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An Approach For Determining
The Acceptable Levels of
Nuclear Risk

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The Bureau of Management Consulting is an Agency of Supply
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The development of a conceptual methodology to determine the acceptable levels of nuclear risk required the assistance and cooperation of many people. In particular the authors wish to express their gratitude to Mr. Paul Hamel, Dr. Herb Inhaber and Dr. Harold Stocker of the staff of the Atomic Energy Control Board and to Dr. A.N. Doob of the University of Toronto, who participated in discussions of topics related to both the concepts and problems surrounding a methodology to determine acceptable levels of nuclear risk and also to practical surveying concerns and difficulties affecting the implementation of the methodology.
The objective of this study is to develop a methodology to determine the acceptable levels of risk with respect to nuclear energy. Although illustrative examples are provided to clarify some aspects of the proposed methodology, the development of actual survey vehicles is outside the scope of this study.

This report examines the process of nuclear safety and the role of the AECB with respect to determining an acceptable level of risk for the nuclear industry. That role of the AECB is to determine a suitable risk level within the range of feasible and economic levels of risk for the nuclear industry. From the discussion of the role of the AECB, the nuclear safety process and the definition of acceptable level of risk, we conclude that the AECB should identify the interest groups that impact on its choice of an acceptable level of risk, determine their expectations concerning nuclear safety and balance the expectations of the various interest groups such that the resulting acceptable level of risk is still acceptable to itself.

The report develops the conceptual framework for determining the range of acceptable levels of risk for nuclear safety. The conceptual methodology entails estimating feasible cost-risk combinations from information supplied from experts and estimating acceptable cost-risk combinations from the general public and various interest groups within it. There is an analogue for this latter step in the estimating of prior distributions, for which a substantial and respected body of literature exists. The assumptions underlying that methodology are made explicit and are examined. We conclude that the assumptions are plausible, having both theoretical and empirical precedents or analogues although requiring empirical testing to assure their validity with respect to nuclear safety, and that a reasonable attempt could be made to make the methodology operational.

The methodology was examined with respect to operational considerations. The conceptual methodology can be made operational by undertaking iterative personal interviews of a variety of experts knowledgeable about different aspects of the nuclear safety process, especially the risks and costs associated with various nuclear technologies and modes of operation. The surveying of the interest groups can be done by questionnaire after the information from the experts is obtained and after a questionnaire designed for the interest groups has been carefully pretested. The questionnaire should be designed such that the respondents are given an opportunity to answer in terms of probabilities and costs to which they can relate. On the questionnaire the comparisons with which the nuclear risks and costs are made should be as qualitatively similar to nuclear risks and costs as possible: the most likely candidates for comparison are natural or man-made disasters with very low probabilities of occurrence, large potential consequences, a qualitative resemblance to radiation exposure, and an involuntary nature. The most likely candidates for comparison are accidents involving the excessive use of or exposure to certain chemicals or natural disasters like earthquakes.
In this report we suggest that the determination of the acceptable levels of risk be approached in the following phases: 1) the conceptualization of the methodology, which is provided in this report, 2) the interviewing of experts, 3) the development and pretesting of a questionnaire for the public, and 4) the surveying of the public with respect to acceptable cost-risk combinations. The phases are sequential and are designed to have independent and useful contributions in the event that not all of the suggested phases are undertaken. We conclude that the methodology should be implemented in phases to minimize any risk that may be inherent in the process and that each successive phase of the implementation plan be evaluated before proceeding to the subsequent phase.
1. INTRODUCTION

1.1 Objectives of the Study

In September of 1977 the Atomic Energy Control Board (AECB) engaged the Bureau of Management Consulting (BMC) to develop a methodology for determining the acceptable level of risk in the regulation of the nuclear industry.

The role of a regulatory body or a control group, like the AECB, with respect to safety can be conceptualized as having three essential components: 1) to determine the level of risk acceptable to society for the system being controlled; 2) to measure the level of risk in the system; and 3) to induce the industry to operate the system at or below the acceptable level of risk.* Traditionally, most of the efforts of control groups have centered on studying actual risks and on developing policies or standards to ensure that industry does not exceed certain risks. Two rather recent examples of studies that have restricted their terms of reference to studying factors (2) and (3) above are Professor Rasmussen's study of nuclear reactor safety (14) and Professor Ham's study of mine safety (11). Both of these study groups, however, have pointed out the need and the urgency of determining the acceptable levels of risk in the nuclear and mining industries, respectively. To quote from the Rasmussen study (14):

... The study has presented the estimated risks from nuclear power plant accidents and compared them with other risks that exist in our society, it has made no judgement on the acceptability of nuclear risks. The judgement as to what level of risk is acceptable should be made by a broader segment of society than that involved in this study. (Executive Summary, page 3.)

The objective of the present study is to develop a methodology to determine the acceptable level of risk with respect to nuclear energy. Although illustrative examples are provided to clarify some aspects of the methodology, the development of actual survey vehicles is outside of the scope of this study.

1.2 The Pervasiveness of the Problem of Determining Acceptable Levels of Risk

Despite the fact that control groups have devoted more resources to measuring actual risk and developing safety policies than to determining socially acceptable levels of risk, society has always faced the problem of

* For a detailed explanation of the safety role of a control group see Johri-Milne-Wright (9).
estimating and setting acceptable levels of risk. Typically, the acceptable levels of risk are set implicitly by the actions of the control group. The pervasiveness of this problem is discussed below.

To some observers the notion of accepting or being satisfied with any level of risk other than zero is repulsive. A closer examination of the problem reveals that this view is untenable. The acceptance of some level of risk is a fact of life. For an individual consumer, the implicit acceptance of certain voluntary risks is a routine part of economic decision-making. A car-owner must decide (possibly within some legal bounds) at what level of wear his brakes should be replaced. Many examples can be found of automotive safety items that were generally rejected by consumers because of an unwillingness to bear the additional costs: air bags and inner tires are but two.

For involuntary risks* the case for accepting (imposing) social risks is less clear, but it can nevertheless be made. Some control groups have set explicit acceptable levels of risk. One example is a British parole board. Estimates of recidivism have been estimated as a function of the characteristics of prisoners, crimes and so forth, and one major consideration in the paroling of a prisoner is that his estimated probability of recidivism be less than a certain accepted limit. Hence, the risks to society of expected crimes is accepted as not being worth the social costs of extended incarceration. A more implicit acceptable level of risk is set by the Rail Transport Committee which must decide whether or not to approve an application for the grade separation of a level railway-highway crossing. The hazards and the convenience of a crossing can be estimated as a function of certain characteristics of the crossing, and these values can be compared to the estimated cost of the grade separation. Implicitly, the risks associated with some railway-highway crossings are acceptable.

From these examples it can be seen that the AECB's concern with developing a methodology to determine an acceptable level of risk is justifiable and relevant. Like several other regulatory agencies, the AECB is coming to grips with a problem that typically is one of the most difficult ones to be handled by control groups.

* Following Starr (13), one can divide societal activities into those involving voluntary risks and involuntary risks. These are, of course, conceptual polar cases, and many activities involve both types of risks to some extent.
2. THE NUCLEAR SAFETY PROCESS

2.1 Definition of the Acceptable Level of Risk

The concept of an acceptable level of risk can be viewed from a number of perspectives and, hence, be defined in many ways. A discussion of various definitions and their implications has been provided in a discussion paper (4) that was part of this study. The definition of "acceptable level of risk" that is being adopted in this study is the following:

An acceptable level of risk is one that is acceptable to the regulatory agency and that balances the expectations of the interest groups subject to the constraints of technological feasibility, regulatory enforceability and economic practicality as perceived by the regulatory agency.

This definition is an attempt to synthesize the operational features of empirical definitions without totally losing the value of normative definitions. By adopting this definition of an acceptable level of risk, certain implications follow as to the role of the AECB in the area of safety. These are discussed in the following subchapter.

2.2 The Safety Role of the AECB

The primary implication of adopting the definition of acceptable level of risk proposed in this paper is that the level of risk must be acceptable to the AECB. The AECB must not only find a level of risk that is acceptable to various interests but a level which is acceptable to itself.

In order to determine an acceptable level of risk the AECB must be aware of the following aspects of the nuclear safety process:

1) Actual Risk. To monitor the safety process, the AECB must be aware of the actual and potential risk in the nuclear energy industry. The acceptability of the risk in the system can only be determined if the actual and potential risk is known.

2) Technological Constraints. If the AECB is to demand that the risk in the system be kept at or below a certain level, then it must be aware of the technological limitations on the ability to control the risk in the system. It is simply not technologically feasible to attain some levels of risk.

3) Economics of Nuclear Safety. The AECB must also understand the economic costs associated with the attainment of various levels of risk. Some levels of risk in the system are economically impractical. The economics of nuclear safety is, however, dependent upon alternative uses of and demands for resources; accordingly, economic practicality varies considerably over time.
4) Safety Policy Alternatives. In order to ensure that the level of risk in the system is acceptable, the AECB must enforce its safety policies. There are limits on the regulatory and other safety policies that are administratively feasible.

5) Expectations of Interest Groups. Since an acceptable level of risk must accommodate the values and views of many groups, the AECB needs to have knowledge concerning the safety expectations of various interest groups. Assessing the expectations of the interest groups is not a one-way process. The AECB may be involved in influencing the public's perception of an acceptable level of risk by disseminating information or through the educational process of public hearings.

As discussed in another BMC report concerning organizational and functional aspects of the AECB (3), the scope of responsibility of the AECB in the area of nuclear safety is very extensive. Basically, it encompasses the licensing and regulation of every step on the nuclear fuel cycle from the extraction of natural uranium through nuclear waste management. In addition to controlling prescribed substances, including products like heavy water that are not themselves radioactive but which play an integral part in various nuclear processes, the AECB prepares emergency plans, holds public hearings, represents Canada on the International Atomic Energy Agency and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, administers contracts related to nuclear regulatory research, and administers the Nuclear Liability Act which establishes liability and insurance requirements for Canadian nuclear facilities.

The regulatory role of the AECB is highly complicated by the fact that its relationship with the nuclear industry is not a simple two-way interaction. Rather, the AECB must also interact with various local, provincial, federal and international bodies in setting up its regulatory procedures. Because Canada has been in the forefront of nuclear development for some time, the international input to regulations and responsibilities may have been relatively easy to assimilate in the past. This situation may change as the world nuclear environment becomes more complex. The provincial role in nuclear regulation is strong for the historical reasons discussed in a previous paper (4).

Local governments become active in their concern when nuclear facilities are planned in their jurisdiction. Other federal departments such as Environment, Energy, Mines and Resources, and Health and Welfare also have legitimate concerns in the field of nuclear safety. Consequently, the promulgation and execution of licensing and compliance regulations can be a very slow, complex process. In fact, unless the various expectations of these and other groups can be reconciled rather quickly, technological developments can render the regulations and standards obsolete.

In short, the role of the AECB with respect to determining the acceptable level of risk is to identify the various interest groups and to balance, in some fashion, their expectations about nuclear risk. The notion of interest groups that impact on the safety role of the AECB is discussed in 2.3.
2.3 The Interest Groups That Impact on the Safety Process

Interest groups are defined as groups both inside and outside the power structure that are trying to modify the actions of the control group so that their own interests are protected.

If the AECB is to balance the expectations of the interest groups, then the first step is to identify such groups. Even in the absence of decisions or actions that immediately affect their interests, the identification of all the interest groups remains a non-trivial exercise.

Having identified the interest groups, the positions and the acceptable levels of risk for each must be understood. It follows from the role of the AECB that the balancing of the expectations of the interest groups ought to lead to an active search in identifying the interest groups and in finding out the expectations of each.

In a previous discussion paper on the acceptable level of nuclear risk (4) there is a discussion of interest groups (called "pressure groups" therein). The interest groups described in that paper are not necessarily exhaustive, but that discussion provides the basis for the complete identification of the interest groups.

It is not, however, within the scope of this study to exhaustively identify the interest groups, and the assignment of the weights to be put on them, implicitly or explicitly, must by definition be done by the AECB.

2.4 The Nuclear Safety Process

Having defined the acceptable level of risk and given an overview of the role of the AECB with respect to safety, we are now in a position to review the nuclear safety process and examine the context into which the AECB's acceptable level of risk fits.

A schematic representation of the nuclear safety process is provided by Figure 2.1. Many non-safety aspects of the various nuclear industries are de-emphasized by Figure 2.1 so that we can concentrate on the safety process. The width of the arrows is intended to indicate the importance or the directness of a safety-related process on the overall safety process.

The management of many heterogenous and diversified industries in the nuclear field interact with three conceptually distinct systems: the physical system, the economic system and the value system, which are explained in more detail below. Most of the industries in the nuclear field also have substantial non-nuclear concerns, so the "management" of nuclear industries is in no way an integrated entity although strong interrelationships exist among the various managements. Moreover, we are using the term "management" in a broad, generic sense that includes union or labour input and all other private sector factors that influence the industries' allocation of resources. Resource allocation by management is affected by information concerning output from the physical system, profits and demand from the economic system, and various types of information and
MODEL OF NUCLEAR SAFETY PROCESS

Figure 2.1

PHYSICAL SYSTEM

ACCIDENTS
- Injuries
- Environmental Damage
- Property Damage

SOCIO ECONOMIC LOSS
- Power Generation, Industrial Products
- Revenue
- Domestic/Foreign
- Profit/Loss

ECONOMIC SYSTEM

NUCLEAR INDUSTRY MANAGEMENT

INPUTS
- Labour
- Capital
- Material

RESOURCE ALLOCATION

SAFETY POLICY

ACCEPTABLE LEVELS OF RISK

AECB
- Control of prescribed substances
  - Health
  - Strategic Security
  - Safety
- Licensing and Regulations
  - Evaluation of Application
  - Issuance of Licence
  - Compliance Inspection
  - Development of Standards
- Administration
  - Regulatory Research Grants
  - Nuclear Liability Act
- Preparing Emergency Plans
- Public Hearings
- Representation of Canada
  - International Guidelines
- Impact
- Media
- Technical Support for Negotiation

INTEREST GROUPS
- Provincial, Federal, Local Government
- Business
- Labour
- Media
- Environmental Groups
- Religious Groups
- Universities
- Nuclear Researchers
- International Organizations

MANAGEMENT INFORMATION

VALUE SYSTEM

MANAGEMENT INFORMATION
pressure from the value system, as shown by the feedback loops in Figure 2.1. The way in which the nuclear industries allocate (or would like to allocate) resources very directly affects nuclear safety and, this is discussed in more detail below when the development of safety policy in the value system is described. The allocation of labour, capital and nuclear materials by management also directly determines the constitution of the physical system and the risk inherent in it.

The physical system consists of: 1) various production facilities such as nuclear power-generating stations, heavy water plants, radio-isotope manufacturing plants, uranium mines and refining facilities, and other facilities involved in the commercial production of nuclear materials or nuclear-related outputs; (2) research and development facilities, which are engaged in the development of equipment and technology; (3) the procedures, mechanisms and facilities related to the control of output quality, risk, and national or strategic security; (4) the nuclear fuel and waste storage facilities; and (5) the distribution facilities, which include such diverse infrastructure as power lines and transmitters for nuclear power plants and transport facilities for radio-isotopes, fuels and wastes, heavy water, and so forth. The physical system produces many nuclear related outputs, such as natural and refined uranium, electric power, medical and industrial radio-isotopes and other products, that become part of the economic system. It also produces risk to people, environment and property, and that aspect of the physical system is most relevant in understanding the safety process. The risk in the physical system is manifested by the occurrence of accidents resulting in personal, property and environmental damage. Like the nuclear-related outputs, the socio-economic losses from nuclear accidents impact on the economic system.

The economic system is characterized by an exchange of money for the goods and services of the physical system. Of more immediate interest to us, however, is that certain costs must be borne in the economic system as a result of risk in the physical system. The socio-economic losses result in damage costs; from a societal point of view these damage costs may be greater than the initial costs considered by the nuclear industries. The damage costs include loss of revenue, or reduced system capacity, property loss, and compensation paid to employees, users, shippers and third parties, as well as non-monetizable losses like environmental damage. In addition, there are prevention costs* that are incurred as a result of the safety programs of management (which represent management's major contribution to safety policy, as depicted in Figure 2.1) and the safety policies of several interests in the value system, most importantly those of the AECB.

The value system represents the set of institutions and the interactions among them that develop and communicate norms concerning the physical and economic systems. With respect to the safety process, various

* The concept of prevention costs is a useful abstraction to aid in the understanding of both the safety process and the conceptual methodology developed in the following chapter. In practice, however, many expenditures for "safety" cannot be separated from expenditures on operations.
interest groups in the value system make known their norms and preferences to the main control group, the AECB, partially on the basis of information coming to them from the physical and economic systems and partially on the basis of preconceived notions. Some of the interest groups depicted in Figure 2.1, like some provincial governments and some federal agencies other than the AECB, impact on the AECB and the determination of its acceptable level of nuclear risk more than others, as mentioned in 2.2; the interest group box in Figure 2.1 provides a listing of some of the groups that impact directly on the AECB. In Figure 2.1, the AECB is depicted as the main agent through which social values on nuclear safety are expressed, reflecting its role and scope of responsibility, as discussed in 2.2. Furthermore, the acceptable level of risk is shown as part of the AECB itself representing the implication of the definition stated in 2.1: the level of risk in the system must be acceptable to the AECB. By balancing the expectations of the various interest groups and the desired resource allocations of the nuclear industries, the AECB implicitly develops criteria for acceptable levels of risk; and these criteria form the basis of the safety policies arising in the value system. The safety policies impact on the physical system as specific programs and guidelines and on the economic system as risk prevention costs.

The AECB fulfills its role in determining the acceptable level of risk in part by imposing descriptive and prescriptive programs on the industry. Descriptive programs provide information to the AECB concerning the physical and economic systems, allowing the AECB to monitor the risk in the physical system and the economic consequences of that risk in the economic system. An example of a descriptive program is statistical data gathering. Prescriptive programs are those which alter the behaviour of the physical system such as regulatory orders, standards, rules and their enforcement; other possible but presently unutilized prescriptive programs would be tax incentives or penalties and subsidies. The feedback from descriptive programs eventually impacts on safety policy, through implicit expressions of the acceptable level of risk, and hence on prescriptive programs. Therefore, the central determinant in the safety process is the AECB's implicit acceptable level of risk.

In the remainder of this report we discuss how a more explicit and methodical acceptable level of risk can be determined.
3. THE CONCEPTUAL METHODOLOGY FOR DETERMINING THE ACCEPTABLE LEVEL OF RISK

3.1 The Total Cost of Risk Function

In the previous chapter we have defined the acceptable level of risk and shown its relationship to the nuclear safety process. The purpose of this chapter is to explain how the acceptable levels of risk can be determined. At a purely conceptual level, the search for an acceptable level of risk can be formalized as being the range of feasible combinations of cost and risk that are acceptable. To determine that range, let us examine the relationship between two functions: the total cost of risk function and the acceptable level of risk function, which is explained in 3.2.

The concept of a cost of risk function has a firm theoretical basis. It has been neatly summarized by Starr (13) and Wynholds (16), and has been expanded recently by Johri-Chant-Konecnny (8) and Eastman-Johri-Konecnny (6), especially with respect to the policy implications for a regulatory body.

Consider a function, T, that translates various types of risks (conveniently collapsed onto a single axis of risk) into the various costs (also expressed by a single cost index) that must be borne as a result of the risk levels. As illustrated by Figure 3.1, the total cost of risk curve, T, can be conceptualized as having two components: 1) a prevention cost function, P, that increases at lower levels of risk, and 2) a damage cost function, D, that increases at higher levels of risk. Hence, the sum of those two yields a total cost of risk curve that is quadratic in shape. It is possible to determine conceptually from the T curve an economically optimal level of risk, R, in Figure 3.1. In practice, however, it may be impossible to know empirically what that economically optimal level of risk is, or it may be politically impossible to attain it. In other words, the economically optimal level, at least in the short run, may be politically or socially unacceptable.

Three key points should be noted concerning the total cost of risk function, T. Firstly, the only portions of T that are economically relevant are the downward and flat portions of it. For all upward sloping portions of T the same amount of total costs can achieve lower risks, so cost-risk combinations to the right of R in Figure 3.1 are not relevant. This notion is discussed more fully in 3.4.

Secondly, it is only at a purely conceptual level that T is a mathematical function; in practice, it is only "known" as a mathematical correspondence, a range of probable feasible cost-risk combinations. For example, let us assume that our knowledge concerning the cost of total risk in the system comes from the combined opinions of many experts. It is
Figure 3.1 - TOTAL COST OF RISK FUNCTION
reasonable to suppose that different experts would have different perceptions or opinions as to what the actual prevention and damage costs would be. Figure 3.2 illustrates a situation in which the prevention costs are estimated to range between a low of $P_L$ to a high of $P_H$, and the damage costs are estimated to lie between $D_L$ and $D_H$. Both the levels and the shape (nature) of the costs can be perceived differently by different experts. Hence the total costs of risk may lie anywhere between the lowest estimates of total costs, the sum of $P_L$ and $D_L$, to the highest estimates, the sum of $P_H$ and $D_H$. This range is depicted in Figure 3.2 as the difference between $T_{LL}$, the sum of $P_L$ and $D_L$, and $T_{HH}$, which is $P_H$ plus $D_H$. Because $T$ is in reality a correspondence or a "fat" function, there is considerable merit in determining acceptable cost-risk combinations rather than attempting to locate economically optimal risk levels, which in Figure 3.2 may lie anywhere between $R_H$ and $R_L$.

Finally, it is not necessarily sufficient for the control group to base its choice of the level of risk in the system on the $T$ curve(s). In general there may be other constraints upon the level of risk that can (or should) be selected. Some portions of the downward sloping part of the total cost of risk functions may be politically or socially unacceptable; even a range of $T$ containing the economically optimal level of risk may be unacceptable. To determine those ranges of the $T$ curve(s) that are acceptable, the control group also has to have information about acceptable cost-risk combinations. Hence, an understanding of an acceptable level of risk function must be obtained.

3.2 The Acceptable Level of Risk Function

In economic analysis a considerable body of thought has been developed concerning consumer utility and utility functions. Samuelson (12) and Allen (1) provide two of the more respected and concise treatments of the topic. Essentially, utility functions increase up to some limit as a consumer receives more of an economic good, everything else remaining equal. If one considers an analogue of a utility function whereby two "goods" are "consumed" that both have negative economic value or disutility, one can conceptually develop a disutility function such that the upper terminus of the function represents the maximum disutility that is tolerated and the origin of the function represents minimum disutility that need be suffered from "consumption" of the two "goods". An acceptable level of risk function is such a disutility function.

Consider a function, $A$, that describes the level of risk that is acceptable to an individual consumer for a given cost. If the cost of controlling risk in the system is zero, then the acceptable level of risk is zero, no risk at all. The consumer suffers the minimum disutility in this situation. For example, if the system in question is the entire braking mechanism of the consumer's private automobile that is unconditionally guaranteed by the manufacturer, then the consumer would be expected to tolerate no identifiable risk in the car's braking system. However, as the
Figure 3.2 - The variation surrounding various estimates of the actual costs of risk in the system.
cost to control risk increases to the consumer, the level of risk that is acceptable also increases up to some point at which further risk or costs are unacceptable.

Extending the previous example, if the consumer himself had to pay for repairing or replacing his car’s braking system, he would tolerate some levels of risk before incurring the cost of a brake job; at sufficiently high risks (sufficiently poor brakes), he simply would not drive the car until the brakes were fixed. Likewise, if the costs of the brake repairs were too high in the judgment of the consumer, he would sell or not use the car.

The interpretation of an acceptable level of risk function varies slightly depending upon whether the risk to be incurred is voluntary or involuntary. For voluntary activities the acceptable level of risk function describes the costs that one would be willing to incur to avoid various levels of risk associated with the activity. For activities imposing involuntary risks, the interpretation of the acceptable level of risk function is that it shows the amount of the benefit that would be required to offset various levels of risk from that involuntary activity. However, the significance of the terminus or end point of an acceptable level of risk function is same for either voluntary or involuntary activities: the terminus of an acceptable level of risk function represents the cost-risk combination beyond which one would prefer not to use an activity rather than incur additional costs or risks.

Many types of behaviour are possible, and the concept of an acceptable level of risk function does not lead one to expect that one type of behaviour is more rational or predictable than another. Figure 3.3 illustrates several kinds of risk acceptance. The function $A_1$ describes attitudes that are relatively intolerant of risk and also relatively intolerant of the costs associated with having risk; persons with a cost-risk attitude such as that represented by $A_1$ would be prone to shut down or not use a system unless it could be operated at a relatively low level of risk for relatively low costs. An intuitively appealing shape for the $A$ function is illustrated by $A_2$, which depicts a relatively risk-tolerant attitude at low levels of risk, a relatively cost-tolerant attitude at higher levels of risk, and a return to risk-tolerance as the total costs of risk approach the maximum costs that are acceptable. An attitude that is both relatively risk-tolerant and cost-tolerant is shown by function $A_3$.

Having discussed the concept of the acceptable level of risk function, a comment on its potential measurability is in order. In addition to there being a conceptual analogue to acceptable level of risk functions in the form of disutility functions, so also is there an analogue for the empirical measurement of such functions. The measurement of acceptable level of risk functions is similar to the measurement of prior distributions in Bayesian statistics. Prior distributions are the probabilistic expectations that one has concerning events before actual or empirical information is received. Acceptable levels of risk are cost-risk combinations that
Figure 3.3 - ILLUSTRATION OF VARIOUS ACCEPTABLE LEVEL OF RISK FUNCTIONS
are acceptable to one before he learns whether or not these acceptable cost-risk levels are feasible. Fortunately, a considerable body of knowledge exists on the measurement of prior distributions, as exemplified in the successful and respected work of Winkler (15), Good (17) and others.

Now let us examine the relationship between the total cost of risk function and the acceptable level of risk function.

3.3 Ranges of Acceptable Levels of Risk

Generally, the curve of cost-risk combinations that is of most concern to the control group is the total cost of risk function, $T$, not the acceptable level of risk function, $A$, as long as the terminus of $A$ lies above and to the right of the lowest point of $T$. This concept is elucidated graphically by Figure 3.4, which shows $A$ and $T$ as single-valued functions for simplicity.

As depicted in Figure 3.4, the party (let us suppose it is the "society") whose cost-risk attitudes are described by the $A$ function is willing to incur at the maximum the disutility associated with cost $C_Z$ and risk $R_Z$. The populace is unwilling to pay risk-related costs in excess of $C_Z$ or bear risks greater than $R_Z$ at any cost. Hence, the range of acceptable risks is $R_0$ to $R_Z$. However, since costs above $C_Z$ are unacceptable, the range of economically feasible acceptable levels of risk is $R_A$ to $R_Z$. In other words, levels of risk that are safer than $R_A$, the minimum economically feasible acceptable level of risk, cannot be achieved without incurring costs that are unacceptably high as shown by the $T$ curve, the actual costs of risk management. For levels of risk to the right of (more risky than) $R_A$, the actual costs of maintaining those risk levels are lower than what would be acceptable (over the domain for which $A$ is defined); therefore, the control group can improve the safety in the system by moving to a less risky level and still maintain the total costs of risk management below acceptable levels. Moreover, since the control group would never want to set the risk in the system at a level of risk more risky than (to the right of) the economically optimal level of risk, as explained in 3.4, the desirable range of acceptable levels of risk can be further restricted conceptually to those levels of risk that are acceptable and economically rational. Referred to as economic acceptable levels of risk in Figure 3.4, this range lies between the minimum economically feasible acceptable level of risk, $R_A$, and the economically optimal level, $\bar{R}$, if the maximum economically feasible acceptable level of risk, $R_Z$, is greater than $\bar{R}$.

In Figure 3.4 it so happens that the economically optimal level of risk, $\bar{R}$, is included in the feasible acceptable range, but this need not necessarily be the case. For a relatively risk-tolerant population, like that one depicted by Figure 3.4, the actual cost curve or the experts' estimate of it is the only cost-risk curve that need be considered by the control group. On the other hand, for a more risk-adverse population, like that illustrated by Figure 3.5, the range of feasible acceptable levels of risk may be so narrow as to exclude the economically optimal level of risk. For such a population, the control group must either attempt to alter the population's willingness to accept risk or the costs associated with reducing the risk or they must confine their own acceptable level of risk to the range of risks $R_A$ to $R_Z$ in Figure 3.5, for which the public is willing to accept the costs.
Figure 3.4 - THE CONCEPTUAL DETERMINATION OF A RANGE OF ACCEPTABLE LEVELS OF RISK
Figure 3.5 - RANGE OF ACCEPTABLE LEVELS OF RISK FOR A RISK-ADVERSE POPULATION
It should also be noted from Figure 3.5 that the acceptable cost-risk combinations that are technically feasible are those shown by the shaded area. The efficient acceptable cost-risk combinations are those along the T curve between $R_A$ and $R_Z$; it is the responsibility of the control group and the industry to select a cost-risk combination near or on that border.

From a policy viewpoint the most important point on the A function is the upper terminus or the end point. It is necessary to know the levels at which the various segments of the population are unwilling to accept either more risk or more cost to reduce the risk. The terminus of A is the cost-risk combination beyond which a population is willing to shut down a system rather than accept higher costs or greater risks. There is, however, some benefit in knowing something about the shape of A, especially in the neighbourhood of its terminus. A knowledge of the fashion in which A approaches its terminus may aid in understanding the psychology of the nuclear safety process. It is beneficial for the control group to have an awareness of the cost-risk psychology of the populace because one likely outcome of determining acceptable cost-risk combinations is that some extent of education by the control group to the populace or to some interest groups in it may be desirable. For such education it would be advantageous to know if the groups to be persuaded are more cost-tolerant or risk-tolerant in the neighbourhood of the terminus. In other words, are they more likely to accept additional costs or risks?

An even more important reason to attempt to estimate a substantial portion of the A function rather than simply its terminus is that in reality the A curve, like the T curve, is likely to be "spongy". The cost-risk combinations that are acceptable are not likely to be known exactly at any point in time, and they would change over time. Hence, it is advantageous to have knowledge about the shape of the A curve. This point is illustrated by Figure 3.6. Consider two types of attitudes about risk. One is a cost-tolerant attitude in the neighbourhood of its estimated terminus, $a$, as depicted by $A_1$, and the other is risk-tolerant in the neighbourhood of its terminus, which is estimated to be the same point, $a$. Although the point, $a$, is estimated to be the terminus for both $A_1$ and $A_2$, there may be, however, uncertainty as to the exact upper bounds of both functions; in this example, the actual terminus for $A_1$ could lie anywhere along the broken line $a_1a$, and the actual terminus for $A_2$ could lie along $a_2a$. Likewise, in this example, there is uncertainty as to the risk that actually exists in the system, so the control group in selecting $R_Z$ as its maximum acceptable risk level can only be assured that the system is operating in a neighbourhood of $R_Z$. In Figure 3.6 the system may be operating anywhere in the range around $R_Z$ indicated by the parentheses; for the sake of the example, let us assume that it is operating at R. Let us further assume that the actual termini of $A_1$ and $A_2$ are $a_1$ and $a_2$, respectively. Thus the actual cost-risk combination in the system, shown on Figure 3.6 as cost, C, and risk, R, is acceptable to the group characterized by $A_1$, but it is not acceptable to those characterized by $A_2$. Moreover, no
cost-risk combination selected by the control group (no risk level in the neighbourhood of $R_Z$) would have been acceptable to the $A_2$ group if the actual terminus of $A_2$ turned out to be $a_2$. Moreover, for simplicity, $A_1$ and $A_2$ were shown to be "spongy" only with respect to their end points; in reality, the acceptable level of risk curve would probably be "fat" as well. Thus, given the uncertainty and variability surrounding the $A$ function, it makes sense to gather as much information as possible about the overall shape of the curve rather than relying exclusively on an estimate of the terminal value of the acceptable level of risk function.

3.4 Axioms of the Methodology

Having explained the conceptual methodology, let us explicitly examine the assumptions that underlie it. Some of the assumptions are axiomatic and are discussed in this subchapter. Other assumptions take the form of testable hypotheses and are mentioned in 3.5.

The first axiom is that, for exactly equivalent total costs, people would prefer to incur prevention costs rather than damage costs. The basis for this axiom is that there is less uncertainty surrounding prevention costs than damage costs and that, in principle, the prevention costs can be shared more equitably.

A second axiom is a corollary of the first. Only the downward and flat portions of the total cost of risk function are relevant to the selection of economically desirable levels of risk. Equivalently, economic levels of risk in the system are always found in the range of risk in which marginal damage costs are less than or equal to marginal prevention costs. To illustrate this point, let us return to a representation of the total cost of risk curve, $T$, as a quadratic function, as depicted in Figure 3.7.

Suppose the population is quite risk- and cost-tolerant as illustrated in that figure. The range of feasible acceptable levels of risk is $R_A$ to $R_Z$. At risk $R_1$ the population would be willing to incur costs of $C_1$; however, for the same costs, $C_1$, a much lower risk, $R_Z$, could be achieved in the system. In general, any level more risky than the economically optimal level of risk (the range $R$ to $R_Z$ when $R_Z$ is more risky than $R$) need not be considered by the control group. If $A$ intersects an upward portion of $T$, the control group can choose any acceptable level of risk that is economically desirable, and it will necessarily be acceptable to the populace.

3.5 Testable Hypotheses of the Methodology

The methodology makes several assumptions that cannot be supported by logic alone, but rather they can only be accepted or rejected by empirical testing. As discussed in the following chapter, there has been a substantial amount of practical work done in coping with surveying problems related to the hypotheses listed below, and so there is some evidence that the following
Figure 3.6 - UNCERTAINTY AS TO THE EXACT TERMINUS OF THE ACCEPTABLE LEVELS OF RISK
Figure 3.7 - RANGE OF ACCEPTABLE LEVELS OF RISK FOR A RISK-TOLERANT POPULATION

- ECONOMIC ACCEPTABLE RANGE OF RISK
- FEASIBLE ACCEPTABLE RANGE OF RISK
hypotheses can be substantiated. However, only testing can determine if
the hypotheses are valid in the context of nuclear safety.

To transform the conceptual methodology into a practical tool,
the following assumptions must be verified with respect to nuclear safety:

1) Experts can be found that can relate the cost-risk
combinations that are feasible for various modes and
levels of nuclear power production. It is preferable
for the experts to be able to distinguish between
prevention and damage costs. If the assumption is valid,
this probably would be the case since different experts
would likely be relating different kinds of costs. However,
strictly speaking the assumption is only that the feasible
total cost-risk combinations can be identified.

2) The risk can be defined and presented to both technical
and non-technical audiences in a fashion that is com­
prehensible to them. In reality, there are several
different types of risk that can result from nuclear
power generation. These various risks must be communicable,
though not necessarily as a single index.

3) Similarly, the various types of costs can be described in
ways that are identifiable and comprehensible.

4) People can relate to cost-risk combinations for involuntary
risks and communicate their preferences.

5) People can relate to or differentiate among risks with very
low probabilities. This assumption does not mean that
people must be willing to accept higher costs for lower
risks at all levels of risk, for at some very low risk
levels people could quite rationally be risk-tolerant.
Rather, it means that people must understand the difference
between, for example, a probability of $10^{-6}$ as opposed to $10^{-7}$,
although probabilities would probably not be stated in
explicit mathematical terms.
4. OPERATIONAL APPROACH FOR DETERMINING
THE ACCEPTABLE LEVELS OF RISK

4.1 Survey Design for Experts

Having examined the methodology conceptually, we turn to the operational aspects of it. In order to determine the total cost of risk function or some points along it, we must obtain information from experts as to the actual cost-risk combinations that are feasible. To approximate points along the acceptable level of risk function, we must get information from the various interest groups. Aspects of the survey design related to the surveying of the experts are discussed in this subchapter, and aspects of the interest group surveying are discussed in 4.2 through 4.4. Subchapter 4.5 discusses the combining of the acceptable levels of risk of the various interest groups by the AECB.

There are a variety of methods available to collect the information from the experts, including mail, phone and door-to-door questionnaires, several types of Delphi approaches, semi-structured interviews, conference interviews, and hybrid combinations of these techniques. Descriptions of these techniques and their advantages and limitations have been provided in a previous discussion paper (4).

For several reasons a hybrid personal interview/Delphi approach is probably the best technique for obtaining the required information from the experts. Personal interviews are especially well suited to the problem at hand because they allow the interviewer to probe into the responses of the experts; many times the initial responses of experts will raise questions or insights in the mind of the interviewer that were non-existent at the time of the original survey design. An interview allows the expert to expound on an idea, unconstrained by a questionnaire format. In general, the interviewing process itself is beneficial in understanding the problems. Furthermore, the depth and detail that can be obtained in an interview lends a high degree of credibility to the results. Moreover, the experts can be questioned in a way in which they are trained to answer. One advantage of the personal interview is that the format of the questions can be varied during the interview and that different questions can be posed to different experts. In general, not all experts would be in a position to answer every question.

Because the second stage of the proposed methodology, the surveying of acceptable cost-risk combinations for segments of the general population, becomes easier if the maximum consensus is obtained by the experts in the first stage with respect to the (perceived) real cost-risk combinations, it is probable that at least one iteration of the interviewing would be desirable to provide the various experts with feedback from the other experts. This aspect of the Delphi technique tends to narrow the divergence among the expert opinions, producing a narrower range of feasible cost-risk combinations for input into the second stage
of the surveying. It may be possible to undertake second or third round interviewing of some of the experts in a conference or more structured fashion for the sake of economy.

From the interviewing of the experts, several types of information are required to accommodate the conceptual methodology:

1) Critical Variables. Some experts need to identify the variables that impact most significantly on cost and risk in the production of nuclear energy. An example of this type of question is: "What are the different ways in which nuclear risks could be reduced? Please be specific with respect to the construction of the plant and facilities, the location of the plant and so forth."

2) Cost-Risk Relationships. Some experts must indicate the appropriate feasible (or potentially feasible) technologies and operating conditions that yield different levels of cost and risk. It is not necessary that any one expert be able to estimate cost-risk combinations; rather, it is likely that some experts can provide information on various risk prevention possibilities, some can supply estimates of risk prevention costs and some can give information on risks and damage costs. Information from existing studies, like the Rasmussen report (11), can also be input to estimate cost-risk relationships. Examples of this type of question are: "If you had $X to reduce risk in nuclear energy plants, what would you do with it? What would the effect of this be in reducing risks?" Or: "If you had to produce the same amount of energy with $X less, how would you plan this nuclear facility differently? What would the effect of this be on safety?"

3) Alternatives. Some experts need to indicate the consequences of not providing additional (or any) atomic energy. The consequences need to be estimated both in terms of alternative means of production and in terms of the conservation effort that would be required if the energy were foregone completely. For example: "If we were not going to build a nuclear plant, but instead were going to use alternate means of energy, what would be done to provide this much energy? What would the short and long term costs be of the alternate source of energy?" Or: "If it were critical to use less energy over a long period of time as a result of not building (shutting down) nuclear generating plants and of alternate sources not being found, what energy conserving plans would have to be followed in order to survive on the lower amount of energy?"

4) Process Information. In addition to technical combinations, the experts can provide information concerning the nuclear safety process that would be valuable in structuring the questions in the next stage of the methodology. For example, different kinds of risks and costs could be identified for various levels of output. Also, the groups affected by the various risks and costs could be identified, which would assist not only the structuring but also the sampling for the latter stage of surveying. For example: "What are the specific kinds of risks and costs that result from atomic energy? Please identify environmental and non-monetary kinds of risks and costs as well as those that can be defined in monetary terms. What groups are most likely to be affected by each of the risks and costs?"
4.2 Survey Design for the Interest Groups

The general idea of the second stage of the methodology is to query the interest groups involved in the nuclear safety process, including the general public, to determine whether or not various cost-risk combinations are acceptable to them. Whereas a hybrid interview/Delphi approach was suggested for the first stage of the methodology, a questionnaire is recommended for the second.

There are several reasons for this. When querying the attitudes and values of a general population, a standard format for the questions is desirable both for reasons of economy and of statistical comparability. Since a much larger sample will have to be drawn for the interest groups and the general population than for the experts, surveying by means of a standard questionnaire has a substantial economic advantage over in-depth, probing interviews. Whereas the main concern of the first stage of the methodology is that the responses be technically sound, the main objective of the second is that the values expressed be statistically representative. Technical credibility is required in the surveying of the experts; statistical credibility is demanded in the surveying of the populace.

The development of the actual questions on the questionnaire would only be done after the surveying of the experts. The data from many studies and other sources of information would be blended with the additional information provided by the experts. The questions would then be put into a format that was comprehensible to the target population. This is accomplished by an iterative process of pretesting.

The first stage of the pretesting of any questionnaire is to see if people understand the questions. As in all questionnaire construction the only way of finding out with any degree of certainty whether or not the questions are being understood is to administer the questions to a sample of respondents and then interview them to determine if they understood the questions. If they do not appear to have understood the questions, the reasons for that must be determined.

At the same time, a number of other testing procedures have to be performed. For example, it would have to be determined whether or not the response scale should contain a "midpoint", thus allowing the respondent to indicate indecision. One problem with having a midpoint is that it can be used by the respondent as an easy way of avoiding the thought necessary to answer the question. Furthermore, it if is desired that people be forced to make a decision on limited information, then the midpoint could interfere with this. On the other hand, one reason to keep a midpoint, at least early in the pretesting stage, is to assist in determining if the respondents understood the question; respondents using this alternative would be interviewed in greater depth to determine if they are actually undecided or simply are not really understanding the questions.

Another example of the kind of factor that would be examined in the pretesting stage would be the possible existence of an "agreement bias", which would have the effect of increasing the proportion of respondents who, given the wording being tested, would appear to favor the use of additional funds to increase nuclear safety.
Another issue raised by recent research is that people do not appear to use probability information in a "scientific" or "rational" way. For example, Carroll (5) demonstrated that simply thinking about an event made people believe it was more likely to occur. Borgida and Nisbett (2) showed that people sometimes give higher weight to single events than to aggregate data. These examples may be special cases of a general discussion of distortions in subjective probability by Kahneman and Tversky (10) who demonstrated that the "availability" or salience of an event can have dramatic impact on its perceived likelihood of occurrence. It is clear that the issues raised by these findings need to be examined in some detail during the pretesting stage.

During the pretesting the importance of variables presumed to affect the acceptable levels of risk could be examined. For example, the levels of the cost and risk variables can be systematically varied in such a way as to indicate whether people are, in fact, cost conscious in determining an acceptable level of risk. Furthermore, they can be asked whether or not they are in agreement with a proposed course of action as a function of the cost of that action.

The point to keep in mind with all of these comments about pretesting is that they are standard procedures in questionnaire construction and do not involve any unknown factors. The process is simply a series of iterations whereby the questionnaire is tried out on a number of respondents (similar to the target population); the question format, exact wording, responses allowed and so forth are altered in light of this experience and then tested again. Only when the respondents appear to be understanding the questions without difficulty and responding easily to the alternatives that are listed can the pretesting phase be considered to be finished.

Before presenting some examples of questions for the interest groups, we examine some of the factors affecting a choice of an acceptable level of risk. These factors have implications concerning the types of events that should be selected for a comparison with nuclear risk.

4.3 Factors Affecting Choice of Risk Comparisons in Survey for Interest Groups

In order to develop the specific questionnaire for the various interest groups, it is necessary to present the risks and costs associated with nuclear safety to a wide audience. For these risks and costs to be comprehensible to the typical respondent, they must be compared to some risk with which he has some knowledge or experience. Moreover, whereas criteria for optimal levels of risk can be established through strictly economic analyses, the acceptability of a level of risk is to a large extent a psychological matter. There are a variety of factors that can influence the psychological acceptance of a level of risk. Hence, comparisons of risk must be made that are as comparable psychologically as possible.

For many reasons, some of which are outlined below, it may be improper to infer acceptable levels of risk based on comparisons of
accident rates irrespective of, for example, the distribution of the size
of the accidents. In general, the following factors should be taken into
account in the selection of risks to be compared with nuclear risks:

1) The Maximum Size of the Accident. Apparently, people are
more adverse to large, conspicuous accidents than to more numerous, small
accidents. A case in point is that Canada's 6,000 or more annual fatalities
in automobile accidents seem to attract less public clamor for increased
safety than one airplane crash that kills 400 people. Although several
other factors are involved in the comparison of automobile versus airplane
fatalities, it is difficult to avoid the inference that ten accidents
involving injuries to one person each are not necessarily perceived to be
as serious as one accident injuring ten people. The larger accident is
likely to be more salient in people's minds.

2) The Seriousness of Actual Accidents. The resultant severity
of accidents is undoubtedly a factor in the extent of subsequent risks to
be tolerated, even if the seriousness of an accident is in fact random.
For example, an explosion or a fire at a factory that occurs with the
workers absent causes less alarm than an identical accident that occurs
during a workday. Yet, if the cause of the accident is not related to
the presence of workers, the risk in the system is the same. People tend
to judge risk not by the probability of an accident times the potential
consequences but rather by the actual consequences of accidents. This
can lead to distortions in the perception of risk when risks that have
yielded different actual severities are compared, even if the risks are
in fact equal in terms of expected or probable consequences. Moreover, it
is in the short term comparison of risks with very low accident rates that
actual consequences can appear to deviate from expected consequences, even
when the accident probabilities have been estimated correctly.

3) The Familiarity of the Risk. Risks that are or seem to be
more unknown may well create more concern than risks where the consequences
are known and understood. One of the problems faced by the nuclear industry
is that its very safety record leaves doubt in many people's minds as to
the dire consequences of a major nuclear accident. Where uncertainty exists,
the worst is frequently expected. However, nuclear risks and risks com­
parable to them are probably becoming more familiar as more is learned about
the effects of radiation and about the effects of non-radioactive agents
such as some pesticides and poly-chlorinated biphenyls that also have the
potential for genetic and cancer related damage.

4) Involuntary Risk. It has been frequently observed that, where
the victim or potential victim has control of the factors creating the risk,
the risks are perceived to be more acceptable than involuntary risks.
Similarly, if the victim has control over whether or not he puts himself
in a situation of risk (for example, selecting a dangerous occupation), then
the acceptable level of risk is assumed to be higher than if he were not
regarded as having some control.

5) Recency or Salience of Accidents. The salience of the accident
is likely to affect the perception of the likelihood of such an accident and,
consequently, is likely to affect the acceptable level of risk. In other words, if a particular kind of risk has existed for a given period of time and one accident has taken place, the risk is likely to be perceived as being greater if this one accident occurred in the recent past rather than in the distant past. For example, there is much current debate concerning safeguards against falling satellites, provoked by the recent incident of the Soviet satellite that crashed in the Northwest Territories. Undoubtedly, that incident has affected acceptable levels of risk for falling satellites.

6) Means of Payment for Risk Reduction. As was discussed in Chapter 3, an acceptable level of risk is in part a function of the cost of the risk prevention to the party selecting an acceptable risk level. More generally, even if the party concerned does not actually pay for a share of the costs of risk reduction, the determination of acceptable levels of risk may still be partially dependent upon who does pay for the risk reduction and how those costs are shared.

In summary, a consideration of the above factors indicates that the types of risks most suitable for comparison with the risks of nuclear power production are risks that have very low probabilities of occurrence, large potential consequences, some qualitative resemblance to the risks from radiation and an involuntary nature. The risk should also have produced consequences that are salient enough to relate to, but not so recent as to radically distort perceptions of the probability of the risk. People should be able to relate to making payments for the control of the risk. If all factors cannot be accommodated simultaneously, this last factor may be the most expendable by virtue of the fruitfulness of people's imagination; for example, perhaps people could imaginatively relate to payments for the reduction in consequences from earthquakes.

The types of risk comparisons that seem most appropriate in view of the above factors are large natural or man-made disasters, such as flooding caused by breaches in dams, volcanic activity, earthquakes, the accidental overuse of pesticides, excess exposure to poly-chlorinated biphenyls, or (when the present frenzy surrounding the Soviet satellite incident subsides) crashing satellites. Differences in accident probabilities can be partially accounted for by varying the time of risk exposure. Likewise, if it is desirable to determine acceptable levels for different types of nuclear risks (for example, radiation damage to human beings and property or environmental destruction), it is possible to compare different aspects of nuclear risk with different kinds of risks in separate questions.

4.4 Examples of Questions for Interest Groups

For illustrative purposes, three prototype questions are shown below exemplifying the kinds of questions that could be asked on a questionnaire. These illustrative questions are not even at the pretest stage. Before they can be pretested, certain key pieces of information will have to be provided. For example, "real" cost-risk combinations derived
from experts should be substituted for the hypothetical ones that are part of the questions. An event which actually does approximate that probability should be used as the "standard" of comparison. The risk reduction that is possible for a given cost will have to be inserted into the question. Only when all of this factual information is available will the pretesting be able to begin.

Validation of these techniques also needs to be done to test for rational patterns of responses. The questions below have been written in such a way that various quantitative statements that logically relate to acceptable levels of risk can be varied. If the responses do not relate to experimental variations in a rational fashion, then the measures of the acceptable levels of risk are not valid.

In summary, all aspects of the following questions other than the general format can be altered. The main considerations underlying the general format of the questions are that:

1) people must be given the opportunity to respond in terms of probabilities that have some personal meaning;

2) the costs must be expressed in personal not aggregate terms; and

3) the risks and costs must be combined in each question.

(a) **Example 1**

Imagine this situation: A nuclear plant is going to be built (one/five/fifty/two hundred) mile(s) away from where you live. The best estimate of the chances of an accident occurring suggest that an accident is very unlikely to occur. Specifically, it is estimated that the chances are less than one in ten million that an accident involving nuclear energy will occur in this plant in the next fifty years. This is approximately equivalent to the chances of your being hit by a falling airplane during the next fifty years.

To reduce the likelihood of the occurrence of an accident by (10/20/50/90)% would mean an increased cost of electric energy that would have the effect of costing you (various monetary costs) each month in addition to what you pay now directly and indirectly for electric energy.

Should this additional money be spent to reduce the likelihood of an accident by (10/20/50/90)% even though it means additional costs to you?

___ Yes ___ Probably yes ___ Undecided ___ Probably not ___ No
(b) Example 2

The Province of Ontario has a number of nuclear generating plants in operation or in the planning stages. At present, the likelihood of a nuclear accident involving death or injuries is equivalent to the likelihood that you or your children will be killed by an earthquake within seventy-five years.

The government is considering requiring nuclear generating plants to be safer than they are at present. However, there will obviously be some costs involved in this safety program. It is estimated that in order to reduce the likelihood of an accident by X% (i.e. reducing the likelihood of an accident to the equivalent of the likelihood that you will be killed by an earthquake within fifty years) you will have to pay an additional Y% on your electricity bill for direct and indirect costs of energy.

Do you recommend that this money be spent on reducing the risk of a nuclear accident?

___ Yes ___ Probably yes ___ Undecided ___ Probably not ___ No

(c) Example 3

At present, the risk in Canada of a nuclear accident in one of the nuclear generating plants is approximately equivalent to the risk of an airplane crashing because it was hit by a falling satellite. Additional safeguards could be constructed that would reduce this likelihood even more (to the equivalent of the likelihood that a person will be killed before reaching 10 years of age by being killed in the crash of a plane that was hit by a satellite).

However there are costs of doing this. In particular, to reduce the costs of a nuclear accident this much would mean that you would have to pay additional money each year for this increase in safety. How much would you be willing to pay for this increase in safety?

___ I would not be willing to pay anything to achieve this increase in safety.
___ I think that the risk is acceptable now.
___ I would be willing to pay up to $X to achieve this increase in safety.

OR

However, there are costs in doing this. Specifically, it would mean that (all buildings would, by law, be heated no higher than $66^\circ F/19^\circ C$ during the winter and buildings could not be airconditioned in the summer to temperatures lower than $80^\circ F/27^\circ C$) (the production of commodities requiring a relatively large amount of electricity, like aluminum products, would have to be severely restricted) (the use of appliances drawing relatively large amounts of electricity, such as space heaters, would be severely restricted).

Do you think that these "costs" are worth the increase in safety.

___ Yes ___ Probably yes ___ Undecided ___ Probably not ___ No
4.5 The Weighting of the Various Acceptable Levels of Risk

Having obtained from the surveying of the various interest groups in the general population estimates of the cost-risk combinations that are acceptable to them, the problem arises of combining or amalgamating the acceptable levels into one societal cost-risk combination. In other words, how should the revealed acceptable levels of risk be weighted in order for the control group to approximate the socially acceptable level of risk?

First of all, there are many advantages and insights that the control group can realize without doing any weighting at all. In many respects knowing the expectations of the various groups is more important than determining an overall acceptable level of risk that is a blend of those expectations. Understanding the acceptable levels of risk for various interest groups allows the control group to anticipate and identify the political support or opposition to be expected with respect to decisions concerning nuclear safety. It also indicates the extent of the education concerning nuclear safety that may be desirable and the specific groups to which it should be addressed.

At some point, however, decisions concerning the construction and operation of nuclear plants will require the determination of a socially acceptable level of risk. For this the acceptable levels of risk must be weighted, implicitly or explicitly, by the AECB to determine a socially acceptable level of risk.

There are some advantages of providing an explicit weighting. It might be advantageous for the Board to construct safety policies such that decisions could be made at lower levels within the AECB so that the Board itself would not have to be constrained to make decisions that could be made elsewhere within the AECB; to develop such policies with respect to decisions involving acceptable levels of risk, an explicit weighting to be applied to the various interest groups would have to be passed down. It is also possible that different explicit weights could be given to the various interest groups depending on the issue involved.

On the other hand, it may not be necessary to provide an explicit weighting of the interest groups. A revelation of explicit weights to be applied to various interest groups could be politically sensitive. Also, the weights to be assigned to the interest groups would be time-dependent and issue-dependent; explicit weights would have to be continually reviewed and modified. Moreover, an implicit weighting could be obtained by providing representation to the various interest groups on the Board of the AECB. The political decisions of the Board can provide an implicit weighting for the values of the interest groups, assuming that the representatives understand the attitudes and values of the interest groups that they represent, thus making explicit weighting not strictly necessary.

In conclusion, the final input from the surveying effort concerning acceptable levels of risk is to provide the AECB with the acceptable cost-risk combinations for the various interest groups. In order to move from the estimated acceptable cost-risk combinations for individuals or groups to those
for society (especially when substantial variation can be expected among
the groups), the AECB itself must implicitly or explicitly determine the
weights to be applied to each group. The Board is aided in its ability to
accommodate the views of the various interest groups to the extent that
it is representative of them.
5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This report has examined the process of nuclear safety and the role of the AECB with respect to determining an acceptable level of risk for the nuclear industry. That role of the AECB is to determine a suitable risk level within the range of feasible and economic levels of risk for the nuclear industry.

The report has also developed the conceptual framework for determining the range of acceptable levels of risk for nuclear safety. The conceptual methodology entails estimating feasible cost-risk combinations from information supplied from experts and estimating acceptable cost-risk combinations from the general public and various interest groups within it. There is an analogue for this latter step in the estimating of prior distributions, for which a substantial and respected body of literature exists.

The conceptual methodology can be made operational by undertaking iterative personal interviews of a variety of experts knowledgeable about different aspects of the nuclear safety process, especially the risks and costs associated with various nuclear technologies and modes of operation. The surveying of the interest groups can be done by questionnaire after the information from the experts is obtained and after a questionnaire designed for the interest groups has been carefully pretested.

The questionnaire should be designed such that the respondents are given an opportunity to answer in terms of probabilities and costs to which they can relate. On the questionnaire the comparisons with which the nuclear risks and costs are made should be as qualitatively similar to nuclear risks and costs as possible: the most likely candidates for comparison are natural or man-made disasters with very low probabilities of occurrence, large potential consequences, a qualitative resemblance to radiation exposure, and an involuntary nature. The most likely candidates for comparison are accidents involving the excessive use of or exposure to certain chemicals or natural disasters like earthquakes.

In this report we suggest that the determination of the acceptable levels of risk be approached in the following phases: 1) the conceptualization of the methodology, which is provided in this report, 2) the interviewing of experts, 3) the development and pretesting of a questionnaire for the public, and 4) the surveying of the public with respect to acceptable cost-risk combinations. The phases are sequential and are designed to have independent and useful contributions in the event that not all of the suggested phases are undertaken. These phases are reviewed and discussed in more detail in the following three subchapters.
If the methodology is completely implemented, the AECB can obtain the expectations of the various interest groups and weight balance them in such a way as to determine the acceptable levels of nuclear risk. The AECB can also check its assumptions concerning the expectations of the various interest groups and realize the extent of the education that may be required for some interest groups.

5.2 Benefits and Costs of the Proposed Methodology

In this subchapter, we identify the nature of the benefits and costs of the proposed methodology*. In the discussion of benefits, we have assumed that one of the roles of a control agency is to determine the acceptable level of risk. We, therefore, do not examine the desirability of determining the acceptable level of risk, but only focus on the costs and benefits of the proposed methodology to determine the acceptable level of risk.

The proposed methodology is designed to be implemented in phases, as is discussed more specifically in 5.3. One of the benefits of this approach is that it can accommodate varying degrees of success in the sequential phases.

The first step of the methodology, the surveying of the experts, can provide useful input into several areas of decision-making facing the AECB. It provides a formal derivation of the cost-risk combinations that are believed to be feasible. It is also of assistance to have an explication from experts of the different types of risks and costs that can be expected to result from different technologies and modes of operation. For many types of decisions concerning the safety process something similar to the first stage of the proposed methodology (estimating the prevention and damage costs from nuclear risks) would have to be undertaken anyway, although it may be done in a more implicit, less structured fashion than that discussed in this report. The proposed approach would also determine if experts can relate costs to risks, even if it is done in a very technical fashion that is difficult to communicate to a wider audience, before a simpler version of that task is put to the public.

The second stage of the methodology (determining the acceptable levels of risk for the various interest groups) can result in a variety of different types of benefits depending on the degree of success. At the very minimum, one can ascertain whether or not the general public (or certain segments of it) can relate nuclear safety to costs. The surveying can determine if acceptable levels of risk that are known to be extant for voluntary risks can also be determined and communicated for involuntary risks. If not, then it implies that the role of the AECB should be more concentrated on educating the public concerning nuclear risk.

* No attempt will be made in this report to quantitatively estimate the benefits and costs of this methodology since this is beyond the scope of this study.
The surveying could also determine what the critical variables are that produce various attitudes toward nuclear risk. It would be helpful to know for planning and licensing purposes whether attitudes toward risk were determined by controllable factors, such as the distance of the atomic plant from the respondents or the type of risk that was involved, or by factors over which the AECB had no control.

Finally, at a high level of success, it would be valuable to know the range of acceptable levels of risk for the interest groups. It would allow the AECB to validate its assumptions about the expectations of the groups. The AECB could more easily anticipate the reactions of various groups to certain of its safety-related decisions. By identifying the potential opposition and support for certain decisions, the AECB could determine to some extent the type and direction of education necessary for the different groups. This allows the AECB to adopt a more active, rather than reactive, role as a regulatory body. Along these lines, the formal soliciting of public input into the decision-making process is, and is seen to be, a measure that attempts to "open-up" the decision-making process in an area that does impact on the whole society, which is in tune with professed governmental objectives. As discussed below, however, this final point is not an unmitigated benefit.

There are three main actual or potential "costs" of the methodology. The most obvious and probably the most important is the direct cost of the surveying. The development, distribution, and analysis of both personal interviews and questionnaires tends to be expensive, and the developmental and surveying costs increase with the complexity of the survey. Furthermore, the surveying of experts and interest groups is more difficult than the surveying of the general public in many respects, such as the identification and definition of the members or representatives of the appropriate interest groups and the sampling of those interest groups.

If it is decided to provide explicit weights for the acceptable cost-risk combinations of the interest groups, that decision may have to be justified. Essentially, justification could have to be made as to why a risk level was chosen that was acceptable to some groups but not to others.

Finally, there are some "costs" associated with querying the attitudes of the public. Having requested public input, expectations may be raised that that information will be used in a conspicuous fashion. Even if the information is used by the AECB, the public may expect to see the results in tangible ways that do not necessarily reflect the purpose of the surveying.

As mentioned in the beginning of this subchapter, the benefits from implementing the proposed methodology are unquantifiable. The AECB must determine if it deems the benefits to be worth the costs in this case.

The following subchapter outlines the specific phases suggested for implementation of the methodology.
5.3 Implementation Approach

As mentioned in 5.1 one of the features of the proposed methodology is that it lends itself nicely to a phased implementation. Moreover, if the methodology is pursued, the phasing can be such that tangible outputs could be produced and evaluated at the end of each phase. If the approach were terminated prior to the completion of all the phases, there would still be valuable information and insights gained from the previous phases.

Specifically, the following phasing is suggested:

1) Conceptualization of the Methodology. Conceptualization is the first stage of almost any approach, and this report constitutes the conceptual framework for the methodology. From this effort many of the conceptual problems and difficulties of determining acceptable levels of risk can be examined and the desirability or usefulness of proceeding further can be evaluated.

2) Surveying of Experts. This phase involves the development of the survey for the various experts, the testing of the interviewing mechanism, the collection of the data from them, and the blending of the information from the survey together with other existing information on the costs and risks of nuclear energy to produce the range of cost-risk combinations that are feasible. The surveying of the experts would also provide useful information in structuring the questionnaire for the general public. Even if the implementation of the methodology were terminated at this stage, a range of total cost of risk functions, as discussed in Chapter 3, could be produced. The range and shape of these functions would be of assistance to the AECB in its normal planning operations and in deciding on approximate economically optimal levels of risk for nuclear plants in the absence of knowledge concerning acceptable levels or under the assumption that economically optimal levels are acceptable. This phase of the implementation would represent a formalizing of information-gathering techniques that are presumably being undertaken already.

3) Development of Survey for the Interest Groups. This phase would involve the development of a detailed survey instrument for the various interest groups, including the general public, and the thorough pretesting of it. At a high level of success, the output from this phase would be a detailed survey instrument that could be circulated in a subsequent phase. At worst, this phase could indicate whether or not the various interest groups could relate to and communicate concerning acceptable cost-risk combinations for involuntary and low risks. It would also provide an informative, empirically tested format for other questions regarding nuclear safety for which public input is sought.

4) Collection and Analysis of Public Survey Data. Assuming that a fully pretested survey instrument has been developed, the final phase involves disseminating the questionnaire, collecting the data, and analyzing the results. Ranges of acceptable cost-risk combinations for each interest group would be determined. The assumptions of the AECB concerning the
acceptable levels of risk for the various interest groups could be evaluated. The range of acceptable cost-risk combinations could be compared to the feasible ones, and the groups whose acceptable costs and risks lie outside of feasible ranges could be identified.

5.4 Conclusions and Recommendations

In this study we have examined the safety role of the AECB and have suggested that it is desirable for the AECB to determine an acceptable level of risk. The following working definition of the acceptable level of risk was adopted in this study:

An acceptable level of risk is one that is acceptable to the regulatory agency and that balances the expectations of the interest groups subject to the constraints of technological feasibility, regulatory enforceability and economic practicality as perceived by the regulatory agency.

From the discussion of the role of the AECB, the nuclear safety process and the definition of acceptable level of risk, we concluded that the AECB should identify the interest groups that impact on its choice of an acceptable level of risk, determine their expectations concerning nuclear safety and balance the expectations of the various interest groups such that the resulting acceptable level of risk is still acceptable to itself.

Subsequently, a theoretical framework for a methodology to determine the acceptable levels of risk was developed. The assumptions underlying that methodology were made explicit and were examined. We concluded that the assumptions are plausible, having both theoretical and empirical precedents or analogues although requiring empirical testing to assure their validity with respect to nuclear safety, and that a reasonable attempt could be made to make the methodology operational.

The next step in the development of the methodology was the examination of operational considerations. Our examination revealed that a survey method could be developed to elicit information from nuclear experts on cost-risk combinations that are feasible and that another type of survey could be developed to obtain acceptable cost-risk combinations from representatives of interest groups. The estimation of prior probabilities in statistics provides an analogue for this latter type of surveying. We concluded that the methodology should be implemented in several phases, as discussed in the previous subchapters, to minimize any risk that may be inherent in the process.
It is recommended that the first operational phase of the implementation plan be undertaken, this consists of:

a) the development of the interview vehicle for the experts, and

b) the interviewing of the experts.

It is recommended that each successive phase of the implementation plan be evaluated before proceeding to the subsequent phase.


