RISK AND UNCERTAINTY

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Summary

This paper presents an overview of the risk literature, concentrating on general approaches to risk analysis and risk assessment. We believe that this is an essential first step towards the setting of guidelines or the adoption of a regulatory procedure for all situations where risk to humans and their environment is involved. We have used the term environmental risk to encompass these situations. Of necessity, political risk is also a factor.

The main points made in the paper are reviewed here under their original chapter headings.

Chapter 3. What do we mean by risk and uncertainty?

Risk and uncertainty are an integral part of all decisions made in the real world. The decision-making process involves a set of actions and outcomes, each of which have a probability associated with them. The distinction between risk and uncertainty hinges on the ability of 'experts' to agree on a set of probabilities (risk estimates) for the set of possible outcomes. The characteristics of risk are therefore, a choice of action, a magnitude of loss, and a chance of loss.

The magnitude of the risk is determined by its character (type), extent (size) and timing. Only part of this magnitude can be quantified in commensurate units: assessments of magnitude are heavily value laden.

The probability, or chance of loss can be measured in different ways. Thus, four types of risk can be distinguished: real risk, statistical risk, predicted risk and perceived risk. Real risk cannot be measured. The term 'actual' risk usually refers to statistical or predicted risk.

Although the terms 'subjective' and 'objective' risk are often used to describe risk, the calculation of 'objective' risk estimates requires value judgements and assumptions which mean that they need not be consistent.

Chapter 4. Approaches to risk - what is risk analysis?

Risk perception is concerned not only with perceived risk as described earlier, but with all aspects of individual and group perceptions of risk. Risk perceptions are affected by a large number of factors, including the voluntariness of the risk, the expectation of control, the severity of the consequences, the equity of distribution of risk and benefits, and the perceived benefit itself. There does not appear to have been any adequate work done on the ranking of these factors.

Risk assessment may be broken down into risk determination, incorporating risk identification and risk estimation, and risk evaluation which is the explicit social evaluation of the risk. However, risk determination includes implicit social judgements, for example in the value of life calculation. Value judgements are also used with regard to the necessary assumptions involved in the technical estimation.

Methods of risk estimation include direct statistical estimates, modelling procedures using historical and experimental data, and risk comparisons.

Risk evaluation applies selected criteria to a project before making a decision. These criteria may be quantitative, or qualitative, or most likely, a combination of both. Examples of methods include risk comparisons, cost effectiveness of risk reduction, cost-risk-benefit analysis and combined systems.

Acceptable risk is an emotive term used to represent a level which society believes is 'good enough'. A more detailed analysis, however, suggests that risks are not acceptable, but options are. We are really talking about accepted risk. There is no such thing as a safe risk. Methods used to determine acceptable risk are similar to the methods of risk evaluation.

Risk preference approaches are used to try to measure perceived risk, which can be used as an estimate of accepted risk for risk comparisons. The revealed preference method uses statistics of behaviour to infer underlying preferences. This approach assumes that present and past accepted levels of safety are applicable to the future. The expressed preference method obtains information directly from individuals. It assumes that people fully understand the implications of the questions, and that they will behave consistently and rationally.

Risk management is often used as a catch-all phrase. More specifically it is concerned with examining the policy options with a view to decision making. Problems arise when politicians and decision makers become remote from the technical process involved in estimating the risk.

Chapter 5. Experience with risk assessment

Essential additional steps to the risk assessment process involve the implementation and communication of the chosen option, and the monitoring of the outcomes. Quantitative Risk Assessment (QRA) is the technical process of risk determination. Some form of risk assessment should be a required step for any project where there is the potential of harm to humans or the environment.

The media is often criticised for biasing reports and unnecessarily frightening the public. However, it has become increasingly obvious that the members of the public 'want to know' and do not believe that things are being done for 'their own good' unless they have the option to take part in the decision-making process. The media have a very important part to play in informing the public, and ways in which their performance can be improved need to be investigated.

The conflict between perceived risk and actual risk is often based on values rather than lack of information on the part of the public. It is only when specific interests are involved *that conflicts can be solved by means of compromise which may involve compensation or communication.*

The subjective nature of technical risk estimates must be explicitly recognised and clarified. Where estimates have been obtained by experimentation, then conditions of use in the real world must be taken account of in decision-making.

Chapter 6. *Alternative approaches to risk decision making*

The two main approaches to risk decision making are the adversary approach and the authoritative approach. These are often used in combination with a consensus approach or a corporatist approach.

Historically, the United States, Japan and West Germany have used the adversary approach, which is cumbersome, time consuming and expensive but open to scrutiny, and Great Britain and the Nederlands have used the authoritative approach which is efficient, but closed to the public.

Experience with the use of regulation versus voluntary agreements in areas where risk is involved suggest that in general voluntary agreements do not work, and that regulation is required. Regulation must be monitored.

Chapter 7. *Areas requiring further research*

Because of the increasing awareness of the problems of risk and uncertainty for humans and their environment, Further research into particular aspects of risk research which are relevant to our particular circumstances should be initiated.

Increasing public awareness and interest in projects involving risk requires that we carefully review our present institutional approach to risk in our environment.

1.0 An introduction

Risk is an important part of our everyday existence. We continually expose ourselves or are exposed to risk over which we may have little or no control. Our perception of the risks we encounter varies according to factors such as whether our exposure is voluntary or involuntary, how much control we feel we have over the risk, and whether or not we feel that the risk is 'fair'.

Increased knowledge, as well as technological and institutional changes are giving us greater control over our environment and at the same time allowing us to modify it at a much faster rate than previously. The number of risks involved is increasing and as greater knowledge does not necessarily reduce total uncertainty, the magnitude of technological and environmental risk is also increasing. Man is now able to create his own catastrophic events, without the aid of God. Thus the danger of proceeding with new projects and activities without careful examination of the possible consequences is becoming increasingly apparent. Therefore, it is important that we make greater efforts to understand the risks involved in new projects and technologies so as to avert possible future disasters.

Some of the types of risks we encounter as a society include environmental, psychological, physical, future oriented and political risk. It is noteworthy too that as well as having varying perception as to the degree of risk involved in a particular activity, individuals and groups have different perceptions if the types of risks involved.

People concerned with the study of risk include philosophers, sociologists, business managers, economists, engineers and politicians. Of these, philosophers, sociologists and economists are concerned primarily with the characteristics of risk and choice under uncertainty, engineers are concerned with quantifying risk, whilst managers desire to manage and reduce risk. Politicians and decision makers rely on information obtained from the other groups to make decisions which will in part reflect the risks involved and in part be the result of other contributing factors.

There are a number of different approaches to the study of risk which depend largely on the type of risk involved. Some of these include decision theory approaches which concentrate on the theory of choice under uncertainty and often involve specifying subjective probability functions in terms of expected values or expected utilities. Statistical risk and predicted risk measurement depend on specialised mathematical processes including systems theory, small sample statistics, reliability theory and extreme value theory. Other approaches try to measure peoples' perceptions with regard to risk using preference theory, and finally, there is a field which concentrates on attempting to quantify, in monetary terms, the value of a life. These approaches are often interdisciplinary by nature.

Risk can be incurred either involuntarily or voluntarily and may involve individuals, social groups or communities. An individual may take a voluntary risk by choosing to put the washing out on a doubtful day having decided that the likely benefits are greater than the possible cost. A community (plant, animal or human) may be put at risk involuntarily as a result of a motorway routing decision. This latter example illustrates the distributional problem where the benefits resulting from a decision will affect one group (motorists predominantly from outside the area) whilst the costs fall on another group (present users or inhabitants).

Risk has two major components: a probability of occurrence and a magnitude of loss (or gain). These two are often combined as an estimate of the value of the risk. Since the magnitudes are often noncommensurable, there is an obvious difficulty in comparing risks.

Because we cannot eliminate risk from our society, a common objective in all risk studies and analyses is the reduction of risk, or the minimisation of loss (maximisation of gain). This is particularly important when we do not know with any certainty what the effect of our choosing a risky action is likely to be. The most appropriate way to reduce risk is by improving our understanding and thus increasing our ability to manipulate situations so as to get 'good' results.

Rowe (1977) writes in the preface to his definitive book "An anatomy of risk" that his original objective was a three to four page paper on the subject of risk as an adjunct to a larger project. He found that every question posed, presupposed a further 10 questions and the 'small' paper ended up as a 200-page monograph which took 18 months to write (and was later extended to a 400-page book). My intention here was to summarise current thinking on risk and uncertainty in roughly 30 pages. My greater success (though exceeding 30 pages) will be due to basic theoretical surveys such as those prepared by Rowe (1977) and Rescher (1983), as well as a growing number of conference proceedings and short seminar reports on risk topics. These are mainly concerned with applied risk management and illustrate an increasing awareness of the problems associated with the presence of risk.

2 *About this report*

The aim or goal of this information paper is to examine the problems caused by risk and uncertainty with particular reference to public sector decision making and environmental management, for the purpose of providing a basis on which proposals can be made for a consistent set of policy guidelines regarding risk analysis and risk assessment procedures. This paper will not attempt to detail these policy guidelines but will merely provide a rational and consistent basis from which they may be derived.

Risk-related problems tend to enter the public domain when the magnitude of the potential outcome is so great that it might have possible severe or even catastrophic consequences for large land or sea areas or big population groups. These population groups may be identified by geographic, demographic or other social boundaries. Large development projects may be initiated by private enterprise but often require governmental approval before development can proceed. Obtaining this approval may involve seeking a direct political decision or alternatively, a public hearing may be required. This introduces the concept of public participation. The conflict between technological estimates of risk and the public perception of the same risk is a very important element in this area.

Many businesses incur risk on a smaller scale which does not require recourse to the public decision-making process but which may have potentially harmful effects on the surrounding environment or a particular section of the population. Difficulties occur when the population at risk cannot be identified geographically, but is associated demographically, socially, or by occupation. Uncertainty associated with the risk may not be recognised and this may lead to potentially disastrous situations. Current examples of this include the thalidomide tragedy, with its international repercussions, and the continuing arguments regarding the use of 2,4,5-T. If harmful effects do occur, then often the public becomes involved through litigation, such as in the case of the Dalkon shield law suits. The international aspects of these incidents and the difficulties and inequities resulting from the different legal and institutional arrangements in the different countries involved suggest a need for an international approach to risk management procedures.

The specific objectives of this paper are therefore:

(1) to examine the literature relating to risk and uncertainty, looking at the different approaches and attitudes taken by philosophers, social scientists, economists, engineers and private and public sector decision makers;

(2) to summarise present concepts of risk and uncertainty, paying attention to individual disciplinary goals, to provide a framework for further understanding;

(3) to briefly survey related areas such as public perception, social attitudes to risk including the value of life discussion and the insurance mechanism;

(4) to critically examine some examples of quantitative risk assessment, concentrating mainly on European and North on European and North American experience;

(5) to categorise risk assessment procedures; and

(6) to propose areas for further research.

As a basis for pursuing these objectives the following questions have been posed.

(1) What are risk and uncertainty and how can we characterise them?

(2) How do we analyse risk?

(3) How can we manage risk?

(4) Is there such a thing as acceptable risk?

(5) What lessons can be learnt from international experience?

(6) Should the Ministry for the Environment adopt a specific regulatory attitude towards risk and uncertainty?

(7) Which areas require further investigation with particular regard to the New Zealand context?

Question one is considered in Chapter three. Questions two through four are dealt with in Chapter four, and separate chapters are devoted to questions five, six and seven. The final chapter summarises the main points of the paper. An appendix contains a list of the definitions or terminology developed through the paper. This is consistent with, although not identical, to proposals made by the Royal Society Study Group (1983). It was their wish, which we endorse, to promote consistent use of terminology in risk studies and risk assessment projects.

There is emphasis throughout this report on the need for greater understanding of the risk process and improved communication between the 'experts', the decision makers, the groups who are at risk, and the public at large. A major part of risk management is concerned with conflict resolution, and this aspect has been the subject of a number of recent papers and reports by eminent risk researchers.

The prime intention behind this report is to present an overview of the risk literature as a means of providing a consistent base for the further study and proposal of a mechanism for the setting of regulations and procedures appropriate to risk management as a part of the public decision-making process in New Zealand.

3.0 What do we mean by risk and uncertainty?

There have been attempts to classify risk according to a variety of criteria. This is useful only if the classification is relevant to the intended application. Although this paper is concerned mainly with the problems of risk and uncertainty in the public area, the lessons from management and classic decision theory are useful. If we adopt the position of a decision maker, then all decisions in the real world involve a degree of uncertainty. This uncertainty may be part of the environment in which the decision is being made or it may be connected with the outcomes resulting from the actions or decisions themselves. Outcomes in this context may have financial, social or environmental implications. For any particular system under study there may be descriptive uncertainty or uncertainty with regard to the variables defining the system, and measurement uncertainty which is uncertainty with regard to the value of the variables. From this derives the information paradox that as uncertainty with respect to the variables is resolved, uncertainty with regard to valuing the variables is introduced. Similarly, reducing uncertainty does not mean that the risk will be reduced, and, as we will see later, reducing risk in one area may in fact introduce further risk in another.

The decision-making process begins with the decision that a problem exists, and in any decision-making process there will be a number of value elements about which value judgements must be made. These judgements are necessary because there is seldom a commonly accepted 'correct' approach. Rowe (1977) divides these value judgements into three groups:

(1) technical value judgements;
(2) social value judgements; and
(3) managerial value judgements.

Technical value judgements are important, since very often the 'experts' who make technical risk estimates do not recognise that these estimates are in fact value judgements because of the uncertainties and assumptions involved in their calculation. Social and managerial value judgements are more readily accepted as such because they are generally more open to scrutiny by external observers.

Often there is no valid basis for comparing or classifying different risks because we are concerned with unique events which require us to make both an estimate of the risk and a value judgement about the reliability of the estimate. Therefore we need to look for social preference information and utility estimates which measure the social values associated with the decision components. Events resulting from decisions are assigned probabilities, and behavioural patterns and attitudes towards risk affect the criteria used to select from the different possible outcomes. Two key components of the process of risk assessment are risk determination, which identifies and quantifies the risk in terms of likelihood of occurrence, and risk evaluation which estimates acceptable levels and considers methods of avoiding or controlling risk.

3.1 Distinction between risk and uncertainty

Risk and uncertainty are often treated as synonymous, however, there is a distinction which needs to be understood, even if under most circumstances it does not have to be preserved. In a decision-making context, risk and uncertainty are associated with actions and outcomes. The three basic elements of risk are:

(1) a choice of action or an exposure to loss;
(2) a negativity of outcome or magnitude of loss; and
(3) a chance of realisation or chance of loss.

Elements (2) and (3) may alternatively be referred to as the existence of possible unwanted consequences and an uncertainty as to the occurrence of these consequences. Risk can also be associated with gain, particularly in financial management concerns. In this paper we will generally refer to loss and assume that man is by nature risk averse (although we will later see that this can depend upon the certainty of the loss or gain). We can then adopt Rowe's (1977) definitions of risk: that

> *"Risk is the potential for realisation of unwanted negative consequences of an event"; and*
>
> *"Risk aversion is action taken to control risk".*

Decision analysis uses decision trees to present choices as actions and outcomes. Figure 1 shows a simple example of a decision tree with two choices.

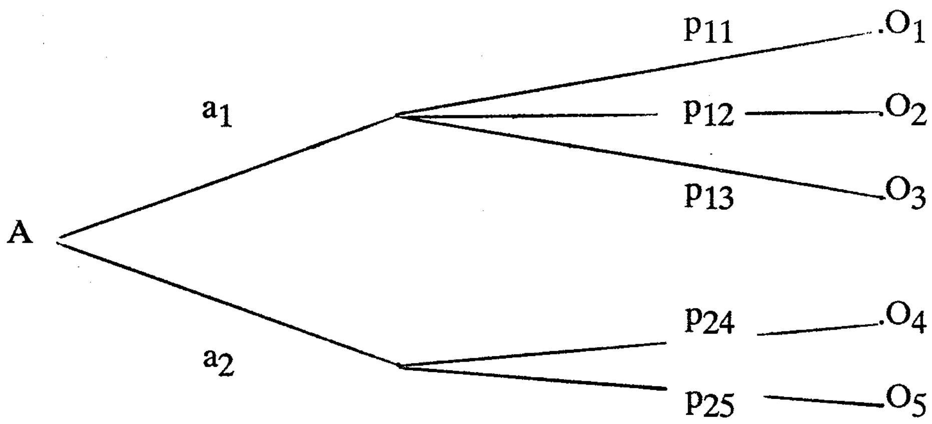

Figure 1: Simple decision tree.

A is the decision point and a_1 and a_2 are the alternative actions which may be taken at this point. O_1, O_2 .. O_5 represent the outcomes eventuating from these actions and p_{ij} is the probability of outcome j resulting from action i. For each action the sum of the probabilities is unity. In this small example the five possible outcomes are shown as being unique, however, it is possible for the outcomes to overlap so that one outcome may be able to reached from several actions.

Following Baker (1984) the characteristics of decision making under uncertainty can be summarised as:

(1) that the physical outcome (or value attached to the physical outcome) of some action is not completely known beforehand;
(2) that the uncertainty (associated with the outcome) may be affected by the action taken;
(3) that each action has an associated set of possible outcomes each with a probability or likelihood that only one of these outcomes will eventuate; and
(4) a decision is a choice between actions.

It is important to remember that the probabilities associated with the outcomes are not strictly mathematical probabilities as defined using long-run average likelihood. Mathematical probability is not relevant to one-off and behavioural situations. For example, when tossing a single die, the long run probability of throwing a four is one sixth. This relates to the expected number of fours which would be obtained over a large number of throws. This probability has very little relevance when only a single throw is being made. When we are considering much less likely events, for example the 50-year flood, where the probability estimate has been made using small sample statistics or modelling techniques, such probabilities are even more irrelevant. Therefore we introduce the concept of a subjective probability. This measures a 'strength of belief' that a particular outcome will occur. The difference between objective and subjective probabilities is referred to later in the context of defining different types of risk.

The difficulty of working with small probabilities becomes a very practical one when we are considering 'safe' dose calculations. In most cases lower limits are deduced by extrapolating from experimental data relating to higher dose experiments, because the number of experimental subjects required to test for very low dose exposure would be astronomical. Thus there is no experimental data available to confirm or refute the predictions made.

The distinction between risk and uncertainty hinges on the probabilities of occurrence. We say that a risky situation is one where the set of possible outcomes is well known and where a probability distribution for these outcomes can be agreed upon by a set of 'relevant experts' (this probability distribution may be objective or subjective). An uncertain situation occurs when either the set of outcomes is unknown (uncertainty with respect to the environment in which the decision is being made) or where agreement as to a probability distribution cannot be reached.

Some writers, including Hertz and Thomas (1983a), expand this distinction to include strategic risk and tactical risk. Strategic decision-making situations involve strategic uncertainty or uncertainty about the structure of the problem as well as its outcome, and strategic risk is therefore particularly pertinent to the public decision-making process.

Another dimension to the distinction between risk and uncertainty is that the uncertainty does not imply risk if there are no direct consequences to the individual or decision maker. Uncertainty is therefore a necessary condition for risk, but it is not sufficient and, as stated earlier, reducing uncertainty in a system does not necessarily reduce risk.

3.2 Risk versus hazard

The terms hazard and risk are sometimes also confused. Following Covello et al. (1981), hazards are threats to humans and what they value. Hazardousness is therefore a description of those threats in terms of a causal sequence of events, and risks are quantitative measures of hazard consequences. Risk identification is therefore equivalent to hazard identification. Lee (1981) defines a hazard as a situation or activity involving events where consequences are undesirable to some unknown degree and where future occurrence is uncertain. We would refer to this as a risky situation. An occupational hazard arises when conditions in the workplace put workers at additional risk, often in an indirect manner. For example, uranium mine workers in Canada who are also smokers show rates of lung cancer which are considerably greater than those of smokers in the general population. This is an interesting example of a combination of voluntary and involuntary risk.

3.3 Characteristics of risk

The three components of risk were described in Section 3.1 as:

(1) a choice of action (exposure to loss);
(2) a chance of realisation; and
(3) a magnitude of loss.

The first of the three components concerns the alternatives that risk may be voluntary or involuntary. Individuals and groups voluntarily take risks, often without explicitly recognising that they are risks. Economists are generally not concerned with the choices or preferences expressed by these actions. They use the theory of choice as a tool in exploring other aspects of welfare economics, for example. Behavioural scientists, however, are interested in the choices and attitudes, and use questionnaires to elicit information on individual and group behaviour. Involuntary risks occur when an individual or group is put 'at risk' or exposed to risk by the action of other groups or individuals. Other elements of exposure include whether the population at risk is delineated locally (regionally), globally, demographically, statistically (randomly) and whether the risk is continuous, time dependent or cumulative in nature. Very often, the likely benefits resulting from a risky action will fall to one group while the costs are borne by a separate group. Attitudes towards risk depend a great deal on whether a risk is voluntary or involuntary, and also, whether or not the risk is seen to be fair.

The chance of realisation is the probability that the event will occur, or the measure of the risk. As seen in Section 3.1, the distinction between a risky situation and an uncertain situation depends on the amount of information available about these probabilities. In general, we are concerned with uncertain situations since this type of situation is characteristic of environmental management problems. This is expanded further in Section 3.4 which discusses the type of risk, which is dependent upon the derivation of the probabilities.

The magnitude of loss represents a quantification of the different outcomes as shown in the decision tree in Section 3.1. This quantification may represent possible dollar loss in a financial or business situation, or at the other end of the scale it may represent the number of lives lost as a result of a chemical plant explosion. Rescher (1983) lists the determinants of the magnitude of the negativity (in terms of philosophical risk) as:

(1) character;
(2) extent; and
(3) timing.

Character refers to the type of loss: financial, environmental, injury or death, political etc. The extent of the loss is concerned with whom the loss is likely to affect, and the size of the loss. This includes specifying who or what is at risk, how big this group or population is, and whether it can be uniquely identified. Finally, examining the magnitude of a negativity involves determining when it is likely to occur, and its likely duration.

Assessments of magnitude are not value free. Often we do not know what the potential effects are likely to be, and subjective judgements will be required. Attempts to compare risks need to take careful account of all these elements of the magnitude of the loss, and not merely the apparent negativity. For example, road accidents may claim 10 lives over a holiday weekend, and a mining accident at the same time may result in 10 deaths. The magnitudes of the two risks (driving that weekend and working as a miner) are not the same. Measurements of magnitude should include full information as to character, extent and timing.

Naive risk estimates often ignore any attempt to quantify or evaluate the magnitude of the risk. Catastrophic risk is described as occurring when the probability of the outcome is very low, but the magnitude of the possible consequences is very great. An example of this is the risk of a nuclear power plant explosion in a heavily populated area. When there is considerable uncertainty regarding the probability estimates, then the magnitude of the outcome assumes greater importance in evaluating the total risk.

MacCrimmon (1986) suggests that as well as the three components of risk which we have been discussing, there are three determinants of risk: lack of control; lack of information; and lack of time. He further suggests that if we had complete control of any one of these determinants then we would be able to choose the best outcome without risk. The objective in risk management is therefore to improve our knowledge and control of a situation so as to reduce the inherent risk. Although MacCrimmon's particular application relates to business management, the principle is of general applicability. There can, however, be a dangerous fallacy in the control determinant. Often we have an illusion of control which is not borne out by subsequent events. This is particularly evident when voluntary risk (which financial risk is generally characterised as) is involved.

3.3.1 *Quantification of risk and decision criteria*

Figure 2 shows the decision tree of Figure 1 with sample numbers replacing the probabilities and outcomes.

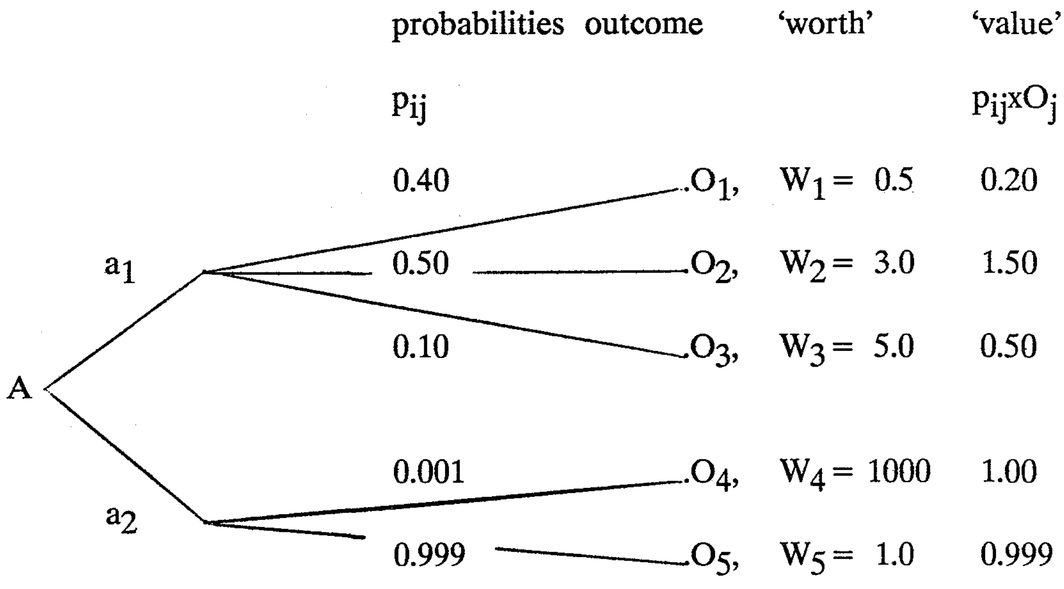

Figure 2: Quantification of risk.

W_1 to W_5 are numbers representing the 'worth' of outcomes O_1 to O_5. A 'value' for each outcome can be calculated as p_{ij} multiplied by W_j. In this example the 'worth' and outcomes are all positive, representing gain. It has been presented in this way because it is more typical of managerial decision-making problems, and also because the criteria used to measure success are more easily understood in these circumstances.

Decision analysis uses a number of different criteria for measures of success (Baker, 1984) for each possible choice. The simplest of these criteria is maximisation of the expected value. The expected value for each action is calculated as:

$$EV(a_i) = \sum_{i} p_{ij}W_j$$

The expected value for Action 1 is +2.2, and the expected value for Action 2 is 1.999. Therefore, the maximisation of expected value criterion which uses long run average results would select Action 1.
Examples of some other commonly used criteria (Daellenbach et al., 1983) include the maximax criterion which selects the action with the highest payoff regardless of which event may occur (that is, no probabilities are required), and the maximin criterion which selects the action maximising the lowest possible payoff (similarly no probabilities are required). In this example, both the maximax and maximin criteria would select Action 2.

These criteria are associated with the decision maker's attitude towards risk. Maximisation of expected value is a risk neutral criterion, whilst maximax is risk prone and minimax is risk averse. Looking at our example, the maximum 'worth' for Action 1 is 5 and the maximum for Action 2 to 1000. Therefore the maximax criterion selects Action 2. The minimum 'worth' for action 1 is 0.5 and for Action 2 it is 1.0. Therefore the maximin criterion selects Action 2. This rather contrived example is interesting because both criteria select the same action.

Concentrating on Action two, the difficulty of using a single figure to represent a value of risk is seen. Multiplying the probability and the worth for Outcome 4 we get a value of +1. The similar value for Outcome 5 is +0.999. However, the character of each outcome is quite different. Outcome 4 has a low probability of occurrence, but a very high worth. Outcome 5 has a high probability of occurrence and a low worth. This shows one of the major limitations of the expected value criterion which cannot distinguish between the two cases.

This example can also be worked with negative outcome values. This would be more representative for an example where risk to health or the environment was concerned.

3.4 Types of risk

How do we measure risk in the real world? Several authors describe the different ways in which risk may be measured. The best description is given by Starr et al. (1976). They define four measures of (future) risk.

(1) Real risk: determined eventually by future circumstances when they develop fully.

(2) Statistical risk: determined by currently available data, typically measured actuarily.

(3) Predicted risk: predicted analytically from systems models structured from historical data.

(4) Perceived risk: seen intuitively by individuals.

Statistical risk and predicted risk are often called objective estimates whereas perceived risk is known as a subjective estimate or sometimes, a personal probability. The differences between these types are quite subtle. Both statistical risk and predicted risk are derived from historical information. The difference is that statistical risk is based on observed frequencies which can be evaluated by normal statistical means whereas predicted risk is a theoretical probability valid only to the extent that the model from which is has been derived is able to be validated. They are both 'objective' probabilities and can be challenged as being irrelevant in one-off situations.

Real risk is often never able to be evaluated. It can only be determined in the future if the risk is well defined temporally. This temporal element is very important in any form of risk analysis since risk is inevitably oriented towards the future. Perceived risk is a 'subjective' measure of risk. Commonly, perceived risk and predicted risk will represent maximum and minimum estimates of real risk with statistical risk lying somewhere in the middle.

The distinction between 'objective' and 'subjective' risk estimates will be explored further later in this report. It is, however, very important to remember that our so-called 'objective' estimates often contain considerable subjective bias as a result of lack of raw data and the need for assumptions in the estimation process. We have already mentioned this connection with the area of technical value judgements.

Starr et al. (1976) use air transportation to illustrate the difference between risk types. Restating his example in a New Zealand context, the travel insurance company calculates the statistical risk of flying using recorded events and numbers of people flying, the passenger makes his own perceived risk estimate which is quantified when he selects the amount of insurance cover he wishes to purchase, and the air traffic controller uses models to estimate predicted risk.

It is important to preserve these distinctions so that risk analysts are aware of exactly what type of risk they are concerned with. An example of possible confusion in terminology occurs when risk analysts use the term 'actual' risk. This usually means a statistical measure of risk. It is not real risk as defined here because it is measured in the past. For example, the actual risk of a ski-ing injury could be measured as the total number of injuries in a particular (past) year divided by the number of skiers in that same year. It is relevant only to the specific period for which it has been calculated. If this measure of risk is used to predict the number of accidents likely to occur in the future then it becomes statistical risk, not real risk. Some analysts use

the term actual risk as if it were synonymous with real risk (which in this case would be the fraction of injuries occurring in the current year, which can only be measured after the risk has been incurred).
Statistical estimates of risk are used when there are sound statistical data available for the particular event being studied. In this way, we can make reasonable estimates of the risk to the child from a mother smoking during pregnancy (using long run average frequency estimates). The difficulties arise when, for example:

(1) the historical data being used is not sufficiently specific for the purpose for which it is being used;
(2) the data does not cover a sufficiently long period;
(3) the estimate obtained is applied to a different population to that from which it was derived; or
(4) the probability of occurrence is very low.

These problems are well known to statisticians, however, unfortunately the statistics are still often misused. When these inadequacies are recognised, predicted risk estimates obtained by systems modelling can be used. These estimates require additional subjective assumptions to be made.

Very small probabilities pose considerable difficulties when estimating risk, particularly when they are combined with potentially catastrophic outcomes. The classic example is the risk of a nuclear power plant accident. The probability of the occurrence is very small, but the hazard is immense. Statistical measures are inappropriate, because historically there have been very few occurrences.

Risk estimates for this type of eventuality can be made using predictive models and reliability data. Event tree and fault tree analyses are used to determine possible ways of breakdowns occurring, and reliability statistics are used to evaluate the sequences, and predict risk of failure. Historical data in the form of reliability figures are the basis of the estimates. This type of modelling involves evaluating all possible events and outcomes, including complex interactions between subsystems. There is always considerable uncertainty involved because of the difficulty in ensuring that all possible outcomes are considered, and because of the difficulties in incorporating the possibility of human error, which to date is the most common cause of such failures.

Some risks are considered to be so small that they are called 'effectively zero risk' and are treated as being negligible. The difficulty is in determining what level of risk can be treated in this manner. Unless the magnitude of the outcome is also small, we must be very sure of the accuracy of the risk which we label as being effectively zero. Statistical risk estimates have poor reliability in cases where events are of very low occurrence. Therefore predicted risk estimates are generally used. These are based on subjective judgements and assumptions which must be carefully evaluated before the effectively zero risk judgement can be made. This judgemental aspect of risk decision making is considered in more detail in Section 4.4.

Even so called objective risk estimates are not necessarily consistent with one another. Two experts using the same base information can arrive at quite different estimates of risk for a particular risky action. This can be a common occurrence. Some of the reasons for this are: that all the relevant data may not be available and may have to be estimated; there may be moral and ethical differences in the attitudes of different analysts which will affect the assumptions made; and estimates will vary according to who is likely to be affected.

3.5 Risk factors

Freedman (1987) introduces the concept of a risk factor as "something which causes a risk". His example is smoking, where the action of smoking is the risk factor and the chance of developing lung cancer is the risk incurred. In our terminology the hazard is lung cancer. This distinction is quite consistent with the definitions of risk used in this paper and adds depth to the concept of risk as a probability of occurrence and a magnitude of outcome. The recognition of risk factors is particularly useful later when we discuss acceptable risk and risk thresholds.

4.0 Approaches to risk - what is risk analysis?

Chapter 3 has provided an introduction to the more practical aspects of risk analysis. Chapter 4 uses the background material of Chapter 3 as a basis for exploring practical risk analysis. The first section in this chapter looks at risk perception. Risk perception is not only concerned with 'perceived risk' which we have mentioned in Section 3.4, but with all aspects of individual and group perceptions of risk. The factors relating to perceptions of risk are particularly relevant to the applied areas of risk assessment and risk management, which are considered later in this chapter.

Risk perception is also a key element of any attempted evaluation of acceptable risk. Acceptable risk problems are decision problems because they require choices between different courses of action. They are also value laden, involving trade-offs between a variety of considerations concerned with societal well-being.

There is some difficulty in deciding how to group the various topics in this chapter. Risk perception is described first, because it is important to our understanding of all areas of risk analysis. We must be constantly aware that perceptions of risk vary according to the source of the risk, and the identity of the risk taker(s) and the individuals or population put at risk. This must be accounted for during any evaluation of risk. There is a clear distinction between the various aspects of risk assessment which is both useful and important. Whilst the component parts can be usefully separated, they must all be present for meaningful risk analysis. We can use the distinction to analyse the respective roles of the analyst and the decision maker.

A major part of the risk assessment process, and in particular risk evaluation, is concerned with acceptable risk. There is considerable controversy regarding some of the calculations which have been used in this field. Some analysts believe that there is no such thing as acceptable risk, but only accepted risk.

Risk management is an even less well-defined area. Theoretical risk management is concerned with examining policy options and setting and using decision criteria to determine the 'best' proposal. Practical risk management considers the results of such decision analyses in view of social, political and cultural realities. An integral part of risk management should be the implementation of the selected option along with the constraints placed on the process by the evaluation procedure. Most projects which have been the subject of quantitative risk assessments also require extensive monitoring and control. The risk assessment should therefore include details about the way in which this monitoring is to be done, who is responsible for it, and allow for flexibility in the implementation process as new information becomes available.

4.1 Risk perception

The variance between perceived risk and actual risk has been the subject of a large number of books and papers, mainly as an introduction to the problem of assessing risk. The distinction is sometimes made as being between 'subjective' and 'objective' probabilities. Although the emphasis in these studies is on risk perception there has in some cases been a notable misconception regarding the definition of actual risk. Referring to Section 3.4, there is a clear distinction between real risk (which usually cannot be measured) and the two so called objective estimates, statistical and predicted risk. Actual risk is often used as though it means real risk, whereas, in fact it is itself an estimate only, with its own judgements and values attached. The use of this term "actual" biases the reader towards the impression that it is real risk. We will therefore try to avoid using the word actual as a descriptor. When it is unavoidable the term "actual risk" is used as a substitute for statistical risk, with the implication that it has been measured in the past.

Perceived risk is the individual or group, judgement or valuation of the magnitude and likelihood of the possible 'bad' outcomes which may result from an action. Our willingness to take a risk is measured by the subjective probabilities which we place upon the alternative actions and our judgement as to the possible magnitude of these outcomes, which depends upon the environment in which the actions are taken.

Slovic et al. (1980), Griffiths (1981) and Covello et al. (1981) list some of the factors which affect our perceptions of risk probabilities and outcomes.

They can be summarised as:

(1) whether the risk is voluntary or involuntary;
(2) whether the consequence is likely to be immediate or delayed;
(3) whether the subject is familiar or unfamiliar with the risk;
(4) whether the risk is known to science or not;
(5) what measure of control over the risk the subject has;
(6) whether it is a 'new' risk, or whether it has been previously experienced (not necessarily directly);
(7) whether the effects are chronic, cumulative or catastrophic in nature;
(8) whether the consequences are common or dread;
(9) the severity of the consequences;
(10) the size of the group exposed to the risk;
(11) the distribution of the risk - is exposure equitable;
(12) the effect on future generations;
(13) the degree of personal exposure;

(14) the global catastrophic nature of the risk;
(15) the changing character of the risk;
(16) whether there is seen to be any easy way of reducing the risk;
(17) the availability of alternatives;
(18) the necessity of exposure;
(19) whether the hazard is encountered occupationally;
(20) whether it affects 'average' people;
(21) whether there is likely to be misuse; and
(22) whether the consequences are reversible.

There is uncertainty associated with most of these factors. They may reflect the perception of the risk taker or the individual or group at risk. It is our perception of these factors which affects our estimate of the risk.

Often people's risk perceptions are not borne out by accident statistics. For example, few of us consider driving across a railway line as dangerous, but a surprising amount of accidents occur on railway crossings. In the United States attempts to increase voluntary usage of seat belts has consistently failed despite evidence showing increased chances of survival in the case of accidents. People have an 'it wouldn't happen to me feeling'. On the other hand a number of people have a particular fear of high places, and go out of our way to avoid them in disproportion to the statistical risk involved.

Some studies, generally using psychological research methods to elicit perceptions have shown good agreement between perceived risk and statistical risk (Lee 1981; Thomas, 1981), in particular cases where the subject is asked to scale hazards and magnitude of severity. The main factor in this apparent contradiction appears to be the subject's perception of his or her degree of personal involvement.

Fischhoff (in Covello et al., 1981) lists six reasons why disagreements occur between the public and the experts:

(1) the distinction between 'actual' and 'perceived' risk is misconceived;
(2) lay people and experts are talking different languages;
(3) lay people and experts are solving different problems;
(4) debates over substance may disguise battles over form and vice versa;
(5) lay people and experts disagree about what is feasible;
(6) lay people and experts see the facts differently.

We have addressed the first of these already. Fischhoff himself, however, is not particularly clear as to the distinction. Reasons (2) and (3) are questions of information. If the public and the experts can inform each other then the expectation is that the gap between the perceived risk and the statistical or predicted risk will narrow. This is only possible, however, if the conflict is caused by a lack of knowledge.

If the conflict results from different value systems, then we come to the fourth reason which suggests that the problem is that lay people and experts may not want to understand each other: this relates to Reason 5, that they disagree as to what is feasible and to Reason 6 that they see the facts differently. Certainly, the literature enforces the opinion that the two sides may in general not want to be reconciled.

There is a notable feeling of smugness in a number of articles and reports by industrialists claiming that they are adequately informing the public and that the problem is that the public really does not know what is good for it. On the other side, lobbyists may not accept the information that they are being given on the grounds that they have been misinformed in the past. It is futile for both sides simply to present their view of the 'facts' and expect the other side to accept it. They must be prepared to discuss and analyse the situation together to find common ground. Unless there is willingness to co-operate then nothing will be achieved. Conflict resolution is discussed more fully in Section 5.2.

Griffiths (1981) uses the Windscale Inquiry in 1977 as an example of a circumstance where the participants were not discussing the issues on the same basis. He suggests that the discussion should have been about values, not facts, since the 'facts' were not incontrovertible.

Public perception may also vary as to the type of risk incurred by a particular activity. Thomas (1981) reports the results of a survey regarding nuclear power production. This survey showed that people whose declared attitude was pro-nuclear power felt that the risks associated were physical and psychological only. People who were against nuclear power felt that it also imposed environmental, future oriented and political risk. Whether the perceptions affected the attitude or vice versa is not known.

Differences in risk perceptions do not just relate to the risk estimates themselves. There can often be disagreement as to the role of the risk analyst in the decision-making process. Engineers and technologists view their task as the examination of a particular project or system. Their objectives are to understand the system, to find likely performance and failures of the components, to question the assumptions and to identify the weak parts by formal analysis (e.g. event trees and fault trees). Their analysis is project oriented. They are not directly concerned with the consequences of an action and they generally avoid making value judgements. Unfortunately, they are sometimes placed in the position where they are required to answer questions concerning the 'value' of a project, which is beyond their professional competence. When this occurs, there can be difficulty in separating the objective and subjective parts of their evaluation.

There is no general method for dealing with the differences between perceptions and technological judgements. Society's inputs are perceptions and values which are made visible through the political system, the legal system and the public's willingness to pay.

People respond to the hazards they perceive and even when there is good statistical data available, subjective judgement is needed to interpret the estimates and results and to evaluate their significance (Slovic et al., 1982). Understanding the factors that contribute to risk perceptions is therefore crucial to effective decision making.

4.2 Risk assessment

The aim of risk assessment is the choice of 'good' actions, and as such it is a decision-making problem. As our ability to alter our environment through technological change increases, the necessity for better assessment of the risks inherent in this new technology increases. There is a tendency to assume that this ability to alter our surroundings also implies an ability to control. This is not necessarily the case, and this perception of control can be dangerous if it is not acknowledged appropriately. Thus, there is increasing need for careful analysis and assessment of the risks and uncertainties introduced by new processes which must be weighed against the benefits introduced.

This risk assessment or risk analysis as it is sometimes termed, is the process of identifying the risks involved in a particular activity or system, and evaluating the risks in terms of their societal acceptability. Figure 3 shows one way of illustrating the components of risk assessment.

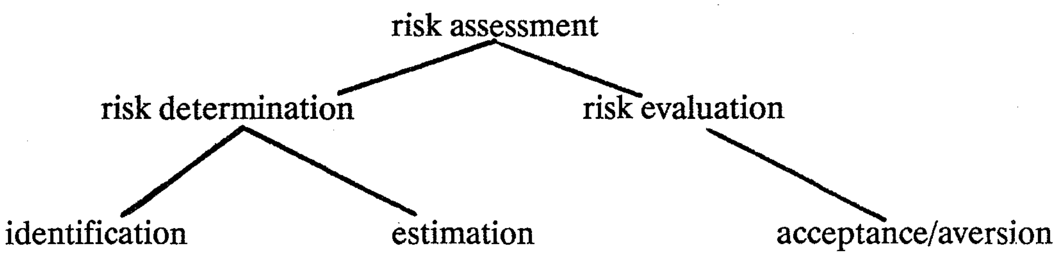

Figure 3: Components of risk assessment.

In similar terms, Lowrance (1976) describes risk assessment as defining the conditions of exposure (who), identification of the adverse effects (what), relating exposure to effect (how much), and finally, estimating the overall risk.

Risk determination consists of the identification of all possible outcomes and their quantification in terms of probability and magnitude. In general, scientific and technological means are used to estimate the likelihoods (probabilities) and magnitudes of occurrence. There is often, however, considerable uncertainty involved in the specification of the consequences and in their valuation.

Risk evaluation is sometimes called social evaluation (Kates, 1978) as it is concerned with society's behaviour, as manifest in the collective behaviour of individuals, and society's attitudes towards risk. Examination of this topic involves further mention of the theory of choice under uncertainty. Social evaluation techniques include benefit-risk and cost-benefit procedures. From this emerges the concept of 'acceptable risk', and the setting of acceptable risk levels or risk thresholds. In this paper we have separated the two areas of risk evaluation and the determination of acceptable risk because of the value-laden nature of the second topic. Risk evaluation is concerned with analysing the risk in terms of its probability and magnitude. The methods of risk evaluation may require recourse to 'acceptable risk' levels, however, they are not themselves concerned with the calculation of these levels.

Figure 3 shows risk determination and risk evaluation as separate entities. They are often treated independently, largely because their application requires different skills. However, risk assessment is a process, and any particular risk analysis must consist of a progression from identification to estimation and finally evaluation. As Griffiths (1981) suggests, it can be beneficial to differentiate between the "objective process of risk quantification and the essentially subjective interpretation of the significance of estimated risks". However, the two components as described here are incomplete without each other. Risk assessment can also be considered as an iterative process, with new information about the system derived from the evaluation phase being used to reduce the uncertainty inherent in the identification and estimation phases.

This process of risk assessment is not complete, however, unless the further steps of implementation are considered. These include communicating the results of the risk assessment to the decision makers, the affected parties, and the public at large as well as ensuring that proper controls are in place for the putting into practise and control of the selected options. This control may consist of a constant monitoring process or simply a one-off check that the restrictions imposed by evaluation are adhered to.

The objectives of 'good' risk assessment as applied to physical engineering risks are summarised by Farmer (1981) as potential benefits:

(1) to understand the system;
(2) to find likely performance and failures of various plant items;
(3) to question assumptions with particular regard to complex phenomena; and
(4) to identify weak points by formal analysis.

These objectives are equally applicable to other forms of risk that we are concerned with in this paper such as environmental, managerial and political risk. The first of these is particularly relevant. It emphasises the importance of risk identification, which is often overlooked. Unless there is careful attention paid to this initial step, then there is a real danger that the system which is 'understood' may in fact not be the system which is under study, in which case the most careful estimation and evaluation processes are meaningless.

4.2.1 Risk identification

Risk identification is the process of analysing the available alternatives and identifying all source of risk, or all possible outcomes or consequences which may result from each particular action. It involves the consideration of the causes or origin of the risk and the individuals or population at risk, as well as the definition of the conditions of exposure to the hazard. In many circumstances, there may be considerable uncertainty involved with the set of outcomes. The objective of identification therefore must be to carefully examine all possibilities of harm regardless of the likelihood of occurrence.

In many cases the process of identifying the risk is closely linked to the process of estimation in that the method used for estimation may be an extension, or simply a quantification, of the method used for identification. Lowrance (1976) lists a number of factors which are used in both identifying and quantifying risks. They are:

(1) traditional or folk medicine;
(2) commonsense assessment;
(3) analogy to well known cases;
(4) experiments on human subjects;
(5) review of inadvertent and occupational exposure;
(6) epidemiological surveys;
(7) experiments on nonhuman organisms; and
(8) tests of product performance.

These factors are all commonly used in industrial situations to identify which risks are likely to be present or result from the procedure being investigated. Other common approaches include the setting up of scenarios, and the Delphi approach to group study and consensus decision making.

In assessing the chance of failure in the construction of systems such as chemical processing plants, technologists commonly use event tree and fault tree analyses to examine and later quantify all possible routes to failure. This is in fact a scenario approach to risk identification, since although the objective is to examine all possibilities, in practice it is likely that some options will be either overlooked or ignored. Although not perfect, it is a careful systematic approach which arguably can be easily applied to a wide variety of situations. A detailed description of this type of analysis can be seen in Barlow et al. (1975). Further examples of specific methods can be found in Lees (1980).

Here also, the identification and estimation phases are closely linked. This emphasises the need to 'get it right' in the first place (the identification). Additional information can be gained by use of iterative procedures which use knowledge acquired during the evaluation of the risk to reduce uncertainty present in the identification phase. This approach is valuable, though it often leads to greater uncertainty by the introduction of new variables and control factors.

There are a number of factors related to risk perceptions which introduce uncertainty into the identification process. These include the possibility of human error, the difficulty in predicting the behaviour of complex systems, overconfidence in current scientific knowledge, and incomplete knowledge of the likely effects of actions which cannot be tested easily. The dynamic nature of risk introduces uncertainty. As people's attitudes and expectations change, their perception of what constitutes a hazard changes also. Education and greater availability of information are important factors here.

Risk identification is therefore not as objective as we would sometimes like to think, since the process of identification depends upon subjective evaluations of what constitutes a risk. It is in this area that 'experts' and lay people often have the greatest difficulty in resolving disagreements.

Starr et al. (1976) group methods used to identify risk into three categories which can be summarised as "empirical evidence, statistical inference and postulation based upon a transfer of experience or the laws of nature". Risk identification is perhaps the most important part of the risk assessment process because of the dangers due to uncertainty if consequences are discounted or ignored. It is itself a decision making process with choices offered as to whether or not a risk needs to be included. There is no general process which can be followed for all problems, though experience can provide guidelines. The route which involves the greatest uncertainties is that described as "postulations based upon the transfer of experience". This method must be employed when there is no formal historical experience offering guidelines. Where new potential risks are involved, there is a temptation to discount them as negligible because of this lack of experience. The effectively zero risk problem has been mentioned previously. When combined with potentially catastrophic outcomes, then the magnitude of the risk becomes very great. Therefore, it must be emphasised that during the identification phase, all possible risks must be included.

4.2.2 Risk estimation

The process of risk estimation has two parts. Firstly, there is the process of estimating probabilities or likelihoods for each of the possible outcomes or consequences, and secondly there is the problem of determining consequence values.

Once the set of possible outcomes has been identified, the process of attributing probabilities to these outcomes is often a fairly mechanical task. This is the "objective phase", where, whenever possible, statistical probabilities are used. Where it is not possible to obtain these, predicted risk estimates are calculated. We have already discussed the main differences between these estimates. An alternative approach to obtaining risk estimates, where no historical or experimental data are available, is to use risk comparison procedures. This is similar to the 'experience transfer' method of risk identification except that quantitative methods are employed. Risk comparison involves attempting to find an equivalent risk which is quantifiable, and applying the same probability of occurrence to the unknown risk.

We have classified an uncertain situation as one where a group of 'experts' cannot agree about the relevant probability estimate to apply to an event. The use of the term 'experts' implies some specialised knowledge relating to the event. Because of the uncertainties involved in risk estimation it is not uncommon for different 'experts' with similar specialised knowledge and using the same base information to arrive at different conclusions regarding a specific risk. This highlights the point that the 'objective' probabilities obtained from historical data are not absolute, and reflect the perceptions of the person making the calculations.

It is possible too that the public may perceive these risks in an entirely different light. If public participation is part of the decision-making process, then the divergence between the perceived risk and the estimated risk may be crucial. Therefore it is important that the process involved in the quantification of the risk estimates should be presented in a form that is generally comprehensible. If that is not possible because of the technical nature of the estimates, then the assumptions made in reaching those estimates should be readily available. The credibility of the 'expert' and the decision-making process is at stake.

This applies also to the estimation of the magnitude of the outcomes, where similar techniques are used for the estimation process. As Starr et al. (1976) state, the two processes of estimating probability and outcomes are not completely separable as the degree of harm involved in the outcome often influences the implicit and explicit perceptions of the probability, and vice-versa.

Methods of risk quantification are often refinements or extensions of the methods used to identify the risk. These approaches include quantification of the factors attributed to Lowrance in Section 4.2.1 as well as reliability and failure analyses, event and fault tree analyses and consequence modelling (Royal Society, 1983). One of the primary requirements for the effective use of some of these techniques is the availability of 'good' data: that is, reliable and robust data. There are currently a number of excellent reliability data banks available, with data relating to specific component failure as well as complex combinations. Such material, however, is not necessarily immune to misuse. It is important that the risk analysis remains sufficiently flexible that the 'expert' is able to revise the approach used, and does not get locked in to an inadequate description of the system being studied.

In Section 3.3.1 we discussed the quantification of risk without mentioning the units used to measure risk. Because the decisions involved usually require some form of risk-benefit, cost-benefit analysis it is often necessary to quantify as many as possible of the factors in monetary units. Since risks are commonly measured in terms of number of injuries or deaths per unit head of population at risk, there is considerable pressure on the risk analyst to provide estimates of the value of specific injuries and the value of life. This is also an integral part of risk-benefit analysis. As a result, a considerable body of literature has been developed on the 'value of life' discussion.

The ways of measuring the probability of individual risk include estimating:

(1) the number of deaths per population at risk;
(2) the number of deaths per unit measure of the activity;
(3) the loss of life expectancy (using life tables and demographic data); and
(4) the calculation of frequency versus consequence lines derived from statistical records.

All of these approaches require the availability of extensive, reliable, and relevant statistical information. As mentioned earlier such data is often not available in the required form and deductions and inferences are made.

An important part of a number of risk estimation processes involves making estimates of the value of a human life. These calculations require good statistical information and commonly used methods include making estimates based on;

(1) insurance premiums;
(2) court decisions;
(3) human capital, in terms of discounted future earnings;
(4) personal risk, measured in terms of willingness to accept compensation for increased probability of accident; and
(5) implicit societal measures estimated in terms of the amount spent in the past to avoid accidents.

McCormick (1981) suggests that insurance premiums are unreliable because insurance is designed to compensate the survivors, rather than reduce the probability of an accident. The usefulness of court decisions suffers because there is divergence and considerable inconsistency in the amounts determined. The human capital approach is socially inequitable because it does not take social value into account. It also requires using past data to predict future events. The difficulty with the personal risk approach is that the individual is assumed to know accurately the level of risk involved in an activity and be willing to accept an appropriate 'margin for risk'. In cases such as asbestos it has been seen that individuals cannot know this. Lack of appropriate data is the limitation in the implicit societal method. Estimates are made of the number of lives assumed to have been saved by safety actions in the past, and this is balanced against the cost of these measures. There is obvious inconsistency in this approach since examples ranging from very low cost measures to extremely high cost measures can be selected. Also, as McCormick points out, these measures refer to decisions made in the past which may not have been optimal in themselves. This field remains highly controversial.

Estimates of perceived risk are also important in the risk estimation process. Sometimes they are used explicitly, and sometimes they are used implicitly in circumstances where the analyst may not recognise the subjectivity of the approach. Tversky and Kahneman (1982) discuss three heuristics that are commonly used to assess probabilities and predict estimates for these probabilities. These are:

(1) representativeness, where a person or event is placed within a scale according to his or her (perceived) characteristics;
(2) availability, where an estimate is made on the basis of recalled instances and occurrences; and
(3) adjustment and anchoring, where an initial estimate is amended as increased information becomes available.

Examples of ways these heuristics are used come to mind easily. We all use our own experience to make our own risk estimates. What we do not recognise often is that our estimates are biased as a result of selectivity in that experience, and the way in which we apply the heuristics. Experts also employ these heuristics, resulting in selectivity of statistical results, hence reducing their objectivity.

As we have mentioned previously, risk estimation does not mean the mere provision of a simple numeric representing the consequence in terms of possible lives lost, number of injuries or land area contaminated etc.; the other factors including temporal and spatial distribution of costs and benefits must be included. This form of social accounting which has often been ignored in the past, needs to be considered when we proceed to the next stage of the risk management process: risk evaluation.

4.2.3 Risk evaluation

Risk evaluation has already been called a subjective assessment as opposed to the objective estimates of risk determination. However, it has also been shown that the so-called objective estimates often contain substantial value judgements. Risk evaluation is an evaluation of the significance of the estimated risk (Griffiths, 1981), or an attempt at a reconciliation of technological and social systems.

Looking at risk analysis in a decision making context, risk evaluation is the step where selected criteria are applied to a project before making a decision about whether it should proceed or not. The criteria used in this context can be either purely quantitative, such as those introduced briefly in Section 3.3.1, or partly or wholly qualitative, depending upon risk perceptions.

Rowe (1980) in "Society, technology and risk assessment" (ed. J. Conrad), classifies methods of risk assessment into four groups. These are:

(1) risk comparison methods;
(2) cost-effectiveness of risk reduction;
(3) cost-risk-benefit balancing; and
(4) meta-systems.

Fischhoff et al. (1980) use a similar classification for methods of determining acceptable risk. Risk comparison approaches compare the risk under study with other risks, benchmarks, or criteria to determine an 'acceptable' level of risk. In general maximum levels of acceptable risk to both individuals and groups are set, and the 'new' risk is compared with these. The main differences in these methods depend upon whether 'actual' risk or 'perceived' risk estimates are used. Early approaches to risk comparison involved primitive comparisons with other risks in society. Starr (1969) made the first attempt at a statistically-based approach. Later approaches have expanded upon his work and introduced other methods including measurements of social response. This will be discussed further in Section 4.3.

The cost-effectiveness of risk reduction approach compares the value of the risk with the cost of reducing the risk. Rowe lists four factors that have been used to define possible actions for reducing risk. These are: technology limits, the value of the lives saved, pure economic factors, and economic plus other incentives. There is considerable literature examining the 'value of life' discussion which has already been mentioned, and which will be further discussed in Section 4.3.3.

The cost-risk-benefit balancing approach involves the weighing of all direct and indirect costs against all direct and indirect benefits. The difference to the cost of risk reduction is that in that case only direct costs and benefits are considered. The difficulties of this type of approach are well understood. The main limitations include the problems of non commensurate scales, distortions due to aggregation, and equity problems relating to the distribution of the costs and benefits.

Rowe's final class is meta-systems, where combinations of approaches are used. He develops one example of this approach and also presents some examples of current usage.

The discussion following Rowe's paper (Conrad, 1980) concurred that Rowe had managed to cover most currently used approaches. There was a suggestion

(Jennergren, L. Peter, 1980) that although these approaches were all in common use, there was considerable disagreement as to their efficacy and applicability. This was in fact foreseen by Rowe who, in his summary, proposed that "it is evident that no single method or process works in all situations. It may well be that the process of risk assessment itself is more important than the method or particular approach used. The visibility of the process and the explicit attention given to all aspects of assessment may be the only underlying paradigm".

Von Winterfeldt (in Conrad, 1980) replied by proposing a set of hypotheses for what should be done in the form of requirements for 'good' risk assessment. (In all cases, by using the term risk assessment these authors are referring primarily to what we are calling risk evaluation.) These are:

(1) for whom is the risk assessment (evaluation) being done, and for what purpose;
(2) risk assessment should be used for specific institutions and ends rather than for purely information purposes;
(3) risk assessment should be seen to be part of a comprehensive analysis, rather than a separate approach; and
(4) decision making with regard to problems involving risk needs to be adapted to the political and institutional requirements of this process.

These proposals are consistent with the benefits of 'good' risk assessment as described by Farmer (1981) and included in Section 4.2, and thus there is general agreement that no one method of risk evaluation is valid for all applications. However, in a regulatory environment it may be desirable that a general approach be adopted. If this is required, then these 'factors' should be considered in defining the approach.

4.3 Acceptable risk

> "It should be a crime to represent nuclear sites as hazardous sites, a crime to represent our good friends and colleagues in industry as being wicked people who simply want to poison us, blow us up or assume they can go ahead with their industry with total disregard to the benefits of the public."
>
> C.W.F. Fairfax, North Western Regional Health Authority (Scientific and Technical Studies, 1981).

Fischhoff (1978) defines acceptable risk in the following way:

"The acceptable level is the level which is 'good enough', where 'good enough' means that you think the advantages of increased safety are not worth the costs of reducing risk by restricting or otherwise altering the activity."

The Royal Society Report (1983) suggests that this definition has been implicit in government and industry in Britain for a long time, but that recent advances have resulted in attempts to quantify and publicise acceptable risk. As an alternative definition they propose that acceptable risk is based on the assumption that "there is a non zero level of probability of occurrence of an accident below which the public as a whole is willing to accept the risk; at this level there will be no bar to direct involvement or endorsement of the activity".

What this is in fact saying is that once a risk has been identified then a decision must be made as which level, if any, should be allowed or persist, or be deemed 'acceptable'. In recent years, the determination of acceptable risk has turned towards the development of quantitative models which are used to set numerical levels below which any estimated risk is said to be acceptable. A common approach is to place 'known' risks on a scale and to rate the acceptability of 'new' risks by estimating their equivalent numerical value and placing it alongside this scale.
Rowe (Goodman and Rowe, 1979) describes a set of conditions which he suggests support the existence of acceptable risk. They are:

(1) risk which is perceived to be so small as to be deemed negligible;
(2) risk which is uncontrollable or unavoidable without major disruption in lifestyle;
(3) acceptable risk levels established by a credible organisation with responsibility for health and safety;
(4) historical levels of risk which continue to be an acceptable one; and
(5) risk which is deemed worth the benefits <u>by the risk taker</u>.

He refers to these as the threshold condition, the status quo, the regulatory condition, the de facto condition and the voluntary balance condition. These are examples of risks which we argue should be termed <u>accepted risks</u>. We further contend that there is no such thing as acceptable risk, but only accepted risk, and that this is what is commonly meant by the term acceptable risk.

The determination of acceptable risk is an integral part of the process of risk assessment. Acceptable risk problems are decision problems because they require a choice between different causes of action, but they differ from other decision problems in that one of the available alternatives involves as a consequence a threat to life or health. This threat may be either direct, with obvious consequences or indirect, being a threat to something which we value as a part of our quality of life.

Fischhoff et al. (1981) modify Fischhoff's earlier definition by saying that acceptable risk is a useful descriptor for a type of decision-making process but that it is not appropriate for describing the results of that process. Thus, risks are not acceptable but options are. Having said this, he lists a series of difficulties associated with considering the acceptable risk problem as a decision-making problem. These are not unique to the acceptable risk problem, and include the uncertainties involved in defining the problem, assessing the 'facts' of the matter, assessing the relevant values, dealing with the human element, and finally in assessing the quality of the decision.

Rothschild (1978) reported in the Listener, implies that the concept of acceptability must be related to other risks which are implicitly accepted by individuals in their lives. He sets his acceptable risk explicitly at 1:7500 per year of exposure, using car accidents in 1974 as a reference point. His approach was based on work by Inhaber (1978 and 1982), and the Rasmussen report (United States Atomic Energy Commission, 1974). In a similar manner the Rasmussen report confidently predicts nuclear accidents will occur at a rate of 1 in 1,000,000 for accidents involving 1000 or more fatalities (based on a group of 100 reactors) and goes on to equate this to the risk of a meteor striking a major United States city and causing the same number of casualties.

All of these works have been severely criticised on a number of grounds. This criticism has highlighted the difficulties involved in transferring risk acceptance from one activity to another without taking account of the factors involved in risk perceptions, and the implicit subjectivity attached to the perceptions of different types of risk. Rothschild, Rasmussen and Inhaber have shown an alarming dependance on statistics derived from quite questionable sources, and have disregarded the need to quantify risk with regard to all the factors involved in risk magnitude. A first reaction to these baldly presented numbers is that they are meaningless in terms of the risks faced by individuals and groups as part of their everyday existence.

There is obvious difficulty with this type of risk comparison approach which equates the risk of nuclear accident to the risk of the increased likelihood of getting lung cancer as a result of an individual smoking one cigarette in a lifetime (The Listener, 1987). In effect this is saying that nuclear power plants are perfectly safe. The comparison is invalid. Another similar comparison which is often quoted is that windmills are considerably more dangerous than nuclear power plants. The source referenced is Inhaber's work, which uses incomplete and poorly extrapolated data. In both cases, the magnitude of the total risk is not considered.

One of the major critics of Inhaber's work is John Holdren (Holdren et al., 1979). Inhaber based some of his calculations on Holdren's earlier work on energy sources. The statistical basis he used for these estimates is invalid which means that his results must be discounted.

However, McCormick (1981) suggests three things which can be learnt from Inhaber's work. These are:

(1) it is important to account for risks from producing the materials used to construct an energy production system (this was apparently a new departure and illustrates the importance of careful risk identification);
(2) it is difficult to perform an accurate comparative risk assessment between technologies with ill-defined and incomplete data (no consensus between experts); and
(3) more needs to be done to assess accurately the comparative risks between energy production methods.

While some of Inhaber's work is interesting and valuable, it is best read in conjunction with the criticism which it generated.

A further point with regard to typical cost-benefit analyses or cost-risk-benefit analyses of nuclear power plants is that generally they ignore the large cost of decommissioning the plant at the end of its useful life, and as a result of the use of high discount rates, the cost of disposal of hazardous materials generated by the process is seldom considered to be a serious factor. Both these problems have begun to be recognised as a result of the present decommissioning of the original Windscale plant in Britain, and increasing difficulties with regard to nuclear waste dumps.

Uncertainty is a very important factor in the consideration of acceptable risk and risk comparisons. Some apparently 'accepted' risks are totally unknown or unsuspected. A classic example used to illustrate this type of risk is the Love Canal in New York State, where development took place on the site of a disused chemical dump as a result of inadequate monitoring. Further evidence to hand from British experience is beginning to suggest that there is a danger of leukaemia from very low levels of radiation which have previously been considered harmless: levels such as might be experienced by people living in close proximity to nuclear power plants.

A recent report from the National Radiological Protection Board in Britain (The Guardian, 1987) suggests that current exposure dose limits are too high, and should be reduced to one third the present level. This results from further evidence from Hiroshima and Nagasaki, and was confirmed by the International Commission on Radiological Protection meeting at Como in Italy two months previously. Interestingly, the latter body, although reaching a similar decision with regard to the risk to health decided that a reduction in the 'safe' level was not warranted. This illustrates two points: firstly, that science does not provide absolute answers, and that scientists must be flexible enough to revise their estimates, and not be overconfident; and, that in the particular case of nuclear safety, our present knowledge is very limited, and that we have remarkably little information about the effects of long term exposure.

The dilemma becomes not what is an acceptable risk, but what is a fair or equitable risk. To whom is the risk acceptable: the policy makers, or those who have to bear the risk? How can we increase the fairness of risk?

Further confusion arises when scientists use the term 'safe' to describe a risk situation. There is no such thing as a safe risk. What they are doing is describing 'permitted' or 'tolerated' levels of risk (accepted versus acceptable).

Probably the most commonly used term in the acceptable risk literature is 'reasonableness'. On its own it has very little meaning. Lowrance (1976) lists a series of criteria for reasonableness, which we have summarised here as:

(1) custom of usage;
(2) prevailing professional practice;
(3) best available practice, highest practicable protection, lowest practicable exposure;
(4) degree of necessity or benefit;
(5) the Delaney principle (US Food and Drug Act, non carcenogenic);
(6) no detectable adverse effect;
(7) toxicologically insignificant levels; and
(8) the threshold principle (the definition of a dose below which no appreciable harm occurs).

These criteria emphasise the point that no determination of acceptable level of risk is valid without consideration of the expected benefit.

In Section 4.2.3, Rowe's four methods for assessing risk were listed and described. All of these approaches are used for the setting of acceptable risk levels. Fischhoff et al. (1980) describe them as follows:

(1) risk aversion, which involves the maximum reduction or risk possible with little or no comparison with other risks or with benefits -standards of zero tolerance and dose-consequence threshold levels are examples;

(2) risk balancing (corresponding to Rowe's risk comparison method), assumes that some level of risk above zero is acceptable and defines the level through comparison with appropriate reference cases, such as similar technologies, natural background levels or risk previously determined to be acceptable;

(3) cost effectiveness (of risk reduction), seeks to maximise the reduction of risk for each dollar expenditure on safety - acceptable risk may be set by breaks in the slope of risk reduction efficiency for a given hazard or by allocating public funds among hazards for maximum risk reduction to society as a whole;

(4) cost(-risk)-benefit balancing, recognises some level of risk above zero, acceptable risk is defined by balancing the benefits of an activity or technology against the level of risk it presents - the risk tolerated increases proportionately with the magnitude of the benefits involved.

Fischhoff has included an additional category of risk aversion. It is an interesting category in that the risk is not related to the benefits or costs associated with the action.

Once again, none of these approaches provides a completely adequate solution, and further, that risk to human health is only one value dimension of acceptability; a variety of other considerations (equity, impact upon institutions, ecological impacts) may take on greater importance in any given case. Also, societal values change and what is viewed as being safe today may be viewed as being unsafe tomorrow (as previously discussed with regard to the setting of limits on occupation levels of radiation). Judgement on acceptability involves the consideration of perceived risks and benefits in light of feasible alternatives.

Moving therefore from these 'objective' approaches to the setting of acceptable risk levels we enter the area of psychometric risk acceptance analyses. The shortcomings of the objective approaches are that they do not take full account of the dimensions of risk which include: the temporal limits, who is affected, how people respond to reduce risk, the difference between accepted and acceptable risk, and the way in which individuals arrive at decisions. Psychometric and sociological studies which estimate perceived risk increase our understanding of how particular benefits are seen by individuals and specific groups.

Starr (1969) and Starr et al. (1976) reject the disregarding of any risk below a particular level and claim that models should take account of tradeoffs between risk to establish risk benefit tradeoffs. Their approach involves the use of revealed preferences. Otway and Cohen (1975) followed this approach but were unable to duplicate Starr's results and concluded that the methodology and results were very sensitive to the assumptions made and the data used. Starr, himself, put a great many provisos on his results. The use of revealed preferences and expressed preferences to improve understanding of risk perceptions is discussed further in 4.3.2.

Determining acceptable risk involves examining the difference between people's perceived risk and the techologist's estimated risk.

There is no obvious way of dealing with these differences. It is perhaps useful therefore to look at ways in which we can measure perceptions as a means of understanding better the way in which these differences arise.

Lee (1981) states that it is specious to assume that the differences between objective and subjective estimates of risk can be attributed to errors or bias by ordinary people. One of the major reasons for this is that risk is not a simple quantitative measurement but a compound of the probability of occurrence of a negative event with the severity of that event. Evaluation of the severity requires consideration of human values and emotions. A further cause of differences arises because subjective estimates are usually based on mortality statistics. Death may not necessarily be the most feared phenomenon, and Lee uses as an example the thalidomide tragedy where very few lives were lost, but a large number of people suffered considerable decrease in their quality of life.

A further example of this is found in Slovic et al. (1979) where it is shown that although lay people (in common with experts) are reasonably accurate in estimating expected fatality rates, their judgements of risk are coloured by factors other than the simple statistics. Risk means more than fear of death as represented by a numeric.

Slovic (1986) looks at the difficulties people face in making unbiased estimates of risk in regard to risk communication. He discusses in particular, the influence of the media, the way in which recent events and experiences colour perceptions, the fact that people's beliefs are difficult to modify, however inaccurately formed, and the ease with which it is possible to manipulate people's views (unformed) by varying presentation format.

One of the more interesting studies in this area is reported by Fischhoff et al. (1978) where psychometric techniques were used to elicit estimates of perceived risk, acceptable risk and perceived benefit. The study group was an educated informed section of the League of Women Voters. The most interesting result was the consistent relationship between perceived benefit and acceptable level of risk. This is consistent with our early statement that you cannot separate determination of acceptable risk from the expected benefit.

The quotation at the beginning of this section highlights the size of the rift between the technical experts and the lay public. Fairfax was directing his comments primarily at the press. The press, or media in general, however, are only expressing the fears and concerns of the general public who either do not understand the opinion of the experts or, as a result of previous experience, do not believe or trust the information they are being given. If a concept such as acceptable risk is to exist and be 'acceptable' then both "objective" and "subjective" assessments of risk are valid, and interested parties in risk debates must work together to try to achieve a common basis for discussion.

4.3.1 Risk comparisons

The risk comparison approach to setting acceptable risk levels depends on setting maximum and minimum levels of risk to individuals using known and accepted risk levels as a scale of reference. The 'new' risk is then estimated and deemed acceptable or unacceptable according to where it lies in this risk scale.

There are two ways in which risk can be measured:

(1) objectively - using historical statistical data or modelling projections; and
(2) subjectively - using perceived risk estimates and preferences.

Risk comparison is a form of extrapolation and there are a number of obvious difficulties associated with its use. As we have already stated, the setting of an acceptable risk level involves a number of value judgements. If objective risk estimates and referents are used, there is considerable subjectivity involved (even ignoring the problems of taking account of all aspects of magnitude). There is a danger that the risk analyst and expert may forget the subjective nature of "objective" estimates. Lord Rothschild's estimate (Rothschild, 1978) is a classic example of this. In using road accident deaths as a referent for acceptable risk (employing the logic that since people are prepared to drive they must be prepared to accept this level of risk), he has forgotten to take account of the different factors involved when people choose to drive a car and when they are forced (by economic circumstances, or through ignorance) to take occupational risks. He has also ignored the other factors associated with risk magnitude which affect risk perception and the choices people make. These must also be taken into account if valid risk comparisons are to be made.

As an example of the difficulties involved with risk comparison, we look at the work of Burton et al. (1978) who address the problem of natural hazards and conclude that there is no appropriate way of comparing the magnitude of different types of natural hazard. It is often not possible to conveniently compare two events even of similar type. Earthquakes are an example of this. There are two common scales used to measure earthquakes: the Richter scales measures the energy release and the modified Mercalli scale measures the effect on man and structures. Both aspects are very important to quantifying the risk involved in an earthquake, however, if two earthquakes are measured with similar magnitude on one scale, their magnitude measured on the other scale may be quite different. This illustrates the complexity of natural hazards.

With this warning in mind, there are times when the risk comparison approach can be both useful and valid. This is when a 'new' risk can be shown to have similar characteristics to other risks for which we have good statistical information and from which we can construct a suitable scale of reference.

Starr (1969) was the original proponent of using economic data to reveal patterns of socially acceptable risk trade-offs. Later, utility-based approaches were used to try to assess the decision maker's expectation of social utility.

Ideally, we should be flexible enough to change our determination of acceptable risk as new information becomes available. We have already mentioned the recent report from the British National Radiation Protection Board recommending immediate modification of working practices at British nuclear power plants as a result of new information from Nagasaki and Hiroshima. (This illustrates the importance of monitoring.) There are several 'giant strides' between the discovery of this type of new evidence and the putting into practice of such a recommendation (altering the regulations). If acceptable risk has been determined properly and equitably in the past then it is hard to see why scientists attending the International Commission on Radiological Protection meeting at Como in September 1987 should have firstly accepted the new evidence but consequently decided that dose limits did not require amendment. The public finds this logic difficult to follow.

4.3.2 Preferences

A second approach to the problem of determining acceptable risk, which was developed as an extension of the naive risk comparison approach, used utility-based methods to assess the decision maker's expectation of 'social utility'.

There are three types of preference present in most decision-making problems: value, time and risk. They all represent judgements of the decision maker or individual. Value preferences are the concern of multiple attribute theory; time preferences refer to discounting concepts and rate of return; and risk preferences are risk attitudes and relate to concepts of utility or wealth. Our concern is with these risk preferences.

It has been generally accepted by behaviouralists that overall, people act in a risk averse manner. However, Kahneman and Tversky (1979), using prospect theory, have shown that people tend to react in a risk averse manner when certain gain is involved and as risk takers when faced with certain loss - in particular when very low probabilities are involved. The experiments from which these deductions were made were associated with financial gain and loss. A further conclusion was that people tend to discard components shared by all the prospects, which leads to inconsistency when choices are presented in different ways. This occurs with both sophisticated and naive respondents. As a result Kahneman and Tversky have developed a method which assigns weights to gains and losses rather than fixed assets. Probabilities are replaced by decision weights.

Whilst this approach is a useful addition to the risk analysts tools, and the attitudes exhibited should be borne in mind, it does not necessarily follow that these attitudes are likely to occur in areas where health and safety are involved.

There have been a number of approaches employed in the measurement of perceived risk. These are generally classified as the revealed preference, implied preference and expressed preference methods (Crouch and Wilson, 1982).

The revealed preference method, initially proposed by Starr in 1969, is based on the assumption that society has adjusted to a balance of risk and benefit that it finds acceptable. Rowe (1980) represents this as a nearly optimal balance. A second major assumption is that this balance is static and will continue into the future. Statistics of behaviour are then used to infer underlying preferences. Two further assumptions are involved in this approach: firstly, that costs and benefits can be measured in the economic market place; and secondly, that people have sufficient information available to them to make intelligent (rational) choices. A major limitation of this approach results from the assumption that past accepted levels of safety are applicable to the future. These levels are based on current income distribution, social structures and value systems which may or may not be desirable. But society does not have a fixed set of values: value systems are dynamic, as can be seen by the increasing concern about risk in our everyday environment. Apart from this the method has considerable measurement difficulties which have been pointed out by Otway and Cohen (1975) and others.

The method of expressed preferences involves questioning individuals and eliciting information directly. There is thus no need to convert values into dollars as is required in the revealed preference method. The main assumptions are that people understand the questions they are being asked, that they are given enough information to make an informed answer and that their behaviour is rational and consistent. This method has been used by Fischhoff et al. (1977, 1978, 1980).

Implied preferences are ascertained by looking at the institutions which society has set up with regard to risk in the past. These standards reflect current values and imply tradeoffs between costs, risks and benefits. Rowe (1980) sees this approach as a compromise between the revealed and expressed preference approaches.

In summary, the revealed preferences approach uses statistics of behaviour to infer underlying preferences, whereas the expressed preferences approach elicits information directly from individuals.

McCormick (1981) suggests that a revealed preference study is "an adequate guide of people's perceptions" only if you believe that rational decision making should be left to experts who use past policies as a basis for prescribing future actions. Expressed preference studies will therefore be effective only if you believe that people's present opinions should be the primary basis for decision making, and also, if you believe that people act on their expressed preferences.

Douglas and Wildavsky (1982) describe a further 'natural standards' method of "whatever levels of risk man and animals have lived with in the past are supposedly tolerable for the future". This, however, does not take account of changing values or of the great changes which man has already imposed on his environment which counter this spirit. Also, it is subject to individual or group bias which may be manipulated to reflect whichever version of reality the decision maker wants to see.

The Royal Society (1983) concludes that currently, the most favoured ways of analysing risk involve the use of revealed preferences, cost effectiveness (of risk reduction), and risk balancing. However, the validity of these methods has been questioned by a number of authors who believe that most people do not in fact tradeoff costs and benefits, but values, and it becomes a question of whether or not you believe that it is possible for people to make tradeoffs between positive and negative social values.

There would appear to be a certain amount of vogue attached to the use of the two approaches to eliciting estimates of perceived risk: implied preferences and revealed preferences. A number of researchers are currently working in this area, and their work should be followed. A small applications study under New Zealand conditions is proposed in chapter 8.

4.3.3 Value of life

We have touched upon the main methods used to value life for risk assessment in Section 4.3.2, and mentioned the difficulties associated with each approach. Lord Ashby (1978) makes a strong philosophical argument against cost benefit analysis by saying that "in order to quantify a fragile value you have to simplify it. This divests it of the essence of the value you are quantifying, so that what you quantify is not the value you started with, but a residue of it, drained of much of its meaning."

Most advocates of cost benefit analysis would agree that there exist some intrinsic values which are not completely quantifiable. The differences will arise in determining which elements of a project or proposal these can be attributed to. Most attempts at valuing life are pseudo valuations or shadow prices, used to infer a value which can be used for the purposes of cost-risk-benefit analysis. There is, however, a danger that these values can be used for more than the purpose for which they are calculated and extrapolated to different situations and perspectives in which they have little validity.

Current research in this area is very strong and it is likely that a number of new approaches, or strengthening of old approaches will be available soon. The Environmental Risk Group associated with the School of Environmental Sciences, University of East Anglia at Norwich is presently looking at quantitative estimates of value of life with a view to recommending a standardised approach. In New Zealand it should be possible to incorporate further research with the Accident Compensation Commission.

4.3.4 *Acceptable risk as a decision-making problem*

So far, although we have looked at acceptable risk problems as decision-making problems, we have not considered any of the special difficulties which are associated with this type of public decision making. These difficulties are not unique to risk-related issues, but affect all public sector decisions, and require further consideration on their own account. We will confine ourselves to pointing out some of the characteristics of this type of decision making which will have a bearing on the approaches used in the estimation of acceptable risk.

Public sector decision-making problems tend to be multiple objective decision-making problems. There is no single objective to be maximised, and often the units in which the different objectives can be calculated are non-commensurate.

Also, it is very likely that in most cases of environmental risk decision making there will not be a single decision maker, but a group of decision makers. In all these types of problems the interaction between the analyst and the decision maker(s) is very important. Where multiple decision makers are involved, additional complications are introduced, particularly if the decision is to be made on a series of different levels, where different decision makers may have differing goals. Decision making must in this case be seen as a process rather than as a single step.

Kunreuther et al. (1983) present a series of case studies of liquified energy gas facility siting projects in four different countries. They take the viewpoint that risk is a political problem. This is consistent with Douglas (1982) who states that "..the problems of risk perception are essentially political" and that "..public debates about risk are debates are debates about politics".

We concur with this position, and feel that it is important to separate the role of the (risk) analyst from the decision maker or politician who must make his decision with the overall goal of ensuring societal wellbeing. Similarly, we agree with Wynne (1982) who suggests that we should study risk perceptions as part of the political and social organisational context in which decisions are made.

4.4 *Risk management*

> "If we don't know the risks we face how can we cope with unknown dangers"
>
> Douglas and Wildavsky, 1982.

We have used as a basis for this paper the proposition that since it is not possible to eliminate risks then we must try to manage risk to produce 'good' results. From the section on risk perception, it can be seen that understanding the meaning of 'good' in this context must be a major part of management. Adequate risk management therefore requires co-ordination of all aspects of risk including risk determination, risk evaluation and risk reduction.

Druker (1973) sums up the business attitude to risk as follows:

> "To try to eliminate risk in business enterprise is futile. Risk is inherent to the commitment of present resources to future expectations. Indeed economic progress can be defined as the ability to take greater risks. The attempt to eliminate risks, even the attempt to minimise them, can only make them irrational and unbearable. It can only result in that greatest risk of all: rigidity."

The ability to take greater risks implies a measure of control over risk. There is a danger in this area, that as a result of unrecognised uncertainty, control may be an illusion. The Titanic was sent to sea with understocked lifeboats, and with inadequate training for either crew or passengers because of a fake sense of security. It is the outcomes or actions which we do not anticipate which cause the greatest problems.

In recent times, businesses have become aware that they may carry greater financial and moral responsibility for their products than they have previously been willing to accept. In other words they are becoming more aware of the full magnitude of the risks involved which has largely been forced upon them by the fear of litigation.

Examples of this include the case of the Pinto car in the United States. It was apparently known at construction time that a design fault meant that there was a danger of petrol tank explosion under certain rear end collision circumstances. The manufacturers felt that such collisions were rare and did not warrant the high per car cost modification which would be required to remove the risk. However, some such accidents did occur and subsequent law suits against the company resulted in all the cars at risk being recalled and the fault corrected. The resulting cost to the company was substantially greater than the original modification would have been. In this circumstance a calculated business risk resulted in risk to human life and subsequent financial loss. The company would probably argue that the risk was worth taking. The public counter that the risk was too high. (It would be interesting to know how many less cars would have been bought if the modification had been done when the cars were originally built, resulting in a higher initial cost to the consumer.)

O'Riordan (1979) proposes that it is no longer possible to reduce total environmental risk on the grounds that any action we might take to reduce risk in one area is likely to introduce further risks in other areas. The nuclear versus coal fired power station illustrates this. If Britain does not build any more nuclear power stations, it will need to build more coal fired stations (ignoring the arguments of conservation), thus accentuating the greenhouse effect, and increasing the risk of polar ice cap melt and higher sea levels.

O'Riordan further suggests that risk management has become such a specialised technical process that there is no chance for anyone except the technicians themselves to be able to understand the processes and the results. Thus politicians become remote from the decision since they have no proper basis for making a decision. A further danger arises because very often experts cannot agree themselves on the interpretation of a particular set of data, and decisions get made on the basis of the most influential scientific advice on a 'flavour of the month' approach.

This is a very important point since it concerns one of the critical factors of the decision-making process, which is the need to clarify the distinction between the analyst and the decision maker. The analyst presents the material, including relevant tradeoffs, to the decision maker who must chose the preferred option. The onus is on the analyst to ensure that the material presented is properly understood by the decision maker.

Scientific rationality believes that facts can be divorced from values. Political rationality, however, deals with what is 'good' and 'bad' for people. Because of the technical aura surrounding many risk questions, the public decision-making process faces a danger of being overcome by scientific rationality , which is particularly dangerous in light of the subjectivity of many of the apparently objective 'facts' which are part of the risk assessment process.

Risk management in broad terms involves the examination of policy options with a view to decision making. Its methods generally involve valuing the associated variables or attributes and then setting rules for weighting and combining these variables, to develop an ordered list of options. The final decision on whether or not a project should proceed should also use societal determinations of acceptable risk, which will very likely vary according to the circumstances of the risk. Since risk decision making is often part of the public decision-making process the option chosen may not necessarily be the one which would be preferred by the risk analyst himself. The political viewpoint, whilst taking account of all of this, may chose an option which might be considered suboptimal in a technical sense. Societal values must be incorporated into the decision-making process if we are to achieve the sought after 'good' solutions.

5.0 Experience with risk assessment

Before we go on to examine the use of risk assessment procedures, we should recall our earlier definition of risk assessment. Risk assessment is a combination of the technical process of risk identification and estimation, and the qualitative evaluation of the risks. Quantitative Risk Assessment (QRA) is a commonly used descriptor which refers only to the first part of the process of risk assessment.

We earlier described risk assessment as being a part of the general decision-making process. There are two further steps in this process which we have not considered so far. These are:

(1) implementation and communication; and
(2) monitoring.

When we examine the success of current risk assessment procedures, rather than looking at the numerous cases where no harm or hazard occurs (or has yet to occur), we tend to concentrate on the accidents. This is not necessarily bad or biased, because by looking more closely at areas where things have gone wrong, we can attempt to improve the process, so that risks are in fact reduced, or at least better understood by those at risk. In some countries where there is little public input into the planning process, it is only when an accident occurs that people become aware that there is a risk at all.

Slovic et al. (1982) list a number of examples of accidents where experts have misjudged either the outcome or its magnitude as a series of failures on the part of the expert:

(1) failure to consider the ways in which human errors can affect technical systems;
(2) overconfidence in current scientific knowledge;
(3) failure to appreciate how technical systems function as a whole;
(4) slowness in detecting chronic, cumulative effects;
(5) failure to anticipate human response to safety measures; and
(6) failure to anticipate 'common mode failures' which simultaneously affect systems which were designed to be independent.

There is a tendency amongst the proponents of technical risk assessment (QRA) to attribute greater reliability to their estimates than is really justified by the processes by which they are obtained. There is an equivalent and growing tendency amongst sections of the public to scepticism with regard to these same estimates.

Superficially, it would appear that much of the conflict between experts and laypeople could be resolved by a bridging of the 'information gap'. This, however, is only possible if the conflict is founded on a lack of knowledge.

The media have been accused by both experts and interest groups and individuals of biasing reports and misleading the public about the 'true' risks involved in particular projects and processes. A lot of this criticism comes from experts who feel that the risks are being magnified by sensation seekers. Scientists are concerned about the headline approach to newspaper and radio reporting which gives great emphasis to the conclusions often ignoring the way in which these conclusions have been reached, and necessary assumptions. Lobbyists in turn also criticise the media on similar grounds.

On the one hand, therefore, QRA is gaining greater acceptance by the technical community who see it as a way of objectively presenting the risks that they perceive in projects and processes. On the other hand, the lay public who are concerned that the risks that they perceive are not properly represented are demanding a greater say in the decision-making process.

5.1 Quantitative risk assessment

QRA is a commonly used technical term used to represent a systematic identification and quantification of the risks involved in a particular project. Typical procedures involve some form of event tree or fault tree analysis requiring extensive data in the form of reliability statistics for different components. The success of the approach depends greatly upon the quality of the data available. It can also be a very expensive process. Gilby (1987) reaches the following conclusions regarding the use of QRA by public authorities. In summary:

(1) that QRA's provide useful information regarding prediction of probability and risk, but that opinions regarding their use by public authorities vary greatly;
(2) there is agreement that the techniques are useful in certain areas of application, for example comparing alternative design solutions; and
(3) that there is considerable question as to whether QRA's can be used to demonstrate compliance with specific safety standards.

Gilbey concludes also that greater efforts should be made to establish a basis for various interested parties to develop common judgements.

One of the difficulties with specific QRA's is that because of the mathematical complexity involved, it is very difficult to firstly interpret the results, and secondly, to communicate these to the decision makers. The development of 'canned programs' for particular types of QRA's is of concern, since unless the person responsible for interpretation is fully aware of the process involved and the quality of the data being used, they may not be able to place proper weight on the results.

There seems to be considerable divergence between countries in their attitude to risk assessment as will be discussed further in Section 6. Very few countries require formal risk analyses to be performed as part of the procedure involved in planning for new projects or the extension of old projects (the Nederlands is the only known country where there is such a requirement). In some countries there is an informal agreement that this should be done.

In Britain, the main area where risk analysis is applied is in the nuclear power industry. Because of the decision-making approach used, very little information is available to the public. Usually it is an internal assessment only. In general, the public only gets access when there is an enquiry in the wake of some failure or accident. Although new projects and extensions do not require a formal risk analysis, in most cases one is performed. There is very little public input, and the whole procedure has developed around an existing 'old boy' network.

We believe that in circumstances where proposed projects may have the potential to cause harm to people or the environment (the things they value), that is, where a risk exists, that QRA should be a formal part of the decision-making process. However, the decision should not be made on the basis of the QRA alone, but should incorporate all the social and political factors which are part of the full risk assessment process.

5.2 Communication, implementation and monitoring

Communication is a very important part of any decision making process. The analyst must first communicate his/her results to the decision maker, who must communicate his/her decision to the analysts and the public. This is the first step in the implementation of the decision.

Communicating means more than publishing a technical formal report, or a set of figures and diagrams. Proper communication requires that the information be presented in a form with which the recipient is comfortable. In the age of computers it is very easy to produce a mass of technical information which may in truth have very little relevant meaning.

The public or in particular the group 'at risk' is often either ignored or treated as insignificant in this communication process. Decision makers and 'experts' have a duty to the public (whom they represent) to provide sufficient information for the public to understand and accept the decision. Decision makers who are often elected representatives are generally more aware of this responsibility than the experts because of the pressure to be accountable.

Monitoring of the decision is more difficult in that once a major project has begun, its momentum may make it difficult to objectively re-evaluate the original decision. An example of this may be seen with regard to the construction of the Clyde Dam in New Zealand where information obtained partway through construction suggested that the dam might lie on a geological fault. In this case there was considerable disagreement between experts as to the validity of the findings and considerable bewilderment on the part of the public who felt excluded from an essentially technical debate between experts with different viewpoints.

On the other hand, following the Three Mile Island incident in the United States, a number of half built nuclear power stations were abandoned largely because of lack of financial support from the private sector. Although this was not a formal re-evaluation of the risks to human life or the environment involved in building the stations, it represented a re-evaluation of the financial risks by the lending institutions. It was recently reported that a minor utility company in the north eastern States has been forced into bankruptcy, largely because it was unable to obtain a licence to operate its recently completed new nuclear power plant. This indicates a large shift in public values and attitudes since it should be remembered that emission from the Three Mile Island plant was considerably less than the 1957 Windscale emission which had very little impact on the public's attitude towards the nuclear industry.

Another similar example is the Garrison dam project in North Dakota. Pressure from the Canadian government and environmental interest groups may cause this project to be abandoned as a result of expected environmental damage to rivers flowing into Canada.

It has also recently been reported (New Scientist, 1987) that Italians have voted in a national referendum to abolish three laws that have until now governed the country's activities in nuclear power. The practical effect may be fairly minimal, since Italy imports 80% of its energy, but it will likely result in Italy's withdrawal from the European fast breeder program.

The lessons to be learnt from these examples are that the public does not appreciate being treated like a mushroom and sometimes overreacts when it considers that its interests and values are being affected adversely.

5.2.1 The role of the media

As stated earlier, the media is often criticised by experts for unnecessarily alarming the public by exaggerating the risks associated with drugs and pesticides or particular projects, or taking up 'worst case' scenarios and presenting them as real possibilities.

The public is often more discerning than is given credit by these experts. Members of the public will not necessarily place blind faith in what they read or see presented on television unless the views presented concur with their own opinions and beliefs which may have been reached for entirely different reasons. Greater understanding of how the public reaches conclusions is required.

The media itself answers critics by admitting that indeed, often it is biased, not necessarily always against the technical expert but that the reasons for this bias are associated with the institutional structure of the medium in which they operate. Generally presentation is limited by time and space. Also, their own lack of technical appreciation is not helped by the way in which material is given to them, particularly as they are usually required to reduce the technical content for public acceptance.

An example of this is that journalists are pressured into converting measurements such as likelihoods, frequencies, probabilities etc. into tangible facts that people can relate to. The nature of "what is news" affects a journalist's presentation (T.Williams, 1988). Slovic (1986) adds in defence of the media that the major difficulty faced by journalists is the inherent complexity of risk-related stories, which means that they have to rely on technical expert sources, often in a wide variety of fields. The resultant story will depend upon whoever the journalist can get to interpret for him/her, and reflect the biases of that person. The answer, therefore, may be to establish a group of respected and 'available' experts that journalists can approach for assistance. Further research in required on ways of improving the media's performance in this crucial communication role.

5.2.2 *Conflict between 'actual' and 'perceived risk'*

Dorothy Nelkin (1979) lists four major sources of controversy over science and technology. These are:

(1) the realisation by members of a community that they are expected to bear the costs of a project which will benefit either an enlarged or a different community;
(2) the fear of potential health and environmental hazards;
(3) questions concerning an individual's freedom of choice; and
(4) a perception of the flaunting of traditional (moral and religious) values.

Whether conflict can be resolved is likely to depend upon the source of the conflict and the nature of the underlying perceptions of the parties in conflict. Very few conflicts involve a single issue, however, in cases where specific interests are the primary concern, then some form of compensation may result in a compromise solution.

If the conflict arises from differences in values then compromise is not possible. Typically, in these situations, both sides will use technical information to justify a position which has been taken up for entirely different reasons, based on their values and beliefs.

Since such conflicts can not be resolved by a compromise and no amount of data can resolve such value differences a major question arises as to who should be making the decisions. We reiterate the need to look at these questions within a political decision making framework.

An example of this type of conflict is seen with reference to an article in The Independent (Schoon, 1987). The Nuclear Power Industry in Britain is reported as undertaking a 300,000 pound campaign to convince the 2/3 of women who are opposed to nuclear power that it is perfectly safe and in fact necessary to the next generation.

The two opposing views are summed up by the following statements:

(1) "The Advertisements are saying that nuclear power is inevitable. They're short on facts and I find them rather insidious and dishonest."

Stewart Boyle, national energy campaigner for Friends of the Earth; and,

(2) "I think the difference between the opinion of men and women (only 1/3 of men oppose it) is related to the poor education women have in science subjects. It makes them more susceptible to the scare stories....they need reassurance. Organisations like Friends of the Earth spend a lot of time frightening people with statements that are often inaccurate."

Dr Tom Margerison, director of the Nuclear Electricity Information Group.

Apart from insulting a large number of intelligent women, Dr Margerison has ignored the fact that such attitudes are often based on the values of the individual or group. He believes that information will change women's attitudes. In this type of value conflict it is more likely that attitudes will harden as women suspect that they are being singled out as a soft target. The facts won't 'soften' her attitude since it must be recognised that nuclear energy does carry a finite risk. The type of advertisement being used is not informative, and it is directed towards the emotions (are you hurting your children's future?) rather than the intellect.

In cases where attempts have been made to change people's perceptions, it has been noted that the format used to present information is critical. This has been amply illustrated above. Attempts to reduce the 'perception gap' (Slovic et al., 1982) are too often attempts to change the lay public's perception rather than to initiate any self examination of the experts own perceptions. The technical obstacles which are particularly relevant to the nuclear power industry are that too often there is very little 'fact', and that the public tends to be sceptical of estimates of rare events. Dramatic events have much more impact than expertise. A further psychological difficulty is that experts have been shown to be wrong in the past. This attitude is particularly prevalent in the United States where, for many years after the much publicised and televised moon landing, a large part of the population believed that it had been faked and that man had still not reached the moon.

There is a great deal of suspicion of technology and its advocates in the community which must be addressed before real progress can be made in reducing the 'perception gap', largely as the result of serious errors in the past which include the PVC industry and the West Valley nuclear waste reprocessing and storage facility.

5.3 Is there any hope?

In a more perfect world, perceived risk and statistical risk would be the same. The fact that this is not the case and that the public's perception of risk is different to the experts' perception might suggest that risk analysis is not working. The 'perception gap' is due mainly to the uncertainty inherent in the real world. The area in which the gap can probably be more realistically reduced is that of the dilemma of acceptable risk. The problem is rightly a suspicion of any imposed risk which the public does not understand or feel that it has any control over. In these circumstances the expert, through the decision maker, has a duty to explain the risk to the public.

Difficulties have occurred in the past which have made experts reluctant to take on this role. Scientists who have considered it their duty to explain risks have found that their 'possible' scenarios have been taken up and turned into 'probables' by the media and lay public. Decision makers also are often reluctant to take public responsibility for their decisions and prefer to imply that the experts are the ones who should be accountable.

Increased scepticism on the part of the public has a positive side as it tends to lead to more active public involvement in the political decision-making process. We cannot expect politicians to make the 'right' decisions unless we give adequate indication of our preferences to them. There is also, unfortunately a negative side in that the administrative response to public opposition often leads to the future abuse of the system. Administrators and technocrats, having selected their project on the basis of economic efficiency and technical criteria, may then attempt to structure or manage public opinion to gain acceptance of their solution.

Wynne (1987) suggests that it is dangerous and divisive to continue characterising this conflict as "science versus subjectivism", and that whilst there may be an element of producing figures to suit the position on the part of the technicians and uninformed irrationality on the part of the lay public, these factors do not fully explain the differences.

Two of his examples include the 2,4,5-T conflict and the European Commission decision to ban hormones for increasing meat yield. In the first case, the experts advice about the safety of the chemical was judged correct, and 2,4,5-T was not banned by the Pesticides Advisory Committee in the UK, despite reports of illness by farmworkers.

The common factor in both cases was that the scientific evidence presented was based on laboratory experiments which demonstrated that under conditions of proper use there was no danger to humans. The difficulty is that these conditions do not prevail in the real world. As a much quoted worker's representative said in regard to the 2,4,5-T decision, "it was like asking someone to work in a laundry, but to keep out of the steam".

In the second case, growth hormones were judged by experts to be safe under a set of quite stringent conditions. The rejection of their advice was greeted with outrage and suggestions of a "travesty of rational decision". What they were forgetting was that the decision about whether or not to allow use of the hormones was a social decision which had to take account of the way in which they were likely to be used.

Decision makers should not be asked to make a choice between accepting objective and subjective risk estimates. What is required is that they should recognise that all objective or expert estimates contain an element of subjectivity related to the framework used to calculate them, the selection of available data and the assumptions made, which reflect social judgements made by the technicians. Decisions must therefore be based on technical risk estimates plus a knowledge of the real world and the likely conditions of use that will occur. This social judgement on the part of the decision maker should also incorporate elements of public risk perceptions about the proposed project.

6.0 *Alternative approaches to risk decision making*

Risk decision making involves many aspects of the multiple objective decision-making problem, which is concerned with making value tradeoffs. These problems are all pervasive and at the heart of many public policy controversies (Bell et al. 1978).

There are a number of different approaches taken to risk decision making in different countries. O'Riordan (1979) summarises these as follows:

(1) the adversary approach, where a constitution encourages conflict and controversy which is often resolved by formal, legal or political means;
(2) the consensus approach, where policy is made incrementally by an elaborate system of consultation and compromise;
(3) the authoritative approach, where a great deal of authority is given to technicians in central government to negotiate with industry; and
(4) the corporatist approach, where a mixture of different interests seek to find mutual advantage in collective action.

None of these approaches is used in its pure form in any country. However, generally speaking, the United States, Japan, West Germany and some other European countries use an open adversary approach. This is slow, cumbersome and expensive, but is seen as being credible by the general public which has access to the process. In Britain, the Nederlands, some Commonwealth countries and other European countries, risk management is left in the hands of 'experts' and the 'old boy' system, following the authoritative approach. This is more efficient in terms of the time taken and resources required than the open adversary approach, but it is being severely criticised at present. The public has no access to the proceedings and often very little knowledge about the risks it is being exposed to. There is also considerable scepticism about the capability of experts to make 'good' decisions in a behavioural sense, and one primary reason for this is that experts consistently over-rate their ability to estimate objective risks.

When the authoritative approach is adopted, the roles of the analyst and the decision maker become confused. The decision maker relies on the judgement of the expert to provide the 'best' alternative and a grey area as to the responsibility for the decision develops. There needs to be greater understanding of the decision-making process, and clarification of where the responsibility lies if the public is to continue to accept this type of decision-making approach.

6.1 Regulation versus voluntary agreements

The process of regulation requires setting standards, monitoring, enforcing, and evaluating and assessing the regulatory process in terms of its effectiveness, efficiency, cost minimisation and fairness. Usually, the regulatory function is carried out by an agency which is independent of the industry.

The alternative approach of voluntary agreements, which may be self regulated by the industry has been shown too often not to work. Until recently in Britain there has been voluntary agreement with regard to the use of a large number of pesticides. However, farmers have kept using some chemicals (for example DDT) despite <u>recommendations</u> against their use on the grounds that if it were really unsafe then the Ministry of Agriculture would ban the chemical. The Ministry, on the other hand, says that there have been few reported cases of illness or death from the use of such chemicals and therefore there is no reason to ban them. Careful study (Tait, pers. comm.) shows that there is substantial evidence of unreported illness, which is consistent with chemical poisoning.

This illustrates the problems of lags in information becoming available to both parties, and a need for monitoring of the use of chemicals.

It is also difficult to expect voluntary compliance with a nonregulated standard which will affect the economic wellbeing of a company. Although it had been known for many years that the foam fillings used in furniture were unsafe, it took a series of fires in which a number of children were killed to force the use of foams incorporating fire retardant in Britain. The industry was not prepared to undertake self regulation.

There is apparently new interest in the practice of self regulation, however, there have been too many examples of areas where it has failed for it to be particularly credible. Otway and Peltu (1985) quote an official of the Health and Safety Committee, who stated that it was "because laws without inspection did not work that (inspectors) were first appointed". As they also point out, there is always an element of self-regulation involved because it is not practicable to have continuous inspection.

Regulatory policies have both normative and legitimising aspects (O'Riordan, 1979). That is, they are concerned with the correct way of doing things and the need for adequate implementation. If it is decided that there is a need to regulate for risk, then the regulation which is decided upon must be both acceptable and achievable. This overlaps with the acceptable risk problem.

A set of jargon has evolved in this area. Some examples of this include:

ALARA - as low as reasonably achievable
ALARP - as low as reasonably practicable
BTMA - best technical means achievable
BPM - best practicable means

BTMA is a stricter condition than BPM, and ALARA is accepted as the guiding principle in controlling environmental hazards in Britain. O'Riordan (1979) discusses these terms in detail with particular emphasis on their legal position.

Terms such as these are important to industry and regulatory agencies responsible for the setting and monitoring of these levels, but as with most jargon, they can be very confusing to the general public and the workers who are directly affected by their use.

It must be stressed that regulation is useless unless it can be effectively monitored. Often companies operating under regulation will have their own belief with regard to the requirements for 'safety' and if they believe that the regulation is too stringent, they may operate right on the agreed level. This means that there is not only a need for monitoring of these levels, but also for vigilance about the setting and revising of 'dose limits' as further information becomes available.

Regulation is becoming very complex in some areas, and a chemical plant, for example, may have a very large number of regulations associated with different parts of its operations. Not only does this impose substantial cost on the company, but it places a very large burden on the regulatory authority which has to police these regulations. The very complexity of the regulation makes the practice of self-regulation less feasible. There arises a regulation dilemma, which is likely to increase rather than decrease with an increasing trend towards the setting of international standards for safety.

7.0 Areas requiring further research

In New Zealand risk analysis is in its infancy. We are spared the problems of many other countries in that we do not have a nuclear power industry with attendant problems of waste disposal. Before becoming complacent, however, we must recognise that we have a growing number of industrial plants which store or manufacture hazardous substances that are dangerous to both humans and the environment. One of the main problems is that these industries often seek to locate themselves in populated areas, close to their products' market, as opposed to nuclear power stations which are more often positioned in locations remote from human habitation (in relative terms). We also have the problem of disposal of hazardous materials which have long break down periods. Controversy over the storage and transportation of LPG has demonstrated the need for risk assessment procedures.

Further to this, there is an increasing tendency for hazards to have global significance, such as the hole in the ozone layer over Antarctica and the greenhouse effect increasing world temperatures and possibly resulting in polar ice cap melt. Europe and North America are facing continental acid rain problems.

As well as man-created hazards we are vulnerable to a variety of natural hazards such as earthquakes, floods, tidal waves and to a lesser extent tropical cyclones.

Countries have in the past behaved in an isolationalist manner over their requirements for risk assessment, however, as the effects on the total environment become more apparent the need for an organised approach to risk management is becoming increasingly a continental and global concern.

In New Zealand, as in most countries, there is at present no formal requirement for risk analysis to be performed either for new or extensions to existing projects. However, in a number of cases, including the recent application for planning permission to build an irradiation plant in Auckland, quantitative risk analyses have been commissioned. The danger at present in New Zealand, as well as other parts of the world, is that even if there is sufficient data available for a technical risk analysis to be performed, it is possible that there is not enough expertise and informed opinion to accurately interpret and evaluate the results (Wenman, pers. comm.). We stand in awe of the 'overseas expert' who in fact knows little about New Zealand conditions and cultural values. It is therefore doubly important that any technical analysis should be properly evaluated in New Zealand, and the results communicated to the decision makers or politicians and the general public.

As a step towards improving the credibility of risk analysis in New Zealand and improving our understanding of the process we suggest the following areas as requiring further study, and propose a series of small research projects.

Risk perception

We need to look at risk perception in the New Zealand context. A suggested approach would involve a small case study looking at revealed preferences using one prospective (Christchurch northern motorway) and one retrospective (LPG pipeline) project.

A further study would look at a natural hazard such as the risk of flooding from the Waimakariri river. This could form the basis of a comparative study of the revealed preference and expressed preference approaches.

Acceptable risk

As an approach to the setting of acceptable risk levels, it would be appropriate to look at areas in New Zealand where acceptable risk decisions are currently being made. We then seek to characterise the features of acceptable risk problems, and use this to work out the characteristics of appropriate applications, and identify inappropriate uses of acceptable risk levels.

We need to specify the objectives that an acceptable risk approach should satisfy.

Value of life

An approach to the estimation of value of life requires a full review of the value of life literature, and examination of the data available in New Zealand to make such estimates. The Accident Compensation Commission is likely to be a good source of data.

There are two further aspects with regard to value of life. Firstly, what is the position in New Zealand with regard to liability? The European Commission is about to adopt a policy of strict liability as opposed to the previously used limited liability. Secondly, we need to look at the way in which Accident Compensation Commission determinations are used by the private sector. Are they used as a guideline in all circumstances?

Risk dilemmas

What do you do when whatever action you take there is the probability of some kind of disaster? We propose a small study which would look at this type of situation in New Zealand and consider whether there need to be any general regulatory approach towards such circumstances.

Can facts and values be separated?

As a short answer it would appear that facts and values can only be partially separated. We need to examine our current legislative procedure to ensure that this is understood and allowed for within the decision-making process.

Decision support systems

Decision support systems (DSS) have been used overseas in some circumstances for the re-evaluation and monitoring of some hazardous circumstances. We suggest that this should be examined further to see if it would be appropriate in New Zealand.

Policy modelling

An examination of the ACIDRAIN policy model obtained from Cambridge Decision Analysts could determine whether this type of modelling is applicable to New Zealand conditions. We have been asked by the sponsors of the program to comment on its suitability as an aid to risk assessment.

Flood control and water resource management systems

Risk and uncertainty are major factors in the control of our river systems. Are we using appropriate methodologies for managing these systems? This requires a study of the institutional means used to administer and control the systems.

Biotechnology

The 'new' biotechnology which is developing as a branch of genetic engineering is likely to have major effects on agriculture over the next decade. The risk and uncertainties involved in this area will require new assessment techniques. In particular the effects on future generations will need specific attention. New Zealand decision makers need to be fully aware of the risks and benefits involved in these processes in order to take full advantage of the undoubted benefits which will accrue. We believe that a major study of this topic is required.

In association with these specific topics, there is an immediate need to consider the requirements for the regulation and monitoring of environmental hazards in New Zealand. A suggested program for future research would therefore follow this approach:

(1) discussion with the Ministry for the Environment to specify areas where risk and uncertainty will become important in environmental management, using the above proposals as a basis; and

(2) an examination of the current regulatory procedures followed in planning where risk is involved, and a comparison with European and North American experience. Dr Brian Wynne's work in this area with IIASA will provide a good base to work from.

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Appendix

Terminology

ACCEPTABLE RISK
risk which is judged by society to be acceptable

ACCEPTED RISK
risk which is apparently accepted by society, for example, driving a car

ACTUAL RISK
scientifically calculated or experienced risk
(usually statistical risk or predicted risk)

HAZARD
a harm or negative outcome

PERCEIVED RISK
risk as seen intuitively by individuals or societal groups

PREDICTED RISK
risk as measured by systems models using historical data

REAL RISK
risk which will be determined by future circumstances, and which therefore cannot be measured

RISK
probability of the occurrence of harm (Freedman, 1987), compounded with the magnitude of the harmful event

RISK ASSESSMENT
risk determination and evaluation

RISK DETERMINATION
risk identification and estimation

RISK ESTIMATION
the calculation of the probability of occurrence and the magnitude of the possible outomes

RISK EVALUATION
: the determination of the significance or value or the risk, including study of risk perception and the tradeoff between perceived risk and perceived benefits

RISK FACTOR
: something which causes a risk (Freedman, 1987)

RISK IDENTIFICATION
: the identification of all possible sources of risk and the possible outcomes from particular actions

RISK MANAGEMENT
: the making of decisions involving risk and implementation of these decisions

SAFETY
: an action is safe if its risks are judged to be acceptable

STATISTICAL RISK
: risk measured statistically using currently available data