considerations are included within the Royal Society's risk management phase.

The final risk management stage involves the implementation of the selected control strategy. Each of the models, except those of the NRC/EPA and WHO, stresses the need for risk monitoring and follow-up, so as to modify the risk management strategy currently in place if this is considered inappropriate. All models except the SCOPE model also stress the importance of communication at the implementation stage so that affected parties are properly informed as to both the risks and risk management strategy adopted. The Royal Society model in particular emphasizes the importance of providing affected parties with an opportunity to interact in the decision-making process in an informed way.

The significance of uncertainty in decision making cannot be overlooked, as pointed out by the NRC/EPA and Royal Society. Scientific data, which serves as a basis for decision making, may be incomplete or plagued with uncertainty regarding estimates of the types, Although there is general agreement that the risk assessment/risk management framework can be divided into scientific and policy concerns, Davis (1983) maintains that both science and values play a role in risk assessment and that the steps in the risk control process are more interactive than sequential. During the risk assessment process, analysts may overlook hazards, deem them unimportant, or ignore them because they are difficult to assess. Decisions are often influenced by judgements or policy due to gaps in scientific information.

The NRC (1983) has developed inference guidelines to estimate human risk levels in situations where the data is inadequate for direct calculation from human observations. Such guidelines are explicit statements which pragmatically select one of several inference options for a particular risk assessment situation. The NRC also notes that, despite their scientific orientation, policy considerations virtually always influence the selection of an inference option. The nature of the inference options for any risk is a mixture of scientific fact and consensus, informed scientific judgement, and policy determinations.

4. CONCLUSIONS

In this article, we have reviewed the major models of the process of risk assessment and risk management. All of these models reflect the basic elements of original SCOPE model (risk identification, risk estimation, risk evaluation, and risk management) as described by Whyte probabilities, and magnitudes of the health effects associated with a particular hazard. Of particular concern is the uncertainty inherent in the assumptions made during the extrapolation of animal test data to the human situation and the determination of current and future exposure levels. There is also uncertainty regarding the economic and social impacts of a proposed decision.

One point which remains obscure is the separation between risk assessment and risk management. The original SCOPE model seems to consider risk assessment as encompassing both the scientific enterprises enterprises of hazard identification and risk estimation as well as the more politicized function of risk evaluation. In this model, the term risk management is reserved for the final implementation and follow-up stage. This point of view is also adopted in the Royal Society, ICTC and WHO models. The NRC/EPA, on the other hand, define risk assessment as consisting only of hazard identification and risk estimation.

Taking into account differences in terminology, all models essentially agree on the division of the scientific and social aspects of the risk assessment and risk management process. Hazard identification and risk estimation are clearly in the scientific realm, whereas risk evaluation and risk management fall within the domain of social decision making. Thus, the responsibility for risk analysis rests largely with the scientific community, whereas those responsible for the establishment and implementation of risk management decisions play the leading role in extrascientific matters (Ruckelshaus, 1983).

& Burton (1980). Subsequent models more correctly refer to the initial step as hazard rather than risk identification, reflecting the fact that risk estimation requires a quantitative rather than qualitative description of adverse health effects.

Although all models involve scientific and public policy considerations, the only model which equates these two dimensions with those of risk assessment and risk management is that of the NRC/EPA. In the remaining models, the social evaluation is included in the risk assessment phase, leaving only the implementation of the chosen control strategies to the risk management phase.

The application of the models of risk assessment and risk management discussed here to practical decision making situations should facilitate identification and clarification of the many important considerations in the complex process of risk assessment and risk management. This is particularly true of some of the more recent models which describe the component steps in detail, including the development of a range of viable risk management options and the criteria and tools to be applied in choosing among these options. Other considerations which may otherwise be overlooked include the need for continual monitoring and review as well as communication of information on risks and risk decisions to all affected parties.

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INFORMATION NEEDS FOR ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT

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The Risk Assessment Working Group at the Institute for Environmental Studies, University of Toronto, is preparing a monograph on "Information Needs for Environmental Risk Management in Canada". In September 1985 the Institute sponsored a two-day Workshop in Toronto to bring together a multidisciplinary group consisting of the authors and other interested persons for a peer review and discussion of some 20 papers then in preparation for the monograph.

The material for this paper is mainly derived from the papers and discussions at the Workshop. It is divided into three sections. The Introduction discusses the essential requirement for information, the problem of uncertainty (reliability) of information and the kinds of information needed. The second section deals with the uses of information in risk analysis and management, and the concluding section discusses some of the problems of securing adequate information, especially as these were illustrated at the Workshop.

A list of titles and authors is presented in Appendix 1.

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INTRODUCTION

INFORMATION NEEDS FOR CONFIDENT DECISIONS

Individuals, institutions and government agencies must have **information** of various kinds in order to cope rationally with the risks that confront us everyday. Without information on the nature, magnitude and probability of occurrence of hazardous events it is impossible to devise strategies to manage risks. Information serves to reduce uncertainty; the more information we have the more confident we are that we will be able to reduce the probability of occurrence and the consequences of an adverse event and, thereby, reach a "better" decision. A better decision is one in which confidence about its outcome is increased.

Risk managers and decision makers would certainly agree that we never have all the information needed to make an absolutely confident decision that would reduce a risk to an acceptable level. There is always some uncertainty and sometimes the uncertainty component is very large.

THE PROBLEM OF UNCERTAINTY

Uncertainty arises from many sources, all of which relates to varying degrees of deficiency in information. When the scientific method is used to investigate a hazard or threat there is an element of uncertainty inherent in the method. The scientific method is always open-ended and its application, while yielding information, may raise more questions than it answers; scientific findings are always subject to modification or outright rejection as a result of continuing investigation. As scientific information accumulates and converges we become increasingly confident that we are improving our understanding of natural phenomena but we recognize that the possibility of error is always there. The error may be due to a lack of some essential bit of information or to the use of an incorrect paradigm or hypothesis. Many long-established scientific concepts have been discarded. Thus, our primary method for apprehending the world always gives us uncertain information.

In addition to the uncertainties related to method, there are numerous other factors and circumstances contributing to uncertainty. For example, we may suddenly be confronted with a previously unrecognized hazard with which we have little or no experience or we have information about the nature and magnitude of hazardous events such as earthquakes and floods but have no way of predicting them. In situations of this kind risk management consists mainly of educated guessing, anticipatory precautions and emergency standby measures.

KINDS OF INFORMATION NEEDED

In most cases, however, deficiencies in information arise from:

- neglect;
- failure to set clear objectives for the use of information;
- lack of comprehensive planning to ensure the collection of all relevant information;
- societal and legal restraints as to what data can be collected without invasion of privacy and personal freedom or the revelation of proprietary information; and
- at the most pragmatic level, lack of time, money and manpower.

In many cases we do not recognize the need for information until it is too late or we are in a crisis situation. All these deficiencies were well illustrated in the papers and discusions at the Workshop.

Moreover, risk management involves a great deal more than careful analysis of scientific informatioin and statistics. While sound factual and quantitative data are essential, decisions leading to management measures always require a synthesis of objective and subjective assessments of a wide range of "information" from a variety of sources. Thus, the definition of **information** as applied to risk management goes far beyond formal scientific facts and figures. In some cases the largely subjective judgement of experienced administrators or politicians plays the paramount role in bringing the scientific findings together with the prevailing socio-economic-political frame of reference.

It is apparent that in attempting to define the information needed for risk management we must take a very comprehensive view that begins with the essential scientific information on the nature, magnitude and occurrence of hazardous events and extends to the socio-economic-political setting, estimation of benefits and costs and so on. In dealing with these aspects it is almost impossible to define needs because they vary so greatly with the kind of risk and the circumstances under which it is to be managed. In addition, we have to consider the different kinds of information needed at various levels in the assessment and decision prosesses (Sasseville and Crowley; Torrance and Oxman[2]). The scientist, for example, or other assessor needs comprehensive information which is based on adequate sampling and is as free as possible from confounding factors. Such information is rarely available but even with imperfect data scientists generally have an easier task

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[2] Names in parentheses refer to authors listed in Appendix 1.

than administrators or political decision makers. The scientist can concentrate on "the facts" as they may be perceived, and render a professional judgement which may include an estimate of the degree of uncertainty without necessarily being concerned about the problems of the management decision. Administrators and politicians, on the other hand, generally are handed a concentrated distillation of the scientific information as only one component in a complex of factors they may use in selecting an option to arrive at an acceptable recommendation for coping with a risk. Although deliniating information needs at this level is extremely difficult, a comprehensive set of information is nevertheless essential to decision makers. This must often include cross-sectoral information from jurisdictions outside the decision maker's area of responsibility, up-to-date information on public attitudes, costs and benefits, equity in the distribution of risks and benefits, the political climate and so on. When we speak of **information needs for risk management** we generally mean the "facts and figures" basic to an understanding of the risk but we should not forget that, important as these may be, they may have very little influence in reaching a recommendation for the management of a risk.

How can the information base for risk management be made more useful for risk assessment and for decisions leading to management strategies? If the information was substantially improved would that lead to "better", more reliable decisions?

THE USES OF INFORMATION IN RISK MANAGEMENT

The process leading to risk management may be described in the following steps:

Risk analysis and estimation

1. Identification of a threatening situation.
2. Characterization of the threat or hazard in terms of processes involved and potential magnitude of undesirable consequences.
3. Estimation of probability of occurrence (exposure) and consequent estimation of risk by combining probability with consequences.

Risk management

4. Evaluation of 1, 2 and 3 in relation to other relevant parameters to arrive at a strategy to contain the risk within acceptable limits.

The first three of these steps should be largely objective, scientific procedures and are the one with which information needs are usually associated (Byer). The fourth step involves taking the findings from 1, 2 and 3 and considering them together with other factors that influence the alternatives available to cope with the risk. Contrary to what we sometimes think, this is the step with the most demanding requirements for information and, at the same time, the one in which needs are the most difficult to anticipate and supply.

IDENTIFYING THE THREAT

Most of the environmental risks of current concern took us by surprise. We did not go looking for them. Acid precipitation, impacts of persistent chemicals (PCB's; "dioxins"), AIDS (Acquired immune deficiency syndrome), Legionaire's Disease, nuclear winter, the Greenhous Effect, health risks of asbestos, loss of tropical forests, desertification and pollution of the Great Lakes, either suddenly confronted us or developed slowly under casual observation but were generally neglected until they reached serious proportions.

In hazard identification the primary information need is to establish that there really is a significant risk and to evaluate it as quickly as possible in the perspective of other risks. The initial perception of a risk is generally followed by a crisis of ignorance and a more or less prolonged controversy regarding its nature, significance and methods of investigation, all of which tends to confuse and alarm the public and the politicians and often leads to unnecessary expenditure of effort and money (Fowle; Arnold and Krewski). It is at this stage that the public perception of a risk is established, often as a result of media coverage. Much effort is usually required to narrow the gap between public perception and the perception emerging from the scientific investigation of the risk. As investigation continues there is a gradual reduction in uncertainty which tends to alter the original perception of the risk and often at the same time reduces its significance and reveals unexpected complexity and ramifications.

There is a special problem in hazard identification when the consequences are long delayed as in the case of some carcinogens since retrospective collection of relevant information is virtually impossible.

CHARACTERIZING THE HAZARD

This process begins the moment a hazard is identified. We begin to find out what information we need only after we have identified a threat and begin to characterize it. The extent of the needs will depend upon the degree of significance we attach to the risk as we move through Steps 3 and 4. Scientific study generally reduces uncertainty as to the nature and potential magnitude of the threat. In establishing magnitude it is important to identify clearly the "end points" or measures of severity to be employed in assessing consequences. The common measures are human mortality, morbidity and increase in premature deaths. More recently reproductive effects such as mutagenicity and teratogenicity have become significant criteria for evaluating environmental chemicals. So far little attention has been given to other end points such as measures of the general standard of health of the population, extinction of species, loss of soil, deterioration of amenity and heritage values, loss of natural resources and general decline in the standard of living.

In the initial stages of Step 2 a major source of information is that which can be reliably "borrowed" from the scientific literature, studies carried out elsewhere in the world, and from the experience of others in dealing with apparently similar hazards. Such information relates to general principles and concepts which would be applicable anywhere. This category of information is generally fairly readily available and simply has to be brought together and applied to the particular situation. However, it is usually not sufficiently specific or has not been collected under circumstances comparable to the local setting. This means that information has to be collected or drawn from local data bases, a requirement which takes time and delays moving on to the management step (Toft et al.; Frank et al.).

ESTIMATING PROBABILITY OF OCCURRENCE

When we speak of "information needs" for risk assessment we usually have this step in mind. Estimation of the magnitude of undesirable consequences of a hazard together with estimates of the probability of occurrence leads to the estimation of **risk**. There is no risk until we include the notion of probability. When probabillity is 0 or 1 there is no risk for we are dealing with certainty.

This is usually the most difficult step and the major source of uncertainty. Information needs here are mainly statistical and usually can only be accumulated over time or from wide sampling. We can estimate magnitude on the basis of experience, and perhaps modelling, and reasoning from parallel cases by analogy if we have comparative information. In the absence of experience as, for example, in the case of a core melt-down in a nuclear reactor or in the epidemiology of AIDS we depend on modelling and analogy. As for probability of occurrence, again the only real basis for judgement is accumulated statistics; for example, from epidemiological studies or records of traffic fatalities. From data of this kind we can estimate incidence but not time of occurrence.

SELECTION OF A RISK MANAGEMENT STRATEGY

This is the management step in which the information coming from the other three is evaluated to determine if a significant risk exists. If it is deemed to be significant, the next step is to evaluate the alternatives to contain it within acceptable limits. While science may contribute substantially to this step, a high degree of integrative subjective judgement is needed in weighing and balancing all the factors - scientific, societal, political, economic, moral and so on (Sasseville and Crowley). The demand for information at this level is comprehensive and often multidisciplinary and multi-jurisdictional. Scientific data, which is generally predominant in Steps 1, 2 and 3, become less significant in Step 4 and may, in some cases, play only a minor role in selecting among alternatives. Some subjective components may be almost intuitive, as in taking account of the conflicting perceptions of several publics in relation to a perceived risk or the political feasibility of a management measure.

PROBLEMS RELATING TO INFORMATION NEEDS

The papers at the Workshop cited numerous problems relating to the improvement of the amount, quality and use of information for risk assessment and management. There was general agreement that information was inadequate but the reasons for the deficiencies varied with the discipline and the topic under discussion (Toft et al.; Matthews and Grochowalski). The problems ranged all the way from a simple lack of information through the difficulties which arise in the complex processing and transfer of information in hierarchical organizations (Sasseville and Crowley). Some difficulties were traceable to faulty methodologies (Frank et al.), other related to failures in intersectoral and inter-agency communication (Matthews and Grochowalski), and other to lack of standardization (Spielberg et al.). A few examples are discussed below.

INSUFFICIENT DATA

It need hardly be said that there are no entirely adequate data banks (Friend). In some cases there is virtually no reliable information even for subjective judgements. Hence, a primary conclusion of the Workshop was that there is an urgent need for more systematic and better information if we are to formally assess and manage environmental risks.

IDENTIFYING THE RISKS

The first responses to newly identified risks are usually inefficient, wasteful and prone to provoke unnecessary anxiety. This happens for several reasons: the situation may be new and we have no information to guide us; we have information and manpower to deal with it but they are not marshalled promptly and decisively; the first response is made by persons who are really not qualified to assess the situation; or the political situation may be such that response is delayed or a response is made prematurely before the hazard has been assessed as well as possible at this early stage (Fowle; Rogers). The best response is a considered response based on sound information and made by people who have or can gain the confidence of the public. Obviously, the need is for ready access to information and specialists to interpret it to decision makers and to the public by way of the media.

MONITORING

If there is to be early detection of threats and potential risks we must be on the alert (Toft et al.). The ideal situation would be one in which monitoring of anthropogenic impacts on environmental processes and of environmental changes were sufficiently comprehensive to enable us to anticipate hazards and detect and respond to them as soon as they appeared. It would be very useful to have early warning systems in place to help us avoid surprises. However, apart from the practical difficulties of trying to decide what to monitor, such a scheme would probably not be cost effective. Experience tells us that the most useful information is that which is collected with clear objectives for its use; this was a point which was strongly emphasized at the Workshop.

Nevertheless, in spite of difficulties, we do need more comprehensive monitoring (see, for example, Swedish National Environmental Protection Board 1985), more cooperation among agencies, and cross-sectoral data collecting, improved access to government and private data banks and critical examination of available information so as to begin to move towards standardization, reduction of redundancy, greater comprehensiveness and clearer objectives for the use of data (Frank et al.; Spielberg et al.). Many of the present data bases were collected for administrative purposes or to conform to legislative requirements, not for risk assessment. For this reason they often lack crucial information. For example, vital statistics and epidemiological data files often lack information on occupation, economic status, use of tobacco, alcohol and drugs, and general life style, all of which may be confounding factors when it comes to assessing risks. The current debate about the kind of information which should be recorded regarding persons suffering from AIDS is a case in point.

As has been pointed out, it is not feasible to mount data collection programs in which information is gathered more or less at random in the hope of picking up something which may be useful. It is better to have a focus. In the case of environmental pollutants, for example, the focus is often provided by the list of substances for which standards have been set or which are suspected to be hazardous. For example, in spite of the fact that over 800 chemicals had been identified in the Great Lakes system by 1983, Metropolitan Toronto currently conducts chemical tests three time per year for 170 chemicals selected from the U.S. EPA's list of "priority pollutants". Fifty-one have been identified in drinking water in very minute amounts. For some years pesticides were emphasized presumably because they were perceived to be hazardous (Davies). Such a selective approach is inevitable and we should strive wherever possible to broaden the scope of monitoring and not concentrate exclusively on suspected threats which have already been identified. We risk missing new ones.

Monitoring data is sometimes difficult to evaluate because of a lack of historical "baseline" information which would permit evaluation of conditons before a risk was detected. This was a problem in the case of acid precipitation where there is still uncertainty regarding the "normal" unpolluted pH of rain and snow prevailing prior to the influence of anthropogenic inputs of pollutants (Turner; Burnett _et al_.). The lack of ecological mapping is also an impediment to adequate environmental sampling, rational allocation of resources for sampling and interpretation of information.

It is apparent that long-term monitoring is necessary in many areas in order to provide baseline data and the information needed for risk assessment but a single all-inclusive scheme is impractical. We will still have to depend on the various disciplines and specialties to develop their own programs. But if we are going to get a reasonale return on investment more attention must be given to careful planning for the use of information and to cooperative sharing of information among agencies and commercial organizations. The routine procedures for collecting administrative statistics should be examined to see how they might be adapted to providing information free of confounding factors for risk assessment purposes. The needs for information for risk assessment of transportation of dangerous goods is a good example. Governments and the transportation industries both have records of spills, accidents, numbers of vehicles, frequency of travel and so on, but the records are not coordinated and some of them are confidential and unavailable. Hence, it is extremely difficult to apply risk assessment methods to the management of the transportation of dangerous goods (Matthews and Grochowalski). There is also potential for cooperation in standardization and coding in the provincial health records in Canada so as to increase the pool of information and permit ready access (Spielberg et al).

FAILURE TO USE THE INFORMATION WE HAVE

While failure to recognize a threat or lack of information may be the common problem, there are some cases in which we have had evidence of a threat or have had information but fail to act upon it. For example, the hazards of asbestos have been known for at least 50 years and there were clear indications of risks to health during the previous 25 years (Meek). Yet it is only recently that we have taken steps to control exposure and reduce risk. Radon is another example (Chambers and Low). The universal distribution of radium in rocks and soils has long been known as has the fact that radon, a gaseous product of the radioactive decay of radium-226, is one of the causes of lung cancer. Yet, virtually all research and regulatory actions taken with respect to the risks of radon have been confined to mines and miners. Only recently has the exposure of the general population to radon in confined spaces in homes and other buildings been investigated and found to be significant. This is an example of a narrow rather than comprehensive application of a general principle to the management of risk.

THE PROBLEM OF DELAYED CONSEQUENCES

We are beginning to recognize an increasing number of environmental risks in which consequences are long delayed. The effects of carcinogens and mutagens are well known examples of situations where risk assessment is very difficult and fraught with a high degree of uncertainty. Other examples include: desertification, erosion and loss of soil fertility following removal of tropical forests for agriculture, fuel and timber, and leaking waste storage dumps. The risks involved arise mainly from human activities, and while the consequences of some of them are immediate, others are insidious and ramifying in their disturbance of ecosystem function or in threatening human health. In cases such as these more information on ecosystem function and resilience is required.

HUMAN ERROR

In attempting to minimize risk we go to great length to develop very reliable and fail safe engineering systems for structure and machines, and yet risks remain and disasters of various magnitudes occur regularly. In many cases failures in human judgement, particularly in emergency situations, are often major contributors to events such as airline disasters, accidents with nuclear reactors, highway accidents and process and operating failures in chemical industries. Errors in judgements in setting public policy might also be included under this heading.

We need more research on the extent to which human error foils our best attempts to manage risks and we need research on methods of training those responsible for the operation of activities with a potential for disaster and failure (Ahearne 1984).

INFORMATION FOR EDUCATION

Much money and effort are often expended in attempting to cope with a perceived threat or risk in order to reduce public anxiety and satisfy demand for safety. There are many examples of unwarranted or misplaced allocation of resources resulting from incomplete understanding of particular threats and risks (Fowle; Meek). There is a need for information programs to encourage a more general understanding of the inevitable presence of risks in our lives and the limits of our ability to ensure safety. The inclusion of the concepts of risk in school curricula should be considered. Government news releases and announcements regarding health and environmental risks should be couched in terms of reducing risk instead of emphasizing "safety".

A special effort is needed to encourage the media to adopt a risk vocabulary and to reduce the sensational stress on danger and safety. Since they are the principal sources of information to the public, politicians and public officials, as well as being the channel used by the responsible authorities to convey information to the public, the media are often the chief cause of the gap between "objective" measures of risk and the "perceived" assessment of risks. They are also the main generators of anxiety. The media, therefore, bears a heavy responsibility in the risk management process and should be encouraged to adopt a more rational interpretation of risky situations.

HOW USEFUL IS RISK ASSESSMENT IN SELECTING MANAGEMENT OPTIONS?

Proponents of the application of systematic assessment to the management of risks believe it would aid decision makers in the selection of alternatives and improve the reliability of management decisions. While it seems obvious that a comprehensive analysis of any problem in the public policy area would improve decisions, it may be doubtful that dramatic improvements would result if the information base was improved. For example, there is much evidence to show that comparisons of the risks among various energy options has little to do with the selection of the chosen option. Factors such as economics and security of fuel supply outweigh consideration of risks (Whipple).

Many people in the world, but by no means a majority, live longer lives in a more reliable, low risk world and enjoy a better standard of living than was the case 100 years ago. Obviously, we make and have made some unfortunate decisions about environmental risks but, on the whole, we are doing pretty well in comparison with the past. On the other hand, it can be argued that things are different now and we are confronting an ever increasing array of simultaneous risks which are certainly taxing our management skills. The application of risk assessment can only be helpful.

But the hard-headed decision maker who bears the responsibility for minimizing risks as well as for the resources for studying them may well ask:

- How much improvement in reliability and reduction in uncertainty may be expected from the application of risk management?
- Would it be better if the information base was improved?
- What will it cost in relation to the return?

Enthusiasts for improving the information base for risk assessment would do well to consider questions like these. The general utility of more and better information in policy decisions needs to be clearly argued and demonstrated.

The situation is well illustrated by the recent comments of a senior Canadian official who listed the following questions as the ones he had to anticipate in advising his superiors regarding newly perceived environmental problems:

1. What is the problem?
2. Who will be affected?
3. How will they be affected?
4. What can be done? (Alternatives)
5. What are the costs?
6. What are the consequences of being wrong?
7. What is your recommendation?

Clearly the responses to each of these questions are likely to be uncertain to varying degrees and each requires its own mix of "objective" scientific information and "subjective" judgement. Where can risk assessment play its most useful role?

SOME CONCLUDING THOUGHTS

1. The information base for risk assessment and management is generally inadequate. Systematic, comprehensive assessment is possible in only a very few cases.

2. It is inevitable that decisions will have to be made under uncertainty, regardless of how much information we have. The central problem in risk management is coping with uncertainty.

3. While more information is needed in many areas, a large data base is already on hand but much of it is not readily available because of ignorance of its availability, lack of cooperation, unwillingness to share, lack of standardization and failure to record information on confounding factors.

4. Risk analysis based on extensive "objective" information might not be used as much as we might hope. "Subjective" considerations which must be taken into account in arriving at management decisions often overshadow the formal assessment process. The general utility of risk analysis in improving the reliability of decisions and reducing uncertainty below existing levels remain to be demonstrated.

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APPENDIX I

Proposed table of contents for the Monograph:

"Information Needs for Environmental Risk Management in Canada"

Chapter I.	Introduction
Chapter II.	**P. Byer (IES)** "Elements of risk management"
Chapter III.	**J-L. Sasseville and M. Crowley (Universite du Quebec)** "A market approach to the identification of information needs in risk management"
Chapter IV.	**G. Torrance and A. Oxman (McMaster University)** "A framework for comparative evaluation of risk management programs"
Chapter V.	**A. Friend (Environment Canada)** "Data banks relevant to risk analysis"
Chapter VI.	"Information needs for environmental risk management"
Chapter VII	"Conclusion"

SECTORAL STUDIES

P. Toft, A. Gilman, D.C. Villeneuve and R.S. Tobin (Canada Health and Welfare) Information needs for the management of health risks posed by Great Lakes contaminants

C. Whipple (Electric Power Research Institute, California) Information needs in energy management

J.W. Frank, M. Macpherson (University of Toronto) and B. Gibson (Toronto Public Health) Information needs in epidemiology

A.B. Morrison (University of Guelph) The assessment and management of risk associated with food chemicals in Canada

L.A. Spielberg, L.F. Smith and J. Victor (Ontario Ministry of Health) Provincial data bases and information needs for environmental risk management

M. Matthews and D. Grochowalski (Transport Canada) Information needs on exposure data for the transportation of dangerous goods

CASE STUDIES

C.D. Fowle (York University and IES) Coping with risks in the spruce budworm control program in New Brunswick

D.B. Chambers and Leo M. Low (SENES Consultants, Toronto) Radon health effects

D. Arnold and D. Krewski (Health and Welfare Canada) Saccharin: still a controversial sweetener

R.E. Rogers (Concordia College, Edmonton) The Lodgepole sour gas blowout

H.E. Turner (Environment Canada) Case study on acid rain

M.E. Meek (Health and Welfare Canada) Asbestos

R.T. Burnet, D. Krewski and Claire A. Franklin (Health and Welfare Canada) Health risks from acid rain

Katherine Davies (Toronto Public Health) Use of drinking water objectives to assess potential health risks of chemicals in the Great Lakes.

M. Hotz (Royal Society of Canada) Gasoline lead - a case study

SYSTEMS ANALYSIS IN NATURE MANAGEMENT

S.A. Pegov

The study into society-nature interaction engenders an unusually wide and diverse range of problems requiring solution. What is more, even the long discussed problems, sometimes solved in principle, still remain the subject matter of discussions due to their internal complexity.

The dynamics of the current man-nature interaction results in rapid changes requiring not only accumulation of knowledge and partial decision making, but also the definition of a general development strategy for a complex tangle of arising problems. The changes in environmental chemism brought about by new technologies, and the social aspects of man-nature interaction require the application of a comprehensive, interdisciplinary approach to the analysis of emerging problems. The classical theoretical-experimental approaches are less applicable due to an explicit scarcity of knowledge of the natural dynamic changes and, as a rule, the limited feasibility of experimentation.

Systems analysis involves a combination of methods, ways and means of systems study and design as well as their management. The major emphasis in systems analysis is placed on solution of real problems faced by management agencies, research and other organizations. "Systems analysis is, in the first place, a tool for improving organizational, management, marshalling its structure and functions, its orientation toward problem situations, and accomplishment of goals at earlier dates and lower costs" [2].

The earlier applications of systems analysis to ecology were mostly dominated by mathematical modelling, i.e. a research determined the major components of a problem and tried to represent them in a model. This led to construction of a huge number of environmental mathematical models. In particular, [3] lists over 1,500 models of ecological processes and nature-society interactions. Nevertheless, there is no information on practical application of the majority of the models. This is probably associated with the fact that the problems relating to man-nature interaction are characterized by insufficient objective information which, in the process of model formulation, can be enlarged only with subjective ideas of the researcher about the system variable relationships. In complex models, such as those attempting to describe man-nature interactions, this subjective information influences the results in an unpredictable manner. As a result, complex models are unacceptable for decision makers and do not affect the decision process.

At the same time, the significance of systems analysis is especially great in decision making. It would be appropriate here to recall the A. Enthoven definition: "Systems analysis is a reasonable approach to decision making explicitly defined as "quantitative common sense" [6]. The author is not going to compare systems analysis and decision methods. This question is thoroughly and competently discussed in Larichev [14]. We are interested, in the first place, in the systems approach pattern given in that publication:

Define goals and resources → Determine problem solution alternatives → Compare the alternatives analytically → Select the most preferable alternative

In considering this basic pattern, one may come to a conclusion that at least three stages employ informal procedures. Systems analysis of a problem assumes the availability of data on its essence, structure, its relationships with other problems, availability of resources for the problem solution, etc. Many of these factors do not lend themselves to quantitative evaluation, and hence they may be accounted for only on the basis of knowledge, experience, and intuition of experts in the given or a similar problem. So the purpose of systems analysis is to marshal the diverse information as well as to identify the trends in system dynamics both at present (descriptive) and in the future (forecast).

In the application of systems analysis to ecological-economic systems (a far from adequate term, just like socio-ecological systems - the point is of a system describing nature-society interaction on a certain spatial basis), it is generally the case that, on the one hand, we are quite familiar with physical laws governing the evolution of natural systems but are not always aware of their manifestations. On the other hand, the pattern of natural impacts on the part of the society is often of purely formalizable character. Provided that anthropogenic influences on natural systems always, sooner or later, lead to structural and functional changes of the systems, and the changes, in their turn, affect management of the economic system (primarily through demographic and social characteristics) it becomes clear that we deal with purely structured systems having both quantitative and qualitative variables where the latter dominate in most cases.

The complexity of nature-society interaction has given rise to a number of approaches to decision problems in the area of nature management. There are well known models of global and regional ecological problems [9, 19]. Sometimes, the nature management processes are successfully studied on ecological-economic models [4, 8, 10]. Wide acceptance in the USSR has been gained lately by the so-called territorial complex schemes of nature protection (Terksop) [13] employing for the most part informal heuristic methods (scenarios, expert judgment, relevance trees, etc.) and quantitative techniques associated with statistical and econometric analysis of information, etc. The analysis techniques employed in Terksop are close to the approaches, currently in use abroad, to the solution of nature management problems encompassed by the term 'Environmented Impact Assessment' [7, 21]. Wide-scale application of methods such as the Leopold matrix, cost-effectiveness, adjusted map analysis flow diagrams, the Battelle method and the like, made it possible to solve a number of serious practical problems and develop some methods for environmental assessment and its interaction with economic systems. It is worth mentioning, however, a general shortcoming of this approach to the solution of ill-structured problems: there are considerable difficulties in its application for the analysis of long-range consequences of nature-society interaction.

To some extent, this difficulty is eased by the approach developed by a team of researchers of IIASA [1]. The work suggests the application of an adaptive decision procedure in nature management. Given the emergence or identification of AEAM* aspects of man-nature interaction, not accounted for in the first study, an AEAM procedure of the interaction analysis and assessment is carried out, account is taken of AEAM factors specifying the interaction processes both in structural and

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*AEAM - Adaptive Environmental Assessment and Management.

spatial-temporal dimensions. The expert opinions provide the basis for a specified interaction model and AEAM decision alternatives are generated. This adaptive decision procedure seems most close methodologically to the requirements of systems analysis of nature-society interaction.

It is worth pointing out, however, that it would be wrong both to exaggerate or underestimate the simulation methods of man-nature interaction in the study of ecological problems and decision making in nature management.

The point is that simulation of processes in a pristine environment is based on fundamental natural laws and, given their correct application, cannot but generate substantive results. The major human influences on natural systems are determined by the level of technological development, and hence, their assessment is based on strict engineering calculations. The difficulty is to correctly account for anthropogenic impacts on natural physical and chemical processes. Where such changes have been sufficiently studied (by observation or experimentally, on occasion) it becomes possible to construct adequate models of nature-society interaction. Note, that the overwhelming majority of "successful" ecological models were constructed precisely for such studied interaction cases. Should the consequences of man's impacts be not studied or, moreover, not clear enough, the significance of non-formalizable procedures of systems analysis grows. The role of expert judgment, heuristic simulation, the above-mentioned adaptive approach, etc. also increases in significance.

At the same time, the problems of environmental quality management, decision making, economic assessment of nature management cannot be solved only by formalizable analysis techniques. Especially important here is a reasonable approach to decision making, the very "quantitative common sense" A. Enthoven wrote about [6].

Hence, it would be wrong to place emphasis on and exaggerate the significance of either formalizable or nonformalizable procedures of problem analysis in exploring nature-society interaction. It is only the dialectical unity of these methodological approaches that allows one to decompose a complex ecological-economic system into separate elements-into a set of simpler interactions, express them in quantitative terms, and hence, make a correct decision with greater probability.

Consider one of the possible schemes of systems analysis of nature-society interaction which "represents the problem solution as a process of design, manufacture, and utilization of systems" [20].

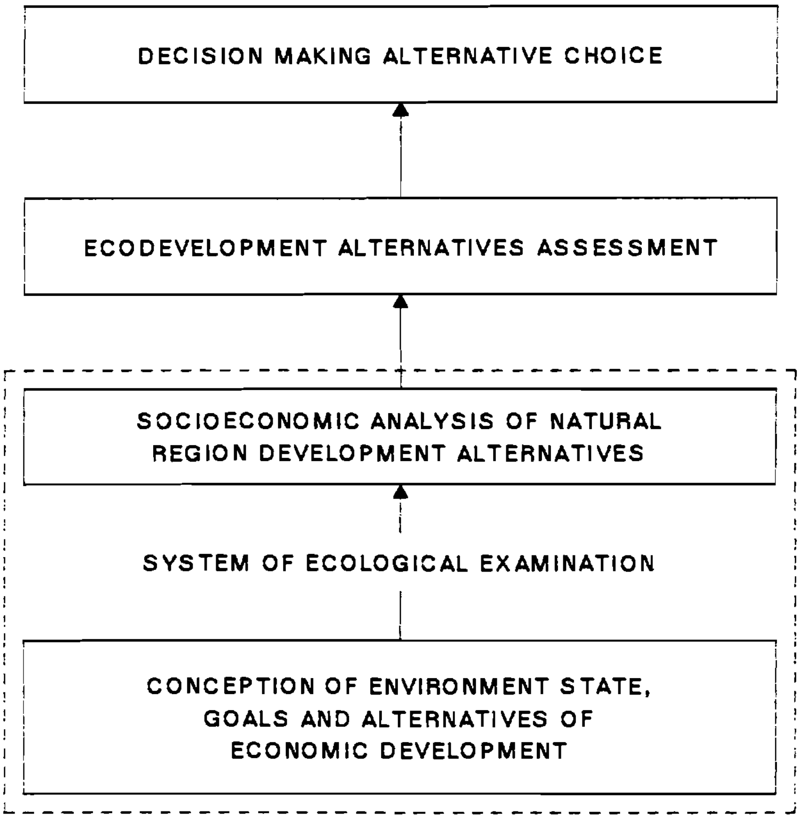

Fig. 1.

The purpose of the first phase of analysis is to form an idea of and assess the state of the environment of the region under study with due account of the changes caused by the existing anthropogenic factors, the goals of economic development and ways to their accomplishment. Evaluation of the technological resources needed to implement feasible regional development makes it possible to single out and identify opportunities for intervention, and reject unacceptable ecodevelopment alternatives.

The second phase is devoted to ecological examination and forecasting. It is a prerequisite for a general assessment of ecodevelopment alternatives. Generally speaking, the conception (first phase) of the current environmental state in the studied region is of prognostic value. But the point is that any human activity may affect natural systems for a long time. As a rule, for large geographic areas - provinces, economic regions - this time corresponds to the characteristic periods of succession processes - tens and sometimes hundreds of years. At the same time, the characteristic cycles in technological and economic conditions within the same region last up to 5, seldom up to 10 years. The consequences of anthropogenic impact accumulate for many years and serious disturbances in natural systems may be of sudden avalanche character following the gradual overwhelming of ecological capacity (stability limits) of the natural system. These specifics of man-nature interaction must be taken into account of when assessing and forecasting environmental state.

The concept of ecological stability (capacity) is for the timebeing a nonformalized notion, though for some simple cases it can be defined [12, 22]. It is clear, however, that this fundamental notion gives rise to both formal and nonformal methods of research into the nature-society interaction.

A set of first and second phase problems can most effectively be solved within the framework of an expert system (a system of ecological examination) [3]. The purpose of an expert system of environmental assessment and forecast is the synthesis of the formal and heuristic knowledge of experts in the field of man-nature interactions and the subsequent utilization of the acquired knowledge.

The economic effectiveness analysis of natural region development alternatives is regarded as a separate phase despite the fact that traditionally it has not involved a systems approach [14]. Application of the systems approach to the study of man-nature interactions has encountered some fundamental problems. First, the analytical comparison of ecodevelopment alternatives requires some common unit of measurement for ecological and socioeconomic systems. A second important problem is the socioeconomic evaluation of ecodevelopment, i.e. ways of interaction between nature, population, resources, and economic mechanisms in the region.

The utilization of monetary untis as a common equivalent is not always possible and justifiable. This has considerably lowered the enthusiasm of researchers who considered the cost-effectiveness technique [21] as most suitable for such problems. As for Soviet scientists, they use a more adequate category of the second differential rent [8] for the socioeconomic assessment of natural region development effectiveness. At the same time, economic estimates are, generally, applicable to individual components of the natural environment such as soil, vegetation, water, etc. Hence, it is highly desirable to develop an integrated estimate of environmental state as a whole that could be easily interpreted by economists and decision makers.

Any kind of technological activity is usually hazardous for environment and health. Naturally, it is always necessary (sometimes quite hypothetically) to take technical and economic measures for protecting human health and environment. The main principle of safety provision, suggested as a basis in decision making, boils down to providing "absolute safety" [16]. Is it possible to secure "absolute safety" by increasing investments in environmental control? Experience shows that it may be possible, but far from always. Fig. 2 gives two different dependencies of risk R on protection cost P [16].

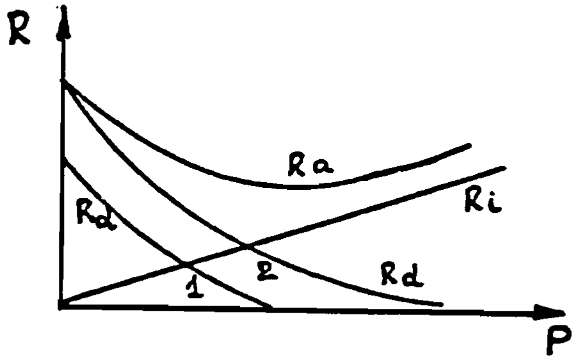

Fig. 2. Dependence of risk R on protection cost P. There are two options of direct risk R_d characterized by the possibility (1) and impossibility (2) to secure zero risk. An indirect risk R_i and aggregate risk R_a relate to (2).

Curve (1) corresponds to the case when "absolute safety" is achievable, for certain $P=P_0$ risk R from harmful impact becomes equal to zero. Examples of such technologies are provided by operations whose harmful discharges or impacts contain factors with threshold values. It is possible to achieve "absolute safety" by establishing standards (e.g. maximum tolerable concentration) providing for a harmful factor not exceeding the threshold value. Curve (2) corresponds to the case when it is impossible to achieve "absolute safety" in principle. Such behavior of environmental control cost effectiveness is characteristic of operations exerting long-range anthropogenic impact on environment (atomic power stations, biological operations, transport, etc.). A desire to achieve, in the second case, the maximum possible safety (ALAPA principle - as low as practically achievable) [18] results in the final count in ineffective investment of resources in environmental protection and health care. This is due to the fact that the indirect risk R_i associated with construction, maintenance, manufacture of protection technology starts growing. Hence, as safety costs increase the direct risk R_d decreases and indirect risks R_i increase. Starting from a certain level of expenses P, additional investments will be accompanied by a growing aggregate risk $R_a = R_d + R_i$ (Fig. 2).

There are many publications [18] and a host of suggestions on the problem of admissible risk. The questions of risk analysis are a standing topic of international conferences and mass media. The purpose of this paper, however, is not to give an overview of risk analysis concepts. This has been done expertly by other authors e.g. [16, 18]. We are interested in the fact that the risk level analysis of changes in environmental state and population health allows one to interpret the notion of ecological risk as a measure of natural system change under man's influence. At the same time, the currently available economic estimates of risk dependence on environment and human health protection costs permit an adequate socioeconomic analysis of the effectiveness of regional development alternatives. It is even possible to offer a risk estimate scale of environmental changes. Thus, maximum risk (100%) for a specific alternative of socioeconomic development as regards a natural system implies that implementing this strategy imposes a risk of destroying the natural system completely (disturb the stability state, exceed the marginal rate of sickness, etc.). On the other hand, if the socio-economic development strategy does not change the structural and functional properties of the natural environment and its demographic characteristics then the risk level equals zero. It is also possible to consider the probability of disturbing the ecological system stability through anthropogenic impact. Then, the above mentioned estimate scale will operate within the range of 0-1.

The use of such extraeconomic estimates for ecosystem stability will probably make it possible to considerably simplify socioeconomic effectiveness analysis of natural region development alternatives.

The assessment of ecodevelopment alternatives and the subsequent decision making (alternative choice) involve the measurement of qualitative characteristics inherent in ill-structured problems as well as problems of collective decision making taking into account the opinions of the different groups influencing the decision. Here we deliberately integrate the two last phases of the systems approach: alternative assessment and choice of a development alternative. This is associated with the fact that these questions are central to decision theory, hence, can be solved with the methods specifically developed for this purpose [15]. Nevertheless, it is necessary to note some specifics of ecodevelopment and decision alternative assessment in the area of nature management and environmental control.

Environmental and ecodevelopment problems are among the global issues of the present [11], i.e. problems concerned with all facets of human activity. Therefore, the interests involved in the solution of ecodevelopment problems may be in direct conflict. It is clear that no procedures can help a correct assessment of alternatives and decision making given well thought out, conflicting policies (e.g. the environment protector versus the proponent of industrial development). What is needed is the development of evaluation criteria and scales permitting trade-off decisions based on the probability assessment of the extent to which each development alternative is correct or incorrect. Each alternative can be estimated from economic, social, political, utility, or unprofitability points of view and the estimates can be expressed both in quantitative form (risk analysis, losses, etc.) or at least by the degree of significance. For example, it is suggested [7] to estimate alternatives in terms of relative indicators:

(1) probable unprofitability (probability of failure multiplied by its cost);

(2) probable utility (probability of favorable consequences multiplied by benefits);

(3) maximum probability of pure gain (probable utility minus probable unprofitability.

The choice of the best development alternative is made possible by the use of several criteria for defining the term "best".

Consider another example. The analysis of "desirability" of individual possible development alternatives, where each one is characterized by a certain degree of meeting the interests of problem solution contributors, makes it possible to have more explicit ideas about the comparative importance of individual aspects of the considered ecological problem, the extent of realized and not realized interests of the participants, and, finally about the ecodevelopment trade-off. Equally important is that it becomes possible to quantitatively estimate the level of ecological risk, and illustrate to each participant the profitability or unprofitability of solution alternatives of ecodevelopment problems, as well as present them graphically in the form of event development lines.

These relative indicators can be measured only on ordinate scales with verbal definitions of quality levels. Future research may make it possible to use qualititative measurement in the analysis of alternatives, and therefore the measurement techniques should employ the factor description language decision makers are accustomed to [14].

One of the possible approaches to alternative and decision analysis, especially for problems with explicitly conflicting objectives, as in nature management, is the development and use of business games [17]. Here the game participants have to view the problem solution from a wider perspective, "feel the elbow" of his or her partner and accept the necessity of trade-off.

What then must be the actual assessment procedures of environment state, alternative analysis, and decision making in problems of nature-society interaction? Most probably these must be iterative adaptive procedures taking account of changes in the goals of economic development and environmental state, and basic principles of state policy in nature management and environmental control. Of course, the nonformalizable elements in such procedures will be central but the development of formal methods of nature assessment and forecast, development of quantitative scales of socioeconomic effectiveness analysis of natural-region development alternatives, and formalization of some aspects of alternatives and decision analysis will make it possible to solve the man-nature interaction problems on a higher level.

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INTEGRATED ASSESSMENT OF ACID DEPOSITION IN EUROPE

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PROJECT SUMMARY

A model system known as RAINS (Regional Acidification Information and Simulation) is being developed in order to support integrated assessments of the complex problem of acid deposition. The flexible, modular design of the system enables RAINS to be used for policy and scientific analyses of both near- and long-term environmental impacts of acidification. The system, when complete, will account for sulfur and nitrogen emissions and their effect on the environment, measured in terms of the acidity of lakes and groundwater, forest soils, and the forest directly. The model user will also be able to undertake analyses of the costs and benefits of various control and mitigation strategies.

1. INTRODUCTION

Issues

As the public debate on acid deposition escalates, governments and industry are hard pressed to decide whether to install additional controls on power plants and other potential sources of pollution; to take steps to mitigate possible effects of acid deposition (e.g., liming of waterways and soils, development of resistant species of biota); or to wait perhaps five or ten years until there is more conclusive scientific information about the complex relationship or emissions and environmental effects. However, acting now to reduce emissions carries the risk that large expenditures will be made with little or no advantages. For example, a common policy being implemented in Europe for controlling acidification impacts is a thirty percent reduction of sulfur emissions by 1993 relative to the 1980 level. Although such a policy will be costly for virtually all of the countries concerned,the actual benefits to the natural environment are not well defined. Yet hesitation poses the serious threat of irreversible ecological damage that might have been prevented by prompt action.

Research aimed at improving scientific understanding of the acidification problem has increased drastically over the past few years. In many countries of North America and Europe large amounts of money are being spent to broaden the understanding of emissions, atmospheric transformation and transport, deposition, biological and chemical effects, evaluation of damages to the environment and the costs of control strategies for acidification [1,2,3,4,5,6,7,8,9,10,11].

But augmenting scientific information about the problem of acidification will not necessarily lead to the identification of suitable policies for controlling acidification of the environment. This information must be structured in a form that can be used for decision-making based on available scientific evidence and credible judgements about the probability of future events.

The design of methods for addressing the acidification problem must take into account both the temporal and spatial dimensions of the problem. Countries differ in the levels of air pollutants and acidifying compounds they produce, as well as in their susceptibility to air pollution deposition. The OECD estimates that at least one-half of the sulfur deposition in Nordic countries is due to foreign sources, with some contributions coming from as far as 1000 kilometers away [1,12]. Moreover, the travel time of air pollutants from one country to another may vary from a few hours to a few days; snowmelt releases acidity to lakes over a few weeks; it may take years or even decades for soils to acidify. Control strategies also have different time scales: some control policies may be effective within a year or two after their adoption, while others will require decades.

In the United States, for example, the National Acid Precipitation Assessment Program (NAPAP) commissioned an interdisciplinary team of Carnegie-Mellon University to develop a conceptual framework for an integrated assessment of the acidification problem (see [13,14]). In Europe a similar task is being performed at IIASA in close collaboration with the United Nations Economic Commission for Europe (ECE), which oversees the European joint efforts in abating effects of acidification (the Geneva Convention on Long Range Transboundary Air Pollution).

Objectives

IIASA has developed a model system known as RAINS (Regional Acidification Information and Simulation) that can be used for synthesizing the vast amount of unstructured information on the acidification problem and for dealing with the many crucial uncertainties associated with pollution emissions and their environmental effects [15,16,17]. The ultimate goal of the Project is a better understanding of the near- and long-term (up to 2030) effects of acid deposition in Europe.

2. PROJECT DEVELOPMENT

Model Design: Current Status

The model system consists of three linked components representing the relationship between pollution generation. These compartments are: pollutant generation, atmospheric processes, and environmental impact. (See Figure 1.) Because of the relatively rich database on sulfur emissions and the established link between these emissions and acidification, RAINS is now sulfur-based and measures impacts in terms of changes in the level of acidity of forest soils and lake water. Since the cumulative impacts of the steady acidification process represents a long-term phenomenon, the time horizon of RAINS is fifty years. Time resolution is one month, in order to simulate seasonal differences.

As a starting point the model user has a choice of three possible pathways for each of 27 European countries considered (including the European part of the Soviet Union) based on ECE data [18]. Sulfur dioxide emissions are computed on a mass balance basis by summing the emissions in nine energy sectors in each country, together with the contribution from non-combustion industrial processes in these countries:

$$S_i^t = \sum_{k=1}^{9} S_{k,i}^t + S_{procs,i}^t \tag{1}$$

where

$S_{k,i}^t$ = sulfur emissions in country i, energy sector k ($t\ yr^{-1}$)

$S_{procs,i}$ = sulfur emissions from non-combustion industrial processes in country i ($t\ yr^{-1}$).

A procedure for model use is shown in Figure 2.

Sulfur emissions in each energy sector (S_k^t) are computed from:

$$S_k^t = E_k^t\, s_k^e (1 - c_k)(1 - \alpha_k)(1 - r_k) \tag{2}$$

where

E_k^t = energy used in energy sector k ($PJ\ yr^{-1}$)

S_k^e = sulfur content of fuel per energy unit in sector k ($PJ\ yr^{-1}$)

c_k = coefficient of sulfur removed by fuel cleaning in sector k (fraction)

α_k = coefficient to account for sulfur removed by flue gas desulfurization devices in sector k (fraction)

r_k = coefficient to account for amount of sulfur retained in energy sector k (fraction).

The sulfur content of fuel in energy units (s_k^e) is computed from estimates of the sulfur content of fuel in weight units and fuel heat value, as well as the relative amounts of hard and brown coals and light and heavy oils used in each energy sector. Annual sulfur emissions, S_k^t in equation (2), are converted to monthly emissions by using the characteristic variation of seasonal emissions reported in [1].

Anthropogenic sulfur emissions in Europe have been reported in various publications (e.g. [19,20,21,22,23,24,25]). Similar estimates for North America are contained ***inter alia*** in [26,27,28,29].

Atmospheric Submodel

This submodel of RAINS incorporates results from a model developed under *EMEP*, the UN sponsored Cooperative Programme for Monitoring and Evaluation of Long Range Transmission of Air Pollutants in Europe. Results of this program have been reported in [30,31,32,23,33,34]. These results are in the form of source-receptor matrices for wet and dry sulfur deposition. Elements of these matrices represent the unit monthly deposition at a particular grid location in Europe due to unit emissions from each European country. Sulfur deposition is computed in some 800 grid elements, each with a dimension of 150 x 150 kilometers. To obtain the monthly wet or dry sulfur deposition at time t and location j due to the sulfur emissions

in country i, the source receptor matrices are multiplied by the monthly sulfur emissions in each country. That is

$$dw_{i,j}^t = S_i^t AW_{i,j} \tag{3a}$$

and

$$dd_{i,j}^t = S_i^t AD_{i,j} \tag{3b}$$

where

$dw_{i,j}^t$ and $dd_{i,j}^t$ = wet and dry deposition in location j, respectively, at time t due to source country i ($g\ m^{-2} mo^{-1}$)

S_i^t = sulfur emission in source country i ($t\ mo^{-1}$) at time t

$AW_{i,j}$ and $AD_{i,j}$ = wet and dry source receptor matrices, respectively.

This approach assumes that deposition at j is proportional to emissions at i.

All contributions at location j are summed to obtain the total monthly sulfur depositions dw and dd ($g\ m^{-2} mo^{-1}$) at time t:

$$dw_j^t = \sum_{i=1}^{27} dw_{i,j}^t \tag{4}$$

and

$$dd_j^t = \sum_{i=1}^{27} dd_{i,j}^t \ . \tag{5}$$

The source receptor matrix used in the RAINS system was provided to IIASA through the courtesy of EMEP's Meteorological Synthesizing Center-West at the Norwegian Meteorological Institute in Oslo. For routine calculations, RAINS uses average matrices from a four-year (October 1978–September 1982) model run. However, the model user has the option to use matrices from any particular year in this four-year period rather than use the four-year average.

Eventually source-receptor matrices from European regional air quality models other than EMEP will be implemented in RAINS, so that a model user can compare results for different sulfur transport models. (See e.g. [35,36,37,38,39,40,41].)

Forest Soil Acidity Submodel

Environmental effects are presently represented by submodels for ***forest soil acidity*** and ***lake acidity***. Initially, the dominant theory for explaining tree damage was the soil acidification theory advanced by Ulrich and his co-workers (see [42,43,44,45,46,47]). Recently, a large amount of alternative hypotheses have been put forward. Some experts have attempted to classify the different hypotheses. For example, Nihlgård [48] has identified three main classes of hypotheses: the acid rain hypothesis, the ozone hypothesis, the stress hypothesis; to this he adds a fourth category: the ammonia/ammonium and nitrate hypothesis. A more detailed evaluation of effects of air pollution on forests can be found in McLaughlin [49]. His extensive review does not lead to one conclusion as to which pollutant or combination of pollutants is responsible for the recent increase in forest damage. Other important contributions to the scientific literature in this field include [50,51,52,53,54,55,56,57,58].

In view of the above we stress that the IIASA forest soil acidity submodel described below should be interpreted only as an ***indicator*** of potential forest impact of acidification. Some definitions are useful at this stage.

Soil acidification has been defined as a decrease in the acid neutralization capacity of the soil [52]. Such a decrease may coincide with a decrease in soil pH. It may also take place in conditions of a relatively constant pH, assuming efficient buffering processes. In such a case the buffering of the soil counteracts the factors tending to decrease the soil pH, so that over long periods of time the soil pH stabilizes at a constant level. Yet the neutralization capacity is consumed and the soil is subject to acidification.

Acid stress is defined as the input of hydrogen ions (protons) into the top soil. Acid stress can result from acidic deposition of air pollutants, from biomass utilization, and from the natural biological activity of ecosystems [44,52].

Soil reaction to the acid stress depends on the soil properties. Acid stress implies the flux of hydrogen ions into the soil, and in the corresponding way the ***buffering properties of the soil*** imply the consumption of hydrogen ions within the soil profile. Buffering is described using two variables, one for the gross potential and the other for the rate of the reaction.

Buffer capacity, the gross potential, is the total reservoir of the buffering compounds in the soil. The unit for the buffer capacity is the same as that for the amount of acid stress ($kmol\ ha^{-1}$).

Buffer rate, the rate variable, is defined as the maximum potential rate of the reaction between the buffering compounds and the hydrogen ions. This variable is needed because the reaction kinetics is sometimes important. Although the buffer capacity is high, the rate sometimes limits hydrogen ion consumption. The buffer rate is expressed in units which are comparable to those of the stress rate ($kmol\ ha^{-1}\ yr^{-1}$).

The proton consumption reactions in soils have been systematically described by Ulrich [42,45]. A consecutive series of chemical reactions has been documented in soils in which the acidification proceeds. Information regarding the dominant reactions has been used for defining categories, called ***buffer ranges***. They are briefly described in the following paragraphs and summarized in Table 1. The name of each buffer range refers to the dominant buffer reaction and the typical pH ranges given refer to the pH of a soil/water suspension ($pH(H_2O)$).

sufficient to buffer the acid stress completely.

Cation Exchange Range. When cation exchange reactions play the major role in the acid buffering, it is necessary to classify the soils into the cation exchange buffer range. The excess stress, not buffered by the reactions of the silicate buffer range, is absorbed in the form of H^+- or Al-ions at the exchange sites, thus displacing the base cations. The cation exchange reactions are fast and, therefore, the buffer rate of soils in this range effectively counteracts any occurring rates of the acid stress. The total buffer capacity (= cation exchange capacity, CEC_{tot}) is generally low, depending mainly on the soil texture. The remaining buffer capacity at any given time is quantified by ***base saturation***, the percentage of base cations of the total CEC. As long as the base saturation stays above 5–10 percent, the excess stress is buffered by the cation exchange reactions and the soil pH takes a value between 5.0 and 4.2, the actual value depending on the base saturation.

Aluminum and Iron Buffer Ranges. Below the critical value of the base saturation, soils are classified into the aluminum buffer range. Hydrogen ions are consumed in releasing aluminum mainly from clay minerals. These reactions merely change the form of acidity from hydrogen ions to Al^{3+}. The leachate thus has a potential of acidifying the adjacent ecosystems. High aluminum ion concentrations characterize the soil solution and may cause toxic effects to bacteria and plant roots.

Aluminum compounds are abundant in soils, so that the buffer capacity hardly ever restricts the reaction. The soil pH is determined by the equilibrium with solid phases of aluminum compounds. As long as the soil pH stays within the range 4.2–3.8, the soil is classified into the aluminum buffer range.

At the extreme stage of acidification (pH < 3.8) soil may be classified into the iron buffer range. Increasing solubility of iron oxides is observed. This leads to

Table 1. Classification of the acid buffering reactions in forest soils [42,45].

Buffer range	pH range	Base saturation	Buffer reaction
Carbonate	8.0-6.2	1.00	$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$
Silicate	6.2-5.0	0.70-1.00	$CaAl_2Si_2O_8 + 2H_2CO_3 + H_2O \rightarrow$ $Ca^{2+} + 2HCO_3^- + Al_2Si_2O_5(OH)_4$
Cation exchange	5.0-4.2	0.05-0.70	clay mineral=Ca + $2H^+ \rightarrow$ H-clay mineral-H + Ca^{2+}
Aluminum	4.2-3.0	0.00-0.05	$AlOOH + 3H^+ \rightarrow Al^{3+} + 2H_2O$
Iron	<3.8	0.00	$FeOOH + 3H^+ \rightarrow Fe^{3+} + 2H_2O$

Carbonate Buffer Range. Soils containing $CaCO_3$ in their fine earth fraction (calcareous soils) are classified into the carbonate buffer range (pH ≥ 6.2). Ca^{2+} is the dominant cation in the soil solution and in the exchange surfaces of the soil particles. The buffer capacity of soils in this range is proportional to the amount of $CaCO_3$ in the soil. In case $CaCO_3$ is evenly distributed in the soil, the buffer rate, i.e. the dissolution rate of $CaCO_3$, is high enough to buffer any occurring rate of acid stress.

Silicate Buffer Range. If there is no $CaCO_3$ in the fine earth fraction and the carbonic acid is the only acid being produced in the soil, the soil is classified into the silicate buffer range (6.2 > pH ≥ 5.0). In this range the only buffer process acting in the soils is the weathering of silicates and the associated release of base cations, since the dissolution of aluminum compounds does not start in significant amounts until at pH less than 5.0. The buffer rate is often quite low. The buffer capacity, in turn, is high as it is formed by the massive storage of the silicate material. The weathering of silicates occurs throughout all buffer ranges. The switch to lower buffer ranges implies that the weathering rate of silicates is not visible (color) symptoms in the soil profile. This is not the case for aluminum, although in quantitative terms aluminum may still act as a dominant buffer compound. The pH values as low as 3.8 indicate toxicity and nutrient deficiency to living organisms.

The IIASA submodel describes soil acidification in terms of the sequence of the buffer ranges. It compares the amount of stress (cumulative value over the time period of interest) to the buffer capacity, and the stress rate (year-to-year basis) to the buffer rate. The comparisons are made separately for the carbonate, silicate and cation exchange buffer ranges. The submodel assumes that values for the buffering variables -- buffer capacity and buffer rate -- are determined separately for each of these buffer ranges [59,60].

All of the buffering variables do not have to be considered in the model. The buffer rates of the carbonate range and the cation exchange range are so high that in practice they can not be exceeded by any occurring rate of acid stress. Moreover, the buffer capacities of silicate and aluminum ranges can not be exhausted in the time scale of hundreds of years. For the aluminum and iron ranges, an equilibrium approach was chosen. The soil pH is assumed to stay in equilibrium with solid phases of aluminum compounds. Thus a buffer rate is not needed. The iron range is also assumed to be quantitatively irrelevant for buffering at pH-values above 3.0. In this way the number of buffering variables actually included into the model reduces to three: buffer capacity of the carbonate range (BC_{Ca}), buffer rate of the silicate range (br_{Si}) and buffer capacity of the cation exchange range (BC_{CE}).

The submodel is used by taking the given pattern of acid stress as the input variable. The program compares the (annual) acid stress to the buffer rate determined for the prevailing buffer range. It also compares the accumulated amount of acid stress to the buffer capacity. With these comparisons the program calculates which buffer range prevails each year, and then computes the approximation of the prevailing soil pH.

Acid stress to the top soil is partly or fully neutralized by the weathering of carbonate or silicate minerals. It is assumed that soils containing free carbonates (calcareous soils) always have a buffer rate high enough to neutralize any rate of acid stress. In this case the soil pH is assumed to remain at 6.2 as long as the buffer capacity of this range is not exhausted. In non-calcareous soils, neutralization depends on the intensity of silicate weathering (silicate buffer rate). As long as this buffer rate is larger than the acid stress, no decrease in soil pH is assumed to occur.

If the acid stress exceeds the actual buffer rate of the silicates, the soil shifts into the cation exchange buffer range. Then the hydrogen ions gradually replace the base cations on the exchange sites of the soil particles, thus decreasing the base saturation of the soil. The capacity of the cation exchange buffer system is depleted with a rate equal to the difference between the acid stress rate and the buffer rate of silicates. This has to do with the equilibrium between the ions attached to the soil particles and those dissolved in the soil solution. The gradual character was introduced also for the recovery. The soil pH is then estimated on the basis of the prevailing base saturation within the cation exchange range and the upper aluminum range at pH from 5.6 to 4.0. If the cation exchange capacity is totally exhausted, the hydrogen ion concentration is assumed to be determined by equilibrium with solid phases aluminum; this implies dissolution or precipitation of aluminum until an equilibrium state is reached.

The specific equations incorporated in this model are as follows. The capacity of the cation exchange buffer system, BC_{CE}^{t}, is depleted with the rate of acid stress, as^{t}, minus the buffer rate of silicates, br_{Si} (see equation 6). A non-linear relationship is assumed between the base saturation and the soil pH within the silicate, cation exchange and the upper aluminum buffer range, as long as $BC_{CE}^{t} \geq 0$, at pH from 5.6 to 4.0 (see equation 7):

$$BC_{CE}^{t} = BC_{CE}^{t-1} - (as^{t} - br_{Si}) \tag{6}$$

$$pH = 4.0 + 1.6\,(BC_{CE}^{t}/\,CEC_{tot})^{3/4}\ . \tag{7}$$

The shape of the pH - base saturation relationship has been adopted from results of an equilibrium model by Reuss [61].

If $BC_{CE}^{t} = 0$, equilibrium with gibbsite is assumed. As precipitation infiltrates into the soil and mixes with the soil solution, disequilibrium concentrations $[Al^{3+}]_s$ and $[H^{+}]_s$ are obtained in the following equations, respectively:

$$[Al^{3+}]_s = V_f [Al^{3+}]^{t-1} \,/\, \left[V_f + (P - E)\right] \tag{8}$$

$$[H^{+}]_s = \left[V_f [H^{+}]^{t-1} + (as^{t} - br_{Si})\right] / \left[V_f + (P - E)\right] \tag{9}$$

where V_f is the volume of soil solution at field capacity and P and E mean annual precipitation and evapotranspiration respectively. On annual basis the infiltrating water volume is assumed to equal $P - E$. The soil solution volume is simply defined by

$$V_f = \Theta_f z \tag{10}$$

The soil thickness, z, is fixed to 50 cm and the volumetric water content value at field capacity, Θ_f, is estimated separately for each soil type based on the grain size distribution in soil. Aluminum is dissolved or precipitated until the gibbsite equilibrium state (equation 11) is reached. This process involves a change from disequilibrium concentrations as defined in equation (12):

$$[Al^{3+}]^{t} \,/\, \left[[H^{+}]^{t}\right]^{3} = K_{so}, \qquad K_{so} = 10^{-8.5} \tag{11}$$

$$3\left[[Al^{3+}]_s - [Al^{3+}]^{t}\right] = [H^{+}]^{t} - [H^{+}]_s\ . \tag{12}$$

Combining equations 11 and 12 we obtain a third-order equation which has a single real root:

$$3K_{so}\left[[H^+]^t\right]^3 + [H^+]^t - 3[Al^{3+}]_s - [H^+]_s = 0\ . \qquad (13)$$

The model developed in this study can be used for quantifying some aspects of the acidification problem of forest soils which have earlier been discussed using qualitative terms. The soil acidification model and the application to the European overview are simplifications, which necessarily include uncertainties. Many solutions, as they stand now, are crude approximations which need clarification.

Lake Acidity Submodel

The harmful effects on surface waters of acidic deposition have been well documented in various parts of the Northern Hemisphere. The causal relationships leading to freshwater acidification are, however, complex and difficult to quantify. Hydrochemical models are one way of quantifying and integrating various processes in the entire catchments. Models have been used for simulating daily variations of water quality in streams, caused by variations in deposition, as well as in catchment hydrology and meteorology [62]. However, many of these modeling approaches have been regarded as tools for data evaluation rather than as tools for predicting long-term acidification of the catchments.

Recently the need for estimates of potential future impacts of acidic deposition has been emphasized. Scientific information can assist in making policies for emission control by describing quantitative consequences of alternative scenarios. There are at present three basic methods for projecting future water chemistry for sensitive areas. The first is an empirical approach which allows the estimation of future steady-state chemical composition of lakes resulting from changes in loading of strong acids on the basis of observed relationships in present conditions [63]. The second method utilizes complex, process oriented submodels for catchment hydrology, canopy chemistry, soil chemistry as well as for stream and lake water quality to provide a scientific link between acidic deposition and lake acidification [64]. The third method defines predictive algorithms that largely retain the simplicity of the empirical models but that have mechanistic process oriented explanations incorporated in their structure, to allow a theoretical basis for establishing confidence in the estimates [65].

Simple models can be applied as part of a regionalized model structure. At the time of developing IIASA's lake acidification submodel, no suitable models were available for this purpose. Therefore, a number of existing process descriptions were simplified, modified to monthly time step and finally linked together to form a simple working method for the evaluation of lake acidification [66].

One underlying principle of IIASA's work has been to use a simplified approach which is warranted for a broad geographical scope. The objective has been to retain the simplicity of the model but to have only a few physically realistic processes incorporated in its structure so as to allow a theoretical basis for assessing confidence in the scenarios. The model consists of four modules that are linked together as shown in Figure 3. The processes considered in each module are summarized in Table 2. The meteorologic module regulates the input flows of water and deposition to the soil and directly to the lake. The hydrologic and soil chemistry modules together determine the flow of ions leaching from the terrestrial catchment to the lake. New equilibrium concentrations in the lake water are then computed in the lake module.

The purpose of the meteorologic module is to determine the volume of water and proportion of deposition entering the catchment within one time step, τ. The division of the total precipitation, P_{tot}^{τ}, into rain, P_{r}^{τ}, and snow, P_{s}^{τ}, is accomplished by Eqs. 14 and 15 [67,68].

$$P_r^{\tau} = \begin{cases} 0 & \text{if} \quad T^{\tau} < T_s \\ P_{tot}^{\tau} \dfrac{T^{\tau} - T_s}{T_r - T_s} & \text{if} \quad T_s \le T^{\tau} \le T_r \\ P_{tot}^{\tau} & \text{if} \quad T^{\tau} > T_r \end{cases} \tag{14}$$

Table 2. Processes considered in the IIASA lake acidity model.

Process	Reference
Meteorology:	
Partitioning between snow and rain	Shih *et al.* [67]
Snow melt	Chow [69]
Release of deposition from snowpack	Johannessen and Henriksen [70]
Hydrology:	
Evapotranspiration	Christophersen *et al.* [68]
Percolation from upper to lower reservoir	Chen *et al.* [71]
Lateral flow	Chen *et al.* [71]
Soil chemistry:	
Carbonate weathering	Ulrich [45]
Silicate weathering	Ulrich [45]
Cation exchange	Ulrich [45]
Aluminum equilibrium with gibbsite	Christophersen *et al.* [62]
Lake:	
Inorganic carbon equilibrium	Stumm and Morgan [72]

$$P_s^\tau = P_{tot}^\tau - P_r^\tau \tag{15}$$

P_{tot}^τ, P_r^τ, P_s^τ ... precipitation rates ($m\ mo^{-1}$);

T^τ ... mean monthly temperature (^0C);

T_r, T_s ... threshold temperatures ($T_r = 2\ ^0C$, $T_s = -1\ ^0C$).

Snow accumulates, whereas all rain during the winter is assumed to run through the snowpack and enter the soil. Also, the melting of the snowpack is set to be proportional to the mean monthly temperature above the threshold temperature, T_s [69,71]:

$$m^\tau = \begin{cases} \beta(T^\tau - T_s) & \text{if} \quad T^\tau > T_s \\ 0 & \text{if} \quad T^\tau \leq T_s \end{cases} \tag{16}$$

m^τ ... temperature induced melting rate ($m\ mo^{-1}$);

β ... melting rate coefficient for forested area

($\beta = 0.0213\ m\ (^0C)^{-1} mo^{-1}$).

The snowpack, SP^{τ}, is obtained by summing the individual P_s^{τ}-values and subtracting the m^{τ}-values, as long as SP^{τ} stays above zero (Eqs. 17, 18; here and thereafter primes refer to an intermediate step, which is used for computational purposes only):

$$SP' = SP^{\tau-1} + P_s^{\tau} \tag{17}$$

$$SP^{\tau} = SP' - m^{\tau} . \tag{18}$$

Deposition is assumed to accumulate when snow accumulates. The same fraction of total deposition as of total precipitation is retained in the snowpack each month:

$$D_s^{\tau} = D_{tot}^{\tau} \cdot P_s^{\tau} / P_{tot}^{\tau} \tag{19}$$

$$DP' = DP^{\tau-1} + D_s^{\tau} \tag{20}$$

D_{tot}^{τ} ... total deposition rate ($keq\ ha^{-1} mo^{-1}$);

D_s^{τ} ... deposition retained in the snowpack ($keq\ ha^{-1} mo^{-1}$);

DP^{τ} ... accumulated deposition ($keq\ ha^{-1}$).

During the snowmelt, the rate for the release of deposition from the snowpack, D_m^{τ}, is assumed to be two times higher than meltwater (Eqs. 21, 22). The "fractionation" effect observed during the snowmelt [70] implies that most of the impurities in the snowpack are found in the first meltwater:

$$D_m^{\tau} = \begin{cases} 2m^{\tau} DP' / SP' & \text{if} \quad m^{\tau} < \frac{1}{2} SP' \\ DP' & \text{if} \quad m^{\tau} \geq \frac{1}{2} SP' \end{cases} \tag{21}$$

$$DP^{\tau} = DP' - D_m^{\tau} \quad . \tag{22}$$

The deposition entering the soil or the lake will be called ***acid stress***, as^{τ}, in the sequel

$$as^{\tau} = D_{tot}^{\tau} - D_s^{\tau} + D_m^{\tau} \quad . \tag{23}$$

The flowpaths of rain and snowmelt water through the terrestrial system are important in determining the susceptibility of lakes to acidification by atmospheric deposition [71]. To provide a method for simulating the routing of internal flows, a simple hydrologic model is applied. A combined version of hydrologic models, Birkenes model and ILWAS model, presented by Christophersen *et al.* [62] and Chen *et al.* [71] respectively, is used.

The IIASA framework sets the prerequisite of a large spatial scale. The ILWAS model is highly mechanistic and contains descriptions of the processes both in the canopy and in several soil layers. There is thus rather little curve-fitting involved. The Birkenes model is very site specific and must be calibrated against the typical features of a given catchment before it can be applied. For the IIASA context, the simple two-layer structure of the Birkenes model is applied. Most of the physical descriptions of the processes for routing the water through these two layers and out of the system are simplified from the ILWAS model.

The terrestrial catchment is vertically segmented into snowpack and two soil layers (A- and B-reservoirs; Figure 4). The A-reservoir is defined as being identical with the uppermost 0.5 meter soil layer modeled by the soil impact model which is used later to account for soil solution chemistry. Physically, the flow from the upper reservoir can be thought of as ***quickflow***, which drains down the hillsides as piped flow or fast throughflow and enters the brooks directly [73]. This water is mainly in contact with humus and the upper mineral layer. The B-reservoir in the model provides the ***baseflow***, which presumably comes largely from deeper (> 0.5 m) soil layers (see [73]).

The basic assumption governing the soil hydraulics is that rainfall or meltwater infiltrates as a whole into the A-reservoir (see [73]). Evapotranspiration is set proportional to the mean monthly temperature, T^τ, above 0°C (c.f. Christophersen *et al.* [68])

$$E^\tau = \begin{cases} \varepsilon \cdot T^\tau & \text{if } T^\tau > 0 \\ 0 & \text{if } T^\tau \leq 0 \end{cases} \qquad (24)$$

E^{τ} ... evapotranspiration rate $(m\ mo^{-1})$;

ε ... evapotranspiration coefficient (0.0039 $m\,(^{o}C)^{-1}mo^{-1}$).

The actual evapotranspiration rate is assumed to be equal to the potential from the A-reservoir; if A becomes empty, it is from the B-reservoir. The intermediate water balance is given by Eq. 25, which considers the water fluxes between the A-reservoir, the atmosphere and the snowpack:

$$V_A' = V_A^{\tau-1} + m^{\tau} + P_r^{\tau} - E^{\tau} \quad . \tag{25}$$

The percolation of water into the B-reservoir is controlled by the maximum possible percolation rate, $Q_p^{(1)}$, the water volume available in the A-reservoir, $Q_p^{(2)}$, and the space left in the B-reservoir, $Q_p^{(3)}$. Any one of these three factors can be a limiting factor for percolation. Therefore the actual percolation rate, Q_p^{τ}, is set equal to the minimum:

$$Q_p^{(1)} = K_s \frac{V_A' - \Theta_{f,A}}{\Theta_{s,A} - \Theta_{f,A}} \tag{26}$$

$$Q_p^{(2)} = V_A' - \Theta_{f,A} \tag{27}$$

$$Q_p^{(3)} = \Theta_{s,B} - (V_B^{\tau-1} - Q_B^{\tau}) \tag{28}$$

$$Q_p^{\tau} = \min\left\{Q_p^{(1)},\ Q_p^{(2)},\ Q_p^{(3)}\right\} \tag{29}$$

and

$$V_A'' = V_A' - Q_p^{\tau} \tag{30}$$

$$V_B' = V_B^{\tau-1} + Q_p^{\tau} \tag{31}$$

where

K_s is hydraulic conductivity $(m\ mo^{-1})$

$\Theta_{f,A}$, $\Theta_{f,B}$ is soil moisture content at field capacity in A- and B-layer, resp. (m)

$\Theta_{s,A}$, $\Theta_{s,B}$ is soil moisture content at saturation in A- and B-layer, resp. (m)

Lateral flow, Q_B^τ, is the limiting factor for the rate at which the water is discharged from the B-reservoir to streams and lakes. It is a function of hydraulic conductivity, K_s, surface slope, S, soil moisture content above field capacity, catchment width, W, and the terrestrial catchment area, A_c [71]:

$$Q_B^\tau = \begin{cases} K_s\, S\, W\, (V_B' - \Theta_{f,B})/A_c & \text{if} \quad \Theta_{f,B} < V_B' \le \Theta_{s,B} \\ 0 & \text{if} \quad 0 < V_B' \le \Theta_{f,B} \end{cases} . \tag{32}$$

Quickflow is formed from two fractions: (i) if the soil moisture exceeds the saturation value, the exceeding volume is assumed to enter the brooks directly, $Q_q^{(1)}$; and (ii) if the soil moisture exceeds the field capacity value, a fraction of the exceeding volume is discharged from the A-reservoir as lateral flow, $Q_q^{(2)}$. The total quickflow at time step τ is the sum of these two:

$$Q_q^{(1)} = \begin{cases} V_A'' - \Theta_{s,A} & \text{if} \quad V_A'' > \Theta_{s,A} \\ 0 & \text{if} \quad V_A'' \le \Theta_{s,A} \end{cases} \tag{33}$$

$$V_A''' = V_A'' - Q_q^{(1)} \tag{34}$$

$$Q_q^{(2)} = \begin{cases} K_s S\, W\, (V_A''' - \Theta_{f,A})/A_c & \text{if} \quad V_A''' > \Theta_{f,A} \\ 0 & \text{if} \quad V_A''' \le \Theta_{f,A} \end{cases} \tag{35}$$

$$Q_q^\tau = Q_q^{(1)} + Q_q^{(2)} \; . \tag{36}$$

The volume of water retained in both reservoirs is the balance between incoming and outgoing water volumes:

$$V_A^\tau = V_A^{\tau-1} + m^\tau - P_\tau^\tau - E^\tau - Q_p^\tau - Q_q^\tau \tag{37}$$

$$V_B^\tau = V_B^{\tau-1} - Q_B^\tau + Q_p^\tau \quad . \tag{38}$$

As a result, the hydrologic module simulates discharges from all reservoirs: snowpack and soil reservoirs A and B. The water from these three reservoirs mixes in the lake within the mixing volume before running out from the outlet.

IIASA's soil acidification submodel is applied as a component of this lake acidity submodel in order to compute the ion concentrations of the internal flows.

The lake module computes the time pattern of water quality in the lake. The impact on aquatic life will be estimated on the basis of simple threshold pH-values and aluminum concentrations. These characteristics are most likely to indicate damage to fish populations and other aquatic organisms.

The change in lake water chemistry will be predicted by means of titration of the base content of the lake with strong acid originating from the atmosphere. The initial conditions — the preacidification water quality — has to be determined for a given lake. The water quality variable of great importance is alkalinity, which expresses the total buffering capacity of the lake water.

In preacidification conditions the only affecting process is assumed to be the weathering of carbonates or silicates. In case the soil contains free carbonate bearing minerals, the lake water can be assumed to be very high in alkalinity (> 1500 $\mu eq\ l^{-1}$). For silicate rocks, Ulrich [45] has defined weathering rates between 0.2-2.0 $keq\ ha^{-1} m^{-1} yr^{-1}$. The original alkalinity, $[HCO_3^-]_0$, of the lake water can be computed by the available information on: the annual weathering rate of the mineral matter (br); the volume of soil through which the incoming water drains ($A_c \cdot (z_A + z_B)$) ; the mean annual runoff to which produced HCO_3^- is mixed ($P-E$). The following steady-state bicarbonate concentration in the outlet of the lake may be calculated on the basis of that information. The bicarbonate concentration obtained is used as the initial alkalinity for the model runs:

$$[HCO_3^-]_0 = \frac{A_c(z_A + z_B)}{(A_c + A_l)(P - E)} \cdot br \quad . \tag{39}$$

In clearwater lakes the carbonate alkalinity can be assumed to be the only significant buffering agent, mainly with reaction (Eq. 40). Reaction (Eq. 41) can be neglected since the naturally sensitive surface waters contain only negligible concentrations of carbonate ions:

$$HCO_3^- + H^+ = H_2CO_3 = CO_{2(aq)} + H_2O \tag{40}$$

$$CO_3^{2-} + H^+ = HCO_3^- \quad . \tag{41}$$

Reaction (Eq. 40) yields an expression for the equilibrium (Eq. 42), where $[H_2CO_3^*]$ represents the sum of $[CO_2]$ and $[H_2CO_3]$.

$$\frac{[HCO_3^-][H^+]}{[H_2CO_3^*]} = K_1 \quad . \tag{42}$$

Combining this with Henry's Law [72]

$$[H_2CO_3^*] = K_H \cdot p_{CO_2} \tag{43}$$

we obtain

$$[HCO_3^-] = \frac{K_1 \cdot K_H \cdot p_{CO_2}}{[H^+]} \tag{44}$$

where K_1 and K_H are thermodynamic equilibrium constants, which depend on temperature. When the drainage water, $Q_q^\tau + Q_B^\tau$, and the direct water input, Q_d^τ, enter the lake and mix within the mixing volume, V_{mix}^τ, disequilibrium concentrations result:

$$[H^+]' = \frac{M_{H^+}^\tau + [H^+]^{\tau-1} \cdot V_{mix}^\tau}{Q_q^\tau + Q_B^\tau + Q_d^\tau + V_{mix}^\tau} \tag{45}$$

$$[HCO_3^-]' = \frac{M_{HCO_3^-}^\tau + [HCO_3^-]^{\tau-1} \cdot V_{mix}^\tau}{Q_q^\tau + Q_B^\tau + Q_d^\tau + V_{mix}^\tau} \quad . \tag{46}$$

The buffer reaction (Eq. 40) continues until a new equilibrium state according to Eq. 42 is accomplished. Equal amounts of hydrogen and bicarbonate ions are consumed:

$$[H^+]^\tau - [H^+]' = [HCO_3^-]^\tau - [HCO_3^-]' \quad . \tag{47}$$

The new equilibrium concentrations, $[H^+]^\tau$ and $[HCO_3^-]^\tau$, can be obtained by solving Eqs. 44–46. A second order equation is obtained, from which the positive root for bicarbonate concentration is accepted. The equilibrium hydrogen ion concentration is then calculated from Eq. 47.

$$([HCO_3^-]^T)^2 + ([H^+]' - [HCO_3^-]')[HCO_3^-]^T - K_H \cdot K_1 \cdot p_{CO_2} = 0 \quad . \qquad (48)$$

The incoming acidity is mixed in the lake within the mixing layer. During the snowmelt that layer is assumed to be the top 2.0 m water layer. The meltwater is colder than most of the lake volume and therefore lighter than the 4°C water at the bottom. In this way the episodic spring time alkalinity and pH declines in the epilimnion can be estimated. The two water layers are then mixed together after there is no snow left in the catchment. During the summer, the incoming acidity is mixed with the whole water body.

Uncertainty Analysis

Long-range transport models play an important role in the assessment of acidification effects. How credible are these models? What is the uncertainty of model results when they are used to evaluate future pollution control strategies? In this sense model uncertainty is the departure of model calculations from current or future "true values".

The following illustrates the step-wise approach taken for the evaluation of uncertainty in the atmospheric submodel of RAINS. (For other examples of sensitivity and uncertainty analysis in atmospheric models, see [74,75,76,77,23,3,78,79,80].)

1. *Inventory of Uncertainty.* To assist in identifying and classifying sources of uncertainty for further analysis, we propose the following taxonomy: ***model structure***: uncertainty due to the particular collection of model variables in a model and how they are related; ***model variables***: uncertainty of ***parameters*** which are constant in time or space and ***forcing functions*** which inherently change with time or space; ***initial state***: uncertainty due to boundary and initial conditions; ***model operation***: uncertainty due to solution techniques of model equations, pre-processing and post-processing of model information. A further

distinction is made between ***diagnostic*** and ***forecasting*** uncertainty: ***diagnostic*** uncertainty concerns model use to simulate past or present conditions, and ***forecasting*** uncertainty arises when the model is used to make forecasts.

2. Screening and Ranking of Uncertainty. The goal is to reduce the number of sources of uncertainty that need to be quantitatively evaluated in step 3. This is accomplished through conventional sensitivity analysis or qualitative judgement and need not have the identical time-space scales specified in step number one.

3. Evaluation of Uncertainty. The sources of uncertainty which remain after step 2 or 3 can be evaluated by a number of different quantitative techniques. Table 3 lists some approaches being taken at IIASA to evaluate the EMEP model.

Table 3. Examples of techniques used to evaluate EMEP model uncertainty.

TYPE OF UNCERTAINTY		TECHNIQUE
Model Structure	•	Model comparisons
Forcing functions, Parameters, and Initial State (Estimation and Approximation Errors)	•	Monte Carlo Analysis
Forcing Functions (International Meteorological Variability)	• •	Matrix Analysis Statistical Analysis of "Grosswetterlagen"
Forcing Functions (Climate Change)	•	Historical data correlation

4. Application to Decision-Making. One example of how to apply uncertainty information to decision-making is illustrated by the RAINS model output in Figures 5 and 6. The RAINS model links a source receptor matrix from EMEP with other submodels describing the production of sulfur emissions and how the terrestrial and aquatic environment is affected by sulfur deposition. The model user can select a number of ***indicators*** to assess the impact of user-specified pollution control program. One such indicator, featured in Figures 5 and 6, is sulfur deposition. In these figures we have also indicated the influence of a ± 13% confidence interval in forecasted sulfur deposition. It is interesting that despite an assumed constant confidence interval, the importance of uncertainty significantly varies spatially (Figure 5) and temporally (Figure 6). This is due to background deposition and the spatial temporal pattern of sulfur emissions interacting in a complicated manner.

Direct Forest Impact Submodel

In 1985 work began on the development of a model for direct impacts on forests. Initially, this model will describe the impacts of atmospheric sulphur on the state of forests in terms of the foliage. The methods developed will also allow for the incorporation of other pollutants, when the required atmospheric submodels become available.

The direct forest impact model has to provide an operational linkage between two different spatial scales. To be informative for the assessment of transboundary impacts, the RAINS framework applies a regional scale with a rough spatial resolution. However, the appropriate scale for forest impact description is not larger than a few hectares, covering a single forest stand. This is due to the great variation in such environmental factors as soil type and altitude which affect the growth and pollutant tolerance of the forest.

A hierarchical approach has therefore been adopted to properly aggregate the high-resolution information on a regional scale. The basic unit at the lower level is forest stand, limited in size by the requirement that the important environmental factors (e.g. soil type, effective temperature sum, annual precipitation) and species composition be uniform. This system is described by means of a stand growth model originally developed to cover a variety of environmental conditions and tree species [81]; immediate pollutant impacts are incorporated as either steady or acute random reductions in the growth rate of individual trees. The stand model applies an annual time step.

The lower level model is used for generating simple I/O relations for the higher level model (regional model) in the hierarchy. The input consists of the pollutant load and the environmental factors; the output is an indicator of the state of the forest. The estimation and validation of the regional model will be carried out in collaboration with researchers monitoring sulphur dioxide and forest damage over the past decades in Europe [82]. Meteorological and forestry data for the description of the current state of environment and forests in the European countries have been obtained from other international organizations, (e.g. FAO).

Control Cost Submodel

In 1986 a submodel for evaluation of the *costs* of control policies will be added. This submodel is regarded as crucial for the planned application of RAINS to policy analyses. Early in 1986 a cost expert group of the ECE-Geneva Convention will meet at IIASA to assist in the further development of this submodel. Collaboration with the Argonne National Laboratory (USA) is under discussion (see *inter alia* Streets [28] for an overview of the work at Argonne). There will also be collaboration with OECD.

Groundwater Acidification

This is becoming an important issue in European research on acidification. During the summer of 1985 one of the participants of IIASA's Young Scientists Summer Program surveyed the literature on this problem, leading to a proposed modeling approach. Development work for such a submodel in RAINS is expected to start in 1986.

Nitrogen Oxide Emissions

A European nitrogen oxide emission inventory for a base year will be constructed, *inter alia*, through collaboration with the OECD and the joint FRG-Netherlands PHOXA project. A model for calculation of future nitrogen oxide emissions will be added to the inventory. Current work in Denmark and Norway is expected to lead to a nitrogen oxide transport and deposition model, which will be eventually added to RAINS. Existing environmental impact submodels will be modified to include nitrogen effects. These submodels will also be subjected to thorough validation tests using measurements made available to IIASA from institutes in Norway, Sweden, and Finland.

Operational Modes

Currently RAINS is a model for scenario analysis. To increase the utility of RAINS, other operational modes will be added. As a start an algorithm developed by Shaw [83] and applied by Young and Shaw [84] has been added to RAINS [85]. Collaboration with IIASA's Program for Systems and Decision Sciences and the Academy of Sciences of the German Democratic Republic in Berlin is expected to yield an optimization algorithm for RAINS.

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THE APPLICATION OF RISK ASSESSMENT PRINCIPLES TO AGRICULTURAL MANAGEMENT

S.E. Pitovranov

Introduction

In many countries of the world, total agricultural production and, more specifically, crop yields have increased markedly over time during the postwar period (see, for example, Parry *et al.*, 1986). This increasing trend can be mainly attributed to improved technologies and management practices in agriculture (e.g. the introduction of more productive crop varieties, increased mechanization, more intensive fertilizer applications, pest and disease control, etc.).

Simultaneously, increases in the fluctuation of agricultural production around the trend have, in a large number of these countries, kept pace with increases in mean levels (Hazell, 1986). According to one assessment, the coefficient of variation relative to rend of total world grain production is close to 10% (Borisenkov, 1985).

To illustrate the large fluctuations in production that are possible in successive years, total USSR grain production for two pairs of consecutive years are shown in Table 1.

Such fluctuations can be largely explained by the influence of seasonal weather on crops. Losses of total income resulting from

Table 1. Total USSR grain production in consecutive years 1975-76 and 1978-79 (million metric tons) (Ulanova, 1984).

YEARS	1975	1976	1978	1979
Production	140.0	227.7	237.4	179.2

can be expressed in terms of monetary value. According to Thompson (1972) the losses of total income from agriculture in the USA are approximately 8 billion dolars per year. However, a proportion of losses such as these could be prevented by adopting management practices based on the use of climatic and weather forecast data. In this way, the value of lost production that could have been avoided in the USA has been assessed by Thompson (1972) as 3.5 billion dollars (about 44% of the total losses). Borisenkov (1985) asserted that future insights into the stabilization of agricultural production might be gained, not from improved agro-technologies *per se*, but rather through the optimal use of more reliable weather and climatic information.

The goal of this paper is to apply some approaches of risk theory to the problem of agricultural decision-making in the face of fluctuating weather conditions.

Basic Strategies

Let us consider the benefit (loss) function

$$B = B(W, D) \tag{1}$$

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This function is defined for all pairs W,D, where $W \in \Omega_W$, and $D \in \Omega_D$, and Ω_W and Ω_D are sets of all possible weather conditons (W) and agricultural decision (D), respectively. Three strategies that are often used in risk theory can be listed as follows:

1. The Maximin (Minimax) strategy defined as:

$$\max_{D \in \Omega_D} \ \min_{W \in \Omega_W} B(W,D) \tag{2}$$

This strategy is designed to maximize the minimum benefit (alternatively expressed as minimizing the maximum loss).

2. The strategy minimizing the deviations (benefit or losses) from average values.

$$\min_{D \in \Omega_D} E_W \{[B(W,D) - E_W \{B(W,D)\}]^2\} \tag{3}$$

E_W is an operator that denotes statistical averaging over the set of all possible weather conditions (Ω_W).

3. The Baiesian strategy

$$\max_{D \in \Omega_D} E\{B(W,D)\} \tag{4}$$

This strategy maximizes (minimizes) the statistically-derived average benefit (loss).

where there is high probability of dry weather conditons during the growing season, and thus a high risk of crop damage.

The analysis will focus on a single administrative district, the Marx district. This is situated in the central part of the Saratov region, adjacent to the left-bank of the Volga river (Figure 1).

The total area of arable land in the district is 201.7 thousand hectares. The whole set of weather conditons during the growing season can be roughly classified into 3 main types: years with a severe deficiency of water for crop growth, years with a deficiency of water, and years with sufficient water supply. Statistics of the water supply for each category of years are shown in Table 2.

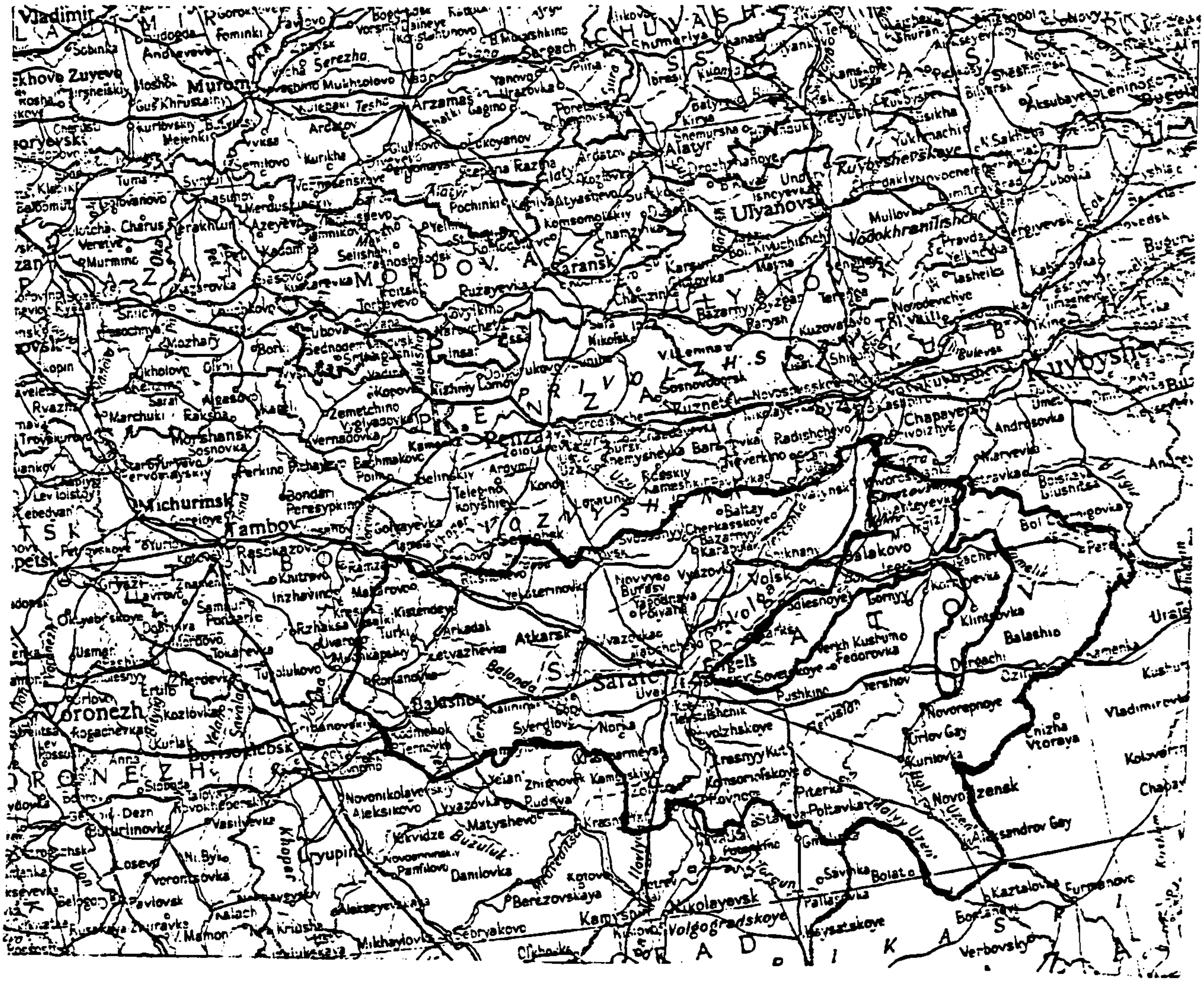

Figure 1. Map of Saratov region of the USSR.

Table 2. Types of years classified by water supply in the Marx district.

water supply	severely deficient	deficient	sufficient
Spring water storage in the top one-meter	< 125	125-150	> 150
Total precipitation in the spring-summer growing season (mm).	< 150	150-250	> 250
Rainless period during April-June (weeks).	> 3	2-3	< 2

The yields of the main commercial crops in the district in three recent years typical of each category are given in Table 3.

Table 3. Yields of seven major crops in the Marx district for three recent years with different moisture characteristics (t/ha) (A. Maximov personal communication).

water supply	1981 severe water deficiency		1982 water deficiency		1978 sufficient	
Crops	1	2	1	2	1	2
winter wheat	0.5	2.54	0.77	1.93	0.72	1.52
winter rye	0.88	2.6	1.31	2.17	0.94	1.73
spring wheat	0.35	1.07	0.95	2.19	1.96	2.34
barley	0.44	2.6	1.8	2.5	2.04	2.56
millet	0.27	0.83	0.99	1.48	1.42	1.82
corn for grain	-	2.03	-	1.81	-	2.68
pea	0.8	-	1.3	-	1.67	-

1 – crop yields on unirrigated land

2 – crop yields on irrigated land

The allocation of land for different crops during this period was practically unchanged in this district. In order to test whether output could have been increased by altering this allocation pattern, it is possible to formulate an optimization problem for land allocation, which optimizes the total district output for single years with characteristics. (F), the optimal allocation requires the solution of the problem:

$$F=\max_{S,s} F(S,s) \tag{5}$$

where $F(S,s)=\sum_i \{(K_i y_i - d_i)S_i + (K_i x_i - B_i)s_i\}$ K_i is purchase prices, d_i and B_i are the costs of production of i- th crop on irrigated and unirrigated land, respectively, y_i and x_i are corresponding yields, S_i and s_i are the corresponding land allocations.

The optimization problem has been solved using the above criteria, with added constraints involving requirements for certain essential management strategies (e.g. crop rotations) and minimum planned quotas. The results are given in Table 4 are compared with the recorded value of output for each year.

Table 4. Optimal and recorded value of district output in 1981, 1982 and 1978 (million rubles).

1981		1982		1978	
actual	optimal	actual	optimal	actual	optimal
1.7	4.3	12.6	14.0	20.2	23.9

With this information on the optimal allocation of land for different types of years, we can construct a benefit function for computing the total output for each weather type.

The benefit function for yields is the following matrix:

$$|B_{ij}| = \begin{vmatrix} 4.3 & 2.0 & 0.6 \\ 10.6 & 14.0 & 11.4 \\ 14.9 & 20.6 & 23.9 \end{vmatrix}$$

Each element B_{ij} of the matrix is the total district output (in million rubles) under weather type j if we have the allocation which is optimal for weather type i.

Use of Risk Strategies with Climatic Data

The probabilities of different types of weather conditions in the Marx district are given in Table 5.

Table 5. Probability of occurrence of different types of moisture-year (%).

	Probability		
	P severe deficit	P deficit	P sufficient
% of years	63	18	19

Let us apply each of the three strategies outlined earlier to these data.

The maximin strategy does not require information on the probability distribution of different types of weather- year, only a knowledge of worst case. This cautionary strategy is oriented towards expectation of severe water deficiency in *all* years. Allocation under such a strategy would thus guarantee a district output of at least 4.3 million rubles *every* year (the "drought" strategy).

The allocation strategy which minimizes the deviations from the mean is also a "drought" strategy which, it should be noted, may be especially convenient if there is limited storage capacity for agricultural production. In contrast, the allocation strategy which maximizes the average output over the long-term would be that oriented towards a "water-deficit" situation.

The average value of output under a "drought" strategy is 7.45 mill. rubles, but for the "water-deficit" strategy it would be 7.7 mill. rubles. Present-day land allocation in the Marx district provides an average output of about 7.2 mill. rubles. In the following we will refer to the use of the climatic probabilities ast the "climatic strategy".

Selection of Allocation Strategies on the Basis of Weather Forecast Information

Let us specify n possible types of weather conditions. The accuracy of different forecasts, F_i, may be described as a matrix of combined probability of occurence of all possible weather types W_j (Zhukovski, 1981):

$$F_i \xrightarrow{P_{ij}} W_j \qquad (6)$$

The matrix of combined probability $|P_{ij}|$ provides the full information for decision-making based on the Baiesian approach. Assume that we receive the weather forecast F_K type. The procedure for finding the optimal Baiesian strategy, corresponding to this weather forecast would be as follows:

1. Define the benefits for all possible decisions D_j , $j = 1,..n$

$$B(D_j | F_K) = \sum_{i=1}^{n} B_{ij} \; P_{i|k} \tag{7}$$

where the conditional probability $P_{i|k}$ can be calculated through the combined probability as follows:

$$P_{i|k} = P_{in} / \sum_{j} P_{jk} \tag{8}$$

2. Identify the decision D_k^{opt} that maximizes the partial benefits:

$$\max_{j} \; B(D_j | F_k) \tag{9}$$

Repeating this procedure for all types of weather forecasts enable us to obtain an optimal strategy $\{D_i^{opt},...D_h^{opt}\}$. In the case where the optimal strategy coincides with the strategy utilizing the forecast, the average benefit from the optimal strategy is calculated by the formula:

$$\bar{B} = \sum_{i=1}^{n} \; \sum_{j=1}^{n} B_{ij} P_{ij} \tag{10}$$

An Example of the Use of Weather Forecast Information

Evidently, it is necessary to "believe" a weather forecast if it provides potentially more beneficial information for decision-making than that based on climatic data alone. Let us illustrate using forecast information with the above example of land allocation.

Naturally, any decision requiring a change in land allocation can be made only if we have reliable advance information about seasonal weather conditions. Such information may be thought of as climatological and meteorological "insight" of the future. For the time being, we can still use forecasts based on factors that change less rapidly over time than the weather itself, such as water storage in the top one-meter layer in spring.

A methodology for constructing matrices that incorporate the combined probabilities of water supply forecasts (on the basis of the inertial characteristics of water storage) and crop yields has been developed by Fedoseev (1971). The matrix of combined probability constructed according to this methodology for the Marx district is as follows:

$$|P_{ij}| = \begin{vmatrix} 0.50 & 0.10 & 0.03 \\ 0.01 & 0.11 & 0.06 \\ 0.00 & 0.01 & 0.18 \end{vmatrix}$$

Calculations using formulas (7)-(9) demonstrate that the optimal strategy in this case would be to "completely believe" a forecast. It is easy to calculate by formula (10), that the average total income of the district with the application of such a strategy will be 9.3 mill. rubles i.e. approximately 20% more than if the "climatic" strategy were conducted.

Conclusion

In this paper some common principles of decision-making based on "unreliable" information was illustrated using an example for agricultural management. The results show that the use of this approach for a specific region might provide considerable benefit for farmers.

Acknowledgement

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UNCERTAINTY AND RISK IN WATER RESOURCE SYSTEMS PLANNING AND OPERATION

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There is little to add to the discussion about uncertainty and risk in the planning and operation of water resource systems. There are many books and papers in which these problems are discussed in great detail, therefore, this paper will concentrate only on some selected aspects of these problems, mostly in relation to the planning of water resource systems.

Water management can be understood as the intervention into the natural hydrologic cycle to exploit the water resources for the social and economic development of man. This intervention may take several different forms, the most advanced of which is a water resource system. As we all know there is a great deal of uncertainty in the hydrologic processes which determine the water supply of the system. But uncertainties also exist in our projections of future water demands. These demands depend on the future behavior and activities of our societies in which there is also a large amount of uncertainty. This is a particularly difficult problem when projections are made for many years ahead. When decisions concerning the balancing of water demands with water supply (which is the essence of water resource management) are made, we have to employ certain criteria for such decisions. Once again, there are serious uncertainties in the economic and social criteria which govern our decisions today. These criteria are not well-defined at present, but may change in the future when the system will be implemented and brought into operation. But what is the length of the implementation period? Usually we make certain assumptions in this regard, but serious delays may occur which are out of control, therefore the implementation period is uncertain as well.

There are many discussions about how risk should be defined. For me, risk is defined as the probability of failure of our system. For example, if there is a water shortage in the system, I consider this to be a failure of the system and it is possible to calculate the probability of such a failure. This is true for other situations we encounter in water resource management, i.e., failures related to flood protection. There is a general agreement among all concerned that water resource systems exhibit two characteristic features. One is their dynamic character, and the other is randomness of nearly all input values. In other words, decisions taken at any particular moment of time have an important effect on the future state and performance of the system. These future effects depend very much on the outcome of several random processes which are difficult to predict, or better said, our ability to predict them is clearly insufficient in relation to our needs. This is true in the case of hydrologic processes, but our inability to predict the future does not exist to any lesser degree for social and economic processes.

Let me start with two very simple examples. Then I will try to draw some lessons from these examples and formulate a few questions for discussion.

The first example concerns the design of a cofferdam — it is not necessary to discuss a complex water resource system to make the point I wish to make. Let us assume that we have to design a cofferdam protecting, for a period of t years, the construction of a hydraulic structure in the river channel. If the construction site is to be protected with a safety factor of α, i.e., we accept the risk of $r - 1 - \alpha$, then the cofferdam should be able to withstand a T-year flood Q_T level upon α. As we all know:

$$\alpha = (1 - p)^t \text{ where } p = \frac{1}{T} = \text{Prob } (Q_{\max} \geq Q_T) \; ;$$

$$\alpha = (1 - \frac{1}{T})^t \; ; \; r = 1 - (1 - \frac{1}{T})^t \; ; \text{ and } T = \frac{1}{1-\alpha\frac{1}{t}} \; ;$$

Let us assume that $t = 5$ and $\alpha = 0.98$ i.e., $r = 0.02$). In such a case, $T = 250$ years, and by application of one of the probability distribution models, we may calculate the related value of Q_T which is a function of T as well as of model parameters.

Now we have to face uncertainties inherent in our simple calculations. First, the duration of the construction period, i.e., the value of t, may change. Second, selection of a give probability distribution model - for example we may choose Gumbel, log normal, or Pearson Type III distribution - also carries large uncertainties. As Klemes emphasized, the same flood discharge may correspond to a 1000 year recurrence according to one distribution (method of fitting) and to 10,000 years according to another. He also stresses that this uncertainty is inherent in flood frequency analysis and cannot be removed by any mathematical trick. Finally, there is considerable uncertainty in the estimates of parameters of a given probability distribution model.

Let us limit ourselves to the first type of uncertainties discussed above: the duration of the construction period. If it changes in our example from 5 to 10 years, the effect is that the risk of overtopping our cofferdam changes from 2% to 3.9%. This means that instead of adopting one single value of acceptable risk - in our example 2% - we should rather consider an interval of acceptable risk because of all the uncertainties discussed above.

Let us go to the second example. It concerns planning of a water resource system to meet the water demands of population, agriculture, industry, etc. The case of the Skane region presented at this workshop is a good example in this respect. Planning the Upper Vistula system in my home country (CP* - Tisza, Vistula Workshop) could serve as another example of the problems which I would like to discuss.

In such planning exercises, we usually analyze a certain number of investment alternatives, each of them including storage reservoirs, water transfer facilities, wastewater treatment plants, etc., and one of the major criteria for evaluation of alternatives is often the minimization of the risk of water shortage. This risk can be defined as the probability that a water shortage in the system will not exceed a given value. For each alternative we can calculate such a risk using simulation techniques. (To perform statistical analysis of simulation results, this simulation analysis is often coupled with an analysis optimizing the operation of the system components.)

There again we have to employ several assumptions which carry significant uncertainties. First, we have to project future water demands for the next 20-30 years. I have already mentioned the uncertainty of this operation. We have also to assume a certain system of priorities concerning resource allocation. It must be recognized, however, that this system of priorities may change completely in the future. Once again, there are uncertainties embedded in the hydrological data we use for simulation of the system operation. Even if we resort to synthetic hydrology and use one of the sophisticated multi-site, multi-period stochastic models for generation of synthetic hydrologic data, there are uncertainties related to the model choice and to the model parameters estimated on the basis of a usually short historical example.

It all leads to the conclusion that before we employ any sophisticated metho-

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*CP-76-5. "Workshop on the Vistula and Tisza River Basins", 11-13 February, 1975. Edited by Andras Szollősi-Nagy.

dology to calculate the risk of water shortage for a given investment alternative, we have to make several assumptions concerning both the present and future state of the system. The result is that in addition to the risk of water shortage - a risk which we would like to minimize by rejection of the most risk-prone alternatives - we have to recognize several uncertainties embedded in our data, assumptions and models which are employed for calculation of the risk value. In light of this, instead of having one risk value, once again I would rather see a risk interval, recognizing that determination of such an interval may be very difficult.

Here is our basic dilemma in water resource systems. If we accept the concept of risk as a probability of failure, as I proposed at the beginning of this paper, then we will always try to use different quantitative methods to calculate this value. But all such calculations are based on a number of assumptions, data, and models which, generally speaking, are not at all certain in describing the real-world situation now and, particularly, in the future.

This brings us to the question: how can we deal with this dilemma? I would like to offer the following suggestions:

(1) We should devote much more time and much more attention to all types of research which may improve our knowledge about natural, social, and economic processes in water resource systems. This especially concerns our knowledge about the possible ways in which system characteristics may develop into the future. There will always be many alternative paths into the future; therefore, the scenario approach (alternative futures) should be used to the largest extent possible.

(2) All uncertainties inherent in the analysis of water resource systems should be examined and clearly described so as to increase our awareness of their existence.

(3) There seems to be a need for more analysis concerning the question of how sensitive our solutions and recommendations to all types of uncertainties inherent in water resource systems (different assumptions, different scenarios, etc.) are. Such sensitivity analysis may lead to a more complex picture of risk than the one we usually adopt in our investigations. As indicated by my two simple examples, instead of one single value of risk, we should rather introduce a notion of a risk interval reflecting our uncertainties about the many processes with which we are dealing.

RISK PERCEPTION:
A SYSTEMATIC REVIEW OF CONCEPTS AND RESEARCH RESULTS

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1 INTRODUCTION

In the year 1968 the Survey Research Institute at Allensbach (FRG) conducted a national poll in the Federal Republic of Germany in which a representative sample of German women were asked what kind of profession the ideal husband should have. In 1968 the most attractive profession for a man was that of nuclear physicist. Eleven years later the same question was again asked of all females between the ages of 16 and 70. In this poll the nuclear physicist was not even mentioned among the first 20 nominations. The top of the list was occupied by a completely different type of professional activity. The winner of the game was forest ranger (Allensbach, 1979)!

What has the attractiveness of male professions to do with risk perceptions? There are two answers to this question:

(1) The shift of prestige assignment from a technology-oriented to a nature-oriented profession reveals a semantic change in the public understanding of risk. In the past, technology was predominantly perceived as a powerful means of reducing risks due to natural catastrophes, climate variations, infectious diseases, and biological competitors for food and biotope (Markl, 1980), but in recent years it has become increasingly associated with causing risks and threats to human beings and the natural environment. People have become aware of the fact that the tools that liberated them from natural constraints themselves posed new risks on their lives (Hohenemser *et al*, 1981, p 2; Renn, 1984; Renn and Swaton, 1984).

(2) The change of professional prestige in modern societies further demonstrates the interdependences between perceptions, general social attitudes, values, and world views. There is no doubt that science is dependent on the concept of isolating specific phenomena from their natural or social context in order to construct modes of causal or sequential relationships with the aid of analytical techniques. This is also true for studies of risk perception. However, it should be kept in mind that in real life risk perception does not exist as a distinct psychological process among other types of perception, but forms an integral part of assembling and representing beliefs and perceived characteristics of an object or event in the mind of the individual. Considerations of risks may or may not play a major role in this opinion- or judgment-forming process. Potential benefits, side effects, symbolic meanings, value orientations, the attitudes of reference groups about the risk source, and the prestige and image of those who promote or oppose implementation of the risk source are just some of the many factors, apart from risk considerations, that influence people's perceptions of objects or events (Pearce, 1978; Hoos, 1980; Thompson, 1980; Conrad, 1981b; Lee, 1981).

Division into features relating to the risk and those relating to the risk source is admittedly a purely analytical expedient for psychological research. In reality, people judge objects, events, and activities only, and not risks (*cf.* Brown and Green, 1980).

Would it then not be better to remove the concept of risk perception from the terminology of cognitive psychology and to replace it by object perception? This sort of recommendation can indeed be justified in view of the often unthinking use of the concept of risk perception, but it is not necessary from the nature of the case, for perception of an object naturally also includes perception of the hazardous consequences of this object, their mental assimilation, and the development of general mechanisms to cope with the situation of uncertainty (Renn and Peters, 1982). Thus the hierarchical rank of aspects related to risk, benefit, and uncertainty with respect to object assessment can be analytically investigated. In the same way the separate measurement of object and risk perception can answer the question whether there are typical patterns in the intuitive perception of risk sources which can give some pointers toward the "common sense" assimilation of uncertainty owing to potential danger sources.

2 BASIC CONCEPTS OF RISK PERCEPTION

For the purpose of reviewing the major theoretical concepts and empirical studies in the field of risk perception it is necessary to define the main terms frequently used in the literature on risk perception.

Object perception

Object perception describes the process of mentally representing and assimilating information and experience with respect to a physical object or entity (Renn and Peters, 1982).

Values

A value is a conception, explicit or implicit and distinctive of an individual or characteristic of a group, of the desirable which influences the selection from available modes, means, and ends of action (Kluckhorn, 1951).

Beliefs

A belief represents the cognitive images a person has of a given object, i.e., it is a probability judgment whether an attribute is or is not, and to what degree, associated with the perception of an object. The subjective feeling of goodness and badness which is linked with each attribute refers to the effect a person might have and is called subjective evaluation (Fishbein and Ajzen, 1975).

Attitude

Attitude is a mental and neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related (Allport, 1935).

Concerns

A concern refers to a state of positive or negative responsiveness of individuals to awareness and processing of any information or personal experience regarding salient areas of interest on that matter (Renn and Swaton, 1984).

Risk perception

Perceived risk is the combined evaluation that is made by an individual of the likelihood that an adverse event will occur in the future and its probable consequence (Royal Society, 1983, p 34).

In *Figure 1* an attempt is made to illustrate the interconnections between beliefs, concerns, values, attitudes, and perceptions. The model includes five basic categories: physical environment, social environment, cultural environment, psychological motives, and socialized motives. Any individual is confronted with a specific object that is embedded in a social situation and a cultural context

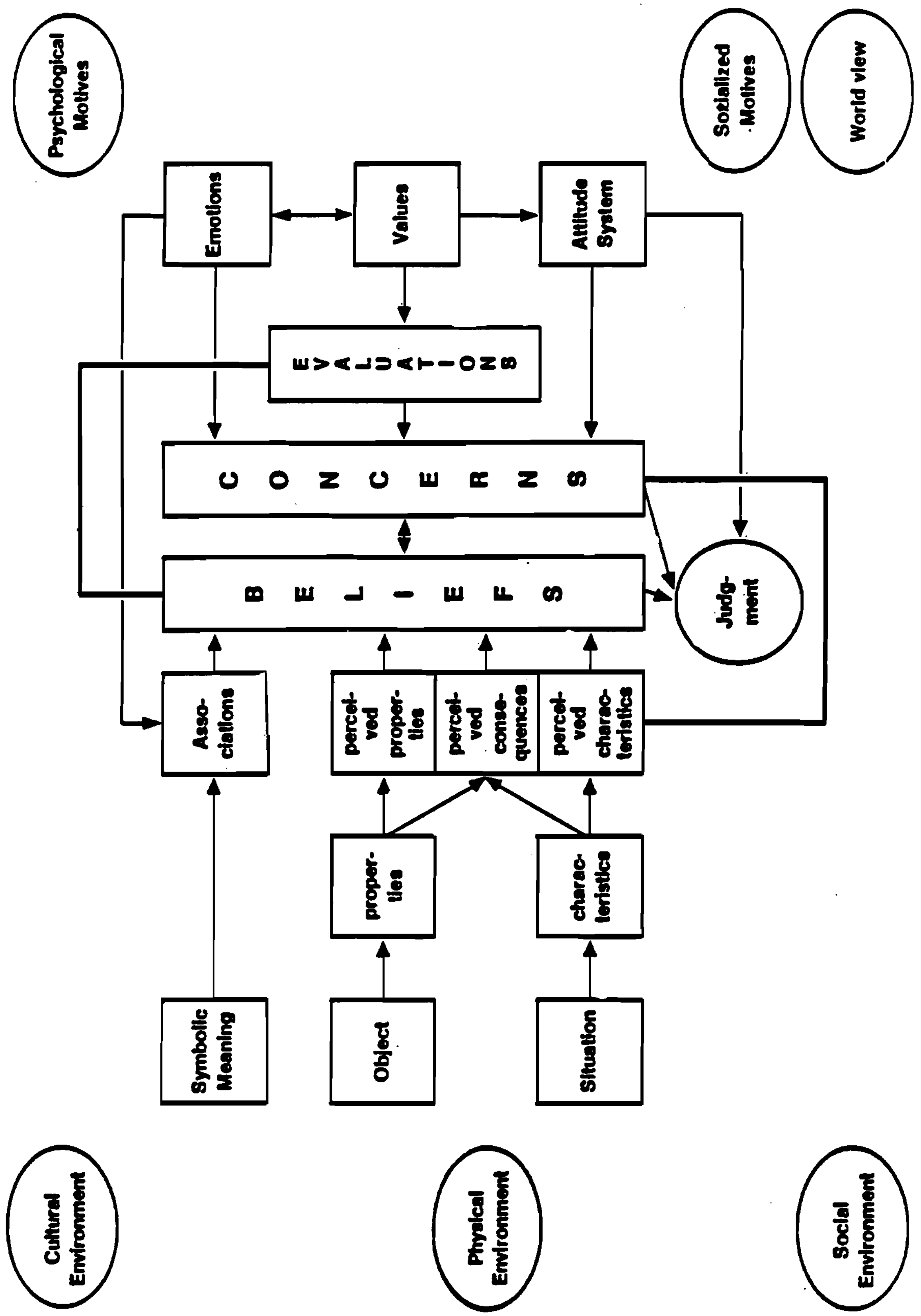


Figure 1 A conceptual framework of the interdependences between beliefs, concerns, values, and attitudes.

(symbolic meaning). The physical properties of the specific object and the characteristics of the situation are elements of the individual perception process. The perceived properties are not necessarily identical with the real properties. Limited access to information, intuitive selection filters, and preevaluations bias the perception process. In parallel with the perception of properties the social characteristics are assembled and perceived; both processes are combined in the subjective assessment of consequences that are associated with the object. Associations divided from the cultural context or from personal experience are also activated at this stage and are compared with the subjectively assessed consequences.

The next step refers to the phase of processing the perceived object properties, situational characteristics, predicted consequences, and associations into a belief system. The selection of what enters the belief system, the mode of abstraction from personal experience and mediated information in order to form generalized convictions, and the way of ordering the perceived items into salient clusters are influenced by the value orientations, emotions, and attitudes toward similar objects. In addition, general heuristics and personal style of reasoning have to be taken into account.

The last step refers to the process of balancing positive and negative beliefs, aiming toward a general evaluative judgment with respect to the object. For this purpose, beliefs are ordered according to their subjective importance, the judgments of reference groups are incorporated, the personal consequences of each possible judgment are assessed, and the possible outcomes are compared with earlier experience with similar objects.

This outline is, of course, just an analytical tool for understanding the process of attitude formation. The various stages are interlinked in the real world and proceed much more unconsciously, as pointed out here. However, it represents a theoretical framework that helps to analyze our research concepts and the results of risk perception studies.

According to the analytical framework of object perception and attitude formation risk perception studies focus on three key questions:

(1) What are the social goals, values, or motives that drive persons or social groups to attribute special concerns to specific risk sources?

(2) In what way do people process information about risk sources, and what kind of logical structure and reasoning do they follow in arriving at an overall judgment on the acceptability of a perceived risk?

(3) What kind of motivational or cognitive biases are incorporated when people select information from the various sources to which they have access, and why do they apparently violate their own rules of reasoning?

A more integrated approach to the investigation of risk perception can be developed by taking these three questions into account. For this purpose, we can divide risk perception studies into four rough categories: classical decision analysis, psychological decision theory, social–psychological judgment and attitude theory, and sociological concepts including policy analysis.

Classical decision analysis focuses on the rationality of the decision-making process under the assumption that we can make use of formal axioms to optimize our own judgment (Keeney and Raiffa, 1976). If we go a step further and demand that the optimization process be adapted to the individual metarational criteria of reasoning, this kind of research fits exactly into our key question (3) above.

Psychological decision theory (including social judgment theory) has put its emphasis on the individual process of common-sense reasoning, incorporating the social desirability of perceived consequences and specific motivational factors in processing uncertainty (Hammond *et al.*, 1978). Research in this field can best be classified under key question (2), because its purpose is to head toward the individual process of understanding the representation and assimilation of perceived hazards and their probabilities, which leads to the formation of an overall judgment. Risk perception is being understood as a process of deriving attributes about specific objects from general social values and personal attitudes and linking these attributes to the perceived properties of the risk object or risk situation (Janis and Mann, 1977). This research lies on the borderline between key questions (1) and (2).

Finally, sociological research addresses the problem of group responses to risk and concentrates on the influence of social values, institutional constraints, reference group judgments, communication, and power interchange (Nelkin, 1977b; Otway and von Winterfeldt, 1982; Frederichs *et al.*, 1983). It is interesting to note that the sociological concepts of risk perception, in particular studies of power and pressure groups, have some features in common with the concepts of mathematical decision analysis – the other extreme of the scientific spectrum. Both concepts assume that individuals try to maximize their own utility (in sociological terms, their interest) and that objective measures can be identified to indicate whether individuals or groups are better or worse off after the risk has been taken. In decision theory the expected utility is an objective measure of a person's gain or loss; in sociological theory gain or loss of power is an objective yardstick for measuring social influence. In our framework sociological research deals primarily with key question (1).

Table 1 gives an impression of the scope of scientific research in the field of risk perception. It should be acknowledged that the systematic overview simplifies the complex situation of risk research and ignores much of the conceptual differences within each class. For a more detailed classification reference should be

Table 1 Classification of risk perception studies

Research scope	*Short description*	*General assumption*	*Application to risk perception*
Decision	Matching the decision process with normative model of rational reasoning	Maximizing utility of individuals or groups	Investigating the discrepancies between normative risk assessment and intuitive perception
Psychological decision theory	Analysis of the individual decision-making process	Existence of typical sequential structures to make judgments under uncertainty	Investigating the cognitive structure of the risk perception process
Social-psychological theory	Analysis of the social environment as a determinator for the decision-making process	Dominance of social influence factors in perceiving and evaluating risks	Investigating the influence of value commitments, social judgment, and communication processes on the individual decision-making process
Sociological theory	Effects and implications of social interrelations between groups and institutions on collective decision-making	Risk taking as an element of social exchange regarding resources and power	Investigating the interests and social positions which impose specific risk perception procedures

made to the corresponding literature (see Otway, 1977; Becker *et al.*, 1980; Covello, 1982; Royal Society, 1983; Renn, 1984).

3 RESULTS OF RISK PERCEPTION STUDIES

According to the various disciplines involved in risk perception research various conceptual frameworks have been used to determine the main factors that influence people's judgment on expected consequences and their likelihood. Researchers who work with utility concepts investigate predominantly the individual balancing procedure and intuitive heuristics that govern the process of assimilating and evaluating information about risks. The most frequently applied instruments in this category of research studies are psychometric scales, semantic differentials, and correlation circles for determining spatial differences between various risks (Pellicier *et al.*, 1977; Fischhoff *et al.*, 1978; Vlek and Stallen, 1981; Pagés *et al.*, 1982).

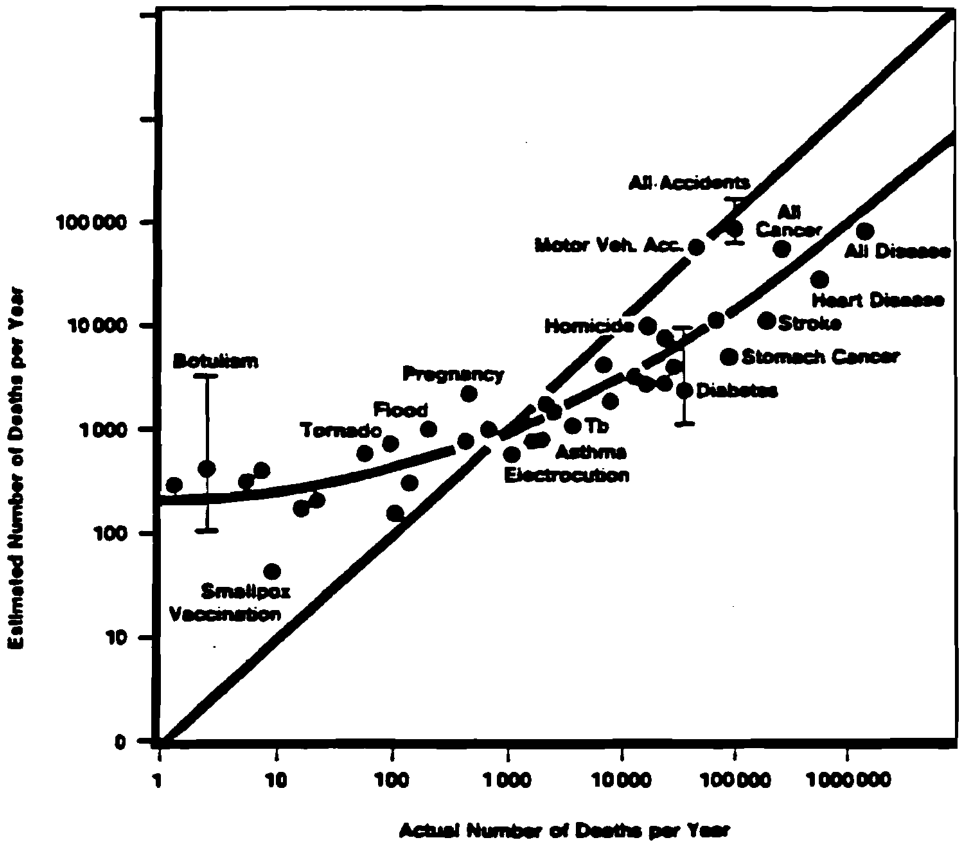
Researchers who pursue the attitude concept are searching for salient beliefs and effects that determine the overall feeling of an individual toward the object and influence the willingness to take actions in correspondence with that feeling (Otway, 1980; Thomas *et al.*, 1980; Swaton and Renn, 1984). Attitude researchers usually use questionnaires to collect beliefs and affective patterns, which are later processed by factor analysis in order to detect the salient factors of risk perception.

Researchers who focus on value commitments and concerns analyze the course of social interaction between promoters and opponents of the new risk object or risk activity. The also observe the process of attitude formation as a function of avoiding dissonances between value orientations and the selective perception of information concerning properties of the risk object and the position and values of the people associated with the object. Within this research tradition surveys and direct observations are the most common instruments to analyze the causes of the development of various positions toward a risk source and to reveal the social constraints that filter the information that each individual is exposed to and which predetermines the willingness to take account of positive and negative consequences (Bechman *et al.*, 1981; Conrad, 1981a; Wynne, 1984).

In addition to these three basic concepts, more sociologically oriented approaches have to be mentioned which regard risk perception as an element of the continuous struggles of social groups for power and social influence (prestige, status, etc.). However, since this approach takes no interest in the investigation of the underlying psychological and social factors of risk perception, it does not need a more specific consideration in this paper (Mazur, 1975; Nelkin, 1977a; Kitschelt, 1980; Douglas and Wildavsky, 1982).

The three perspectives of risk perception are not exclusive, but focus on different aspects of the perception process: the rationale of people to produce a balanced judgment, the genesis of beliefs about objects, and the social dynamics of processing and evaluating information. Hence it is not necessary to present the results of empirical studies separately for each research tradition. Rather, it seems appropriate to initiate a review based on a more fundamental insight into the individual process of forming beliefs about risk and risk sources, and to enlarge the discussion step by step with more remote factors, such as value orientations and trust in sources of information. Since the field of risk perception has become rather popular in recent years and numerous studies have been published, the following review can only address the highlights and discuss the main results. In order to be as brief and precise as possible, the review is organized as a collection of theses:

(1) In general people do a good job in assessing the magnitude of a risk that is familiar to them. In principle they are quite aware of the threats and dangers to which they are exposed. *Figure 2* shows the results of two surveys, one American and one German. A random sample of persons in Germany and several groups in the USA were asked to estimate the average losses per year from various sources of hazard: estimated values are plotted on the y axis and the actual statistical figures on the x axis. There is a general tendency, in both the USA and Germany, to overestimate low risks and underestimate high risks, although the German sample tends rather to exaggerate the real figures. Nonetheless, the extent of agreement between estimated and actual values is fairly high (Lichtenstein *et al.*, 1978; Slovic *et al.*, 1979; Renn and



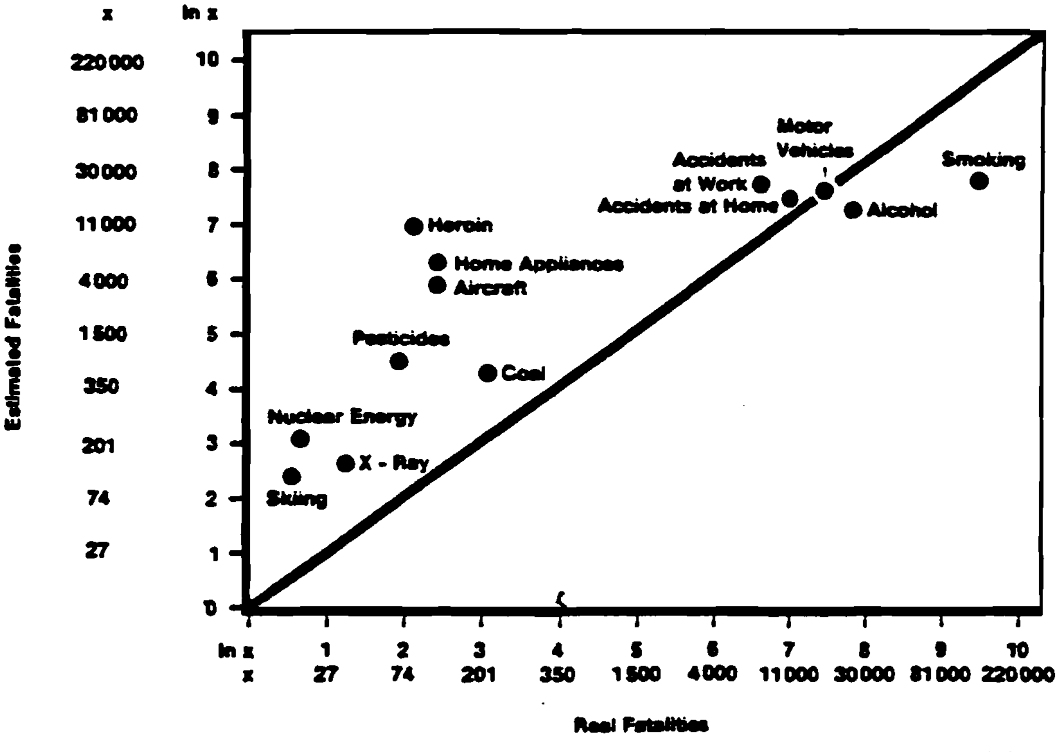


Figure 2 Respondents' estimated number of losses for the various risk sources compared with the statistically computed values. The upper graph shows the results of an American poll and the lower graph those of a German poll.

Peters, 1982).

(2) The intuitive ability to determine the order of magnitude of risk disappears as soon as questions are asked relating to the number of lives lost in a catastrophic year, to be expected once during the span of a lifetime. Either all risk sources are graded almost uniformly, assigning around 3000 losses for each risk source, or exorbitant estimates are made, e.g., an average of 22 000 deaths for drug abuse, 4000 for skiing accidents, and as many as 600 000 deaths caused by nuclear power (all these figures are related to the Federal Republic of Germany) (Renn, 1981). When estimates are made for a normal average year, experience and common sense can bring about a relatively good approximation of the statistical values. However, when questions are related to disasters that can be expected over 80–100 years, the intuitive evaluation processes will not function since the extent of catastrophes cannot be drawn directly from a person's own experience (Slovic *et al.*, 1979; Renn, 1981; von Winterfeldt *et al.*, 1981).

(3) If statistical or intuitively estimated values for expected losses are related to the intuitive rating of the benefit level, or to a risk–benefit ratio, an astonishing result is obtained. Presumed loss rates per year and risk perception (also risk–benefit perception) are practically independent of each other, i.e., most people do not assess risk sources according to the presumed losses per year but concentrate on other points of view (Renn and Peters, 1982). This insight is true not only of the German interviewers; American, English, French, and Australian studies confirm the low correlation between the public's loss estimation and risk perception (Slovic *et al.*, 1979; Glennon, 1980; Pagés *et al.*, 1982; Royal Society, 1983). Thus most people are more or less aware of the expected value of well-known risks; however, the expected values are merely one factor among many in the perception of these risks and,

as correlation analyses show, a factor with only slight explanatory value.

(4) Most people are not familiar with the rationale of probability. When the probabilities of adverse effects are not intuitively comprehensible (as in the unlikely example of a jumbo jet crashing into a football stadium), the perceived degree of riskiness is likely to be related to the worst imagined accident. If the imagination of catastrophes is enhanced by media coverage, the negative risk perception is further reinforced. This coping mechanism tends to evoke high sensitivity for low probability–high consequence risks and a strong degree of disinterest in high probability–low consequence risks (Tversky and Kahnemann, 1974; Ross, 1977; Jungermann, 1982).

(5) The attendant circumstances, i.e., the way in which people are exposed to a certain risk, are considered in the literature as qualitative features which influence the perception process. According to the investigations of Slovic and coworkers, three main factors shape the intuitive assimilation of risk-related information: the severity of losses when they occur (dread), the familiarity with the risk, and the "degree of personnel exposure" (societal versus personal risk-taking) (Slovic *et al.*, 1980, 1981). Studies of the quality of hazards lead to similar results. The Dutch researchers Vlek and Stallen came to the conclusion that risk perception is dependent on the "size of a potential accident" and on the perceived "degree of organized safety" (Vlek and Stallen, 1981, pp 235 *ff.*). Green and Brown report a high preoccupation of people for natural versus man-made risks, necessary versus unnecessary activities, major consequences versus minor impacts, personal control versus out of control, and easy versus difficult to escape (Green and Brown, 1980; Perusse, 1980). In contrast with the above studies, which use aggregational procedures for all risk sources in order to reveal universal factors for characterizing risk qualities, the studies by Gardner *et al.* (1980, pp 26 ff.) and by

Renn (1981) were designed to analyze the independence of qualitative characteristics for each risk source (Renn, 1981). *Figure 3* shows the significance of individual qualitative features to the evaluation of the risk in question for nine risk sources. The corresponding correlation coefficient is on the y axis, i.e., the intensity of the relationship is depicted, and boxes with individual feature classes for nine different risk sources are given on the x axis.

If we first consider the primary factors, i.e., the features that exert the greatest influence on risk evaluation, it becomes apparent that benefit-related points of view predominate. People first of all evaluate risks according to the possibilities and accompanying circumstances of their application, e.g., whether they themselves can profit from them, whether they are of benefit to everyone or only a minority, and whether there are not further alternatives that provide the same benefit with less risk. In the case of nuclear energy, pesticides, and electrical appliances the emphasis is on risk features. Whereas the voluntariness of utilization brings about a positive weighting of the concomitant risk in the case of electrical appliances, the dominance of the factor "catastrophic consequences possible" in the case of nuclear energy and "possibilities of long-term damage" in the case of pesticides has a negative effect on risk perception. It is thus clear that statistical loss rates are not the decisive motives for skepticism toward nuclear energy and pesticides.

(6) Apart from qualitative risk features, which are believed to be universal factors in the risk perception process, research has been conducted to find salient clusters of beliefs relating to different sources of risk. Large-scale experiments carried out by the Risk Assessment Group of the International Atomic Energy Agency, Vienna, showed that people classify their attitudes toward energy systems according to the following criteria: indirect effects from the risk source (e.g., health hazards); economic benefits (e.g., increase

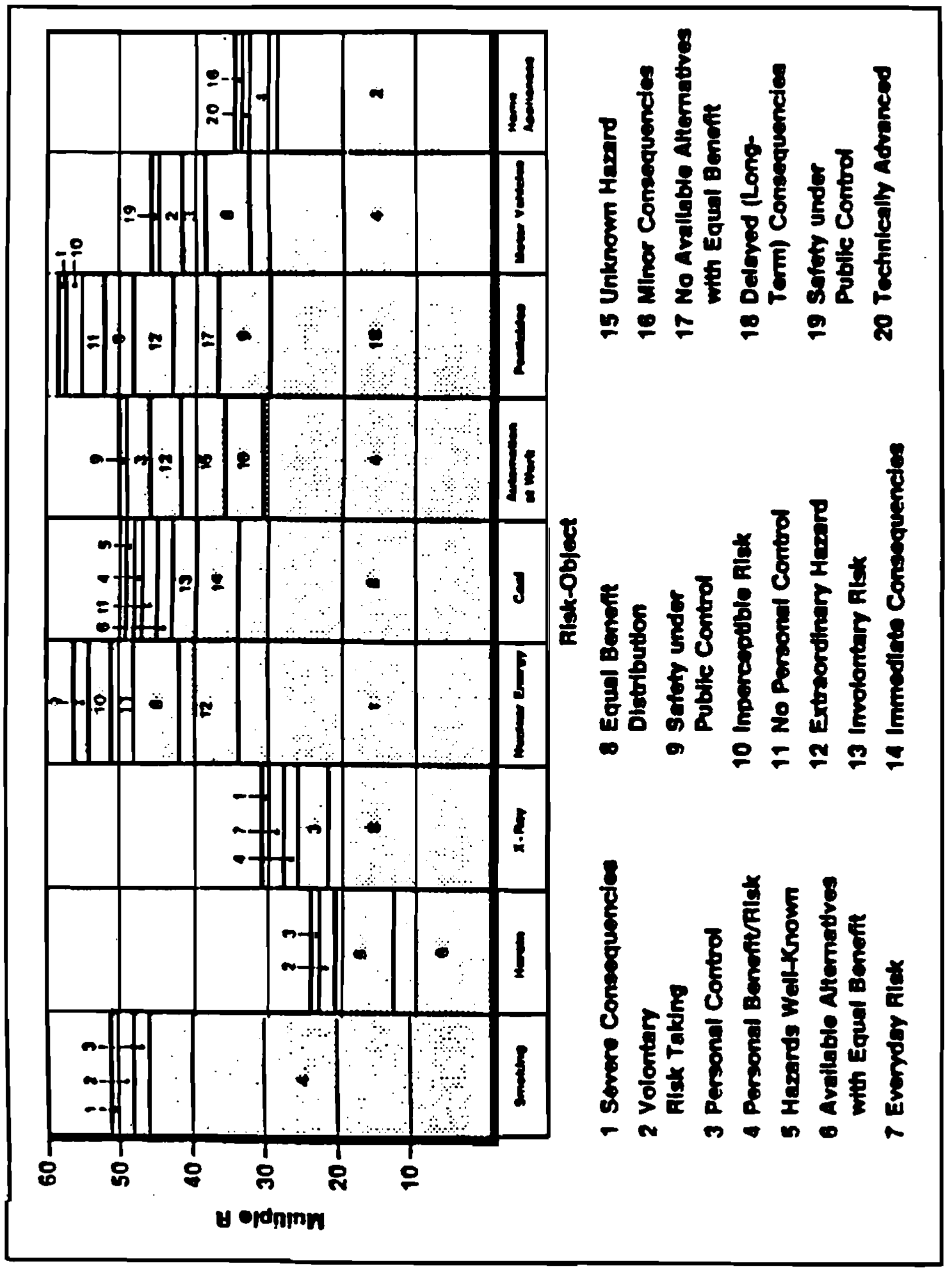


Figure 3 The influence of qualitative risk and benefit characteristics on the general perception of risk and benefit from various risk sources (multiple correlation coefficient).

in the national income); environmental risks (e.g., pollution); psychological and physical implications (e.g., capacity for control of the risk, artificiality of the risk source); effect on social and technical progress (e.g., providing security of supply, social leveling). These five dimensions in attitudes were obtained on the basis of the results of surveys of the assessment of various energy systems (Otway, 1980; Thomas, 1981). Since energy systems only cover some of the possible risk sources, we conducted a similar experiment in the form of an intensive survey involving 12 different types of risk source. The aim was to discover the most important attitudes and their systematic structure. Various statistical procedures were used to trace the attitudes subjected to enquiry back to their central basic pattern (factor analysis) and comparable sets of factors were developed by means of aggregation. This interpretation gave rise to an allocation and, finally, to an evaluation of risk sources under the following five points:

(i) Effects on the person himself and on the social environment (health, supply level, security, etc.).

(ii) Extent to which persons are directly affected (personal benefits, damage, comfort, well-being, liberty, etc.).

(iii) Effects on economic and social welfare (employment market, social leveling, general standard of living, quality of life, etc.).

(iv) Sociopolitical and social values (social justice, democratic rights, equal distribution of benefits and detriments, etc.).

(v) Effects on the conditions for coping with the future (maintaining output level, defense of liberty, ensuring supply level, etc.).

Not all of these five criteria are brought to bear for every risk source and the significance of the individual factors varies greatly. In order to obtain an overall view of the intensity and composition of the five criteria for various risk sources, the average values of the individual factors have been compiled for six risk sources in *Figure 4*. The bars that extend below the zero line show negative estimations with respect to the risk source under consideration, while the bars above the zero line show the corresponding positive evaluations (Renn, 1981).

(7) People seem to avoid risks that pose a pending danger to them. The randomness of occurrence is perceived as a potential threat because a dangerous situation might occur at a time when the individual is not prepared to react in an appropriate manner. Instinctively, human beings react to dangerous situations with the responses of aggression, escape, or playing dead. If a dangerous situation is to be expected, stress is likely to occur so that the instinctive reaction can be performed fast and almost automatically. Stress, however, cannot be sustained over an extended period of time. Therefore, people feel uneasy if a dangerous situation can occur at any time without prior notice. In this situation they prefer risk avoidance behavior. If they cannot initiate action to move away from the dangerous situation, they demand collective regulation as a means of maintaining control over the impending danger. This aversion to randomly occurring hazards is not related to any probability, but just to the nature of randomness. The feeling of uneasiness is reinforced if people have the impression that there will be no time to flee or protect themselves against the potential hazard (Green and Brown, 1980; Perrow, 1984).

(8) Risk refers to a compound judgment constructed on the assessment of personal utilities and associations with the risk source. This explains some of the

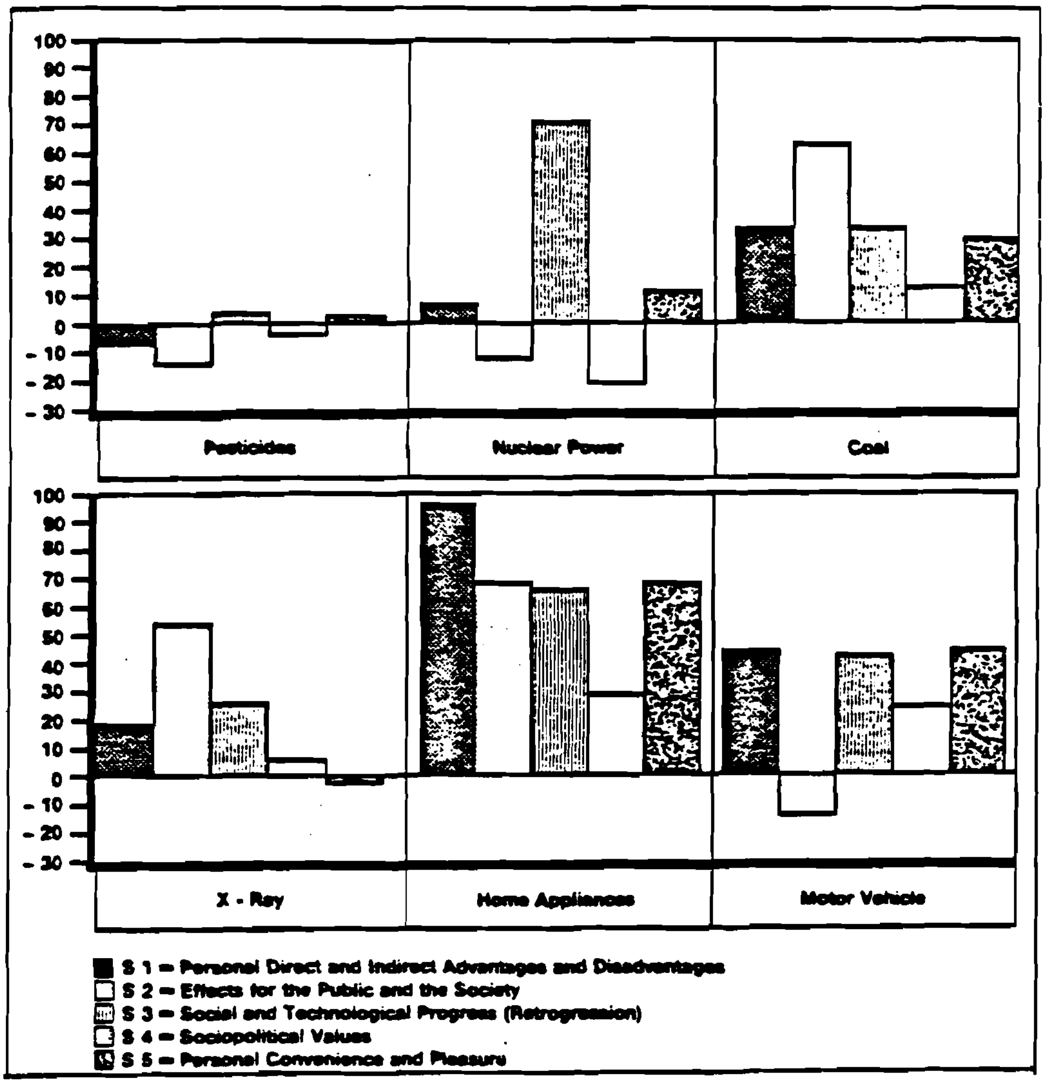


Figure 4 Importance of five belief clusters with respect to estimates of the risks of various technologies.

difficulties that experts encounter when applying risk comparisons in public. Risk in connection with skiing, for example, has a different connotation from risk related to nuclear energy. Risk in the former application is perceived as a peculiar thrill to the individual. In the latter case, however, nuclear energy is perceived as a threat to personal health. Any attempts locally to compare the two risks fail to convince anyone except the risk expert (Gardner *et al.*, 1980; Renn, 1985).

(9) People are willing to accept risks more frequently if they feel that risks and benefits are distributed equally. Thus justice is a key factor in risk perception. When risks are confined to an identifiable population (e.g., the neighborhood in the vicinity of a hazardous waste disposal site), this population is likely to respond negatively to them. The notion of justice implies two categories: equity of risk and benefit distribution, and exclusiveness of exposure to risks or benefits (Keeney, 1980; Renn, 1984).

(10) In general, it has been proved that value orientation and the general attitude system will increasingly influence risk perception if the risk sources have already undergone politicization. For example, scientists of the Arbeitsgruppe Angewandte Systemanalyse (Working Group on Applied Systems Analysis), Karlsruhe, discovered that the formation of judgments on nuclear energy strongly depends on the value orientation of the individual (more materialistic, more postmaterialistic, more environmentally conscious) which, however, has practically no bearing on the perception of coal (Frederichs *et al.*, 1983). With respect to nuclear energy a relationship between value orientation and risk assessment was also revealed in studies performed by Renn. Even if general value orientation – similar to the studies carried out by the Social Science Research Centre, Los Angeles (von Winterfeldt *et al.*, 1980) – is hardly directly related to the determining factors of risk perception, it

nevertheless codetermines the perception process indirectly via the formation of related attitudinal patterns (Renn, 1981). With regard to perception of the nuclear energy risk, the perceived risk level is particularly influenced by five sociopolitical attitudes *(Figure 5)*. Low confidence in statements by scientists and technologists combined with a high priority for environmental protection produce a more negative perception of nuclear energy risks at the outset. Conversely, confidence in science and technology and a low degree of environmental awareness represent an attitude that, from the start, tends to develop positive expected values. However, there is no deterministic relationship between attitudes in the sociopolitical field and those toward nuclear energy.

(11) The credibility of the source of information about risks and risk sources has turned out to be a crucial factor in risk perception. If a person distrusts the source of information, he or she is more inclined to pay attention to counter-information and to demonstrate a risk-averse behavior in order to be on the safe side. In particular, scientific dissent and politicization with respect to risk sources lead to a risk perception process that is highly governed by sympathies and value commitments in favor of one of the involved parties. Symbolic beliefs are substitutes for instrumental considerations (Tubiana, 1979; Wünschmann, 1984). However, the perception of objects does not depend solely or even primarily on widely acceptable solutions within the scientific system. First, scientific dissent will only have an impact on public perception if scientists themselves regard the issue as political and therefore transfer the dispute into a public debate. Second, the general public will only be aware of any scientific dispute if its consequences affect either their own living conditions or their belief system. Thus it is essential that the perceived consequences of any technology are evaluated as salient with respect to the

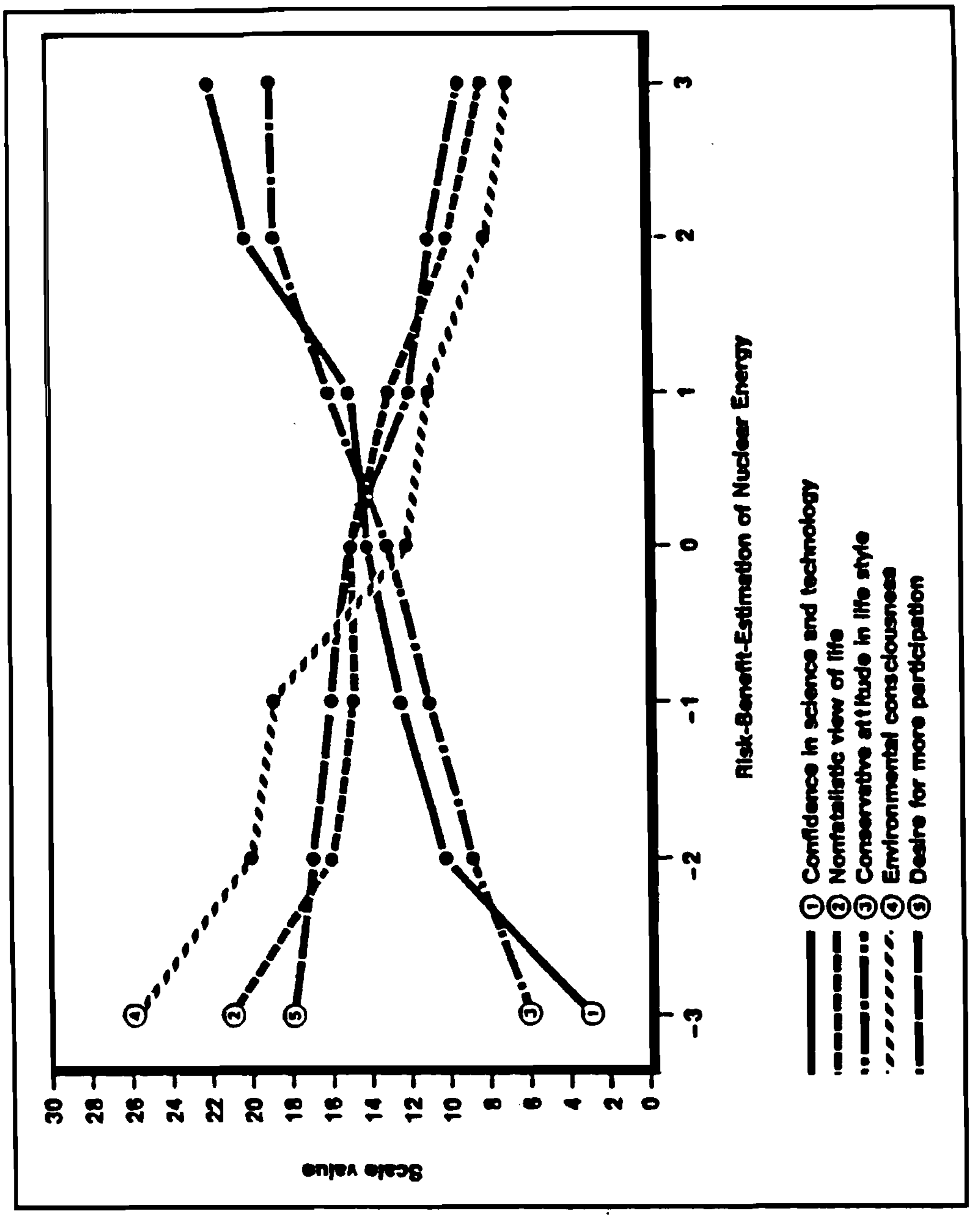


Figure 5 The perceived risk–benefit ratio of nuclear power as a function of five sociopolitical attitudes (x axis, degree of risk–benefit ratio; y axis, strength of attitude).

individual formation of attitudes before an issue gains political weight. Finally, empirical studies by Renn (1981) on the loss of credibility by social institutions involved in the peaceful use of nuclear energy show that, despite the loss of confidence in science and politics, a maximum degree of credibility continues to be given to scientists working in the field of nuclear research and in universities as well as to the pertinent politicians (e.g., Minister of Research and Technology). This statement applies to both proponents and opponents of nuclear energy.

4 CONCLUSIONS

The aim of this paper was to review the state of the art in the field of risk perception with specific emphasis on European studies. As in any review a selection has had to be made with respect to the concepts, the analytical frameworks, and the empirical results reported. The review is certainly biased by the author's subjective preferences and interpretations, but an attempt was made to include all relevant information and to put the results of the research studies in perspective. Only a small fraction of the empirical research conducted could be presented in order to keep the paper brief and concise, but enough cross references have been given for those who want to study the formation of risk perception more intensively.

What has been learned from the numerous studies of risk perception? Among the major results of the risk perception studies conducted by psychologists, sociologists, and decision analysts, the following have immediate impact on the process of risk management and policymaking:

(1) The expected losses over time are only one, and even a minor, element of the public perception of risk. Even the catastrophe potential cannot be regarded

as decisive in the sense that the number of perceived victims in a disaster is related to the degree of the perceived riskiness. Rather, subjective probability regarding the strength of belief that a catastrophe can happen is one of the main characteristics that people apply in judging the magnitude of risk.

(2) Two kinds of variables are found to be important for the process of risk perception: qualitative risk characteristics and beliefs about the risk source. People will pay special attention to risks that are perceived as dreadful, involuntary, unaccustomed, and personally uncontrollable, and will be eager to obtain more information about the risk source.

(3) Beliefs about risk sources vary from risk to risk. There is no universal threshold for risk acceptance either for different risk sources perceived by a single individual or for a single risk source assessed by different individuals.

(4) Social, psychological, and sociological studies show that judgments of risky technologies or activities depend not only on psychological factors like those mentioned above but also on reference group judgments, salient beliefs about the risk source, degree of loyalty toward official policymakers, and commitment to social values and cultural ideas. Since all these factors, including the psychological ones, are interrelated and sometimes reflect mere postrationalizations of unconscious feelings and social constraints, it is very difficult to set up a reliable model of how people actually perceive and evaluate risks. What we know is what matters, and partly to what degree it matters, but analysts are still searching for a theory that can explain the process of people's judgment on risks.

What, in the light of these premises, are the main lessons for policymakers on risk management considering the results of perception studies so far?

Primarily, it has become evident that the artificially constructed contrast between the rational assessment of experts and the supposedly irrational assessment of laymen has not only disguised the true relationships in the current discussion about risk, but has also put considerable difficulties in the way of the dialogue between the two sides. The technological calculation of risk dimensions must be regarded as an important component of any decision concerning risk sources and is also an ideal instrument for constantly improving the safety measures for protecting the public. However, the public is not disputing the fact! To make calculations of this kind the sole criterion for "acceptability" and/or "desirability" of technologies or of other civilizing risk sources, however, contradicts the intuitive view of risk acceptance and is also unreasonable from political and social standpoints. This should not be misunderstood as a plea for substituting scientific risk assessment with risk perception analysis. The analysis of perception has also demonstrated that the assimilation of uncertainty and the intuitive mechanisms for coping with risks are biased by heuristics, personal experience, media coverage, and other factors. Modern societies cannot afford to substitute science with common sense.

If the purpose of science is to explain and predict phenomena, we can expect scientists to make a better job of prediction than other people. Otherwise science would be superfluous. Scientists have a better access to the collected general experience of society (empirical knowledge) and are better trained to use systematic and consistent models of extrapolating past experience (methodological knowledge). The superior degree of accuracy does not mean, however, that experts are not susceptible to cognitive biases, errors, or misperceptions, but that they are less so than all the other members of society [*cf.* the model of graduated rationality given by Renn (1981)].

Therefore, risk management has to incorporate the results of risk perception studies in two ways:

(1) First, the dimensions of each risk source or class of risk sources that are perceived as potential violations of the individual's own values or interests.

(2) Second, the prevalent trade-offs between conflicting values, e.g., cost versus environment, which reflects the desire of each citizen for the living conditions preferred in the future.

In a pluralistic society the values of each citizen should have the same impact on policymaking as those of experts or policymakers. The technical approach adopts those values that experts deem to be adequate with respect to the problem. However, such an adequacy does not exist. The decision analytic approach feeds in the values of the client, usually the regulator. His or her values are either homemade or reflect the regulator's perception of what the public really wants. Asking the public directly seems to be the optimal solution, but is not as easy as it sounds. Values and beliefs are interrelated. If beliefs are erroneous or their underlying cognitive heuristics are biased, many values formed in accordance with theory are distorted. Innovative survey methods combining attitude measurements, information, and participation have to be developed to meet this new challenge to social science. A first attempt in this direction has been made by a research team at the Nuclear Research Center, Jülich, and the University of Wuppertal who have used the method of "planning cells" to investigate the preferences of ordinary citizens for future policies on risk management (Dienel, 1980; Renn *et al.*, 1984).

Risk perception is a complex phenomenon that requires more investigations on a multidisciplinary scientific level. For the purpose of risk management it is essential to understand the structure of perception and to recognize the concerns that underlie the overt resistance against modern technologies that impose risks on the public.

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POLICY PROCEDURES ON THE CARBON DIOXIDE QUESTION: RISK UNCERTAINTIES AND EXTREME EVENTS

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There is no doubt that atmospheric concentrations of CO_2 and other "greenhouse" gases have been increasing and will continue to do so for the next several decades at least. Climate models predict that this will lead to a significant rise in world temperatures, particularly in the polar regions, during the next 50 - 100 years. However, there is uncertainty about the timing and magnitude of the warming, as well as about the strategies that ought to be adopted to try to reverse the trend, or at least cope with it.

A Question of Risk Assessment

I believe that the greatest single blunder in contemporary efforts to understand the practical implications of the carbon dioxide question is the continuing focus on "most likely" rather than "possible" impacts and consequences (1). In the short run, the greatest single addition to usable knowledge about the carbon dioxide question might well come from recasting it as a problem of risk assessment and management.

Every responsible scientific assessment of the last several years has noted (if not always emphasized) how thoroughly uncertainties pervade the carbon dioxide question. Both the policy makers and the scientists who write the assessments are concerned that continued releases of carbon dioxide and related substances ***might*** bring about changes in the planet's climate, sea level, water flow, forest productivity, and agriculture that would be sufficiently large to fundamentally alter the structure and function of modern civilization. On the other hand, the changes ***might*** not occur and, even if they do, ***might*** be beneficial or ***might*** not be big enough to matter. How to weight these contending possibilities in assessing the practical implications of the carbon dioxide question is not clear. But experience with other situations presenting a small chance of big changes makes it seems virtually certain that the most useful approach will not be one which simply assumes that the actual outcome will lie half way between the extremes.

For most environmental questions where scientific uncertainty is important, the policy analysis community has come to view its task as one of risk assessment and management. For the carbon dioxide question, the policy analysis community has, almost without exception, ignored the uncertainties and their implications altogether (2). This lack of analytic attention has left the uncertainties in the carbon dioxide debate open to unconstrained use as propaganda by all extremes of the political spectrum. Those governments and other parties that simply don't like the policy implications of treating possible impacts of carbon dioxide and related issue seriously have found it convenient to declare that the uncertainties make any assessment premature. Those who do like the policy implications have used the same uncertainties to support their arguments for precipitous action "just in case". A risk assessment approach could not be expected to eliminate such posturings. It might, however, constrain them and provide more usable knowledge for those parties seriously interested in understanding the practical implications of the carbon dioxide question (3).

The methods of risk assessment are relatively well developed, and a healthy critical dialogue now exists regarding their strengths and weaknesses (4). General frameworks for risk assessment in the context of climate change have been discussed by several authors (5). Early applications to problems of long term environmental change were flawed in ways that could have been avoided through better familiarity with the basic methodological literature. An example is the National Defense University's naive use of expert judgement distributions to characterize the probability of various climate changes to the year 2000 (Stewart and Glantz 1985). Several examples of good practice with useful results do exist, however, including the work of the Tukey Committee on Impacts of Stratospheric Change (National Research Council 1979a,b) and of Morgan et al. (1984) on deposition and impacts of sulfur emissions from power plants. These could serve as models for useful work on the carbon dioxide question. The major obstacle to their application is the absence of usable uncertainty estimates from the scientific research community.

Scientific uncertainties in the carbon dioxide question: Until very recently, little effort had been made to provide systematic, quantitative estimates of the scientific uncertainties relevant to the carbon dioxide question. At the level of basic data measurements and model calibration, of course, conventional error bars have often been provided. But these are not generally aggregated to give "higher level" uncertainty estimates of atmospheric concentrations of carbon dioxide or climate response. The few higher level confidence limits that have been given, such as the Charney Committee's frequently cited average global temperature increase of 1.5 to 4.5 degrees Centigrade (C) for a carbon dioxide doubling, have lacked explicit methodological foundation and almost certainly suffer from the same kinds of biases identified by Stewart and Glantz for the NDU study (6).

An example of what can be done through systematic efforts to estimate higher level uncertainties in the carbon dioxide context is provided by Nordhaus and

Yohe's (1983) study of possible global carbon dioxide emissions and concentrations to the year 2100. The authors used a simple globally aggregate model of energy economics, coupled it to an even simpler model of atmospheric retention, estimated uncertainties for the component parameters, and calculated the resulting range of emissions and concentrations using Monte Carlo simulation. A sample of their results for the year 2100 is given in Figure 14. Note that these calculations give a 95% confidence limit of about 450 to 1450 ppm.

The implications for climate of such uncertainties in the levels of future carbon dioxide concentration have been explored by Dr. Robert Dickinson who, through his work with the previously mentioned Tukey Committee, probably has as much experience with the derivation of aggregate uncertainties as anyone in the atmospheric science community. Drawing on the Nordhaus and Yohe analysis, and including his own estimates of uncertainties for emissions of other radiatively active trace gasses and for climate sensitivity to such emissions, Dickinson (1985) calculated the range of possible "greenhouse" warmings of the earth's average climate. He concludes that by the year 2100 this could total more than 9 degrees C with a probability of about 10^{-2} - 2 1/4 and more than 15 degrees C with a probability of 10^{-2} - 3 1/4 to 10^{-2} - 4 1/4. Either possibility would produce "conditions as warm as the Cretaceous era of 100 million years ago when polar temperatures were 10 to 20 degrees Centigrade (C) warmer and tropical temperatures were perhaps 5 degrees warmer than present" (Dickinson 1985). A substantial rise in sea level, perhaps accompanied by disintegration of the West Antarctic ice sheet and an ice free Arctic Ocean, would almost certainly accompany such a drastic change.

If we knew for certain that environmental changes of the magnitude described by Dickinson would accompany continuing releases of carbon dioxide and other gasses to the atmosphere, a number of extreme social responses could be both economically justified and politically feasible. Common habit, however, has been to let the very small probabilities of drastic warming totally rule out consideration of such responses. To determine whether this habit is justified or rational would require that the probabilities of drastic impacts related to carbon dioxide be compared with probable drastic impacts of measures that might be taken in response to increasing concentrations of carbon dioxide and other greenhouse gasses. The necessary analysis has not been done. As an illustrative example, however, it may be useful to consider some of the risks associated with possible responses to the carbon dioxide question that involve substitution of nonfossil energy sources.

The relative risks of response options: Large hydropower dams, for example, have a probability of failure of about 10^{-2} - 4 1/4 per dam-year (Weinberg 1985). A given new dam therefore has something on the order of a 10^{-2} - 2 1/4 chance of failing by the year 2100 — the same chance that Dickinson gives a 9 degree C global warming. The U.S. Nuclear Regulatory Commission has set a design goal that would have light water reactors experience core damaging accidents at about the same rate as dams fail, i.e., with a chance of 10^{-2} - 4 1/4 or less per reactor-year, or 10^{-2} - 2 1/4 per reactor by the year 2100 (Nuclear Regulatory Commission 1983). Most such accidents, like the one at Three Mile Island, would not kill anyone. In contrast, the worst-case nuclear power accident envisioned by the Rasmussen Reactor Safety Study is predicted to cause 3000 early fatalities, 45000 early illnesses, and a highly uncertain number of delayed cancer deaths among the 10 million people exposed to radiation in the accident scenario (Nuclear Regulatory Commission 1975). Note that the predicted casualties are thus of the same order as those actually resulting from the chemical disaster at Bhopal. The worst-case nuclear reactor accident was given by the Rasmussen Study a probability of 10^{-2} - 9 1/4 per reactor-year. Under reasonable assumptions about the growth of the nuclear power industry (i.e., 100 to 1000 LWRs in operation), this means that the chance of such a worst-case nuclear power accident occurring somewhere in the world before 2100 is probably between 10^{-2} - 4 1/4 and 10^{-2} - 5 1/4.

To the extent that one believes any of these figures, the chance that the world of 2100 will have witnessed a single local nuclear power catastrophe is probably 10 and perhaps 10 times *less* than the chance that everyone in the world will be living in a Cretaceous-like hothouse, perhaps with beaches several meters above their present levels. This assessment jars common sense, which is exactly why careful risk assessments of the carbon dioxide question and the possible social responses to it should become a priority task. To enable such assessments, the first need is for more scientific research to be focused directly on estimating the uncertainty of important higher level components of the carbon dioxide question. Moreover, it may be that research designed to define and bound the uncertainties will be of a qualitatively different nature than research designed to refine estimates of most likely outcomes (Dickinson 1985). These possibilities need to be seriously investigated and taken into account in funding priorities for research on the practical implications of the carbon dioxide question.

Changing Frequencies of Extreme Environments

Most efforts to assess the practical implications of the carbon dioxide question have focussed on predicted or postulated changes in mean properties of the environment. Relevant studies of climate impact, for example, have usually dealt with changes in annual or seasonal values for temperature or precipitation. We know, however, that some significant impacts of the environment on societies and ecosystems are due to extreme events, i.e., to fluctuations around the mean condition. And some of the best recent impact work has shown that one of the most useful forms in which climate change forecasts can be presented to policy people is as changes in the frequency of significant climate anomolies (Parry et al., 1986).

Extremes in time: Most of the literature on extremes deals with fluctuations in time. Some analysts have written of a split between analysts emphasizing the "slow change" and "extreme event" views (Warrick et al., 1985). The academic split has been reinforced by political disagreements over the relevance of short term versus long term impacts. This is not, however, a useful dichotomy. The overwhelming message of the data is that the environment varies at all scales, and societies can respond to such variations at all scales. If carbon dioxide and related emissions change the climate, they will change the global means and the spatial distribution and the frequency of climatic anomalies. Societies could and probably would simultaneously respond to such changes at the global and regional and local scales. The challenge is not to select one scale as the key to understanding, but rather to understand the interactive roles played by environmental changes and social responses across the overall spectrum of spatial and temporal scales. Efforts to meet this challenge should benefit substantially from recent studies on the role of extreme events in determining the response of social and ecological systems to environmental change. Here I will try to clarify some of the central themes of that writing, and to suggest some useful points of departure for further research.

The general thrust of the "extreme event" argument in climate impact studies was developed by Martin Parry (1978) and has been summarized by Wigley (1985) as follows: "Impacts accrue... not so much from slow fluctuations in the mean, but from the tails of the distribution, from extreme events. In many cases, an extreme can be defined as an event where a climate variable exceeds some absolute threshold." There are two distinct components to this argument: 1) the relation between changes in mean environmental properties and the frequency with which specified extreme environmental conditions are exceeded, and 2) the nonlinear or threshold responses of social, agricultural, and ecological systems that give those extreme environmental conditions their significance. My discussion will focus (with most of the literature) on the problem of climate change, though the argument should hold for other valued environmental components as well.

Means and higher moments: The most common assumption in the "extreme event" literature is that a shift in the mean climate occurs with no shift in variability. Fukui (1979) introduced this convenient relationship at the World Climate Conference with his oft-reproduced figure of two bell curves of precipitation, identical except for the relative displacement of their means. There is, however, little reason to expect that actual changes in mean climate would preserve variability. Dickinson (1985) has pointed out that the General Circulation Models (GCMs) presently used to evaluate the mean climate changes resulting from increased greenhouse gasses actually simulate a wide range of weather and climate fluctuations. Their output could be sampled to yield a great variety of more realistic variability statistics. At present, however, the assessment community has generated insufficient demand for particular variability statistics to keep them from being discarded by climate modelers who find more meaning and less confusion in simple means. This waste could be avoided if the impact assessment community could come to agreement on what kinds of variability data would be most useful for the modelers to save. I will have more to say on this shortly.

The probability of exceeding arbitrary values: Because of the bell-like shape of most climate variability distributions, the frequency with which an arbitrary value of climate will be exceeded can be very sensitive to changes in the mean and higher moments of the distribution. Mearns et al. (1984) calculate this sensitivity for changes in weather variability. Wigley (1985) provides a graphical summary for normally distributed properties in the form of Figure 15. He argues that "a change in the mean by one standard deviation would transform the 1-in-20 year extreme to something that could be expected perhaps 1 year in 4, while the

1-in-100 year extreme becomes a 1-in-11 year event. Changes in the probability of two successive extremes are even larger." Which of these transformations is most significant for assessing the practical implications of carbon dioxide- related environmental changes? There is no purely statistical reason to focus on the 1-in-20 or 1-in-100 or 3 -consecutive- bad- years scenarios. But if the extreme event perspective is not to become a mindless quest for all manner of variability statistics, then the assessment community will have to tell the climate modelers and other environmental scientists just which changes in what extreme events most concern them. Some general guidelines have been discussed by Parry and Carter (1985). Once again, however, real progress requires that the assessment community devote much more attention to characterizing the specific "thresholds" that matter in particular social and ecological systems.

Thresholds and nonlinear impacts: The key to the whole "extreme event" argument is the existence of threshold or nonlinear responses of social or ecological impacts to changes in climate. If impacts over a given period were directly proportional to the total amount of rain or heat or whatever provided by the fluctuating climate over that period, then knowledge of the mean climate for the period would provide all the information we needed to predict or explain the impact. For some social activities like transportation, such a linear (additive) relationship between climate and impact may indeed be the case (Palutikof, 1983). For many other properties of interest, however, the relationship between climate and impact is highly non linear, and the distribution of extremes relative to threshold levels may therefore be significant in assessing the practical implications of climate change.

An additional dimension of the nonlinear response argument is fundamental to (but often only implicit in) the "extreme events" view of climate impacts. Parry's (1978) pathbreaking work on the significance of extreme events in assessing the impact of climate change on society focussed on the abandonment of marginal farming land when successive extremes of bad weather exhausted farmers' adaptive buffers. The key nonlinearity or threshold in Parry's farming system was that once the buffers were exhausted and the farmer abandoned the land, a return of several years of unusually good weather would not bring the land back under cultivation, even though the biological capacity for production had been restored. What had not been restored was the stock of labor, capital and social structure necessary to sustain farming in the area. These could be destroyed by a few years of bad weather, but only restored through a much longer run of good weather.

Multiple equilibria: The cases cited here provide specific examples of the properties of multiple equilibria and bifurcation found in many nonlinear social, ecological, and physical systems, especially those operating at multiple time scales (7). Typically in such systems, slow variation in one property can continue for long periods without noticeable impact on the rest of the system. Eventually, however, the system reaches a state in which its buffering capacity or resilience has been so reduced that additional small changes in the same property, or otherwise insignificant external shocks push the system across a threshold and precipitate a rapid transition to a new system state or equilibrium. Once this rapid transition has commenced, reversal of the slow variation trend, removal of the external shock, or other returns across the threshold generally do not restore the system to its original equilibrium. Like an automobile driver caught in the one-way streets of a big city, getting back to the place just passed requires a circuitous and time consuming journey. Recent reviews of such discontinuous, imperfectly reversible change in ecological systems (Holling 1985) and sociotechnical systems (Brooks 1985) provide a number of real world examples and the beginnings of a general understanding of the key processes and relationships involved.

The time is ripe for the "extreme event" element of the carbon dioxide debate to tap this emerging understanding. The goal should be to describe what kinds of thresholds are relevant to the way social and ecological systems will respond to carbon dioxide- related changes, what kinds of events are sufficiently extreme to push those systems across their respective thresholds, and how the frequency of those events will respond to increases in carbon dioxide and related emissions. Progress towards meeting these goals will first of all require analyses of the stress responses of specific social and ecological systems that are sufficiently detailed and realistic to capture the multi-equilibrium, multi-time scale, imperfectly reversible phenomena alluded to above. The research program of Martin Parry and his colleagues at the International Institute for Applied Systems Analysis (8) shows how such studies can be done for a wide range of agricultural systems. Exciting beginnings have also been made in the study of relevant forest ecosystem response characteristics (9).

Still needed are efforts to extract from such studies characterizations of the specific kinds of changes in variability and extremes that impact assessors would find most useful as a research output from climatologists, atmospheric chemists and other environmental scientists. When such specific characterizations have been made of *which* environmental extremes would have *what* significant practical implications, it will be reasonable to ask that research in the natural sciences begin to focus on the carbon dioxide-related changes in the the distribution of those extremes that might be encountered in the future.

Extremes in space: The question of extremes in space has been much less discussed than that of extremes in time. It is not clear, however, that the spatial issue is any less important. Experience of the last two decades shows, not surprisingly, that when droughts occur simultaneously in several major grain exporting areas the practical implications for the world food picture are much more serious than when the same overall rainfall deficit is distributed evenly, or concentrated in less critical zones (Hopkins and Puchala 1978). Flohn (1980) suggested that to the extent that droughts or other climatic anomolies (i.e., extremes) have a characteristic spatial scale, nations significantly larger than that scale should be less vulnerable to climate fluctuations than nations significantly smaller. Under changing mean climates, however, the spatial scale and locations of anomolies may also shift. Both model and analog studies of carbon dioxide-related climate changes indeed suggest that the globally averaged values of temperature, precipitation, and other properties can be expected to vary significantly through space. Some regions may even become cooler as the global average temperature increases. The question remains virtually unasked, however, of whether carbon dioxide related climate changes are likely to change the scale and location of anomolies in ways that are particularly significant for societies (10).

As in the case of changes in the temporal distribution of climatic extremes, the first step in addressing the problem must be for the assessment community to specify the kinds of spatial anomolies — their sizes, locations and relationships to one another — that could have a disproportionate impact on society. Parry's work on climatically marginal areas again provides one of the strongest beginnings we have, but much more work in this direction is needed (e.g., Parry et al., 1986). The climatologists and other environmental scientists could then focus their studies on determining how likely such specific spatial extremes might be in a future of carbon dioxide-related changes.

In conclusion: The carbon dioxide debate has now reached a stage at which further advances in coping with its practical implications will require much closer integration of political and environmental perspectives than has until how been the case. Many approaches should be exposed, including the "polex" recommend at the recent Villach Conference on Greenhouse Gases. But whatever the details of the approach, the practical implications of risk uncertainty and extreme events will have to be dealt with more rigorously. This note has sketched some directions that work on these central issues might pursue. Some form of policy exercise, aimed at writing future histories of the carbon dioxide problem and societies' responses to it, seems to offer the most likely prospects for fostering such integration. Over the interval leading to the next Villach Conference, several experimental policy exercises might profitably be conducted, each involving perhaps a dozen of the most informed and creative scholars and policy people concerned with the carbon dioxide question. The only way to discover whether we would really learn something useful from such an experiment will be to try it. At a minimum, I suspect it would be fun.

Notes

1) This paper is drawn from a longer version (W.C. Clark, 1986. On the practical implications on the carbon dioxide question. WMO, Geneva) prepared for the WMO/ICSU/UNEP International Assessment of the Role of Carbon Dioxide, and other radioactively active constituents, in climate variations and associated impacts (Villach, Austria, October 1985).

2) The most notable exception is Nordhaus and Yohe's (1983) analysis of uncertainties in energy emissions performed for the US National Research Council (1983) study of the carbon dioxide question. The carbon dioxide studies of the US Environmental Protection Administration have made some useful beginnings on the treatment of uncertainties. The US Department of Energy's has repreatedly spoken of its plans for addressing uncertainties of the carbon dioxide question. The studies implementing those plans were not officially available for review at the time this essay was completed. It seems, however, that the joint work of J. Edmonds, J. Reilly and R. Gardner on uncertainties in carbon dioxide emissions and atmospheric retention will provide a significant additional perspective to that of Nordhaus and Yohe.

3) I have explored this question in some depth in Clark (1985d).

4) See, for example, the forthcoming proceedings of the US National Academy of Engineering's "Symposium on Hazards: equity, incentives, compensation" (Washington, June 3-4, 1985); National Research Council (1982); and SCOPE (1980).

5) See, for example, Heal (1984) and Winkler et al. (1983).

6) See, for example, National Research Council (1979d, 1983) and Rotty (1979).

7) The general phenomenon is known as "hysteresis" in the literature of topology and catastrophe theory. For specific applications see Holling (1985) for ecological systems, Day (1981) for economic systems, Lorenz (1984) for climatological systems, and Brooks (1985) for sociotechnical systems.

8) This program is briefly described in WMO (1984) and documented in full in Parry et al. (1986).

9) See, for example, Shugart (1984), Emanuel et al. (1985), Kauppi and Posch (1985) and Solomon et al. (1984).

10) I am not aware of any analysis of spatial changes from GCM results. Some useful perspectives are provided by various efforts to construct scenarios of warmer climates based on historical data. See, for example, Jaeger and Kellogg (1983), William (1980), Wigley et al. (1981), Vinnikov and Kovyeva (1983), Pittock and Salinger (1982), and Palutikof et al. (1984). Flohn (1980) is one of the few scholars to address directly the question of changes in spatial scale that might accompany a changing climate.

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COMMUNICATION STRATEGIES IN CRISES SITUATIONS

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ABSTRACT

At the time of major risk, those organizations in charge can find themselves facing huge problems of communication as a result of technological breakdowns. This brings in its wake operational paralysis and a destruction of public image which might be described as extremely worrying, to phrase it mildly. A lack of equipment and especially a heritage of a less demanding past-awareness of risk realities, which did not require such great internal mobilization, such highly developed external networks, such close links with the media and public opinion, has often led to spectacular failures. One needs to have a thorough look at the dossier again, in all its complexity, in order to try to give a clearer definition to better considered preparation of strategies of communication.

We will first examine in this text (1) the classic scenario which leads the first difficulties into a quagmire which swiftly swamps an ever-growing number of parties concerned. How should the challenge be met? (11) Understanding the situation - a game of numerous partners - fashioning new tools and rules constitutes a first step in the right direction. But one must guard against allowing oneself to become too readily fascinated by some over-simplified model: attitudes and reactions are largely determined by the "mentalities" of the organizations concerned; crisis situations are highly conflicting; the stakes are often considerable. In part three (111) this text touches on those delicate issues which are the heart of the strategies of the handling of a crisis.

PRESENTATION

"The waste from Seveso: is it in France?" (1).

"Is the North Sea drowning in Uranium?" (2).

"Rue de la Magdaleine, in Rheims: is dioxin in residence at No.21?" (3).

Dioxin drums from Seveso, the wreck of the Mont-Louis with its drums of uranium hexafluoride, the explosion of an Alkarel transformer in Rheims (150 km east of Paris): these three affairs which occurred recently in Europe have shown us only too well how crucially important communications are in post-accident situations - even when risks are not excessive. When disaster can strike on a grand scale, as it did in Bhopal, then it is more than time to create new ways of coping.

The possibility of an event of enormous gravity; the disconcerting incertitude which marks the phenomena at play; the complexity of the organizational systems implicated; the rapidly developing domino effect which continues to spread in the ensuing months and hits hard and irreparably at multiple and colossal interests ("Union Cabide fights for its life" (4)); the irresistible power of the media when it trains its cameras on the "fissure"... have now become the factors which structure post-accident dynamics (5 to 8).

In such a highly turbulent context, "getting through" - communication - becomes a strategic factor of prime importance. We are not, let us insist, talking here of communication as simply a superstructure whose sole concern is to protect a public image in some way, but rather of a vital key without which there is a huge risk of even losing the capacity of immediate action; and from there on slipping rapidly from hesitation into a skid, and from a skid into a scientific, technical, organizational, economic and political swamp.

Communication holds this key role for fundamental reasons:

- The problems posed are technically difficult to define: diagnoses can only be established if numerous experts are in liaison.
- Interests, points of view, attitudes, "mentalities" which have to be taken into account are those of a very wide and diversified range of concerns: decisions can only be reached through extended consultations and joint-efforts.
- Notions of probability and conviction (less of certitude) are central points of reference in the procedures adopted: the chosen options can only acquire a firm operational nature if they are regarded as pertinent and credible by the majority of those concerned (especially when the phenomena remain invisible and so cannot be perceived by the senses).
- These events take place while the media puts all under permanent and particularly acute pressure, with little or no let up over an extended period: manifestly inadequate information leads in no time to stinging failures.
- A better informed public is more exigent than was the case in the past, and at times immediately suspicious as a result of attitudes adopted until recently with regard to information. This public develops a resolute suspicion at the first signs of incoherence, and is radically rejectful at the slightest hint of dissimulation. Any difficulty or failure in communication leads rapidly to a firing of ill-conceived, even wild accusations at all and sundry: a veritable gangrene, this, in all fragile post-accident situations.

Immediate operational action, such as the long term exercising of economic and administrative responsibilities, demands communications of a very high quality. The internal communications of the organizations concerned, inter-organizational communications, communications with the public via the media (or directly, in case of extreme urgency): experience shows just how necessary it is to master these multiple lines of communication.

Here is where we are going to concentrate our attention in order to try to view more clearly:

The most common pitfalls: on such an explosive field of action a clear perception of "natural" errors is a preliminary and indispensable requisite. It is important to emphasize here that instructions and rules of response concerning a crisis situation should thus carry an initial heading: "Actions you will almost certainly take, and which you must avoid at all costs".

The necessary abilities and tactical tools: this concerns the assembling of all the key factors in order to construct a communication base with respect to the crisis situation (an analytic and dynamic table of all parties concerned;

working guides to operate in this complex set-up).

Crucial questions for the establishing of strategies of communication: rarely well pinpointed, these questions weigh heavily on the implicit choices made in controlling communication, and rush one into the dangerous reflex action mentioned above, so hindering the triggering off of proper responses and required techniques. Work undertaken at this level must at all times lead to the avoidance of failures, and, more positively speaking, leave ones thinking unfettered, and ready to introduce any required innovation whatsoever.

Let us emphasize, here, that the simple search for "techniques" of communicating remain quite inadequate, even if it is the case that they provide useful assistance - as we will, indeed, demonstrate later in the text. The point is rather, though, to weigh up all aspects of the problems thoroughly, so that it is possible to build in-depth strategies of communication as required by present-day post-accident situations.

1. UNDER THE WEIGHT OF THE EVENT: ALL COMMUNICATIONS DISINTEGRATE

The event takes place. It imposes its law: turbulence, elusiveness, continual new developments. What is important is to be able to arrest this whirlwind which threatens to carry all off with it through a process of wearing down, explosion, implosion ... But before attempting to draw up a list of tactical recommendations, it would be advisable to stop and take stock of what experience has taught us. This we will try to do here, using a consciously simplified analysis.

1.1. Rapid failure, arrived at through three convergent paths

1.1.1. Technical and organizational problems characteristic of a state crisis

With regard to the number of major problems radically affecting the dispatching and reception of communication, one might here cite:

- *Problems of transmitting information*

  Here we have a basic problem: the means of enabling the ready conveying of information in post-accident situations are regularly lacking. Having a central telephone system on site, as was the case when 216,000 persons had to be evacuated in Mississauga (near Toronto, where on 10 November 1979 there was a rail accident involving a chlorine car), comes under the category of the anachronistic. The jamming of telephone lines, the impossibility of getting through to those in charge (duties not carried out, or carried out by unqualified personnel) are the classic obstacles. The same scenario in Mexico, following the earthquake in September 1985, with the loss of the communications building, an unprotected strategic point. Likewise in Andorra, during the floods of November 1982, where communications with the outside broke down - two central telephone exchanges (linking Andorra to France and Spain respectively) housed in neighboring premises, both disappeared under lakes of mud. Men had to be sent out on foot to sound the alarm (9).

- *Problems of understanding messages*

  Informing the population in cases of disaster is a determining factor. A careful reading of emergency plans can have some surprises in store at times. For instance, in Canvey Island (England, an industrial site on the Thames estuary), the handout issued to the teachers in the zone stated that they were to lift children onto the tables should a "heavy" gas cloud descend over the schools, but that the children should be made to lie down flat under the tables if the gas were relatively "light". What was hardly made clear was how the teacher should arrive at such a diagnosis. In the area surrounding the Union Carbide factory - meanwhile - the object of very particular attention in the wake of the Bhopal accident, as Newsweek reports (10), few people were aware of how they should react in cases of emergency. Admittedly, according to the plant spokesman, a letter outlining the plant's emergency programs had been addressed to them every year since 1975 - but few had received it. And Newsweek goes on to state: "If they had, they might still be confused. According to the letter, two three-second blasts of the plant's whistle means a fire or medical emergency; three three-second blasts means a gas release; two-second blasts every three seconds for two minutes means a major disaster, with two-second blasts every 30 seconds until the danger has passed. (Last year, when a valve broke on a chemical barge moored at the plant and a neighborhood had to be evacuated at 3 a.m., most people were sleeping with the windows closed and never heard the whistle.) Instructions for what to do next are equally confusing: If the wind is blowing favorably, stay put. If the wind is blowing toward you from the plant, evacuate <<by going crosswind>>. <<In some cases, you can see the fumes as a white clouds>>, the letter added. <<However, this is not always the case so don't depend on your eyes>> (10, p.40 and 44).

- *Technical incertitude*

  If the means of transmitting exists, one must still have something to communicate. Here one hits a second problem: the impossibility of making a rapid diagnosis. Take Seveso in July 1976: no-one knows how much dioxin escaped, nor the exact toxicity of the product. At Three Mile Island, the chief technical officer (H.Denton, NRC Commissioner) speaks of an"Einsteinian black hole" (11, p.206). As for Bhopal, Union Carbide, denied access to the site, is lacking information (12).

- *Organizational confusion*

  The Three Mile Island (TMI) case is a model of the genre. The Governor is advised by the federal bureau of the NRC (Nuclear Regulatory Commission) to prepare himself for the imminent evacuation of one million persons, whilst the same agency's regional bureau orders no such a thing. Moreover, no evacuation plans are available, seeing that the possibility of such a scenario has always been excluded (the local authorities received written affirmation of this under the double signature of the operator of TMI and the regulatory authorities). The mayors threaten the Governor with taking unilateral measures as a result of the authorities shortcomings.

Such problems do not remain without effect. The void of information being intolerable for those in charge of operations and even more so, for the public communication channels are soon abounding in contradictory messages whose reliability becomes increasingly questionable. Such has been the case on TMI, where the mayors no longer know whom they should trust: "Use your own judgment. We dare not tell you to leave your homes" (13, p.111). A general absolution has been granted in the local parishes... (14).

And a second line of breakdown appears to render the situation more fragile.

1.1.2. A crisis-generating "mentality": the reticence inspired by information about the risk

Numerous cases give ample demonstration of the inhibition felt. Quite obviously, caution and intelligence are not to be frowned upon, as we will be reiterating further on - the vehicle of the media, in particular, not being exempt from producing the undesirable, to put it mildly. But what should be emphasised here is less the necessity of knowing how to cope, than the irresistible compulsion of which those in charge often show themselves to be prisoners. Deep-rooted reflexes drastically inhibit the margin of mental maneuverability and lead almost immediately to "suicidal" points-of-no-return.

Practically with no delay and with a regularity which borders on caricature, the following mechanisms appear as soon as there is a failure or threat of a major problem:

- *Silence heavily marked by embarrassment*

  The very first reflex is to draw a veil over technical breakdowns. So as not to "panic the population". In order that the public image should not be tarnished in any way. In order to be spared "a media test". Or, more profoundly still, because the acknowledgement of difficulties would go against the unwritten rule: equipment and the experts are both infallible (this is the central point of reference of a scientific and technical society with too many milk teeth). Information not being slow to filter through, those in charge rapidly find themselves in an embarrassingly defensive position ... from which they attempt to extricate themselves by a route which exacerbates their strategic position still further.

- *The relentless denial of risk*

  Let us return once more to Seveso. It took a fortnight before it was acknowledged that the situation was one for concern, and to abandon declarations of the "everything is under control" variety. And not before the Hoffmann-La Roche director of medical research had thrown the cat among the pigeons by declaring "the situation is very serious indeed, requiring draconian measures"; in short, removing the top 20cm. of earth, burying the factory and destroying the houses" (15, p.14). While the regional minister of health attempted a final evasion: "I have the impression", he said, "that this person is bluffing, and am not convinced that the gentleman concerned is as aware of the gravity of his declarations as he ought to be" (16, p.18). This complete denial continued through to the most damaging capitulation for an authority. Scarcely had the gravity of the situation been denied for the last time, in the most solemn tones, when it was felt that one was going to have to "accept the evidence" and let the evil drop. Thus, this communique issued by the Lombard authorities at the conclusion of their exhausting battle against reality: "179 persons will have to evacuate their premises within the next 24 hours"(15, p.14).

- *Information given as a rearguard action*

  The principal is a general one: defeat follows on the heels of defeat, as the retreat is conducted in an increasingly clumsy manner, the authority digging in to try to defend, at each stage, positions already lost. The enormous confusion which reigns, imposes its law, as in Seveso. "Crumbs of information were handed out, following a calculated system of reticence, misrepresentation and partial admission (which were given, or else extracted), affirmations and denials; all this being conducted in such a manner that the elements of certitude remain invisible and, in particular for the population affected, completely elusive - so much so, in fact, that the most extraordinary reasonings and conclusions end up by making it impossible for those involved to react as the circumstances require they should "(17, p.89-90).

- *Blank refusal, to the point of provocation*

  At Three Mile Island, Metropolitan Edison's Vice-President (J. Herbein) declared at one press conference: "I don't see why we need to ... tell you each and everything that we do specifically" (13, p.120). The Presidential report comments: "It was that remark that essentially eliminated any credibility Herbein and Met. Ed. had left with the press" (13, p.120).

There you have only some of the features of the dynamic which can develop. One could go on to review the miscellaneous array of defense mechanisms identified by Freud. Any and all might be used in this systematic evasive action - rationalising featuring very high, in the second row of action behind bald negation. And what is more, this doggedly determined denial, stifling lucidity, is only more marked in contact with the media; though the same scenario is played out within the very organization itself and between the organizations in charge:

- This is why one very often sees that the senior management of a corporation is informed very belatedly, each echelon not reporting the problem to its superior echelon until it is already too late. In a certain case which we have made a very close study of, the top management was more or less assured right until the end (the explosion of the affair in the media) that the situation was not at all one to cause concern.
- The case of the accident in Taft, Louisianna (a Union Carbide plant, an accident involving an acrolein tank, 1982) illustrates what reticence there is to inform the other organizations concerned; the management refusing throughout the episode to establish the proper relations with the relief, rescue and public order authorities (18), which naturally gave rise to unbearable situations of confusion and tension. The public, hearing rumors of an evacuation of personnel from the factory, started calling the Emergency Operation Center to enquire what evacuation routes the law and order authorities had chosen... only to discover that the authorities appeared completely in the dark. "Evacuation? ... What evacuation?" asked the surprised authorities. Worse was yet to come. When the specialists arrived at the site, at the authorities request, they were taken in hand by ... the public relations department, with no access to the technical crew. "Nobody knew nothing, nobody was telling us anything", one of the officials observed (18, p.29). And, in the midst of all this, the authorities were responsible for having 17,000 persons evacuated, blocking off the Mississipi for 50 miles, and preparing themselves to face up to the worst - the damaged tank, to make matters even more alarming, being extremely close to five other acrolein tanks.

Everything is conducted as though any information concerning risk were perceived of as far too "delicate" to be handled by obscure mechanisms, themselves as elusively shadowy as the reality posing problem.

As one will see immediately, however, technological risks, major accidents, cannot benefit from any right to absolute secrecy in a society of open and free communication. On the contrary: anything which potentially affects a large number of people, anything out of the daily routine, will find those whose work it is to keep the public informed concentrating the greatest attention on it. This mentality, some of whose contours have just been mapped out, collides head on against another mentality, that of the media, equipped as it is with means and powers it proves suicidal to challenge lightly.

1.1.3. The norms and practices in a society of open information

Information can no longer be reported in a thoroughly "anaesthetised" way for the "outside world" once the affair has been brought to a conclusion, having been directed in an honorable fashion. A radical change has come about. Any system which fails, can no longer be considered as isolated from the observation and action of sundry third parties.

Major risk (which does not respect the boundaries of the plants), on the one hand, and the development of our society of communication, on the other hand, demands that there should be quite different mental checkpoints. Affected either directly or potentially, the public is ever more vigilant and concerned. The media now take an interest in what has become a problem for everybody, and not only a question of the internal activity of an enterprise. This would often appear to escape the observation of those in charge, still labouring under the conviction that factory premises offer some sort of absolute protection and that the economic activity, in general, comes under the aegis of "reason of State", preserving it in advance from any "outside interference".

Here then we have industrial activity exposed to the high winds of public opinion and the media. The TMI case (just an example among many others one might have chosen), enables one to measure the magnitude of the challenge to be met by any who discover the rules of his new world.

- *The lightning speed with which critical information can spread*
  "A Harrisburg music station broke the story of TMI-2 on its 8:25a.m. newscast. The station traffic reporter uses an automobile equipped with a CB radio to gather his information. About 8:00a.m. he heard that police and fire fighters were mobilizing in Middletown and relayed this to his station. [The] news director called TMI and asked for a public relation official. He was connected instead with the control room to a man who told him: "I can't talk now we've got a problem" [13, p.103] - and to telephone Met Ed's headquarters. He finally reached the company's manager of communication services who said there was a general emergency: "There's no danger off-site. No danger to the general public" [13, p.104]. "I tried to tone it down so people wouldn't be alarmed" the radio director declared to the President's Commission [13, p.104]. "At 9:06a.m. the Associated Press filed its first story - a brief dispatch teletyped to newspaper, television, and radio news rooms across the nation. The story contained only six sentences in six paragraphs, but it alerted editors to what would become one of the most heavily reported news stories of 1979" [13, p.104].

- *Information not flowing in the usual direction*
  As a result of the power and maneuverability of the media, the officials barely have breathing time to call a discreet committee meeting in order to discuss how and when the information should be made available. The classic procedures fly out the door, the news already being on the air before it has been possible to contact quite a number of officials: they will learn the news through the radio stations.

- *The formidable power of the media*
  "Reporters took down license numbers at each shift at the plant; got the names and addresses from the state motor vehicle department ... Then (they) started knocking on doors. Many employees were belligerent, most were exhausted but fifty agreed to interviews"[19, p.48]. "Parked directly across the Susquehanna from the plant, Nordland (a reporter) tooled with his fancy scanner radio searching for TMI transmissions. Nothing on the utility band nor the police band. He switched to a frequency the instruction booklet said was reserved for "federal interagency cooperation during nuclear war". And they were there"[19, p.52].

- *The media: a power which reserves the right not to be held up to ridicule.*
  One might quote the commentary of a European radio ("RTL" - Radio Tele Luxembourg) Washington correspondent, broadcast on 2 April 1979. It shows that in a crisis, the henceforth classic "Washington-Post/Watergate" model can somewhat upset the fine prescription "reason of State/Economic reason", if the official communication appears too suspect. "What irritates Americans is the feeling that they are being badly, very badly informed. The spokesman for the owner company of the plant announced right from the start that everything is just fine. He is obviously lying. As for government experts, their opinion alters every two hours. So, what Americans seem unwilling to put up with is that nobody has the honesty to come out into the open and say: "We just don't know what is going to happen". On this same note everybody noticed in Le Monde, April 1979, a scathing caricature bearing the simple caption: "American engineers are asses" - signed: "EDF". (Note: EDF = Electricite de France).

These three paths slide steadily together, their negative effects combining. Organizations put barricades up from the inside, consequently their networks become deaf and blind and information filters through under the worst possible conditions. The media take a close interest in the accident - by now transformed into a darkly mysterious affair. The difficulties experienced serve only to increase the strain felt by one and all. The "mentalities" mentioned only serve to weigh heavier on people's responses: problems mushroom ... one teeters towards the precipice and topples over the brink.

1.2. How giant quagmires are formed

The cases most pertinent for analysis are precisely those which presented the least effective risks, and which produced catastrophes which were almost entirely media events. We will take three recent examples, concentrating our attention on the initial phases of those episodes - decisive moments in the dynamic of all crises.

1.2.1. The "Seveso drums" affairs

This is the biggest "media-affair" France (and even Europe) has ever known concerning the environment. For two whole months, the suspense more often than not monopolising the front pages of the newspaper; Europe was trying to track down 41 drums of waste material from Seveso. It is an affair abundantly rich in the matter of communication, revealing how it is possible, at every instant, to maintain a crisis at its apex of activity, by continually distilling half-truths, half-lies, half-denials, implicating some new party with every passing day, everything and everyone unfailingly coated in a thick, muddy layer of confusion-dissimulation apt, quite naturally, to provoke the most searching enquiries [20].

Without entering into every single one of these points, here we will take a look at a relatively little emphasised aspect of this crisis (which exploded on 25 March 1983 with the publication of a bombshell article in the journal "Science et Vie"). We will examine how communications during the affair, from as early as October 1982, set in motion the conditions most favourable for the development of a crisis.

- 2 and 6 October: Greenpeace denounces a project to dump, at sea, waste material from Seveso (ACP, AFP [Agence Centrale de Presse; Agence France Presse]).
- 14 and 16 October: to gain the favour of their citizens, the Lombard authorities offer up to the public extracts from the dossiers on Seveso's waste material... needing twilight or even dusk for the dark stains of trouble to go unspotted. Some facts: 2,200 kg. of waste from Seveso, placed in 41 drums, were buried outside Italy, having crossed the French border at Menton (near Nice) - the final destination remaining unnamed (AFP, 14/X). All that implied a strange underlying significance: the authorities claim they do not know which country, adding the while "only Givaudan knows". This can only trigger trouble, suspicion. Another element is introduced: there is a red hot dossier which everyone tries to discard into other hands (GDR in particular, which denies having been the final destination of the shipment) before it gets burnt.
- 19 October: Givaudan enters on the scene and declares he is unaware of the whereabouts of the "42" (and not 41 as was said by Italian authorities) waste drums. "The firm responsible for the transportation alone knows, but Italy and Switzerland may be excluded; the deposit was made in complete respect of all regulations of the country concerned".

The whole crisis sphere is by now rapidly becoming a potential minefield: surprising ignorances concerning an explosive dossier, exclusions which will not fail to be picked up on as indelicate and, even more, stupefying in their admission ... Everything is transformed into a dangerous rendering of "pass the parcel" or "musical chairs", guaranteeing a swiftly developing snowball effect. The crisis did not break out on the spot: few of the press were taking an interest in the trivial news. One might have noticed, though, an article in the "Quotidien du Medecin" (26/10) which took a look at the entire issue (six months ahead of the "Science et Vie" article). The question is let drop. But there is just a surface calm. On 5 January 1983 "Le Canard Enchaine" (French satirical journal) whispers: "Somewhere in Europe there are people likely to wake up with a nasty surprise one day".

On 25 March the media explodes with irrepressible force. Over 40 organizations, half a dozen countries are involved, with searching rapid-fire questions thrown to the music of machine-gun clicking of press cameras.

1.2.2. The wreck of the Mont-Louis

The first news bulletin is broadcast on Saturday 25 August 1984 at 16:10: "Collision off the Ostend coast between a French cargo vessel and a ferry. There has been no victims" (AFP). At 20:56 (AFP) one learns that, following the collision which occurred shortly after 14:00, the Mont-Louis cargo vessel sank. Here are some extracts of teletexts of 26 August. They are key-passages taken from the original texts published by AFP. We have only underlined certain particularly important words.

> *AFP, 15:01.* "According to Greenpeace the Mont-Louis may have been transporting uranium".
>
> *AFP, 16:23. Urgent.* Several containers holding radioactive waste material were on board the French cargo vessel, said a seamen's union official, speaking in Le Havre on Sunday. A representative of the CGM (Compagne Generale Maritime), the owners of the Mont-Louis, acknowledged that it was, indeed, a case of products with a radioactive content, but failed to specify the exact nature".
>
> *AFP, 16:41.* When first speaking, the CGM representative stated that he was ignorant of what the containers were holding, hinting that it was <<possibly medical materials>>".
>
> *AFP, 17:48.* "Having in the first place stated ignorance as to the content of the containers, then saying they were <<possibly medical materials>>, the CGM representative has finally admitted the presence of radioactive matter. It has been impossible up to now, late Sunday afternoon, to obtain any indication whatsoever of the degree of noxiousness, and the danger which the submersion of these products might represent, following the capsizing of the Mont-Louis".
>
> *AFP, 18:48. Urgent.* Sunday evening, the CGM has let it be known that the vessel was transporting, in particular, 450 tons of uranium hexafluoride (UF-6). According to the CGM, quoting the CEA (Commissariat a l'Energie Atomique), <<the temporary submersion of these containers of gas represents no danger whatsoever>>. The CGM has also let it be known that the ship's officers have been able to assure themselves that the containers had remained perfectly sealed after the accident".
>
> *AFP, 19:50.* "The Mont-Louis survivors were sworn to silence concerning the nature of the cargo they were transporting, the secretary or the National Seamen's Union (CFDT) stated on Sunday evening. <<A CGM representative met them in England shortly after their disembarkment from the car-ferry (which had rescued them). On their arrival in Le Havre, several survivors explained to me that they had been advised to remain silent as to the nature of the content of the containers>>. During these brief exchanges with members of the Mont-Louis crew, the CFDT official noted that a CGM representative <<always managed to be present to listen in on the conversations and thus to discourage any possible divulging of confidences>>."
>
> *AFP, 19:52. Sworn to silence (continued).* "In fact, journalists present at Le Havre airport were struck again by the overwhelming silence of the survivors, manifestly ill at ease when it come to speaking about the containers. It had, however, been possible to gain from some of them, and in particular from a young officer who had been on board, the confirmation of the presence of containers carrying radioactive material. After having tried to elude the journalists' questions, a CGM representative who had earlier notably tried to say that it concerned <<possibly medical materials>> finished by admitting that it was none other than radioactive materials in the containers."

AFP, 20:13; 20:28. "It was the ecologist organisation, Greenpeace, then the seamen's trade union, CFDT, which on Sunday afternoon revealed the presence of uranium hexafluoride on board the Mont-Louis [...]. The survivors of the French cargo vessel, according to the seamen's trade union, CFDT, were, on their arrival in Great Britain, sworn to silence by the company, as to the cargo. It took the insight of the ecologist organization to break down the wall of silence."

One image appeared immediately to colour everyone's perception of the affair: that of dissimulation. It was to be headlined all over the French press: "Le Monde", <<Silence>> (Editorial, 28/8); "Liberation", <<Uranium: Silence, Sunk>> (28/8); "VSD", <<The Law of Silence>> (30/8); "Le Quotidien de Paris", <<A More Dangerous Cargo Than Was Said>> (31/8); "L'Express", <<A Dossier Marked By An Astonishing Discretion!>> (31/8); "Le Point", <<The Sound of Silence>> (3/9); "Le Canard Enchaine, <<The Silence of the Sea>> (5/9); "Le Journal du Dimanche", <<What France Hid>> (16/9); etc.

And now the media crisis was being coupled with the beginning of a diplomatic crisis of which RTL (Radio-Tele-Luxembourg) (27/8) made mention "nearly live": the Belgian minister in charge of the Environment - while at the same time affirming in a communique that there was "no danger whatsoever" - complained strongly through the media about the total lack of information coming from France. So the dissimulation, denounced by a foreign government (a hypothesis certainly not foreseen in the plans for the control of information), acquired a new status. But this did not prevent the Belgian minister from "reassuring" his fellow citizens about this dossier, which he had not yet managed to lay his hands on, he was still able to affirm "there was no danger whatsoever".

The first 48 hours had been catastrophic: a media crisis had been created, a diplomatic crisis had been avoided by a hair's breadth, the seeds of future crisis had been sown. All this, backing up an idea already too widespread, that "nuclear" can only be linked with "dissimulation". Already the crack was widening, (RTL, 27/8): "No one wanted to reveal how much the material had been enriched...".

1.2.3. The Rheims dioxin affair

January 1985: an Alkarel transformer explodes in the basement of an apartment building, firemen intervene, EDF workers reinstall electricity; for the authorities everything is normal and the residents are strongly urged to come back to the flats they have evacuated for a few hours. March 1985: "Science et Vie" (again) reveals "the astonishing episode which took place in Rheims on 14 January, illustrating once again the irresponsibility of the EDF and the public authorities in matter of safety". This article, based on the victim's viewing of the episode, brings together a series of points which are again just as much ingredients for the development of a crisis [21].

- *Some strange facts, which did not go unnoticed by the victims*

  A flat owner in the building, in talking with one of the firemen, learns that he and his fellow officers have received instructions from EDF to keep their uniforms and boots aside so that they can be collected and destroyed. Why such a precaution?". "A visitor to one of the inhabitants says that he can smell Alkarel in the flat. The inhabitant is a works inspector, and she has no difficulty whatsoever in finding the characteristics of this product documented in her files. What she finds worries her".

- *The impossibility of finding anyone ready to consider the dossier*

  "As early as Saturday morning (16 January), the inhabitants of the building, having received a letter from their managing agent - declining all responsibility for them still being in the building and not being evacuated - decide to leave their flats and find themselves out in the street". "Hoping to find help in being relodged, one of them telephoned the town hall. The deputy mayor knew nothing about the affair. Neither the mayor nor the sub-prefect (local governmental authority representative) was available.

- *Blank rejection, proof of cynicism*

  "Faced with the residents' insistence, a meeting was held [...] which was to lead absolutely nowhere. Just like the meeting held in the local EDF offices shortly afterwards, on Monday 21 January. The EDF experts were not in the least downhearted. To that lady, the works inspector who stated that <<polychlorinatedbiphenils could produce polychlorinated-dibenzofurans and polychlorinated-dibenzodioxins>>, Mr.[...] head of the Rheims branch, replied in a tone both ironic and condescending: <<Apparently, madam, you consider yourself an expert>>.

- *Absolute assurance, but the refusal to commit oneself in writing*

  "<<In any event, there was no risk: there were not the conditions which were going to mean that any toxic products were emitted>> concluded the EDF branch head, refusing nonetheless to commit his words to paper, as asked for by the residents of the building. <<We prefer to wait for the results of the analysis>> was all he chose to say".

- *Some pointers...*

  "The results of these first analysis, however, were to be a long time in coming [...]. It would be learned later that even more samples had been taken [...]. A high-ranking official from the EDF in Paris had had to make a special trip for that. These samples, which the Rheims EDF branch were to feign ignorance of for a long time, were given for analysis to the Centre for study and research of "Charbonnages de France".

- *Some questions*

  "We have just become aware of the results of the first analyses. They reveal the presence of certain products, without giving their concentration [...]. But no dioxins. Is it because there weren't any, or because the instruments were not sensitive enough to register them?".

- *The immediate situation*

  "Meanwhile, the building, which without more searching analysis one does not know whether or not is contaminated with dioxin or furan, remains open. The residents come to water the plants on the upper floors, and collect their mail. The children come to collect their school books...".

The scene was set. Two months later the crisis exploded in the media. Pr. Rappe a Swedish specialist with faultless credentials, who had been asked by J. Denis Lempereur (Science et Vie) to analyse some samples taken in secrecy from the building, had come up with very worrying results. The difficulty of the analyses and scientific interpretations, which were to become most delicate, were to be handled with anything but a light touch in all matters of communication. But in what state were the credibility and the image of the EDF then left? In May, a "Science et Vie" headline read: "Once again the policy of burying one's head in sand has led nowhere" [22].

Today, while the ex-residents no longer know what to fear or in whom to have confidence, the EDF is, on its side, measuring how much it was caught off guard. Persuaded at the outset that the incident could not have really serious consequences, comforted by the first analysis (insufficient), shaken by the result obtained from abroad (Sweden and Canada), reassured yet again by the most recent expert opinions (absence of "Seveso dioxin" which nonetheless does not signify an absence of all dangerous products)... The EDF has still to study in detail the determining factors of this crisis. An episode which presents itself as a real headache for the immediate future, a damaging stain on its image in general, and for its image as a nuclear power plant operator in particular.

Here then we have summed up three cases, all of which outline an infallible recipe for finding oneself trapped in a crisis:

- the construction of a maze in which truth and falsehood are as elusive as those in positions of responsibility;
- the opening up of this maze to the curiosity of observers convinced, by the mistakes of the officials involved, that each line of questioning will lead to a never-ending chain of "revelations".

Other means of competent handling must be arrived at.

2. THE CONSTRUCTION OF COMMUNICATIONS TO CONTROL THE EVENT

The brief outlines already given have landed us fairly and squarely at the crisis. Here we might stand back a little: to fix points of reference; to find other ways of coping with this maelstrom which threatens to engulf all those concerned, both directly or indirectly.

2.1. Understanding the complex system of all involved

Two complementary requirements must be adhered to: always keeping in view the major points of reference: giving ground when necessary to the complexities or irregularities of the situation.

2.1.1. Topological approach

A first look at the network caught up in the crisis allows immediate identification of the major grouping to be taken into account; not a single mind must be over looked (and particularly the last):

- The operator.
- Public authorities.
- Experts.
- Population.
- The media.

But this overview must be broken down at once as each of the categories identified in fact only represents a complex sub-system, in turn filled with its own questions of communication:

- *The Operator.* This includes: those playing a part on the site itself and at the firm's headquarters; such diverse categories as internal experts, emergency staff, press and public relations people, company spokesmen lawyers, the top management; diverse internal forces such as trade unions, safety committees;

diverse bodies also involved such as affiliated companies, direct partners such as clients or suppliers, other manufacturing plants involved in the same processes, etc.

- *The authorities:* This category includes: the emergency services (local, regional, national, international; fire-brigades, para-medics, police, ambulance services, etc.); regulatory bodies; public authorities at local, regional, national level; elected authorities, etc.
- *The population.* Here must be taken into account: those living in the immediate area (organised or not into associations); immediate or potential victims; populations threatened with the same type of risk at other sites; public opinion in general ...
- *Experts.* This category covers the many experts linked with one or other of the categories cited.
- *The media.* A particularly well-represented body which embraces the press in all forms: spoken, written, and televised; local, regional, national and international; general, specialised and scientific, etc.

One could be even more precise still. What is important, though, is to note that complex relationships will be built up between all these sub-groups, often in the shortest possible time, but which will continue to function over long periods. So another approach will be enlarged on here to try to appreciate the nature of the key factors in these networks.

2.1.2. A dynamic approach

Models need to be drawn up to define the ground rules which will govern how communication between those concerned will develop: how do all these people usually function?

In the case of the media, J. Scanlon and S. Alldred [23, p.13-18] have drawn up the following model (this first presentation will be gone into in depth in part three):

1. The media will hear of an event (some citizens will usually call the media: media also monitor the activity and communications of key emergency agencies; major accidents are difficult to conceal).
2. The media will try to obtain more information (they will start to use whatsoever means available; the speed of this activity may be incredible).
3. The media will use their files to add to the story (most major news agencies have substantial libraries; past errors are extremely likely to be repeated).
4. The media will dispatch reporters to the scene (again: incredible speed).
5. All staff resources will be applied to a truly major event (global mobilization of the whole network).
6. The media will use all of their technical resources and ingenuity (specialized vehicles; access to communication networks, etc.).
7. As information becomes available it will be reported (the attention given to immediacy is a canon of journalism; the news is reported as available, however scanty or inadequate the information and however marginal the original source or sources).
8. Information will spread from medium to medium (the various news media are intertwined in a way which makes information sharing inevitable; they also monitor each other in order to pick up information they may have overlooked; a story by one is soon for all).

9. The media will attempt to fit the news into a framework (loss of life, injury, persons left homeless... the media will push very hard for this sort of information to be made available - there is no perception that the confused aftermath of a disaster may make this most impossible to obtain).
10. The media will demand official news conferences at which official statements can be recorded (to give the news form and structure; to clear up conflicts between sources; to be sure not to be scooped; to be able to attribute their "facts" to somebody; etc.).
11. The media will shape the story to suit particular needs (according to their respective audience).
12. The media will persuade people to act in such a way as to conform to news norms (TMI: TV crews asked people to move indoors so they could show deserted streets).
13. The media will have trouble dealing with technical matters (most correspondents go from crisis to crisis: they are generalists rather than specialists).
14. The various media - radio, television and print - will act differently (each medium has its own needs and its own technical and logistical problems).
15. The foreign press tend to support each other and often antagonize local media.
16. The media will make demands on communications, transportation and other local resources.
17. In a truly major incident almost all reporters will share what they have.
18. The media - whatsoever techniques they use to obtain information - will not publish it if they decide it could be harmful.
19. The media will also co-operate with official requests that certain information be withheld (but if anyone should break the agreement, the other would follow suit.

Apart from the basic ground rules, it is imperative that close scrutiny be given to the whole complexity of the system which is plunged into crisis. For every active participant, an attempt must be made to draw up a checklist of his:

- primary objectives and interests;
- secondary objectives;
- decision-making criteria;
- uncertainties;
- internal conflicts;
- imperatives as regards the apportioning of times;
- major loyalties;
- etc.

Major organizational structures equals complexity. It is also imperative to take into account those very exceptional factors which can play such a decisive role in the dynamics of communication. So, additional points not to be overlooked, for example (to take instances observed in cases we have studied):

- The personalities and temperament of those involved in the situation; an ordinary citizen may be an expert of the highest degree; one key person may prove to be terribly determined; some officials can be more outspoken than diplomatic.

- The ties which may grow up between sub-groups which at the outset fell into different categories; hence, a journalist may have privileged relations with the entourage of a centrally placed figure in the affair; several key people may belong to a particular "club" which may diminish other more visible loyalties; a member of a firm may feel a conflict of interests if he has fears for his family (the constraints to silence may be ignored), etc.
- Role changes which can determine the crisis situation: the media can become part of the emergency administration, if information is an essential in the situation (as was seen with Televisa - the main Mexican chain - during the San Juan Ixhuatepec catastrophe [24].
- Problems, slippings and slidings which can come to light in matters of expertise. A lack of serious scientific support surrounding the media and environmental associations has often been observed, but this danger has even been known to appear at the very heart of the bodies responsible: recent events have shown the huge difficulty encountered in trying to establish rapidly the desired communications with the most reliable experts, as jeopardising contacts may be made with "quasi-experts" who know the field sufficiently to exercise a considerable ascendancy over the decision-makers, but inadequately with the very "pointed" questions which arise during a crisis. And questions have a tendency of evolving so often during a crisis that no expert can be sure not to be subjected to the danger underlined. Any expert can become a"quasi-expert" (or a "pseudo-expert', if one would rather use a stronger term).

So it is in the midst of all this complexity that actions to counter the event must be implemented, and especially so in the field of communications.

2.2 Developing fundamental abilities for crisis communication

In the face of the event, the task of communicating is, from all evidence, a delicate one; a key issue is the strategy of this whole activity. But, before tackling the problem, some basic guidelines, illustrated by some relevant examples drawn from experience, should be laid down.

2.2.1. The main working guidelines

a) Internal information

- Assemble the greatest amount of information on the event from all possible sources.
- Contact immediately the relevant people responsible; report regularly.
- Set up a control room, with the means for passing on information (but a control room is more than a series of telephones [25].
- Seek out all available data on the installation and the risk in progress.
- Seek out the most competent experts.
- Designate one official to deal with all press questions - especially the one who should be talking to the TV in the hours to come. This step should be taken immediately, without waiting for the classic situation of "designating a volunteer" at the last moment, abandoning him to the microphones and the cameras, with only the knowledge... that this could be a very damaging situation for him (as we have already observed in several case studies).

- Keep track of all information published by the media.
- Prepare a dossier on earlier episodes of similar events.
- Draw up a dossier on how the event unfolds.

b) "External" information

- Establish without delay all the requisite links with the other people concerned
- Establish these contacts at high level, even if that seems technically difficult or touches on delicate matters of protocol.
- Confirm in writing all oral communications (telex).
- Discuss with all those concerned what communications to establish with the media, roles and responsibilities to be assumed by all those involved in this field of media communications.

c) Information for the media

- Draw up very precise press releases.
- Ensure that information is not only available, but that it actually reaches the media.
- Set up a fully operational press centre.
- See that there is a good flow of information (concentrate on the information actually getting through to the press centre).
- Provide self-explanatory documents so that non-specialists can understand the situation.
- Identify any rumors and correct any errors immediately.

d) Information directly for the population

- In the event of imminent danger it is imperative that the operator intervenes without delay to safeguard people living in the area and anyone who may be passing through the area affected by the accident. Very specific communication channels should be established and tested out.
- This necessity clearly poses legal questions: who is responsible for these flash-interventions and their possible consequences?

2.2.2. Some examples

a) Highly developed technical resources: the CHEMTREC case

Worried by transport accidents involving dangerous materials, American chemical manufacturers set up, in the 1970's, a communication centre capable of performing at peak levels; it maintains an around-the-clock telephone line. Through the use of a data bank which lists more than 35,000 chemical products, CHEMTREC provides information relevant to on-scene conditions. More: this crisis centre includes an information system so highly developed that it allows someone actually on the site of an accident to be kept in touch with numerous other concerned persons: the senders of the goods, the shipper, the experts, the emergency teams, the authorities, etc. Telephone conferences can thus be conducted, involving nearly 20 people participating at any one time, no matter where they might be scattered around the States. This system enables the setting up of a greatly extended network of intervention, for very long periods should it be necessary. Such a backup system of communication enables the problem of transmitting information to be dealt with, particularly a problematic question when it concerns transport accidents which can occur anywhere in the country [25].

b) Organizational procedures rethought: Union carbide's internal notifications processes after Bhopal

Union Carbide has specified the typical accidents that must be considered as "major accidents" requiring strict procedures of internal early notification; it is interesting to observe that it has done so with regard to the problem of information. In the "major accident" category the American group has listed, as general guidelines [26]:

- Multiple fatality accident.
- Explosion or fire likely to result in national publicity.
- Bomb explosion or finding an explosive device placed in or near a Union Carbide facility.
- Product spill or other environmental accident likely to result in national publicity.
- Any threat or allegation relating to the facilities or personnel of the Corporation likely to result in national publicity or demanding a prompt corporate decision.

In the same spirit, the communications management of Gaz de France has brought to the attention of all its personnel that it must be notified about all events which might have a repercussion in the media: here one is again very far from purely technical and quantitative definitions.

c) Policies for what information to give to the media: Dow Chemical

Donald R. Stephenson (Director, Corporate Communications, Dow Chemical, Canada) has clearly set out lessons learned by his company from a certain number of crises [27,p.3]:

1. The public must be fully informed frequently and accurately through the media from the outset. This must be done by one or two highly credible senior spokesmen who understand the situation and can explain it calmly and clearly in lay language. The first 24 hours of a crisis are critical.
2. If this is not done, a public information vacuum probably will develop rapidly - and be filled by rumors or alarms far worse than the real situation.
3. Silence in the midst of a crisis implies guilt, whether justified or not.
4. It is not enough merely to assure the public that everything is O.K. and there's no reason for alarm. To be credible, we must provide details of how that conclusion is drawn.
5. It is vital to realise that reporters face deadlines hour by hour. Information must always be correct, consistent and current, even if all the answers aren't immediately available."

Following suit, Electricite de France has established, in case of nuclear accident, the principle of rapid information being passed on to the local media by the branch heads.

2.2.3. Work still to be done

The investigation should be given further attention and application, there being so many factors to deal with, and such a volume of lessons to be learnt from a wide range of experiences.

The "communication" grid of emergency plans are call for re-examination. Plans do exist. But aren't they too often "paper-plans" as far as communications are concerned? Exercises should be conducted, involving officials, and also the media and the people - as was recently the case in France near Metz with a drill based on a toxic gas leak (it was shown that population reaction was extremely poor and that much had to be done on communication grounds).

Another question is the problem of communicating with the experts in the crisis situation. As an example, here we briefly expand on the case of the Mont-Louis, mentioned earlier. It is clear that the events surrounding the incident - with responsibility falling in the first case to a shipper inexperienced in the handling of crisis, taking place abroad and during a week-end, non-nuclear but chemical but therefore dealt with by the nuclear industry, led to internal communication problems in the network linking experts who would have had the specialised knowledge necessary to handle the situation [28]:

- the steel containers, tested at 15 bars, were in fact at a pressure of 0.1 bar (and not 10 or 12 bars as it was often thought):
- the hexaflouride was in solid state, and not a gas;
- the hydrolysis of UF-6, in theory vigorous, is slow in practice because the oxyfluoride produced hinders the inflow of the necessary water;
- thus the fluorohydrous acid is produced more slowly than feared, and moreover, it dissolves in water (being very soluble) and is neutralized by seawater (basic).

On all these points, a scientist - even of the very highest competence - not thoroughly acquainted with the question, had every chance of making a mistake without suspecting for a single instant that he might be caught out on his "classic" theoretical references. This problem of the quality of the information in the very first exchanges led to such an agitation in the media that it took more than a month to calm it down.

Here we have examined some of the lines for a "tactical" communication reply. But this whole issue should be looked at from another angle, so that one may have access to much deeper realities which play a decisive part in determining all these attempts at tactical improvement. It remains then to explore these fundamental keys on which hinge communications in crisis situations, and from which point more developed strategies may be defined.

3. TOWARDS COMMUNICATIONS STRATEGIES

It would not be possible - and we do not intend to try here, either - to supply "recipes". One can, nevertheless, attempt to brighten the problem, examining the key dimensions of this strategic field which must be brought under surer control. To do this, one must try to identify the difficulties which can so complicate the establishing of the required abilities and skills.

3.1. Developing strategic abilities

Reflection on communication in crisis situations is often limited to the realm of speaking in front of microphones and cameras, whereas, in fact, crises demand more than that. Actual policies are required, embracing numerous aspects and areas. Three might be singled out from a time dimension.

3.1.1. The preliminary phase: avoiding pre-critical set ups

The prevention of a communication breakdown begins well before the disrupting event. It includes being equipped with all necessary material and tools, and the creating of a "capital" which can properly support all activities in communication through outstanding peak periods.

- Emergency mechanisms, featuring strongly the field of information: including here, for example, internal exercises on this theme, exercises involving the media (the mode of application being left wide open to invention according to the particular context).
- A general information policy for risks and emergency situations: here we note the requirement set out in Article 8 (S.1) of the European "Seveso Directive"- "Member States shall ensure that persons liable to be affected by a major accident originated in a notified industrial activity [...] are informed in an appropriate manner of the safety measures and of the correct behavior to adopt in the event of an accident" [29].
- A very serious prevention policy and practice: failing which (the operational turmoil in which) all communication would be marked by extremely severe conflicts to the extent that only a minimal exchange would become possible among those involved. One can quote here the British H. S. E. statement at a recent conference in London on the theme "Chemical Industry after Bhopal": "Put caution into the process, not into the telling"[30].
- An internal organizational "mentality" more open to communication in general and information on risk in particular: the behaviour observed is not due merely to chance; they are patterned by in-depth mentalities. The movement towards openness will be a long and exacting task (the tradition of secrecy not being easily forgotten) which will only be accomplished with firm directives from the management. A sign of these directives is, for example, the status accorded to the "communications departments "in the firms: are they viewed only as "publicity machines" both internally as well as externally?
- Strong positions for credibility and legitimacy: too great a weakness here carries a strong possibility of total failure and uncontrollable situations, no matter the tools and materials or degree of sophistication being applied. The balance to be aimed at needs to be defined, particularly in relation to the gravity of the problem with which one is likely to be confronted.

3.1.2. The instant reflex stage: faced with the shock, instantaneous collapse must be avoided

One overriding rule applies: those "natural" reflexes which lead immediately into a quagmire, must be kept firmly under control; examples of which we have reviewed earlier. The absolute necessity of adhering to this rule cannot be emphasised too heavily.

a) Internal disintegration

The classic outline includes:

- Initial non-awareness of the problem:

(i) because it remains outside the usual threshold of fault-detection (J. Scanlon has given the case of a series of earth tremors in Canada, too weak to set up in motion the scheduled organizational procedures, but sufficiently strong to trigger off a general feeling leading rapidly to the loss of credibility of the bodies responsible [31]);

(ii) or because the problem affects an area to which less attention is normally paid (i.e., it concerns waste materials, and not finished products; "simply" some drums and not a notified installation; a chemical product, and not a nuclear power plant; a factory which is being run down, and not a site which is under constant surveillance...).

- Organizational incoherency, which gets worse, to the point of paralysis when it comes to passing on uncertain, or even more so, worrying information.
- The "isolation" of each of the organization's sub-systems, as the problem becomes clearly visible... at the precise moment when the best possible communications should be in operation.

b) Network disintegration

Fragmentation of the whole can be attributed to numerous factors:

- Technical problems (lack of availability, the impossibility of establishing the desired connections...) cannot fail to provide a justification for the closing in of each organization in on itself.
- The moment (of peak vulnerability) is not the most propitious for establishing links with "strangers".
- The driving interests at stake are seen in a very limited scope: competition overrides, when complementary measures should be taken.
- The obsession becomes to get oneself "individually" out of the affair as fast as possible, leaving other organizations to cope for themselves: but a crisis often rebounds on those who try to get away too lightly.
- Common-mode failures threaten to weigh heavily. So when a large organization assures that there is no risk, all other parties concerned follow suit instinctively. Once one error has been committed everything falls apart (as was the case with the Seveso dioxin drums where everything leant on Hoffmann-La Roche's statements, which later proved to be inaccurate; or in the transformer case at Rheims, in which all hinged on the local officials' conviction of the infallibility of Electricite de France.

c) "Media catastrophes" triggered off by the reflex phase

It is imperative to extract oneself from the all too classic scenario:

- A silence heavy with embarrassment.
- Immediate declarations of the type, "nothing's happened, and besides everything's under control" (releases signed either by the management or professionals persuaded that they are thus rendering the greatest service to their firm.
- Denials, right up until the press "gets to the bottom of it".
- The blank mask response or refusals leading to a media as well as a social combat of the "David and Goliath" type.
- The inability to give details about the event, earlier events, or similar risks.
- An attitude of dissimulation giving rise to thinking that the affair is a real mess and that all determined research will wring out "confessions" which are even more and more devastating for those in charge and fabulous for the media.

d) Instant failures

Everything is played out in a matter of minutes if the kinetics of the accident demand instantaneous reactions and communications. There must then be:

- The ability to provide and pass on precise and operationally relevant messages.
- The very highest credibility: it is evident that a long practice of non-information can here have devastating effects. Would one, for example, wish to confine people at home? In no time at all there would be the risk of seeing a headlong flight taking place on the roads. Here is where the limitations of "paper plans" are liable to show themselves with the greatest brutality.

3.1.3. The development phase: the challenge presented by the complexity and duration

A precise analysis of the evolution of the communication dynamics between those involved is a requirement which must be met. What forces are expressing themselves? On which ground? Where is the action taking place? What are the possible pitfalls? What are the potential gaps already discernible?

Attention must be kept focused on the diverse lines of communication identified: internal, external, with the media, with the public. In particular, the media dynamic must be observed minutely - all the more, too, since certain newspapers can serve as a means of expression to the advantage of some of those caught up in the situation (this method of indirect communication, via the press, becoming one of the rules of confrontation between organizations). The examination in the greatest detail of the Seveso drums case - as a gigantic battle of communication - served as a good illustration of this [20].

The continuous grasp of this ever-changing reality is, of course, nothing other than the point of departure. There still remains to define the rules to work by: the anticipation of the rumbling of turmoil, the concern with the long-term in the actions developed. There must also be set out:

- The key positions which the organization intends to defend absolutely. Where are the regulatory authorities and the State in general concerned: show that they are in complete control of the activity of risk. Where is the industrialist: show that he carries out his activity seriously.
- The ability to give a coherent response. Hence, teams combining together technical experts, communication specialists, members of the management, must have carried out different practice drills, which test not only their particular competences but also their ability in dealing together with delicate situations.

But here a feeling of disquiet can be detected: to be more specific fundamental questions which are generally left hanging in the air must be tackled. They are, nevertheless, those which hinder freedom of action and judgement; and if they are, of course, much too delicate to be "resolved" here, it is nonetheless desirable to mention some points worthy of reflexion.

3.2. Fundamental questions to be explored

3.2.1. Crisis and communication: an extremely complex field - ignore it or invest in it?

Tactical materials and even fundamental strategic abilities rapidly reveal their limitations when an actual crisis situation has to be met head on. The situation unfolds as if in a block, evading any attempt to review "slices" of it, the mass-effect being so destabilising. Bitter conflicts threaten to erupt at any moment. They reflect: the position of those involved, the contexts which date back a long way, particular contingencies (chain of micro-events in particular); and, in great part (not to be underestimated by any model) the unwieldiness of the organizations concerned, which do not always work in their own best interests.

Precisely with a view to avoiding any simple model, a dual case - particularly illustrative - will be studied here. How to deal with the scale of the shock, and perhaps worse still, the shock of repetition?

Union Carbide's fight with Bhopal

- *Acute problems*
- It takes time to gather in information; even longer to appreciate what has in fact taken place. But the media demands immediate explanations. Concoct lightweight scenarios and there is the risk of making mistakes, of rapidly losing all technical credibility. Refuse speculation, and there is the risk of unleashing suspicion along the lines of "they're hiding the truth". It took ten weeks before Union Carbide were in a position to put forward soundly based technical explanations. Only then did the Corporation regain some credibility.
- Those involved were working to different calendars. The Indians, on the eve of an election, chose to publish scenarios... which the American corporation judged inexact, but which, at the time, could not be denounced as such. And later, the Indian government was so much bound, committed, that to put forward denial was still a delicate matter.
- The press must be informed rapidly. But care must also be taken not to commit any blunders: the governments concerned and internal management have to be informed before the media - which, considering the world-wide information network, is not an easy thing to do.
- *Traps at every turn and twist*
- Were the safety measures at Bhopal the same as at the other Union Carbide MIC plant at Institute (West Virginia)? If the answer were "no" that opened the door to charges of exploiting the Third World. If the answer were "yes", there was the risk of stirring up serious upheavals at the American sites.
- Was the firm intending to take immediate steps? To mitigate the effect of an affirmative answer to the preceding question, all MIC production could be halted until what happened at Bhopal were fully understood: but could such a decision take the place of policy, the collection of information being difficult and lengthy?
- Was Union Carbide's safety policy on a level with what was required for such hazards? The reply could only be "yes". But then, how could one account for the avalanche of problems uncovered - "revealed" - at Bhopal? Design faults, maintenance deficiencies, inadequate preventive measures, poorly trained personnel... In its inquiry, the New York Times [January 28, 1985] identified ten violations of rules that ought to have been followed. Whilst it was right to point out that the Indians were responsible for the operation of the plant it could not be pretended that headquarters at Danbury (Connecticut) were not keeping serious watch on these problems which Union Carbide said were a top priority. Nor could there be any question of laying everything at the door of the Indians. Interest in India (and elsewhere), now and in the future, ruled that out.

- Was the company in a position to pay? Here, too, the answer has to be yes, but the patch to be trod was a hairline. Over-assurance could tempt applicants (and their lawyers of which there were plenty) to step up their claims - which could change the group's financial situation. The big question was that of the basis of compensation. If North American standards were used, that could raise some doubts about the firm's ability to pay. Taking a yardstick with more affinity to the country concerned could again spark off the polemic about multinationals and the Third World, strategically a rather dangerous question. A further point was that the firm has also to contend with attacks from within: it own shareholders had filed a court action against the management for having jeopardised their profits.

Then with its accident at Institute

On 11 August, 1985, there was a leak of toxic gas at the plant at Institute (USA). This factory (which in particular treats the product made at Bhopal - MIC -) was the one to which all eyes had been turned, about which everyone had been asking: "Can it happen here? "The incident (130 people hospitalized) showed yet again the possibility of worrying technical faults, and more especially insufficiencies in matters of emergency communications - it seems that there had been a delay of twenty minutes before the alarm had been raised outside the plant. Union Carbide's Chairman had to apologize for this. This "test" of communications proved even more terrible for Union Carbide's image than that of the Bhopal disaster.

Faced with this hyper-complex challenge, an answer does sometimes seem to take shape: it is futile to allocate budgets, to devote energy and ability in order to avert and meet similar situations - situations which are just as uncertain in their occurence as in their development and their consequences... and moreover which may indeed never happen. The reasoning continues thus: it is never sure to be worse... even the best prevention measures can never ensure an absolute guarantee... and, if the worse does happen, it may still not be damning for the organization. But what is sure is the economic crisis: a reality which is immediate, certain, daily. So, in consideration of these issues, the choice may be not to take a stand.

In today's organizations, the "governing" mentality seems to sustain and encourage this sort of reflection. Overall, no one is spontaneously inclined to ask himself about the problem of anything other than minor faults - and this tendency is naturally more marked in the technical and scientific community which originated the systems constructed. The "marketing" mentality, which dominates in many highly successful companies, is besides more receptive to questions about an additional part of the market, the profitability of a new product which can be launched or withdrawn according to immediate results. In this scenario and under very intense daily constraints, the management (which come from the two mileux mentioned) are naturally more drawn to being interested in the short and medium term profitability of monetary commitments, rather in the problem of "crises", which fall into the category of the uncertain.

Another line of response is to say that, from now on, and increasingly so, the life of an organization will indeed depend on its ability to prevent and to control crises. Consequently, it would appear imperative to make available new means, to create an internal mentality appropriate to meeting the challenge. The plea here is for organisations to have more confidence in their ability to confront the exceptional, to absorb the irregular (as much as possible) into the arena of scientific management. A truly innovative company might thus envisage, for example, the addition to its "balance-sheets" and chairman's reports a section devoted specifically to its ability to identify, prevent, and control crises - equally on technical and organisational matters as in communication. The intensification of risks as well as the increased vulnerability of the contexts in which they take place, invite this change in company's reappraisal - seen from the angle not only of its immediate profitability, but also its ability to assure its longevity.

According to the answers chosen, it is clear that the overall reaction of an organization in crises situations will be different. And a second deep dilemma appears.

3.2.2. To inform or not?

The problem posed by the media here is a sixty-four dollar question. In order to understand it, one really has to dig out the grievances which are levelled against the press: they are fixed points which there is no getting round, greatly affecting the attitudes of all involved. The major reasons for conflict are the following:

- Fear of sensationalism and its consequences which may be provoked by the broadcasting of inaccurate news, or even too accurate information. J. Scanlon reports on this, in the field of hostage-taking, the case of the media letting the terrorists know where the sharpshooters are positioned, making them feel they should probably substantially raise their ranson demand [32]. In the field of accidents (it happened in a French pit) one might cite, for example, the case of a radio report which, exacerbating public emotion, produced a forced interruption of a vital rescue operation.
- An impasse caused by the over-technical nature of the problems to be tackled (particularly the question of probabilities).
- A withdrawal as a result of the possible destruction of a public image should the affair be given too much publicity.
- Refusal, faced with the media coming across more as commercial enterprises in search of a share of the news-market, than organisations of information at service of the people.
- Rejection, at the idea of the media being a law unto themselves (acting outside the framework within which regulations can be made on the basis of adjustability), acting with complete impunity (it being impossible to ask for an account of anything written, said or shown; to ask for the source, nor for the editing, etc).
- Deep suspicion, a certain press organization appearing to be manipulated by a party directly involved in the conflict (or even a certain press campaign being seen as directed by a particular aggressive competitor).

These numerous barriers are answered by determined counter-barriers, on the media's side:

- Conviction that accurate information is being withheld.
- Distrust of the ability of those responsible.
- Fear as to what freedom the press will be allowed.
- Acute irritation at the mounting of classic anti-press attacks (in particular: the accusation of being a sensationalist is often put forward but not always justified [33]).

From mental contortions to the desire to say little or nothing, the crisis threatens to become an area for acrimonious confrontation - under the formidable weight of the event. Witness the exchanges between a journalist (Mr. Kilmer) and

Union Carbide's spokesman (Mr. J. Browning) at the time of the Bhopal drama. The reporter wants to make the industrialist admit his guilt. The latter, while if he agrees to accept a moral responsibility, has absolutely no intention of accepting legal responsibility. So goes the dialogue reported by the New-York Times:

- "I think you've said the company was not liable for the Bhopal victims", Mr. Kilmer said.
- "I didn't say that", Mr. Browning replied.
- "Does that mean you are liable?" Mr. Kilmer asked.
- I didn't say that either", Mr. Browning responded.
- "Then what did you say?", the reporter asked.
- "Ask me another question", the Carbide spokesman said.
- "Under what circumstances would you not be liable?", the radio reported asked, his voice rising in frustration, to which Mr. Browning calmly declined to respond" [34,p.30].

It is easy to appreciate that it may be difficult to cope with wide open information:

- the accident (or the risk) may reveal a general problem which the industrialist judges impossible to correct in the short term; difficulties which could have dramatic consequences for the company's image, the entire branch concerned, indeed a national economy (as we have recently seen in a case of a country in South-America);
- the accident may reveal failings in expertise, and threaten to discredit it to an unacceptable level;
- the accident may reveal basic defects in the organization of the public services; etc.

So, we arrive fairly rapidly at the basic question: to inform or not to inform? In reply, three major stances show themselves:

- *The stance for openness and collaboration with the media*

This was the choice of the Canadian authorities during the Mississauga railway disaster. The idea: the population must understand why they have to be evacuated (216,000 persons); for that they need to be very well informed and that demands excellent information from the press. All was done, from the very first minutes, to work in closest collaboration with the journalists.

- *The stance for cautions openness and discretion*

This is the most classic case: one gauges at every moment what one can tell the press, when, and through what channel; one identifies what must be kept to oneself, in order always to have a "reserve stock" of news to distill to the media. In brief, one plays a game which has its rules of fairplay, but does not exclude making use of well guarded silences, or offering pieces of tempting but hardly relevant information.

- *The stance for secrecy and dissimulation*

This is the choice for giving "zero" information, practising disinformation, or at any rate giving the minimum of external communication. The wager? "The less we say, the less trouble we'll have". In many cases this strategy of silence may effectively succeed. At a public session during a recent symposium in Paris (AFFITE, 25 October 1985), an official from the French emergency management agency reported that last April a huge potential accident could have affected 10,000 persons: the Administration had never said anything about it, and no-one had ever known. This line of response continues, leading to very tough confrontations - especially in the wings - if the strategy of the secret is in danger of not sufficing. The case of the Seveso drums is a model of its genre, taken to the extremes. Here one must, to avoid committing the sin of naivety, mention the possibility of the crisis drifting towards modes of response destined to remain obscure. All the resources of the manipulating of sumbols, facts, men and groups will possibly be used. It is Machiavelli and Clausewitz readapted for the great battles of communication. Some of the cases which we have studied have shown us some illuminating examples of this.

The choice between these three models of reference is not always established in the same organization. Circumstances may have one chosen in preference to another; during the one case, options might vary according to what phase the crisis is in.

The choice will be made depending on numerous criteria: the margin of manoeuverability allowed by the crisis, by internal mentality, by the quality of the network with which the event has to be dealt with, by external social conditions in which the event takes place. And equally so: more ethical criteria - personal or of organizations. Thus, a certain large enterprise informed us of its determination about having to refuse business and reject certain strategies of communication going manifestly counter to the demands made by"good citizenship" (a policy, perhaps damaging in the short run, but clearly viewed as the only viable one in the long term).

Not to come down on any one particular side, it should perhaps simply be emphasised that if the parties concerned must reside with the angels, they must also know not to succumb to the fascination which shady manoeuvres can exert - which can reveal themselves far more dangerous and far less relevant than a strategy conducted in a clearer light. Particularly so if one considers the longevity of the organization. It is true that if one regards economic activity in its narrowest possible form, there are some who have nothing to fear from a total shutting off from these questions of communication. They must, of course, be very certain then of holding winning cards. One must also be able to forget to ask oneself about what coherency might exist between such a principle of shutting off and the very fundamentals of western society, in which freedom of information is one of its dearest held values.

CONCLUSION

This text has attempted to fix some points of reference in order that one might be better able to grasp the problems of communication, linked with the dynamics of turmoil, produced in crisis situations. It has pointed out many areas being worked on, as well as the work ahead.

In conclusion, we would simply like to emphasise certain very important points:

- Communication in crisis situations today represents a regularly uncontrolled problem, leading to difficulties which are, at times, of the world of caricature.
- Keeping communication under control is indispensable if one is to cope effectively in a crisis. As J. Scanlon writes:

  "An emergency, among other things, is an information crisis and must be treated as such "[31,p.31].

  "To a considerable extent whoever controls the access to information, whoever is the source of information becomes the centre of operations and control; and if you don't have communications systems operational, if you can't disseminate it, then you also lose the power to have operational control and it will shift to whoever has that "[35, p.17].

"Communications are so important in the aftermath of disaster that the centres of communication may well be the centres of operational control as well "[36, p.429].

- Coping more effectively in a crisis is indispensable for the continuing life of organizations as they have had to or will have to tackle poignantly charged situations increasingly frequently.
- If one is to overcome the all too often observed tendency to failure, then fundamental research, tactical procedures and strategic reflection are all necessary. So too is the choosing of general company policies on the status to be accorded communication in organizations, and more generally on the status to be accorded information for the "outside"; in other words, a society of open communication, in which access to information has a recognised worth.

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Institutional Considerations for Environmental Policy Making

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I INTRODUCTION

The environmental and public health risks presented especially by the use of nuclear and chemical technologies are fundamentally altering the way in which society copes with technological hazards. There has been a significant increase in the number of scientists and analysts whose work is specifically focused on environmental and public health risks; a growth industry has developed in formal risk assessments; an expanded role for public regulatory institutions for controlling environmental hazards has evolved; and there has been a dramatic entrance of the public environmental groups in regulatory processes (Covello and Mumpower, 1985). These developments are not unique to the U.S., but are to varying degrees characteristic of environmental politics in Western Europe, as well.

Despite the increasing role of public institutions and environmental groups in the regulation of technological risks, the developing literature on risk assessment and management has had very little rooting in understanding organizational behavior or political processes. One reason for this has been the presumption that individual decision making models can be easily transplanted to the public arena, but public policy making is fundamentally different from individual decision making since decisions are not "made" by a single individual but are negotiated, not comprehensively, but sequentially by competing groups and institutions (Majone, 1982).

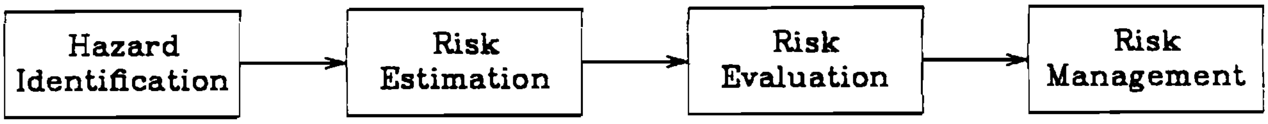
The failure to understand risk management as a political process, where policies are negotiated, defended, and too often not implemented, has led to serious misconceptions about the role of the risk analyst, and science generally, in the risk management process. For instance, one accepted wisdom, "Better (risk assessment) science produces better (risk management) policy", may hold equally well in the reverse, "Better policy (and policy procedures) produces better science". In other words, there is not a simple, one-way input of science into public policy, but the two are intricately intertwined and cannot be easily separated into distinct activities. This science-policy circularity has important implications for future research in the area of environmental risk management, since it implies that improving institutional procedures may be as important as improving the scientific input into these procedures.

In this paper, I will demonstrate this science-policy circularity by referring to cross-national research carried out at IIASA on the siting of liquid energy-gas terminals, the management of hazardous wastes, and the transportation of dangerous chemicals. A close look at these areas of environmental policy making shows that the standard model of risk assessment, where risk analyses are viewed as a one-way input into risk management procedures, is seriously misleading as a descriptive model and possibly unattainable as a prescriptive model. After summarizing the standard model, I suggest three possible alternative models--which are also woefully incomplete--but which shed some important doubts on the accepted notions of risk management. In the final section, I suggest some promising avenues for research on the institutional aspects of environmental policy making.

II THE ACCEPTED MODEL OF THE RISK MANAGEMENT PROCESS

One of the first attempts to lay out a schematic framework depicting the risk management process was a paper addressing the social acceptability of the risks presented by the commercial use of nuclear power (Otway, et al, 1979). In its simplest form, the four-stage process, as shown below, included the identification of a man-made or natural hazard, the (quantitative) estimation of the risks, the evaluation of the seriousness of the risks (social acceptability), and the management of the risks. With slight variations, this framework or model has subsequently been adopted by such bodies as the Scientific Committee for Protection of the Environment (SCOPE), the U.S. National Research Council, The Royal Society, and the World Health Organization (WHO) (see Krewski & Birkwood, this volume). It was one of the first attempts to relate "hard" and "soft" science —risk estimation and risk evaluation—with management decisions. A logical sequence from science to management was described, where it was clear that science was (and is) an input into management decisions, and not vice-versa.

Figure 1.



This model of the risk management process has been elaborated and refined to include, for instance, public perceptions of risk as a legitimate input to risk management (see, e.g. Slovic, et al., 1979) as well as the possibility that risks are not evaluated separately from the technology or hazard (see Otway & von Winterfeldt, 1982). In fact, since the conception of this model, a whole body of literature has evolved to "fill in the boxes", from improved screening procedures for hazard identification, refined analytical tools for estimating probabilistic risks and risk perceptions, to a host of suggestions for judging the acceptability of risks (see, especially, Fischhof, et al., 1981). These scientific endeavors are meant to lead to improved risk management decisions, where the costs of reducing the risks are ideally balanced with the benefits of a safer environment.

This linear concept of the risk management process, which stems from early debates on nuclear power, has been adopted virtually unchanged as a schematic framework for chemical risk management. According to the report of a recent meeting of the European Regional Program on Chemical Safety:

> The risk management process can be conceived as consisting of the following components: hazard identification, risk estimation, risk evaluation culminating in public decisions which are more or less rational [WHO, p.1, 1985].

While overlaps are recognized, this four-stage management process for chemical risks is almost identical to the framework posed ten years earlier for nuclear power risks. The message is also familiar: In order for risk management to become more "rational", better scientific information is needed. In the words of one participant at this meeting:

> Considerable efforts have been made to establish risk management on a fully rational or objective basis, but success has not measured up to earlier optimism... Risk management, as a process, operates on information and its communication, and there is evident need for improvement. Improved effectiveness involves increasing the quality, intelligibility and strength of the signals being transmitted between the elements and subsystems comprising the overall process. Simultaneously, "noise" in the system must be countered. Some of this noise is inherent due to less than perfect data and the resulting uncertainties. Other noise may be injected into the system. Interference may be caused, for example, by competing risk estimates by or on behalf of different interest groups, as well as those advising decision-makers. No stage of the risk-management process is immune from the hazard of misinformation (WHO, 1985, p.3).

This "noise" in the system, due primarily to less-than-perfect information, is compounded by the existence of "bad" science. According to another participant:

> The credibility of the technical inputs to the risk evaluation stage raises the metaphysical point that what is done by scientists is not necessarily science or scientific. Public confusion on this is a serious "impediment" to the risk evaluation process. To improve the situation, ideally decision makers should obtain a scientific consensus on the risk estimates, although experience in the nuclear energy field has shown how difficult this would be. In any case, the scientists should remain in their own role and not be implicated directly in the decision making process. (WHO, p.9, 1985)

What these quotes suggest, and what follows directly from the accepted model, is that failures in risk management can be traced to inadequacies in the scientific input—misinformation as a result of scientific disagreements - representing small disturbances, or "noises", in a system that is otherwise intact. That these disturbances might be ***part and parcel*** of risk management procedures as they exist in most countries is not addressed. Recipes for improvement are, again, familiar:

- Improve risk (and risk perception) estimates with better methodology and practices,
- Keep management considerations (values and politics) separate from scientific risk assessments.

In sum, the message of the accepted model is that better and more value-free science will produce better risk management policies.

III ALTERNATIVE MODEL I: NEGOTIATING PUBLIC POLICIES

Many decisions affecting technological or environmental risks are made on the basis of broader technological issues of which risk is a part: the routing of city traffic; agricultural policies affecting the use of pesticides; zoning policies; and so on. The siting of hazardous facilities is one such multi-dimensional issue, of considerable concern at the present, for which policies are negotiated and settled upon in the absence of any "risk managers". The risk issue generally becomes salient only after the entrance of public groups concerned about safety, and then risk analysts enter the public debate with the implicit purpose of shoring up and supporting arguments of the participants. I will illustrate with a short description of siting a liquid-natural-gas facility in California.

LNG in California[1]:

In 1974, Western LNG Terminal Company applied to the Federal Power Commission for approval of three sites on the California Coast to locate an LNG receiving terminal: Point Conception, Oxnard, and Los Angeles. These applications generated considerable controversy on the federal, state, and local levels concerning the need for natural gas and the safety of locating a terminal at the populated Los Angeles and Oxnard sites. The most frightening possibility was that the storage tanks would fail catastrophically, releasing a large quantity of natural gas which would vaporize into a cloud that might travel over a neighboring population center and then ignite. The conflicts among the many groups involved were exacerbated by the different results of the risk analyses commissioned by different groups. After more than ten years of controversy, the Point Conception site was approved, but Western withdrew its application. Following the deregulation of domestic natural gas prices in 1978, it appeared that California did not need an LNG terminal.

The decision process is described in detail elsewhere (Lathrop and Linnerooth, 1982; Kunreuther, et al., 1984). For our purposes here it is worth noting that:

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[1] This discussion is based on a collaborative study at IIASA. [See Kunreuther, Linnerooth, et al (1983)]. As background it may be helpful to know that:

> 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. For purposes of transporting, natural gas can be converged to liquid form at about 1/600 its gaseous volume. It is shipped in especially constructed tankers and received at a terminal where it undergoes regasification and is then distributed. The entire system (i.e., the liquefaction facility, the LNG tankers, the receiving terminal, and the regasification facility) can cost more than $1 billion to construct.

- There was no single decision maker. The final choice of Point Conception evolved from a variety of actions taken by the many authorities as well as interactions between the applicant, citizens groups and environmentalists.
- The institutions involved were often dealing with many issues in addition to the siting of the LNG terminal, and thus their stands were consistent with objectives related to a multiple of issues, including the long-term survival of their institution. While the problem may have been formulated as approving a certain site, other institutional concerns related for instance to energy policy or regional development often determined a party's position on the narrower agenda item.
- The policy process moved sequentially through a set of questions and at each stage only segments of the problem were addressed. This precluded the use of a broader decision-analytic model in which the tradeoffs between environmental quality, public risk, costs, etc., could be explicitly set out (see Lindblom, 1959).
- How the policy agenda was set, whether the need for a terminal was addressed or the site, and in what order, played an important role in the final outcome (see Levine and Plott, 1977).

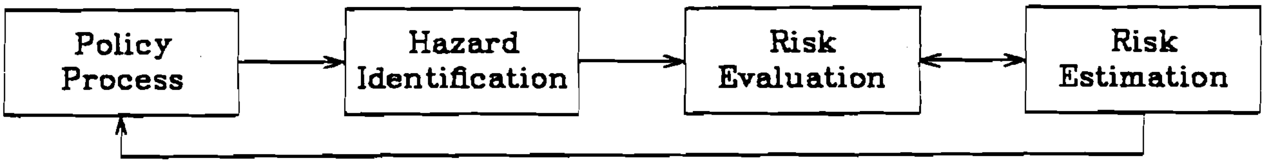
These features of a political decision process are not unique to siting an LNG terminal, and they are addressed in great detail in the literature. The concern in this paper is how such characteristics of the policy process influence the types of analyses produced or the ways in which science enters the political arena.

At least five comprehensive, quantitative risk analyses were produced during the process of siting an LNG terminal in California (for a review and critique of these studies and five more for sites identified in Europe, see Mandl and Lathrop, 1983). These analyses attempted to quantify the very low-probability event of a catastrophic failure of an LNG storage facility. The results of these different analyses differed remarkably, for example, the risk of a citizen living in Oxnard was estimated to be between 10^{-4} and 10^{-7} by one study and between 10^{-7} and 10^{-10} by another—a difference of three orders of magnitude. These discrepancies were, in part, due to the differences in the choices made by the analysts in defining the boundaries of the risk problem they were addressing: One study of the Oxnard site focused on a geographical area that put 15,000 people at risk; another study considered a broader area that put 90,000 people at risk. Two of the three risk assessments done for the Point Conception site considered risks involving transport ships, the transfer of LNG to shore, and the storage tanks on shore; the third study considered only risks involving the transport ships. One major risk to an LNG facility is sabotage and another is war; none of the various California risk assessments, however, included either possibility (Kunreuther, et al., 1984).

The large discrepancies in the results of these studies, the shaping of the problem frames, the assumptions chosen, and the presentation of the results were not due to misinterpretations and scientific errors, but reflect the wide discretion the analysts enjoy in quantifying risks with so large a subjective component. And institutions of all sorts battling in the political arena commission studies that are likely to bolster their cause. The multi-party, multi-issue process described above, where policies are negotiated sequentially, rewards analyses that address a narrow agenda (in this case, public risk) and that make a persuasive case for policy stands that may have already been made on other grounds. The assumptions may be hidden, the uncertainties not calculated, the data carefully chosen, and presentation formats constructed to direct the reader's attention to one aspect or another of the safety of the operation. As Majone (1978) has observed, there is a role for the analyst as "a producer of policy arguments...more similar to a lawyer...than to a problem solver."

This policy perspective presents a profoundly different picture of the risk management process as approximated below:

Figure 2.



Here we find that there are no risk managers, per se, but people and institutions for and against the particular LNG site, who seize upon risk and other issues to support their arguments. This does not mean that the safety of the facility was not of real concern, but the risks of the facility were only one issue in a multi-issue problem. The policy procedures were initiated by Western LNG Terminal Company before the full range of public risks had been identified, which only occurred after the choice of a site became a public issue. The risks were subjectively evaluated by the participants as acceptable or not, and consulting firms were commissioned to carry out quantitative assessments. In contrast to the standard, accepted model, ***risk estimation*** in this multi-party bargaining process was not an ***ex ante*** input into a "risk management decision" but was primarily an ***ex post*** exercise aimed at supporting party arguments.

This brief description of the LNG siting process, where analyses were produced to bolster the arguments of one participant, illustrates the procedural limitations scientists may face in reaching any kind of consensus on their disparate estimates. Analysts are, themselves, participants in a system that rewards "sloppy" analysis, where assumptions are not explicitly stated or uncertainties recognized. These lapses from "ideal" analysis do not represent "noises" in the system due to unintended miscommunication, as suggested by the WHO participant, but are inevitable in a political bargaining process where the participants rely on science to legitimize their policy stands. Risk analyses are, in these cases, tools for achieving political standing; this tool function is strengthened since risk assessment cannot be fully objective, but involves human judgement throughout the estimation process (Cumming, 1981). McColl (1985), has shown that this subjective element is also a significant part of the procedures for assessing the carcinogenity of chemicals:

> Unfortunately, several hidden biases may exist in even the most scientific assessment procedures. These biases are contained in the fundamental assumptions made by scientists in the design of experiments (statistical power), choice of dose response models (low-dose extrapolation), and determination of biological end-points (tumor detection) (p.83).

As the LNG risk analyses demonstrate, these biases allow considerable discretion to the analysts. Among others, thus, Ravetz (1983) calls for the destruction of the myth of scientific objectivity as ineffective and counterproductive in today's debates on technological risks, and suggests that scientific results be regarded not as "hard factual nuggets" but rather as "robust tools". Recommendations calling for more objective and better risk analyses are, thus, doomed to failure unless this tool concept of analysis is recognized, as well as the procedural constraints to "better" science. Better science may only be possible through improved policy making procedures.

IV ALTERNATIVE MODEL II: TOPSY-TURVY REGULATION

The entrance of the public in regulatory processes has fundamentally changed the rules and dramatically increased the need of regulatory bodies to justify their policy stands, in many cases with quantitative risk analyses. This need for persuasive analyses is especially apparent in the U.S. where the system of judicial oversight requires supportive, preferably quantitative, evidence to defend agency decisions (Brickman, et al., 1982). In Europe, with its less adversarial regulatory systems, the role of expertise rarely takes on such political overtones, although this is changing with the entrance of environmental groups and environmental parties on the political scene.

This participatory style of regulation has extensively involved scientists and analysts, if in a defensive role, and contrasts markedly with other less public issues where regulations have often evolved "topsy-turvy", frequently in response to widely publicized accidents and with little need for quantitative risk analyses. This contrast can be illustrated by considering the historical development of regulations for the transportation of hazardous materials (for more detail, see Linnerooth, 1984).

The Transportation of Hazardous Materials

Government officials and the public have reason for their concern that a catastrophic accident on the scale of, for example, the recent Bhopal accident, with over 2500 deaths from a release of methyl isocyanate or the gas explosion in Mexico with nearly 500 deaths, is possible from the transport of hazardous materials (Lagadec, 1985). During the last century, at least half of the catastrophic accidents from dangerous materials have occurred during their transport (Smets, 1985).

This concern with the catastrophic potential of large volumes of literally thousands of hazardous materials criss-crossing the American and European continents has motivated national legislators in most western countries to pass far-reaching legislation to control their transport. In implementing this legislation, regulatory agencies have developed highly complex and detailed systems of control, including measures to convey information regarding the hazards throughout the transport chain (labeling goods, placarding vehicles, and carrying transport documents) and direct safety measures (transport bans on certain goods, routing measures, containment standards, operating requirements, etc.). Since the risk activity, as compared with the risk itself (e.g. air pollution), regularly crosses national borders, there are also numerous international conventions governing all aspects of transportation.

In the U.S., as well as other countries, the controlling structures for the regulation of dangerous substances have continuously broadened the scope of their control as the definition of what is hazardous for transport has expanded. First explosives, and then other materials such as flammable liquids and solids, poisons, and corrosives fell in the category of regulated hazardous materials. The ensuing regulations developed differently for each transport mode, and with the often conflicting rules, shippers were stymied in their efforts to meet the demands of the many governing bodies.

Though the U.S. Congress consolidated the various federal agencies charged with transportation safety in the new Department of Transportation in 1967, still different parts of the organization were responsible for the different modes. This disarray was described in a DOT statement in 1973:

> Ever since the inception of hazardous materials control in transportation... there has been no real direction or coordination of this important safety function. Parts and pieces have been added when the needs were demonstrated by severe accidents and catastrophes, or to accommodate the needs of individual manufacturers and shippers. The body of laws and regulations has grown like "Topsy", piece by piece, package by package, rule by rule. As a result, the structure today is an ill-fitting ramshackle, largely outdated set of confusing and conflicting requirements. (in Marten, 1981)

While the situation has improved in the last decade with the creation of one agency, the Materials Transportation Board within the DOT, to deal with the transport of dangerous goods over all modes, the situation today is still staggering in the complexity of the rules. Five federal agencies, other than DOT, also regulate the transportation of hazardous materials, and the regulations number over 1100 pages. The most detail is found in the packaging requirements[2] and there are efforts underway to incorporate the performance-based packaging rules prescribed in the United Nations Recommendations for the Transportation of Dangerous Goods, a first step in the eventual full adoption of the U.N. system. These international rules will require major adjustments and will increase the already wide gulf between those that produce the regulations and the local bodies (mainly police) that are responsible for their enforcement.

This "enforcement gap" is only one aspect, however, of a serious implementation malady. The problem as it stands is sufficiently complex, considering the severely heterogeneous and ill-structured transport system, to question the viability of any regulatory program. There are enormous volumes of dangerous substances transported (although no reliable statistics exist on the quantities or the structure of the system), thousands of designated hazardous chemicals (and the list may expand significantly if environmental considerations are taken into account), four different modes of transport each with unique characteristics (e.g., fires are of great concern for maritime transport, but are of less concern for road transport—so what should be the relevant flammability limit?) a wide diversity of economic and safety interests among the many handlers of the goods, and several tiers of institutional authority. Informing the regulatory community and stepped-up inspections (and possibly stricter liability clauses) appear to be the key to more effective implementation; yet, present government budgets only scratch the surface in training the thousands of personnel involved (e.g., over 1 1/2 million fire fighters in the U.S.), and generally local police forces

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[2] As an example, TOY CAPS must be packed in containers complying with specifications 15A, 15B, 16A, 19A, or 19B. Specification 15A is for nailed wooden boxes, for which there are nearly 7 pages of specifications. For instance, the ends of the boxes must be "one piece, or equivalent, or cleated as prescribed; joints tongued, grooved, and glued. Style 1 or style 6 boxes may have milled depressions in each end of box for hand-holds, of not more than 3/8 inch in depth and not exceeding one-third of the width of the box, only when ends ore of lumber at least 1/4 inch in thickness" (Title 49, CFR, p.178-214).

do not have the facilities (laboratory and other) to control hazardous materials traffic.

Full implementation of the extensive regulatory codes, therefore, can result only at an enormous expense to government as well as to industry. Can this expense be justified with a rigorous risk-benefit analysis? Possibly not. The U.S. data shows, for example, that in 1983 there were only 8 reported deaths and 191 injuries from some 5,761 incidents involving the transport of hazardous materials (DOT, 1985). While regulators claim that the relatively small number of dangerous goods transport fatalities are a result of the regulations in place, according to a report in the U.S., accident rates increased when the regulations came into force[3] (U.S. General Accounting Office, 1980). This figure of 8 deaths in the U.S. compares with over 60,000 reported deaths from highway transportation alone. Similarly, in the U.K. during the 13-year period from 1970 to 1982, only 1.2 deaths per year can be directly associated with the transportation of dangerous goods on the nation's roads, which works out to be a risk of 0.24×10^{-7} per person (Kletz 1984). Research in the psychological dimensions of technological risks has cautioned against making these types of simplistic "body count" comparisons of one type of risk with another. Still, in this case there appears to be an extreme contradiction between the elaborate detail and expense of the regulations and the number of reported fatalities and injuries which the regulations are designed to prevent.

In sum, the regulation of the transportation of hazardous materials has been and continues to be motivated by concern for the potential catastrophic accident, whereby layer upon layer of regulation has evolved into a vast system of international, national, and local control. This system can be implemented only at

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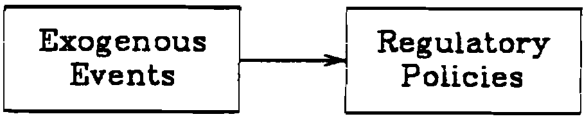
[3] There has been a recent decline, but this appears to be a result in changes in reporting requirements.

very high expense. From a risk-benefit perspective, these regulatory regimes can be justified only by considering the catastrophic event, since available statistics show that only a very small number of deaths and injuries can be attributed to the transportation of hazardous materials. The question, then, is whether the regulatory systems, as they stand, will reduce this catastrophic potential to some "acceptable" level. What role have analyses played in addressing this question?

The answer to this question is virtually none. There have been no formal, quantitative risk assessments except in those isolated cases where the public has become concerned, e.g., the transport of radioactive substances or chlorine through major cities. Even in the United States, where agency decisions require detailed justification, there have been no quantitative assessments of the risks underlying the more than 1100 pages of rules addressing a problem which by some measures might be considered a non-problem, at least where the catastrophic potential is acceptably low. In sum, the rules have developed "topsy turvy", this model is characterized below:

Figure 3.



V ALTERNATIVE MODEL III: COMPREHENSIVE REGULATION

Contrasting with the siting and transportation issues, where public risk exposure was determined through multi-party, political procedures and in response to widely publicized accidents respectively, is a set of issues which are for the most part resolved internally to a regulatory body in light of available scientific evidence. This model comes closest to the standard, accepted model of risk management. The hazard is broadly identified through enabling legislation, and an agency is charged with setting out a regulatory program. This agency turns to the scientific community to identify more precisely the hazard and possibly to supply final risk assessments. This scientific data then becomes an input into the risk management decision, e.g. determining what standard to set based upon cost, implementability, etc.

An important dictum of this process is to keep considerations of risk management separate from the wholly scientific questions concerning the extent and seriousness of the hazard. This theoretical distinction may be lost, however, when institutional considerations are taken into account. When faced with a socially complex problem, a regulatory agency must inevitably reduce the full scope of the potential issue to proportions with which it can cope. At the same time, it must maintain its credibility by appearing to manage the issue comprehensively. This tension between scoping the regulatory issue and managing it comprehensively may inadvertently compel the agency to bound the problem at the early phases of hazard identification and estimation, thus mixing management concerns with scientific "facts". I will illustrate by describing the process whereby the U.S. Environmental Protection Agency established a list and testing procedures for determining which of the thousands of industrial and other wastes are hazardous.

Classifying Hazardous Wastes

With passage in 1976 of the U.S. Resource Conservation and Recovery Act, the EPA was given the task of designing and implementing a comprehensive regulatory system for managing hazardous wastes within the broad directive of a single overriding statutory goal—the protection of human health and the environment. This task would be fulfilled by, among other things, developing a federal classification system to determine what wastes would enter the regulatory system. The difficulties the EPA would face in shaping a regulatory control program can be appreciated by considering the following:

- There are about 7 000 000 known chemicals.
- Approximately 80 000 are in commercial circulation.
- Approximately 1000 new chemicals enter commercial use each year.
- Using the *total* of world laboratory resources, about 500 chemicals per year could be testable for toxicity (at colossal expense).
- One test, for carcinogenicity alone, can involve 800 test animals and 40 different tissue specimens per animal for pathology examinations; that is, 32 000 specimens. This needs approximately $500 000 and 3.5 years to perform.
- there are approximately 14 000 food additives and contaminants. Many natural components are thought to be also toxic (Wynne, forthcoming).

With the potential breadth of the problem, and the underdeveloped science accompanying the issue, the EPA's regulatory attention would inevitably be selective. As expected, artificial boundaries developed for what is and is not hazardous, such as concentration levels and volume cutoffs, which have more to do with pragmatic, administrative necessities than objective, natural science dictates. This can be seen by examining the development of the EPA's policies for listing hazardous wastes.

The EPA set out two sets of criteria for listing hazardous waste: criteria for wastes that are acutely hazardous and for other toxic wastes. An acutely hazardous waste is either fatal to humans in low doses, or has an animal toxicity of oral LD 50 of less than 50 mg/kg in rats or an inhalation LD 50 of less than 200 mg/cubic meter in rabbits. Other wastes, that were not acutely toxic, were to be listed if they were carcinogenic, mutagenic, teratogenic, phytotoxic or toxic to aquatic species.

The waste lists: The EPA developed two hazardous waste lists: (1) the wastes from standard manufacturing or industrial processing operations known to contain toxic constituents, and (2) hazardous commercial products which became wastes when discarded. The industrial waste lists were developed by examining some 200 studies of industrial wastes that had been compiled at the EPA prior to the RCRA legislation. From these studies approximately 125 wastes were identified as hazardous. The EPA estimated, however, that there were over 10,000 major industrial waste processes, so the identified wastes did not begin to encompass the full gamut—this gap would be filled by requiring generators to test their wastes.

The question of concern here is the scientific information that allowed the EPA to choose these 125 wastes and a number of commercial products for listing, as well as the criteria for establishing tests which will be discussed below. The compilation of the lists began with the identification of hazardous (carcinogenic mutagenic, toxic to aquatic species, etc.) constituents. However, chemical testing, especially for carcinogens, is a complicated, costly procedure, and for this reason the EPA relied almost exclusively on other environmental regulation to identify 380 hazardous constituents. Specifically, it took approximately 300 entries from the Clean Water Program, six or so from the Clean Air Program, approximately 20 from the EPA List of Toxic Substances, and approximately 20 from those identified by the EPA Cancer Assessment Group (Dietrich, 1984).

Since data from the Clean Water Program were used so extensively, it is instructive to note how these constituents were compiled. Their history can be traced back to 1974 when environmental groups sued the EPA for not implementing Section 307 of the Clean Water Act, which required the EPA to identify and regulate specific toxic water contaminants. In reaching a compromise with environmental groups the EPA hastily compiled these constituents from the scientific literature—what has been described as a "hasty midnight session where a larger list was whittled down by crude analysis" (Dietrich, 1984). One source provided the bulk of the information, a book titled ***Water Quality Criteria***, edited by McKee and Wolf. This book was first published in 1952 and has been repeatedly revised to its last edition in 1971. It contains a survey of potential toxic contaminants of water with reference to the U.S. and foreign literature, giving general information on effects of pollutants to aquatic life.

In fulfilling its mandate to protect human health and the environment, therefore, the EPA was severely constrained by the availability of scientific data on the hazardous constituents of wastes. The criteria chosen were weighted much more heavily towards protecting aquatic life than human life, because in this area scientifically justifiable arguments could be made based on the precedent of water quality control. Interestingly, much of the scientific basis of the comprehensive hazardous waste regulations can be found in one edited book originally published in 1952.

A waste containing one or more of these 380 hazardous constituents was not necessarily listed—eleven factors were identified which could justify not listing a waste including, for instance, the nature of the toxicity of the constitutent, the concentration of the constitutents in the waste, the quantity of waste generated, and "such other factors as may be appropriate" (Federal Register, p.33121). The actual process was described by EPA staff as follows: If a waste contained one of the 380 constituents identified as hazardous, it was then analyzed to see if the constituents were present in significant concentrations. If so, the waste was listed. The final lists of wastes promulgated by the EPA contains 13 wastes resulting from non-specific sources (spent solvents), 76 wastes from specific sources (e.g. waste water treatment sludge) and more than 400 hazardous chemical products (e.g. acetaldehyde).

The detailed justification for listing each waste in the regulations were contained in background documents. The documents included:

1. A summary of the Administrator's basis for listing each waste.
2. A brief description of the specific industry;
3. A description of the manufacturing process;
4. An identification of waste composition, constitutent concentration; and annual quantity generated;
5. A discussion of the basis for listing each waste stream; and
6. A summary of the diverse health effects of each of the constituents of concern. [Federal Register, p. 33113]

Despite this elaborate justification, the EPA admitted that decisions to list a waste were often based on qualitative judgments, generally involving expert assumptions rather than precise field measurement. [Federal Register, p. 33114]

Testing Procedures: The EPA recognized that its listing procedure would not comprehensively cover the range of hazardous wastes—at least 9,800 major industrial processes had not been examined. To fill this gap, the EPA required generators to test those wastes that did not appear on the lists. The draft regulations originally proposed eight characteristics requiring testing, but these were reduced to four in the final regulations: ignitability, corrosivity, reactivity, and toxicity.

The toxicity characteristic was by far the most controversial, and the EPA encountered great difficulties in trying to develop testing procedures (Quarles, p.54). An Extraction Procedure Test was settled upon whereby laboratory steps were specified to analyze representative waste samples of 14 contaminants listed in the U.S. Federal Drinking Water Standards. If these contaminants were present at levels 100 times or greater than the concentrations allowed in drinking water, then the waste is considered hazardous. This test and the "100 times" standard have been subject to heavy criticism due to the large scientific uncertainty involved (Federal Register, p.33112).

The U.S. is the only country in the western, industrialized world that requires generators to test their wastes if they are not listed. The F.R.G., for instance, has developed a "waste catalog" which supposedly lists all wastes, and those that are to be considered hazardous or "special" are designated in this catalog (for a full discussion of the F.R.G., the U.K., and Austria, see Dowling and Linnerooth, 1984). By requiring the generators to test their wastes, the scope of the regulatory program is significantly broadened--by as much as 90% greater, according to one estimate.

Throughout EPA's five-year period of rule-making, the intended scope of the regulatory program was a subject of continual internal controversy between those preferring a smaller list of high-priority wastes and those who preferred comprehension. It appears that the EPA preferred the latter, which according to the former Deputy Administrator of the EPA was mistaken:

> Certain categories of waste and certain industrial activities clearly present far more serious environmental hazards than do others. By focusing on selected priority problems to impose initial controls, EPA probably could have put a program into effect in half the time it took to establish such a broad and elaborate framework. It could then have expanded coverage to other wastes and other operations with the benefit of practical experience. By attempting to be so ambitious, the Agency delayed the whole program ... Driven by the forces of environmental politics, we have repeatedly committed ourselves to goals and programs that are utterly unrealistic. (Quarles, p. xvi)

As this quote illustrates, many critics of the EPA thought it necessary to go beyond the one-level distinction of high-priority wastes to a multi-tiered classification system, and then to set regulatory priorities accordingly. This was rejected by the EPA on the grounds that there was simply not enough scientific information to make this distinction. There was another angle, however, of the degree-of-hazard question which was suggested both internally and by industry. The hazard posed by a waste, it was argued, depends not only on its physical characteristics, but also on the way in which it is handled. The regulations should, at least initially, be limited to those wastes that present a constant risk and require special care, and should not include those which do not present a risk, when handled in a "normal" manner using standard equipment and containers. Proponents of this argument pointed to the wording of the RCRA statute defining hazardous waste which differentiated between highly toxic wastes and those which pose a hazard "when improperly treated, stored, transported, or disposed of, or otherwise managed".

This argument blurred the distinction between the intrinsic hazard of a chemical waste and the hazards posed by waste management procedures—between risk assessment and risk management—and was flatly rejected by the EPA which emphasized that:

> The fact that a waste is properly managed by particular generators or particular classes of generators, does not make a waste non-hazardous. It is only necessary that the hazard *could* result *when* wastes are mismanaged (Federal Register, Vol. May 19, 1980, p.33113)

In comparison with other countries, the EPA took extreme care to keep the scientific issue separate from the political by its exclusion of management possibilities and costs in defining hazard and listing wastes (in contrast, the costs of managing wastes was an explicit consideration in listing wastes in the Netherlands). Yet, even with such strong intentions on the part of the EPA to keep science separate from policy, we find that it was not entirely a one-way process. As fears mounted within the EPA that the scope of the regulatory program was becoming unmanageable, pressure intensified to draw in the boundaries. These pressures subtly entered those areas where the EPA staff had allowed themselves sufficient discretion, such as:

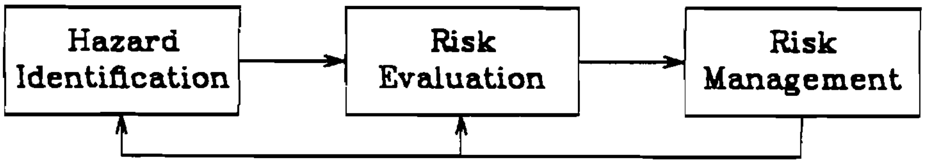
- In deciding whether the concentration of one or more of the 380 hazardous constituents was sufficient to list a waste; or, if the waste was generated in sufficient quantities; or the other nine possible factors that justified not listing a waste.
- By drawing back from the 8 characteristics for testing to determine if a waste is hazardous to 4 characteristics.
- By choosing only the 14 hazardous drinking water constituents to substantiate the toxicity characteristic.

While the EPA justified these imposed boundaries by the inadequacy of the scientific data, the opposite argument can also be made: Because so little is known about the effects of chemical contaminants, it is better to err on the conservative side by, e.g., including all wastes containing hazardous constituents regardless of concentration or quantity, requiring testing for all possible hazardous characteristics even if testing procedures are in some cases rough, and by including all possible contaminants in the definition of toxicity. But expanding the definition into these "fuzzier" areas would have added an unbearable administrative burden on generators and the EPA. In other words, management considerations were an inevitable input into the "scientific" question of what wastes are hazardous.

Again in this case, we find that formal, quantitative risk assessments played no role. According to an EPA staff member, only the most hazardous wastes and the least controversial had been identified and, thus, the EPA was correct in its assessment that there would be no consequent court battles. For this reason, quantitative justification for EPA's listing decisions was not deemed necessary. Once again, quantitative risk assessments appear to be called upon only when the public becomes involved, and as a way of defending an agency's decision.

This model, although the most similar to the standard model of risk management, lacks the formal risk estimation phase and has an important (although in this case subtle) feedback from the policy questions to the "scientific" questions. It is illustrated below:

Figure 4.



The identification of the hazard, a seemingly scientific endeavor, could not be fully scientific in light of the many unknowns. This gap allowed that consideration of program implementability and cost enter into identification criteria, such as in choosing the hazardous constituents and the waste characteristics for testing. Another feedback loop can be found in the evaluation phase, where the somewhat arbitrarily chosen concentration levels for the hazardous constituents and quantity exclusions again permitted risk management considerations to enter what was considered the fully scientific exercise or assessing hazard or risk.

VI CONCLUDING REMARKS

The accepted model of the risk assessment/management process, where the "hard" scientific tasks of identifying hazards and estimating their risks and the "soft" scientific tasks of evaluating these risks flow linearly into risk management decisions—is misleading as a ***descriptive model*** of risk management processes. The "new style" of environmental policy making is a tri-party process involving government regulatory authorities, industry, and environmental groups, each of which calls on analysts to provide "scientific" justification for their policy stands. The highly subjective element of risk estimation lends itself to meeting these conflicting demands, and the result is that risk management decisions are often not based on scientific estimates of risks but rather are justified by these estimates. Analysts are thus caught in a process that rewards correct analyses, but those which may be construed to present an overconfident picture of the certainty of the estimates by not stating assumptions, not providing error bands, and so forth.

The old style of regulation is characterized by the long-term development of complex rules usually in response to highly visible accidents and with little involvement of the public or environmental groups. Formal risk analyses, even in those cases where the authorities would find it difficult to justify costly regulations, have played little or no role. This underscores the finding that risk analyses in pluralistic management processes may be valued more for their enhancement of an agency's bargaining position than as an *ex ante* input into an agency's management decisions.

The accepted model would appear to have more promise as a *prescriptive model*, where the prescriptions for improving the management of risks are both intuitive and attractive:

- Improve methods for estimating risks (promote more "objective"" analyses);
- Communicate these improved estimates to all concerned; and
- Keep management considerations separate from scientific activities (value-free facts)

If, indeed, the problems encountered in managing risks are due to the quality of the information and the inadequacies in communication, then improving the "factual" basis of the estimates and "spreading the word" should result in a more harmonious and efficient risk management process than has been apparent to date. Unfortunately, as shown in this paper, these prescriptions are largely unobtainable given the inherently subjective nature of risk estimates and our current institutions and political processes for managing risks, and even if obtained, may not be helpful in today's debates on technological risks. Risk analysts do not and cannot produce facts; but they can give some important insights, and the analyses should be regarded as "robust tools" for making social choices. Moreover, the identification of hazards and the estimation of their risks is inevitably a process that will to some extent encompass values and pragmatic, administrative considerations. This was seen in the case of identifying hazardous wastes where administrative concerns entered into definitions of hazard as necessary in bounding the scope of the regulatory problem.

In sum, the scientific and procedural reforms suggested by the accepted model of risk management are largely unobtainable in light of the adversarial nature of environmental debates and the inevitably subjective content of formal risk analyses. Furthermore, improvements in the science of risk estimation may not help in highly politicized debates concerning environmental issues. A whole body of research on the perception of risks and the cultural underpinnings of risk debates show that the people and groups involved may operate with different and conflicting rationalities, and formal analyses will do little to change these social and cultural forces.

Rather than following in the same tracks as the long and unresolved social debate on the commercial use of nuclear power (where the resolution of the social conflict surely does not lie in improving scientific estimates of risks), regulators for similarly controversial environmental risks should try to gain an understanding of these social and cultural forces and work towards institutional and procedural reforms that accommodate them. Some promising directions lie in devising better tools for negotiating conflicts in the light of uncertain information, but many questions remain unanswered. For instance, how can highly uncertain and conflicting scientific evidence play a constructive role in these negotiations? What other tools are available? And, most importantly, what types of social institutions would accommodate an open negotiating procedure?

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INSURING AND MANAGING HAZARDOUS RISKS:

FROM SEVESO TO BHOPAL AND BEYOND

Report on an International Conference[***]

by

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and
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Introduction

This paper presents an overview of the results of the International Conference on Transportation, Storage and Disposal of Hazardous Materials, which was held at the International Institute fo Applied Systems Analysis (IIASA), July 1–5, 1985. The Conference brought together representatives of academia, business, and government from East and West to discuss the nature of current problems in the area of hazardous materials. An important objective of the Conference was to suggest steps that could be undertaken by industrial firms, the insurance industry and government agencies to improve the safety and efficiency with which hazardous materials are produced and controlled in industrialized societies.

In July of 1984, the Geneva Association convened a meeting for the purpose of planning an international conference on transportation, storage and disposal of hazardous materials, with special focus on the role of compensation, regulation and insurance. The Geneva Workshop recommended that the Conference be held at the International Institute for Applied Systems

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[***] Paper presented at the IIASA Task Force Meeting on Risk and Policy Analysis Under Conditions of Uncertainty, November 25 through 27, 1985.

Analysis (IIASA) in Vienna, which has been an important focus for international risk research. The recommendations of the Geneva Workshop were strongly supported by the IIASA Directorate. Thus was launched the International Conference on Hazardous Materials, the Proceedings of which follow.

The focus of the Conference was on petrochemical industry problems, with emphasis on regulation and insurance. The Conference had as its major objective a research agenda for the next five to ten years for hazardous materials research in these areas. Given the international nature and scope of hazardous materials problems, participants at the Conference included broad representation from the international community, and a rich mixture of practitioners and scholars.

The basic themes for the Conference were laid out at the Geneva Planning Workshop. They came to be structure under the following headings:

1. *Historical Background.* This topic was intended to provide perspectives on the nature and magnitude of accidents and losses from previous technological disasters, notably Seveso and Bhopal.
2. *Problem Context.* We were concerned with hazardous materials problems in the following contexts: production, transportation, handling, storage and disposal of hazardous materials. These contexts were meant to include both the dangerous goods sector (e.g., chlorine and sulfuric acid) as well as the hazardous waste area.
3. *Risk Analysis.* Here we planned to discuss the traditional problems of hazard identification, risk estimation, risk evaluation and related perception and communication problems. We were specifically concerned with linking risk analysis to available policy instruments for managing hazardous materials risks.
4. *Risk Management and Insurance.* Finally, the prescriptive focus of the Conference was principally on risk management and insurance measures. We were interested in determining what policy instruments could be used to mitigate risks, to reduce or eliminate risks, to spread risk, and to absorb the financial and other loss potential of risks in socially and financially acceptable ways.

Figure 1 below summarizes the above areas and shows the principal stakeholders associated with the hazardous materials problem. The overriding theme of the Conference, as it evolved, was linking theory and practice in the use of policy instruments and legal institutions for resolving conflicts among these stakeholders for the problem contexts depicted in Figure 1.

We now provide a brief overview of the Conference papers to provide the reader a foretaste of the contents of this volume. Thereafter, the research recommendations resulting from the Conference will be presented.

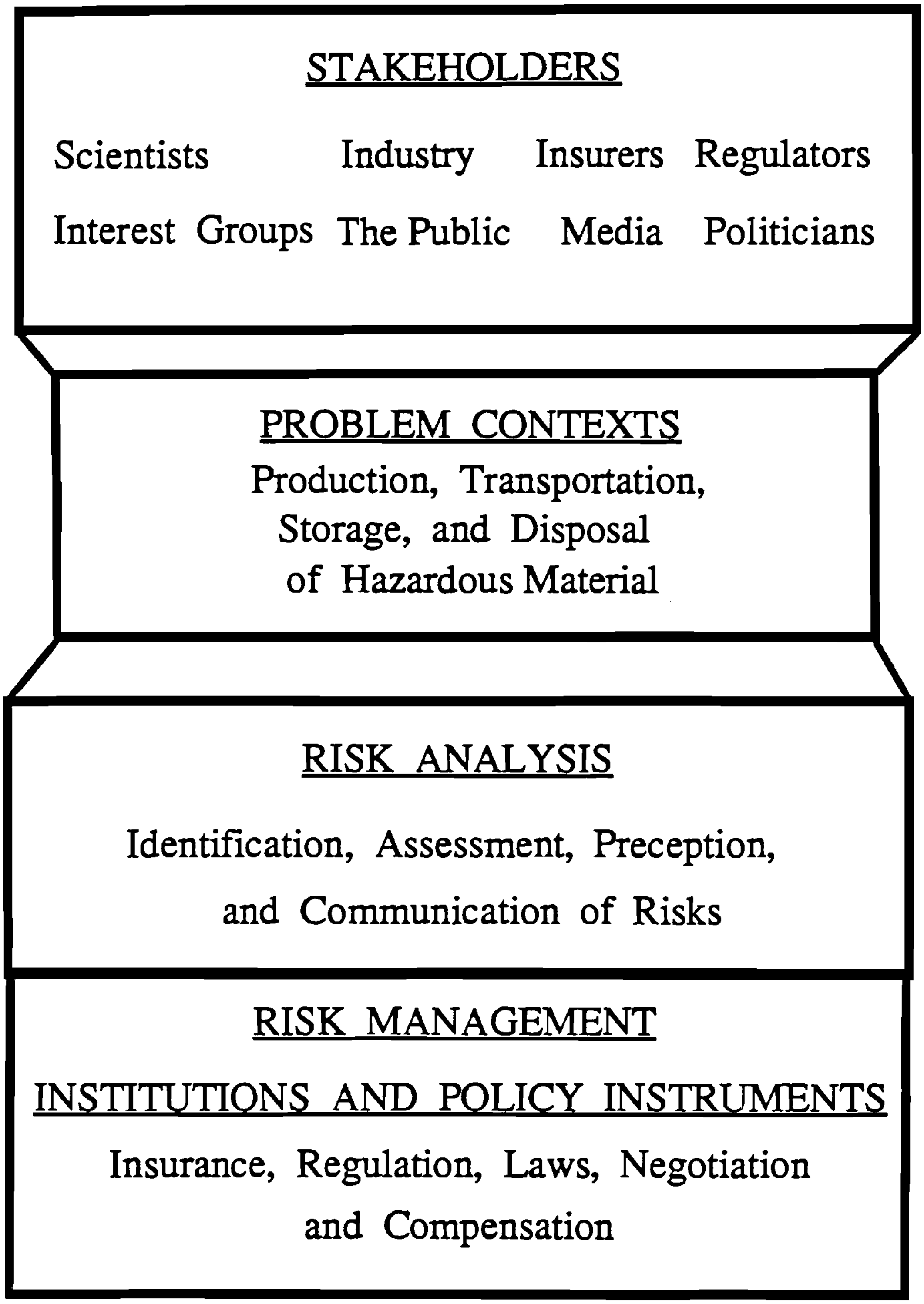

Figure 1: Basic Themes of the Conference

OVERVIEW OF THE CONFERENCE PAPERS

HISTORICAL BACKGROUND

The first group of papers were commissioned to provide historical perspectives on the nature and magnitude of the hazardous materials problem, with particular attention paid to the nature of serious accidents in this area. We were also concerned with providing an overview of the magnitude of losses suffered through man-made environmental disasters.

In the first paper, Patrick Lagadec disusses several case studies of considerable interest in the risk management area. These included the release of dioxin in Seveso, the explosion of a liquified propane gas tank in Mexico City, and the leakage of toxic gas from a pesticide plant in Bhopal, India. He uses these case studies to derive a framework for describing how organizations and public authorities have reacted to crisis situations. Lagadec also uses these case studies to describe means for coping with crisis, including better emergency planning, organizational and institutional design considerations and approaches to the management of crisis.

This paper is followed by one by Giovanni Naschi who describes engineering aspects of severe accidents, with specific reference to Seveso, Mexico City and Bhopal. Naschi's major focus is on errors in technical design and/or management of the operation which lead to catastrophic failure. He describes some of the safety devices in place for the three cases, and indicates why they did not function properly at the time of the accidents. Naschi summarizes his argument by suggesting that the major causes of Seveso, Mexico City and Bhopal were "a combination of design deficiencies, operating errors and managerial mistakes."

The paper by F. Pocchiari, V. Silano, and G. Zapponi describes Seveso and its aftermath in detail from a public health point of view. This paper was presented in a colorful fashion by Professor Pocchiari at the Conference and described both the Seveso incident and the evacuation procedures following the Seveso accident. Professor Pocchiari uses Seveso as a case study to discuss the uncertainties surrounding whether such evacuations should be ordered to safeguard public health.

The paper by Henri Smets addresses the following question: What is the magnitude of environmental damage caused by industrial activities? And, further, are such damages insurable? Smets reviews damage due to oil pollution at sea, accidents involving dams, air, water and noise pollution, as well as environmental impairment resulting from radioactive pollution and hazardous wastes. In each of these cases, Smets looks at the best estimates available on actual damage and the proportion of losses covered by insurance and other payments to victims. He concludes that environmental damage is not, by nature of its magnitude and occurrence levels, an uninsurable event. The magnitude and occurrence levels appear to be no higher, for example, than those associated with commercial airline accidents. This paper set the stage for a lively discussion at the Conference as to what distinguishes environmental impairment accidents, for which insurance is largely unavailable in the U.S. today, from accidents of other types, for which insurance is clearly available. This discussion is reflected in the comments following the Smets paper, as well as in several other papers reviewed below.

PROBLEM CONTEXT

As noted, the theme of the Conference was the use of the policy instruments of insurance, compensation, regulation and negotiation to promote safe and efficient practices in the hazardous materials area. Several Conference papers explored the relationship between these policy instruments and the specific problem contexts of Figure 1, namely the production, transport, storage and disposal of hazardous materials.

The paper by Paul Kleindorfer and Howard Kunreuther investigates the use of insurance and compensation as policy instruments in the context of hazardous waste management. First, Kleindorfer and Kunreuther review the nature of hazardous waste management activities, from decisions by firms as to how much waste to generate, through the decisions related to the transport and disposal of this waste. They discuss the complex interweaving of liability and insurance considerations with these decisions. In theory, there is an opportunity to utilize insurance as a policy instrument for encouraging industrial firms to engage in risk reduction measures. However, recent court rulings in the United States and elsewhere on the nature of liability for health effects associated with hazardous materials have created problems for industry and insurance firms to implement such a plan of action. The paper then describes the current stalemate in siting new hazardous waste facilities. Kleindorfer and Kunreuther recommend the use of insurance and compensation as policy instruments for sharing the benefits to a region from locating a hazardous waste facility with those stakeholders who have to bear the risks associated with such facilities.

Michael O'Hare's paper describes the importance of bargaining and negotiation in risk management in the context of hazardous materials transportation. O'Hare points out the tremendous importance of negotiation both in striking deals to appropriately spread risks and benefits, as well as a means of communication to arrive at an informed consensus about the facts associated with a particular hazard. O'Hare describes the negotiation problem for hazardous materials transportation by considering first the negotiable issues (e.g., classification of substances, handling procedures, and emergency response measures). He then describes the various stakeholders to the hazardous materials transportation negotiation process and the impediments in bringing all of them together in attempting to negotiate the issues involved. These frequently turn out to be very serious problems since the issues are technically complex and there are many stakeholders involved. O'Hare argues, however, that there are also significant opportunities for negotiations to improve the regulation and management of hazardous materials transportation.

The paper by Roger Kasperson has as its problem context the siting of hazardous waste facilities, both for radioactive as well as for chemical wastes. Kasperson points out the very contentious nature of the current stalemate amongst the stakeholders depicted in Figure 1. By now everyone is clear on the nature of the NIMBY (not in my backyard) and LULU (local unwanted land use) syndromes. These acronyms reflect the difficult dilemma facing society when there is substantial benefit to the general population from the production of goods and potential risk to a much smaller set of individuals who are exposed to the risks of having waste products transported and stored from industry in their backyard. Kasperson argues for the increased use of policy instruments such as public communication, benefit sharing or compensation, and public participation in resolving these conflicts. However, given the prevailing scientific uncertainty associated with the consequences of hazardous waste, Kasperson suggests that we have a very rocky road ahead of us in siting hazardous waste facilities. He proposes a set of ethical/equity principles as guiding principles for winning and maintaining public trust in the regulation of hazardous materials and the siting of new facilities.

RISK ANALYSIS

The third group of Conference papers focus on risk analysis, encompassing the traditional areas of hazard identification, risk estimation and risk assessment. We were particularly concerned in understanding the way in which people and firms perceive and evaluate risks.

The paper by Vincent Covello and Miley Merkhofer describes and evaluates prominent methods for hazardous risk assessment for determining the nature of different chemicals. These methods are organized according to the component of the risk assessment process they are meant to address. Methods designed for characterizing a source of risk are discussed initially, followed by methods for assessing exposures, dose response assessments and lastly methods for risk estimation. Covello and Merkhofer explore in detail the complex relationships among the various phases of chemical risk analysis and management illustrated in Figure 1.

The paper by Neils C. Lind surveys current methods of risk analysis and recent advances in this area. Lind describes, through a set of examples, current methods for assessing both the probabilities of failures and their consequences through fault trees and event trees. He also emphasizes the crucial influence of data and uncertainty in risk analysis. This paper triggered an animated discussion on the limitations of risk analysis, which is taken up at length in both of the discussants comments on this paper. These comments describe the practical use and promise, as well as the pitfalls, of risk analysis for insurers and industry.

Paul Slovic's paper discusses the problem of communicating risk to the public. The objective of informing and educating the public about risk issues has triggered a concern among policy makers as to just how to present information to the public. This means among other things finding ways of making technical and scientific uncertainties comprehensible, as well as understanding the public's concerns and anxieties about the risks caused by complex hazards. Slovic describes the current state of research and its possible uses for overcoming these obstacles.

Detlof von Winterfeldt's paper describes a new methodology, value tree analysis, for understanding the values which various stakeholders may have in respect to policies affecting the risks associated with hazardous materials. Professor von Winterfeldt describes the historical and disciplinary roots of value tree analysis in decision analysis and multi-attribute utility techniques. He also describes its use in various applications to date. Value tree analysis allows a hierarchical description of the value structure of various stakeholders associated with a particular hazardous materials problem. Such an analysis may help in diagnosing and resolving conflicts and in evaluating alternative policy options from the different stakeholder perspectives. He illustrates this methodology in an extended case analysis of options for off-shore oil development in Southern California.

RISK MANAGEMENT AND INSURANCE

The final group of papers at the Conference consider the institutional arrangements which society has developed for coping with risks. The key areas of interest involved regulations, both by government agencies and by industry, legal institutions, and, primarily, insurance.

The paper by Timothy O'Riordan and Brian Wynne compares regulatory styles for hazardous waste management in various countries. The authors ask whether there are fundamentally different or convergent regulatory styles in each of these countries induced by the nature of the hazardous waste problem itself. The essential differences across countries relate to centralization versus decentralization of control. However, fundamental similarities are found to be induced by the common problems of scientific uncertainty and technical complexity in regulating hazardous wastes.

Michael Baram's paper considers the legal background of liability insurance and risk analysis for chemical industry hazards. Certainly, the key institution for ajudicating and resolving conflicts amongst parties will be the legal system. For this reason, Baram reviews recent developments in toxic tort law and insurance law. The impact of new developments in the United States and in other countries significantly affect the economic vulnerability of industry and insurers. He also suggests that defensive strategies on the part of firms or insurers in restricting their liability or curtailing insurance will do little to prevent risks or satisfy the public. Indeed, they may lead to further risk regulation which may impose costs on industry and insurers in excess of their own private iniatives. Professor Baram concludes that insurers should join with industry, government and academia in promoting the development of active strategies, based on risk analysis and risk management, to protect both their own interests and societal well-being.

One of the high points of the Conference was the extended discussion elucidating the role of insurance for environmental impairment liability. This discussion ranged from theoretical explanations of insurance and regulation to the realities of insurance in practice.

Alfred Klaus provides an introductory discussion of environmental impairment liability (EIL) for land-based incidents. He indicates that, from the insurer's viewpoint, surprisingly low losses in relation to fire claims have resulted from the well-known recent environmental disasters. This raises a natural question as to why the insurance industry is so concerned about offering EIL coverage. Klaus suggests that, with the possible exception of the United States, where court settlements are prohibitive, EIL is insurable. However, Dr. Klaus also argues that pollution of the environment entails very complex management and insurance issues. He recommends strong adherence to risk assessment and risk management practices on a cooperative basis between insurance firms and companies to increase the likelihood that EIL insurance will be offered on a broad basis in the future.

Enrico Orlando discusses recent developments concerning the transportation of hazardous materials by sea. Orlando points out that marine insurance has a very long tradition; marine underwriters have been willing to provide collision liability protection for ship, cargo and freight. In the area of enviromental impairment liability associated with ocean transport of oil and oil products, various pooling and fund agreements provide workable arrangements for insuring such liabilities. Orlando indicates, however, that attempts to arrive at an international agreement covering transport of other hazardous substances besides oil have not been successful for several reasons outlined in the paper.

The above contributions highlight a perplexing dilemma. The paper by Smets indicates that the nature and magnitude of losses in the environmental area is not extraordinarily high compared to other areas for where insurance is currently available. The papers by Klaus and Orlando propose some workable arrangements for insuring environmental liabilities which might be profitable for the insurance industry. Nonetheless, several participants pointed to the stark reality that many firms increasingly were going "naked," unable to purchase EIL coverage at any reasonable price due to limited worldwide capacity in these lines. The institutional arrangements and decision processes of the insurance industry itself comes under closer scrutiny in an attempt to explain this state of affairs.

Malcolm Aicken describes the basic logic of risk spreading in the insurance industry. He indicates several features which make a set of risks insurable and then comments on the nature of EIL which make it a very risky business for insurers. These issues include the well-known problems of latent effects and gradual occurrence, as well as uncertainties in establishing causality for toxic effects and large court settlements negotiated by toxic tort lawyers.

The final paper by Werner Pfennigstorf considers these insurance specific issues in more detail. Pfenningstorf discusses the manner in which the catastrophic character of certain environmental risks affects the insurability and coverage of these risks. After a detailed comparison of environment insurance in the United States and Europe, Pfenningstorf considers the outlook, challenge and market prospects for insurance in the hazardous materials area. This paper stimulated a very active interchange amongst Conference participants on the reasons for lack of available coverage against environmental risks. Some of the flavor of this interchange is contained in the three discussant comments following the Pfennigstorf paper. One of these, by John G. Cowell, suggests that the lack of insurance in risk spreading for technological and environmental hazards is one of the key problems of our times.

SMALL GROUP SESSIONS & RESEARCH PLANNING AGENDA

A major objectives of this conference was to plan a research agenda for the next decade in the hazardous materials area. The last third of the conference was spent in doing just that. An extended panel discussion, followed by small group meetings, developed an agenda for future research. The research proposals generated by the small group meetings were presented at a concluding plenary session and were based on ideas from the papers included in this volume, and the discussant and participant comments which followed. We summarize these research recommendations at the end of this book in an Epilogue, which we hope will serve as a prologue for significant future work in the area of hazardous materials management.

RESEARCH RECOMMENDATIONS OF THE CONFERENCE

A principal objective of the IIASA Conference was to develop a set of recommendations for future studies between researchers and practitioners that would improve the management of hazardous materials. To this end we invited six practitioners to participate in a panel discussion followed by small group meetings. Each of the small groups was asked to outline a set of research needs in their area with a concern for linking theory with practice.[2] The research recommendations developed by the small groups are presented below by linking them to the following themes highlighted by the conference.

1. Problem Context. There is a need to increase our understanding of the problems and opportunities facing firms which manufacture products that create toxic waste, the alternatives open to transporters of hazardous materials, and the challenges facing interested parties involved in the siting of storage and disposal facilities.

2. Risk Analysis. There is a need to document the potential benefits and inherent limitations of risk analysis both at the assessment level and at the level as to how data are communicated to the different interested parties (e.g., the public, industry). In particular, we need to understand how bargaining and negotiation can facilitate the decision process and enable interested parties to reach compromise solutions.

3. Risk Management and Insurance There is a need to understand the role that legal institutions and regulation can play in facilitating the production, transport and storage of hazardous materials. What is the appropriate role of insurance in dealing with these problems?

We now summarize a set of key ideas by the panel members, open discussions at the Conference, and research recommendations from the small groups by specifying a set of topics related to the above three areas.

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[2] The members of the panel were Karoly Bard (Board of Insurance Enterprize, Hungary); Frederic Bjorkman (Director of the Swedish Regulatory Authority for Transport of Dangerous Goods); Orio Giarini (Secretary General of Geneva Association); Perry Hopkins (Director of Manufacturing Services at DuPont); Ludwig Kraemer (Judge of the Appelate Court in Germany); and Michael Stradley (Engineering Consultant).

I. PROBLEM CONTEXT

PRODUCTION OF HAZARDOUS MATERIALS

In his panel presentation, Perry Hopkins provided a set of principles for firms to follow in preventing and dealing with Bhopal-like incidents. In particular, he emphasized the importance of firms recognizing the need for expertise and safety in technology when they deal with highly hazardous materials which are also essential for meeting society's needs. Manufacturing line management must be full participants in the development and implementation of all business planning involving hazardous materials, and they need to participate actively in developing industry standards, government regulations and laws for the management of hazardous materials worldwide. Hopkins also pointed out the need for improved methods of detection of hazardous materials discharged into the atmosphere from devices that relieve pressure in vessels that might otherwise rupture. Currently, there are no means to neutralize, disburse or otherwise protect the environment from these discharged materials.

KEY RESEARCH AREAS FOR PRODUCTION

*How do we reconcile differences in allowable concentrations or doses in the workplace versus the external environment?

*How can industrial firms remain competitive while still addressing hazard and risk concerns of the public?

*How does one introduce industrial practice and compliance techniques into small firms for problems involving chronic and gradual pollution, as well as possible explosive accidents.

*Determine the effects of various organizational structures and managerial behavior on the levels of risks in a firm.

*Undertake a state-of-the-art survey of current safety apparatus used in industry and its effects on reduction of risk (e.g., the use of dated or modern equipment).

*Undertake case studies of management practices in dealing with risks for firms of different sizes, including a survey of risk levels accepted by safety managers in different types of industrial facilities.

*What are effective procedures for developing trust between the public and firms? How do successful companies deal with this issue?

*How do different firms deal with mismanagement issues? Can risk scenarios play a creative role in this process?

TRANSPORTATION OF HAZARDOUS MATERIALS

In the panel discussion, Frederic Bjorkman stressed the importance of the carrier of hazardous materials as an identifiable party in the hazardous materials process. He indicated that the public is frequently unaware of the sender or the receiver of the goods, but can normally identify and will demand compensation from the transporter. For this reason, local authorities frequently place a number of restrictions on carriers to protect the general public.

KEY RESEARCH AREAS FOR TRANSPORTATION

*What is the linkage between the transportation of hazardous materials and the siting of disposal facilities from the point of view of managing risk and dealing with the costs of an accident?

*Can one determine minimal acceptable standards for transporting hazardous goods? What is the evolution and rationale of international conventions regarding these standards?

*Can one develop regulations for dealing with transportation of goods that have an opportunity of being appropriately monitored and controlled? What is the past experience with these types of regulations in different countries?

*What are appropriate liability and insurance mechanisms for covering transport of hazardous materials? How easily can these be enforced in practice?

SITING OF STORAGE AND DISPOSAL FACILITIES

Research in this area needs to be designed so that consideration is given to the technical, social, political and economic aspects of the siting process. As in the other areas, there is a need to investigate implementation problems associated with siting a new facility and ways of enforcing any rules and regulations. As was pointed out by a number of participants in the meeting, the siting issue encompasses a wide variety of problems at all levels, including legal issues, public participation, as well as the role of policy tools such as compensation and insurance for facilitating the process.

KEY RESEARCH AREAS FOR SITING

*What are the trade-offs between equity and efficiency considerations in making siting decisions?

*What role can risk assessments play in siting decisions? Can one develop a set of criteria for the evaluating the risks resulting from siting in one place versus another?

*Does insurance availability influence siting? What type of insurance would be most useful in this connection?

*How can one bring the public effectively into the siting process? In what ways can technical assistance be useful in enhancing public participation?

*How can one enhance public trust in institutions and facilitate the siting of hazardous facilities?

*What role can compensation and benefit sharing play in conjunction with other policy instruments such as regulations for facilitating the siting of hazardous facilities?

II. RISK ANALYSIS AND DECISION PROCESSES

RISK ASSESSMENT

Orio Giarini, in his panel discussion comments, indicated that in the 19th century it was much easier to determine risks from industrial plants such as a textile mill by undertaking a specific inspection. In the last twenty years, technology has changed so rapidly that it is difficult for those in the plant to fully understand technological risks and even more difficult for outsiders, such as insurance inspectors, to monitor and understand these risks. This may create moral hazard problems if those inside the firm have a better conception of the risk than those external (e.g., insurers). This is one reason that insurance for many types of risk is not available today. To improve the situation with respect to risk assessment, the following research needs have been outlined:

KEY RESEARCH AREAS FOR RISK ASSESSMENT

*Creation of new data bases and coordination of existing ones on the toxicity of chemicals in different environments and on their physical effects.

*Developing simple assessment models that contain only key variables and can be applied to a number of different situations without large expenditures of time or money.

*Conducting a survey of risk assessment activities of international and national institutions.

*Developing worst case scenario methodologies for use in a variety of industrial settings.

*Impact of scientific uncertainty in undertaking risk assessments and settling differences between experts. What role can science courts play in adjudicating the process?

RISK PERCEPTION AND COMMUNICATION

There was considerable discussion at the conference on the different perceptions between experts undertaking risk assessment and the lay public. There was general consensus of a need to study ways of improving the communication of information on the nature of the risk to the general public as well as the costs and benefits of alternative policy strategies.

KEY RESEARCH AREAS FOR RISK PERCEPTION AND COMMUNICATION

*How can one make risk information more relevant to specific interested parties (e.g., top level officials, lower level executives, government agencies). How do different political regulatory statutes and cultural factors affect these communication needs?

*How can one better communicate uncertainties with respect to probabilities, consequences and trade-offs between different alternatives? What is the role of computerized decision support systems in improving the way individuals process this information?

*What information about risks do people feel they need in contrast to information that the government feels may be "good for them"? Do people want to know about the chances of potentially catastrophic accidents in the future,(e.g., an earthquake in California) if they are living in the area? Does framing of data in different forms (e.g., gains vs. losses) change people's cognitions or just their responses?

*What do people feel is a fair political process and how does that affect the way information is/should be presented to them? Is it useful to consider compensation or benefit sharing as a way of facilitating communication?

RESEARCH ON BARGAINING AND NEGOTIATIONS

In his panel discussion, Karoly Bard indicated the need to focus on the different interested parties affected by hazardous materials and to determine the appropriate role of insurance and compensation as policy tools for facilitating bargaining and negotiation. He indicated that one needed to link these alternative mechanisms to the objectives of society. For example, there are differences between socialist economic planning, where insurance is compulsory, and the available coverage in other countries where a voluntary system is in place. Political, psychological, social and economic conditions may set up different atmospheres for bargaining and negotiating on environmental matters.

KEY RESEARCH AREAS FOR BARGAINING AND NEGOTIATION

*What is and should be the role of expert and expert knowledge in the negotiation process? Should expert knowledge be used as a tool for bargaining or is it perceived as a constraint on bargaining?

*What is the best way to prepare people for negotiation? Are existing training programs helpful in resolving conflicts on environmental problems?

*At what stage in the policy process - policy formation, standard setting, implementation - do bargaining and negotiation occur? What opportunities exist for bargaining and negotiation that are not presently being exploited?

*How do bargaining and negotiation processes differ among political cultures? Are there specific lessons that can be transferred from one country to another?

III. RISK MANAGEMENT

LEGAL INSTITUTIONS

In his panel discussion, Ludwig Kraemer indicated that in the European Economic Community Treaty there are over 100 binding legal instruments which relate to risk and the environment. He pointed to the Seveso Directive as a model for dealing with plant safety practices and one that is likely to be exported from Europe to the United States. Since conflicts over values, facts and policy actions will continue to be adjudicated by law, it is clear that legal institutions and practices will be a cornerstone of risk management. The following areas were deemed especially important research topics here.

KEY RESEARCH AREAS FOR LEGAL INSTITUTIONS

*What are the potential reforms to the legal system in the United States with respect to toxic tort and compensation for damages? Are there any lessons from European countries which may be helpful in this regard?

*Evaluate the joint and several liability system in the context of hazardous materials. What are the costs and benefits of continuing with this type of arrangement?

*What are the economic incentives of toxic tort law and liability with respect to product developments, (e.g. pharmaceutical) and health and safety procedures within firms?

*How does the legal framework influence the availability of insurance? What reforms would be helpful in providing increased coverage against environmental pollution damage?

REGULATION

Several of the panelists discussed the importance of regulations, with appropriate monitoring and control procedures, as risk management tools for the hazardous materials problem. When to utilize regulations produces a wide range of responses. In some cultures there is a reluctance to impose regulations unless there is a clear failure of market-like mechanisms such as effluent-charge incentive systems. In other countries, regulations are a way of life. The hazardous materials problem is viewed by most countries as one that needs to be at least partly remedied through regulating activities of plants, transporters and those who operate storage and disposal facilities. In addition, the public is extremely reluctant to sanction new facilities that have the potential of causing damage to health and safety wthout assurance that strict regulatory and control procedures will be enforced.

KEY RESEARCH AREAS ON REGULATION

*What are the interrelationships between standard setting, monitoring and enforcement of regulations in the responses of firms producing hazardous materials as byproducts?

*What is the relationship between self-regulation by firms and externally imposed regulations by government agencies?

*What are the appropriate regulatory authorities and enforcement mechanisms associated with hazardous materials storage and disposal facilities? How will regulations facilitate the siting process?

*What types of regulations can assist the process of bargaining and negotiations for transport, storage and disposal of hazardous materials?

*What role can regulation play for dealing with hazardous materials problems when the causality of certain health effects cannot be ascertained?

*What lessons can be learned from international comparative research on hazardous materials regulations for model regulatory legislation?

RESEARCH ON INSURANCE

In his commentary, Michael Stradley pointed out that the market for environmental impairment liability has collapsed in the United States. Reinsurers throughout the world are reluctant to provide coverage in the United States because of the uncertainty as to the magnitude of claim settlements in court. This has created a lack of capacity in the industry and raised questions as to alternative mechanisms for insuring interested parties against potentially catastrophic losses.

KEY RESEARCH AREAS FOR INSURANCE

*How can uninsurable events be made insurable for protecting against damages from hazardous materials? What actions are needed to increase the capacity of insurers and reinsurers? When can claims-made rather than occurrence-based policies be helpful in this regard?

*Is there a need for government involvement for dealing with catastrophic losses through some type of reinsurance program? Is the Price Anderson Act or the Black Lung Program a useful model for some type of government/private system in the United States.

*What type of self-insurance plans by industry are likely to be successful in filling the gap in insurance protection?

*What are the incentive effects of insurance in increasing the safety level and protective activities of industrial firms?

In order to undertake research on these issues, there needs to be an open dialogue between the academic community and real world practitioners. The Conference on Transport, Storage and Disposal of Hazardous Materials was designed as a first step in this direction. Hopefully, the process will be accelerated in the coming years.

RISK MANAGEMENT IN DEVELOPING COUNTRIES:
SOME STRAY THOUGHTS ON THE INDIAN EXPERIENCE

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INTRODUCTION

Developing countries representing more than two-thirds of the human race and a wide spectrum of ethnocultures and traditions are on the onward march towards attaining a better deal for themselves. The strategy for development or the approaches adopted vary from country to country. Yet one can recognise a uniform pattern and philosophy behind all the developmental programmes currently being pursued in Latin America, Africa and Asia. In most of the developing countries development has become synonymous with a rapid industrial growth and moderanization of agriculture (Holdgate, Kassas and White, 1983).

The transition from a state of underdevelopment to one of development has its own inherent risks. The crux of the problem faced by these countries consists in devising means by which the transition is effected smoothly and achieved in a time span shorter than what it took the present developed countries of the West to reach in the wake of the Industrial Revolution in Europe (World Bank, 1975).

Obviously, the very nature of the problem poses many challenges to developing countries. In the context of the present meeting of the Task Force, some of the challenges that stand out are -

(a) risk identification in the programmes of development;

(b) assessment of the risks involved against a broad framework of social benefits;

(c) evolution of basic developmental policies and plans based on such policies;

(d) capability to make risk-benefit analysis of each one of them;

(e) management of risks by predictive and preventive measures.

An outline of the nature and magnitude of these challenges is presented in this paper. Since population pressure is a burden common to all the developing countries, the slant will be on health associated with developmental programmes.

The author's exposure to developmental problems is necessarily limited to those currently faced by India. It is obvious that the experience of India may be neither typical of nor unique to all developing countries. Nevertheless, other developing countries could use the Indian example as a pointer. Furthermore, the Indian experience can also form the basis for a scientific understanding of the innumerable problems of development. What one desires to achieve in the developing countries is the deployment of the tools of systems approach to analyse situations that are highly contemporary. It is not difficult to develop a model for transition from underdevelopment to development from the past experience of the West. However, policy makers in the developing countries may still be left with the almost impossible task of extrapolating its validity to crisis scenerio emerging today in an entirely different historical setting and socio-political and geographical mileu.

2. IDENTIFICATION OF HAZARDS IN DEVELOPMENT PROGRAMMES:

A net work illustration of developmental problems is presented in Fig.1 in order to simplify the process of identification of situations with a potential for hazards. Briefly, the diagram highlights the following interconnected events:

(i) In order to push the process of the forward movement from underdevelopment to development, there is need to use a strategy for the rapid utilization of natural resources, both physical and biological.

(ii) Exploitation of natural resources expands the mining, mineral processing industries and tends to the setting up new manufacturing industries.

(iii) The need for increased food production requires more intensive agricultural activities, which, in turn, involve transformation of hitherto uncultivated land into man-managed agro-ecosystems and introduction of risk factors arising out of the application of modern forming techniques.

(iv) Even the marginal public health measures introduced to improve the quality of life of the people profoundly affect the demographic pattern as reflected in some of the indicators of Community Health such as extended expectancy of life at birth, decreased infant mortality and reduced endemicity of communicable diseases. Patently, the uncontrolled rise in population has neutralized the gains made in raising Gross National Product. As a result, in spite of innumerable positive achievements in the developmental plans, abolition of poverty and laying the firm foundation for building a better society have eluded the grasp of planners.

Some of the obvious negative pulls exerted by the events initiated by the developmental process as outlined above are:-

(a) imbalances between relatively undeveloped and partly developing regions and inter-regions within the country;

(b) migration of labour from rural to urban clusters or new industrial/mining/power complex townships and social

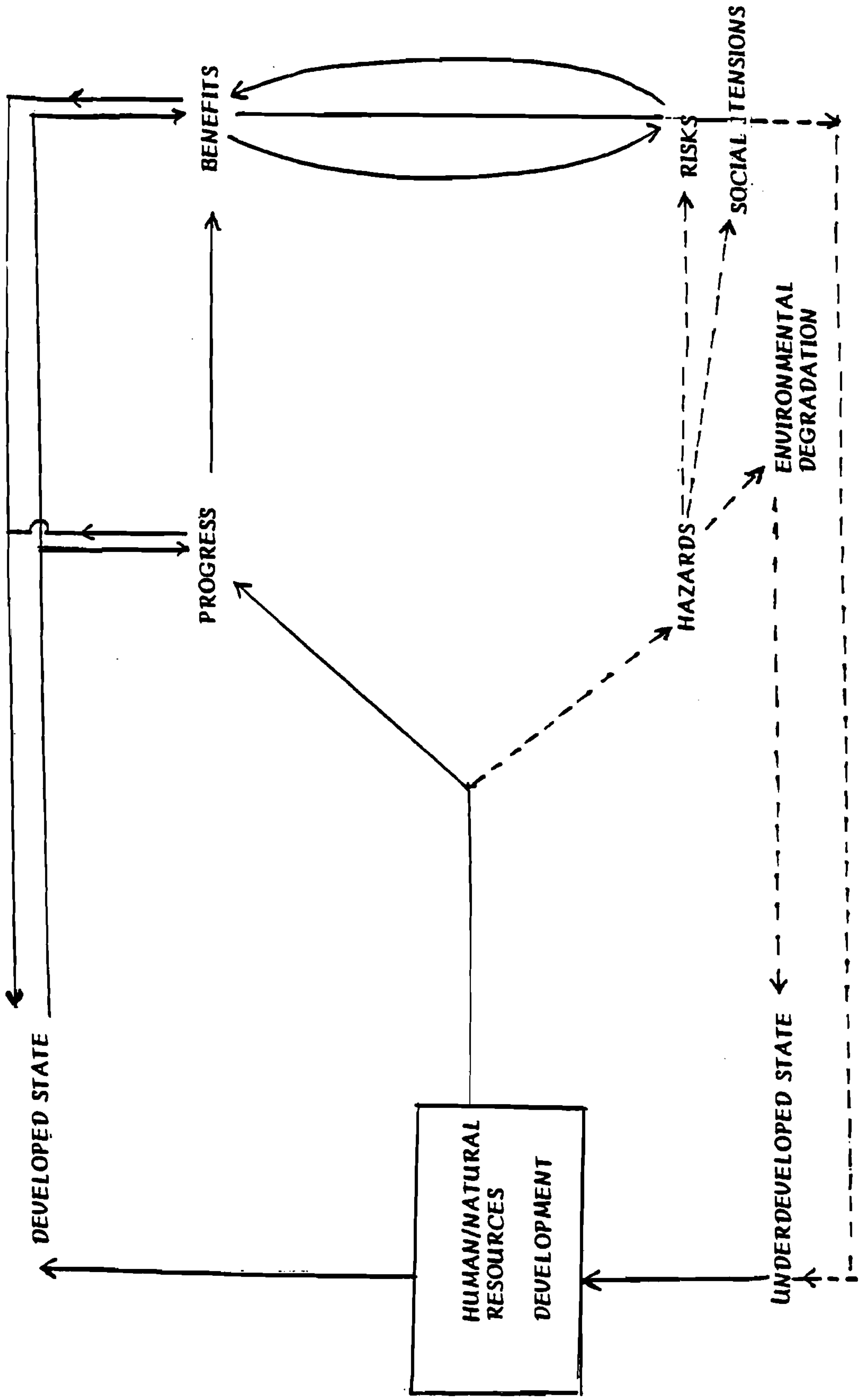
DEVELOPED STATE
BENEFITS
PROGRESS
RISKS
SOCIAL TENSIONS
HAZARDS
ENVIRONMENTAL DEGRADATION
HUMAN/NATURAL RESOURCES DEVELOPMENT
UNDERDEVELOPED STATE

FIG.1

tensions arising out of the conflicting interests of the local over the migrant population,and

(c) environmental degradation including varying degrees of pollution.

One can look for the likely hazards in each one of these links and interactions and prioritize them according to their magnitude as related to impact on the physical environment or on human health (Krishan Murti, 1982). In order to facilitate the perception of risks to human health in the developmental context a conceptual model as shown in Fig.2 tentatively designated the "double burden" model can be used. The basic assumptions made in enunciating this model are that -

(i) the state of underdevelopment compels a citizen of a developing country to carry a primary burden which is a mix of undernutrition or malnutrition, coexistent endemicity of parasitic and infectious diseases arising out of an unhygienic ambient and living environment and low productivity;

(ii) development imposes on the individual its own external burden represented by the stress involved in the change in the life style from a rural base to a semi-urban environment ;

(iii) there are wide uncertainty elements in regard to the outcome of the interaction between the internal stress and the externally applied stress; and

(iv) more significantly the question as to whether the change in life style forced upon the individual will lead to improvement in the quality of life is also under a cloud of uncertainty.

3. EVOLUTION OF BASIC DEVELOPMENT POLICIES AND PLANNED DEVELOPMENT:

India, since her political independence, has embarked on several developmental programmes related to health. The machinery behind planning has been necessarily "elitist" in outlook and training but has appeared consistently to uphold the basic values of the struggle for political freedom. Undoubtedly, in each plan period there has been wide gaps between goals

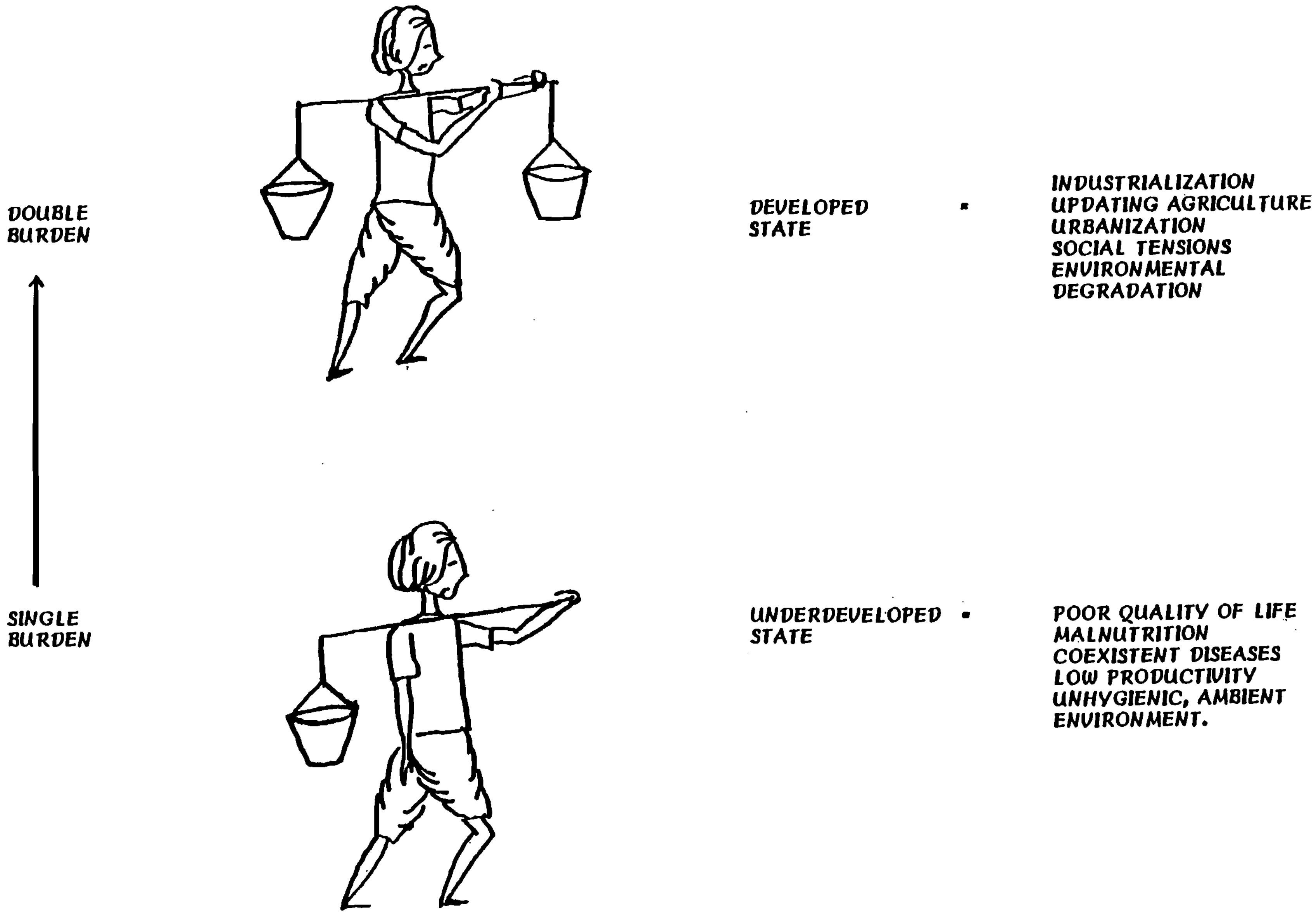
DOUBLE BURDEN
SINGLE BURDEN
DEVELOPED STATE
▪
INDUSTRIALIZATION
UPDATING AGRICULTURE
URBANIZATION
SOCIAL TENSIONS
ENVIRONMENTAL DEGRADATION
UNDERDEVELOPED STATE
▪
POOR QUALITY OF LIFE
MALNUTRITION
COEXISTENT DISEASES
LOW PRODUCTIVITY
UNHYGIENIC, AMBIENT ENVIRONMENT.

FIG.1

and actual achievements. The reasons for the disparities have been widely debated and attempts made to fill recognizable gaps in subsequent plans. The question of finding resources within and without has also been asked frequently. There is also the never ending question of the inherent risk in allotting resources on the basis of short-term or immediate priorities versus long-term priorities. The invisible conflict in the health sector has been prevention by perspective planning versus cure of immediately visible symptoms.

4. CAPABILITY TO MAKE RISK-BENEFIT ANALYSIS OF DEVELOPMENT PROGRAMMES:

Taking environmental health as one of the main themes one can ask what are the main policy issues requiring risk assessment. The World Bank classification of diseases pattern globally (See Table 1) makes a clear distinction between diseases due to the style of living and diseases caused by the environment. In this classification scheme, the developed countries show a high incidence rate of diseases attributable to living style and the less developed countries exhibit a high incidcence rate of aiseases associated with an unhygienic environment.

Against this background if one projects the environmental scenario of the Developing countries, what emerges as priorities are the needs for mitigating the effects of biological pollution. Control of biological pollution in all likelihood will bring valuable long-term returns and must be a top priority. At the same time, planners can ill afford to ignore the signs of industrial pollution which have not only surfaced but also begun to cause concern.

TABLE:1 WORLD BANK CLASSIFICATION OF DISEASE PATTERN ACCORDING TO DISEASE STATUS
(Based on crdue mortality data)

	DEVELOPED SOCIETY	UNDERDEVELOPED SOCIETY
DEATHS FROM DISEASES DUE TO STYLE OF LIVING	70-80%	20-30%
DEATHS FROM DISEASES DUE TO POOR ENVIRONMENTAL CONDITIONS	20-30%	70-80%

In the wake of rapid industrialization many developing countries have begun to acquire indigenous capability to manufacture chemicals. The impact of chemical pollution has begun to surface on an environment already biologically polluted. It becomes imperative, therefore, that the resulting health risks be identified. This is an area where there is a considerable amount of uncertainty, particularly about the validity of adopting health criteria set up for human exposures to industrial chemicals in the developed industrial society to a population with an entirely different environmental background and genetic inheritance now getting exposed to the chemicals. One would like to ask how appropriate it is to apply to India, Bangladesh, Nigeria or Malysia, Threshold Limit Values or Maximum Permissible Concentrations in the work environment used in USA, USSR or Japan.

Environmental impact assessment of major developmental programmes cannot be complete without evaluating health effects on the related ecosystems. Indeed health risk assessment of developmental projects has emerged as a vital area requiring highly sophisticated skills & expertise. There is need for articulation of the problems, however trivial they appear to be on cost considerations. The related strategies for their solution will have to be designed against a frame of reference of social benefits rather than on the strength of conventional cost profit analysis. The social benefits will have to be defined and quantified in terms of employment opportunities and better living conditions conducive of improved health. If it is a new chemical industrial complex being established, factors to be taken into consideration will be siting of the industry, raw-materials, transportation and storage hazards of intermediates and the finished product, "cradle to grave" history of toxic wastes generated, estimates of exposure to the chemicals in the labour force and the community inhabiting the adjacent environs, effluent disposal and environmental protection.

In the case of hazard prone chemical industries, risk assessment will have to lead to the needs for the provision of safety measures during routine operation as well as emergencies. Alarm signals and operations including normal "fire fighting" procedures, rapid evacuation of personnel to safe areas will have to be energised in case of an accident in situations where there may be power failure and it may be difficult to establilsh communication links.

In regard to establilshing industrial complexes in remote underdeveloped regions, several factors will have to be taken into consideration. For example, the background information on the quality of environmental parameters has to be collected. The type of population to be engaged in the different processing operations must be identified so that specially vulnerable groups, if any, can be eliminated from the work force. Facilities for effluent disposal must be set up. These factors become all the more vital in view of the fact that the formulation of pesticides, pharmaceuticals and drugs are now being transferred to remote underdeveloped regions; these are not only hazard-prone but also likely to affect the environment if preventive measures are not incorporated in the package of technology that is used to establish the formulation plant.

In the area of agriculture, the risks associated with increasing use of pest control chemicals and man-made plant nutrients have been hardly identified. The main risk in the use of pest control chemicals arises out of the need to use the same type of chemicals for vector control in public health and the resulting conflict of interests and environmental pollution; unusually high build-up of pesticides residues in human and animal tissues and the increased rate of development of resistance to pesticides by the pests against which the chemical agents are targetted (Krishan Murti, 1983).

5. ANTICIPATORY AND PREVENTIVE STRATAGIES FOR RISK MANAGEMENT.

Environmental Impact Assessment has been introduced in India in recent years as on essential prerequisite for the clearance of all major developmental projects. Public sensitivity to environmental degradation has registered of late a more noticeable vocal expression as exemplified in the Silent Valley Project in the Western Ghats, India, the Mathura Petroleum Refinery Project as affecting the Taj Mahal and the Bharatpur Bird Sanctuary and the Refinery-cum-Fertilizer Complex in Tal Varesht in the coastal belt of Maharashtra as affecting coastal life and recreational beaches. There has been growing concern about environmental pollution without any serious attempt to evaluate the health risk qualitatively and quantitatively.

Expression of public concern with environmental issues does not necessarily mean the existence and operation of sophisticated institutions which can meaningfully articulate the issues and cataluse the creation of adequate control mechanisms. The appropriate disciplines belonging to Natural and Social Sciences are yet to emerge as critical forces.

6. CONCLUSIONS:

Uncertainties have been more the rules than exception in regard to issues related to chemical safety. In the absence of powerful pressure groups and political lobbies, consumer safety and public health have not received adequate attention. There have been constraints in the realm of implementing regulatory requirements. Admissible Daily Intake values of toxic chemicals through food, water and air or Maximum Permissible Concentrations of toxic chemicals in the occupational environment are fixed on what are stated as pragmatic considerations rather than after criteria have been laid down by scientific study and analysis.

Under these circumstances, it will be unrealistic to expect the risk management system functioning in the less developed countries to be the ideal one. The management of accidents associated with the production, transport and processing of chemicals is naturally a "crisis management". Progress has to be achieved in the following directions:

> Tragic consequences of the failure or warning or alarm signals in chemicals installations have to be anticipated in the initial phase of planning such units.
>
> Safety monitoring and safety protection drills have to be done with ritualistic zeal.
>
> The uncertainties in the transfer of package technologies from one cultural mileu to another must be identified.
>
> Above all, the hazard potential of modern technology must be accepted as part of the risk.

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