Social Values in Risk Acceptance

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Since the dawn of civilization man has maintained a wary consciousness of the perils of his environment. However, until rather recently, the nature of these hazards did not change appreciably, their effects were limited to relatively small geographical areas and discrete time intervals. Thus, exposure to these hazards could, to some extent, be influenced by the actions or skills of the individual.

The interest in risk assessment is owing to concerns about the dangers man has created for himself. In recent decades technological systems of unprecedented size have been developed and the side effects of these large scale systems are correspondingly larger, sometimes of world wide significance for extended time periods.[1] A new category of risks which accompany the benefits provided by man's technology, has emerged. Here the actions and skills of the individual are essentially ineffective.

The occurrence probabilities of many of these side effects are not accurately known because there has not been enough experience with these technologies to obtain statisitical measures of risk. Further, there are often uncertainities in the consequences (should a specific side effect occur) because of an incomplete knowledge of the relevant natural laws necessary for prediction. Häfele [12] has referred to an age of "hypotheticality," where theoretical estimates of risk must substitute for experience.

The resulting societal response to these risks has been observed in the emergence of attitudes which tend to regard much that is new as being potentially harmful; the fundamental value of science to society is also being questioned. A variety of individual and group demands have been put forward for a closer

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[1] Some examples of side effects with global implications are potential changes in world climatology due to atmospheric pollution, the global distribution of Krypton 85 and the interaction of aerosol spray propellants with the earth's azone layer.

examination of the benefits and risks of technological innovations and, indeed, many such advances are encountering difficulties in gaining acceptance by the public.

The nuclear energy field presents an excellent case study in risk assessment[2] because the public response to these risks is, in many cases, providing a very real limitation to the development of nuclear power programmes. Further, the nuclear field provides many risk situations that are of research interest such as: examples of cost effective standard setting where operational risks may be reduced by control equipment expenditures; the possibility of large consequence, but infrequent, accidents; accident occurrence probabilities which can only be estimated, thus are highly uncertain; the non random distribution of risks and benefits to different groups of people; concerns about possible future (genetic) risks where benefits are realized at the present time.

One of the prime objectives of the Joint IAEA/IIASA Research Project (hereafter the Joint Project) is to develop information on societal attitudes and response as inputs to decisions in areas such as:

- the design of control and safety systems;
- the development of operational philosophies;
- the setting of rational regulatory standards;
- policy-level decisions on the selection and deployment of energy systems.

Section I outlines the general structure of risk assessment, and in Section II the process of risk assessment as applied to technological systems, such as energy systems, is discussed. The research programme of the Joint Project is reported in Section III and some preliminary results are presented. Details of the Joint Project staffing and organization are presented in the Appendix.

I. The General Structure of Risk Assessment

Risk assessment has been suggested as a general term for the incorporation of risk concepts into the decision-making process (Otway [18]). Risk assessment has been defined as occuring in two stages (Otway [19]), risk estimating and risk evaluation, which will be discussed in detail in this section.

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[2]Pahner [24,25] has hypothesized that nuclear energy represents a general example of societal concerns about technological development as well as a particular example of the psychological displacement of anxieties relating to the military uses of nuclear energy.

The general structure of risk assessment is shown schematically in Figure 1.

Risk Estimation

Risk estimation is the identification of the side effects of a decision and the subsequent estimation of their probabilities and the magnitude of the associated consequences. Some of the earliest formal risk assessments were made in the nuclear energy field by Siddall [2], Farmer [6], Beattie [7], and others [21, 22]. The most recent and comprehensive estimates are those of the "US Reactor Safety Study" [32] which treated risks from accidents in light water cooled nuclear power plants. An example of a risk estimated result from the "US Reactor Safety Study" may be seen in Figure 2, which shows fatalities from nuclear power plant accidents as a function of occurrence probability.

In everyday usage risk is usually thought of as the probability of an undesired occurrence, for example the risk of having an automobile accident. A more formal definition, often used, is that of statistically expected loss in value, for example the sum of all possible losses weighted by their occurrence probabilities. Both definitions are inadequate because they do not include all of the information important in considering risks, for example the magnitude of the consequences of infrequent events.[3] In this paper, risk is defined as a functional combination of event probability, the uncertainty of the probability, the probability of a specific consequence given the fact that the event has occurred, and the uncertainty of this probability. This is shown in Figure 1 by the combination of event E_i and its consequence C_{ij} to form risk R_{ij}. For specific situations this general definition may simplify into one of those mentioned earlier.

Probability is an important variable in speaking of risk. The measurement of probability has a long history of academic debate (see Raiffa [27]). Definitions range from the classical notion that probability is the ratio of favourable occurrences to the total number of equally likely cases (for example the roll of a die or toss of a coin) to the subjective or judgmental view, which holds that probability measures one's degree of

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[3]The statistically expected value of loss for an activity having an accident probability of once per year with one fatality is the same as that for a situation where 1,000,000 fatalities may be expected with a probability of occurrence of one in 1,000,000 per year, for example one fatality/year. The public reaction to these two situations is obviously different.

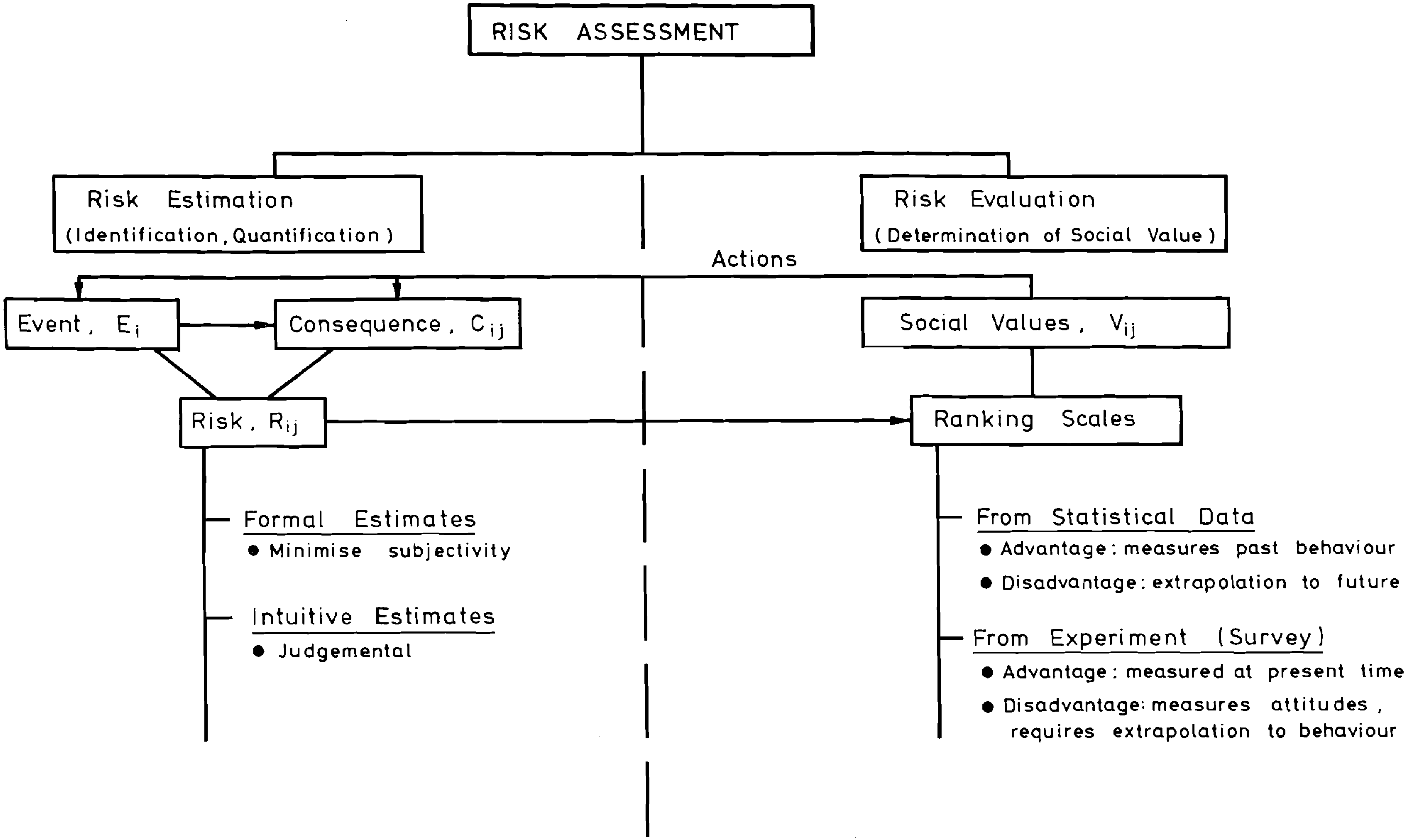

Figure 1. The general structure of risk assessment.

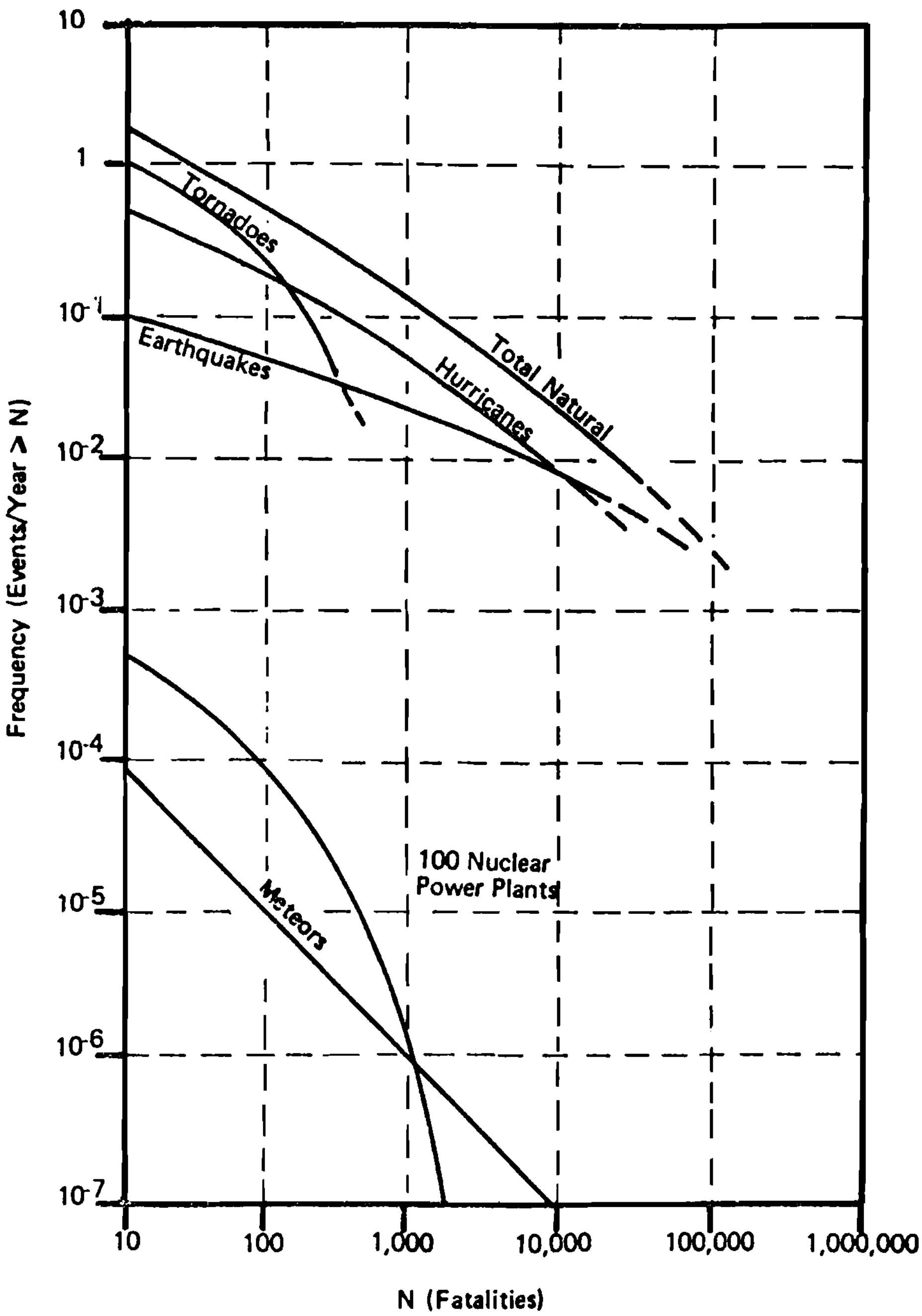

Figure 2. Frequency of natural events with fatalities greater than N ("US Reactor Safety Study" [32]).

belief as measured by behaviour. Risk estimates might be considered as ranging from objective to subjective; however, the technological risks which are of interest to us can never be estimated in a completely objective manner because the necessary data base does not exist. As pointed out by Fishburn [7], "all measurements of probability rely upon human judgement to some extent." What we would like to think of as objective estimates of risk because they are the product of careful calculational procedures are only attempts to minimize subjective aspects through a more formal approach. The estimate of the layman that a risk is too high is the result of an intuitive approach to the same problem. The point is that these two extremes differ only in the degree of subjectivity involved and, therefore, have been identified in Figure 1 as formal and intuitive methods rather than objective and subjective.

Risk Evaluation

Risk evaluation is the complex process of determining the meaning, or value, of the estimated risks to those affected, that is individual, group and society. This has been referred to by Häfele [11] as the embedding of risks into the sociosphere. Evaluation may be thought of as a process of ranking, or ordering, of risks so that their total effects, both objective and subjective, may be compared. This process essentially defines the "acceptability" of risk. The embedding process is shown schematically in Figure 1 as a mapping of risk into ranking scales reflecting societal values toward risk situations. By using the definition of risk proposed earlier we take into account the fact that man is not indifferent to the nature of the event which results in a particular consequence.

A feedback loop is shown through which actions reflecting social values may be taken in order to affect events or consequences. An example of this may be seen in the design of safety systems intended to prevent accidents or to limit the effects should they occur.

One way of understanding value is by means of a scale which expresses the degree to which something satisfies intrinsic needs and desires--a measure of worth, importance or desirability. Ordinal scales rank items only in the order of preference, or the inverse, without regard to numerical quantities. A simple example might be an individual's statement that he prefers exposure to risk A over exposure to risk B, and so on. A cardinal ranking system provides numerical values for various (risk) prospects relative to an arbitrary scale. Here the rank orders of the ordinal scale are supplemented by numerical ratings which provide a better idea of just how strong a preference might be.

Two basic methods of obtaining ranking scales are outlined in Figure 1. The first is based upon the analysis of statistical data to determine the preferences that society has shown in the past towards existing risks. The second is that of experiments (for example, psychometric surveys) to measure attitudes towards risks. The former yields information on past behaviour, the latter on present attitudes.

The most elementary approach to obtaining rankings is to simply compile a table of accident statistics, such as Table 1. A new risk is placed in perspective by comparing a formal estimate of risk with statistical data on existing, and therefore accepted, risks. A limitation of this method is that risk acceptance is situation dependent; many variables determine risk acceptance and they cannot be reflected in such comparisons. Figure 2 also shows a ranking of this type with the comparison being made among a group of involuntary risks of different types. Here the absolute magnitude of the hazard is also compared.

Rankings determined by the analysis of statistical data have the advantage of being based upon actual behaviour. However, they are limited by the assumption that past is prologue, that preferences revealed in the past will be valid in the future. This would not be expected to hold for technological risks because social values are changing with time--primarily owing to changes introduced by technology. Further, behaviour with respect to risk acceptance is multiply determined, that is many factors influence the response to risks and all of these determinants are not even known, let alone clearly identified in the data base.

Risk perception is important since the response to risk depends upon how situations are perceived, but statistical data report things as they were, for example accident rates, demographic variables, public expenditure by categories. Some limitations of rankings based upon these revealed preferences are summarized in Otway [20]. At this point we may observe that evaluations of nuclear power risks made by this method have indicated that nuclear power should be acceptable. However, experience has shown that this is not always the case. This indicates that revealed preferences could be useful in helping decide the risk levels that might be acceptable from an ethical point of view, but tell us little about what the public find acceptable.

A distinction must be made between attitudes and behaviour. The former represent what one says, or thinks, his views are toward a given situation. Behaviour reflects his actions when actually encountering this situation. For example, most people would regard the telling of a lie as bad. In practice they might occasionally find it convenient to tell a lie in an embarrassing social situation. Rankings based upon psychometric surveys provide information on attitudes rather than behaviour, but the attitudes are measured at the present time. An example of a survey-determined ranking scale applied to the perception of health hazards may be found in Table 2 (see Wayler [34]).

Table 1. An example of a rating scale comparing accident statistics (USA, 1966) and theoretical estimates.

Type of Accident	Total Deaths	Probability of Death per Person per Year
Motor Vehicle	53,041	2.7×10^{-4}
Falls	20,066	1.0×10^{-4}
Fire and Explosion	8,084	4.0×10^{-5}
Drowning	5,687	2.8×10^{-5}
Firearms	2,558	1.3×10^{-5}
Poisoning		
Solids and Liquids	2,283	1.1×10^{-5}
Gases and Vapours	1,648	8.2×10^{-6}
Machinery	2,070	1.0×10^{-5}
Water Transport	1,630	8.1×10^{-6}
Aircraft	1,510	7.5×10^{-6}
Inhalation and Ingestion of Food	1,464	7.3×10^{-6}
Falling or Projected Object	1,459	7.3×10^{-6}
Mechanical Suffocation	1,263	6.3×10^{-6}
Therapeutic Medical and Surgical Procedures	1,087	5.5×10^{-6}
Railway (Except Motor Vehicle)	1,027	5.1×10^{-6}
Electric Current	1,026	5.1×10^{-6}
Hot Substance, Corrosive Liquid, Steam	408	2.0×10^{-6}
Animals (Nonvenomous)	131	6.6×10^{-7}
Lightning	110	5.5×10^{-7}
Venomous Animals and Insects	48	2.4×10^{-7}
Streetcar	9	4.5×10^{-8}
Radiation	1	5.0×10^{-9}
100 Nuclear Power Plants (estimated)	0.04	2.0×10^{-10}

Table 2. An example of a survey-determined rating scale (seriousness of illness rating scale).

	Rank	Mean Score
Leukemia	1	1,080
Cancer	2	1,020
Multiple Sclerosis	4	875
Heart Attack	7	855
Muscular Dystrophy	11	785
Stroke	13	744
Blindness	15	737
Chest Pain	29	609
Peptic Ulcer[1]	37	500[1]
Syphilis	42	474
Pneumonia	55	338
Irregular Heart Beats	62	302
Whooping Cough	73	230
Measles	90	159
Acne	104	98
Common Cold	118	62
Dandruff	126	21

[1]Modulus item.

In summary, we have two methods for risk evaluation available to us: preferences and controlled experiments. The former measures past behaviour; it is difficult, however, to anticipate future behaviour based upon observations of past behaviour. The latter provides information on attitudes at the present moment; the problem here is one of anticipating behaviour based upon attitude measurements.

The Determinants of Social Values

The location of a specific risk in a ranking scale is multiply determined; many factors, conscious and unconscious, are involved. We have already mentioned voluntary versus involuntary exposure to risk and that virtually all technological risks, in which we are interested, are essentially involuntary.

People react to a threat based upon what they perceive it to be, not necessarily upon what it actually is. Intuitively derived probability estimates, and therefore risk estimates, tend to be inaccurate due to the effect of psychologically determined factors (see Edwards [5] and Murphy [17]) which influence perception. There has been little research in the behavioural sciences on attitudes and beliefs with respect to the perception and acceptance of technological risks. As a result there is no body of behavioural theory from which to seek guidance. Therefore, identification of the factors determining risk perception and the knowlege of their relative importance is a priority research item. This information would allow the incorporation of new risk situations into existing ranking scales without trial and error experience or detailed surveys. Risk acceptance would then be within the reach of predictability.

II. The Process of Risk Assessment: Technological Systems

Figure 3 introduces social dynamics into the structure of risk assessment developed in the last section. This process includes the contributions of three social groups: the sponsor who proposes a technological development, the public for whom the benefit is intended, and the regulator who has the responsibility of balancing the needs of both groups.[4] In the following discussion the numbers in parentheses refer to the respective boxes in Figure 3.

The Sponsor

The process starts with a societal need which may be satisfied by some proposed application of technology. For example,

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[4]Figure 3 closely parallels the structural hypothesis of mental mechanisms proposed in Freud [8].

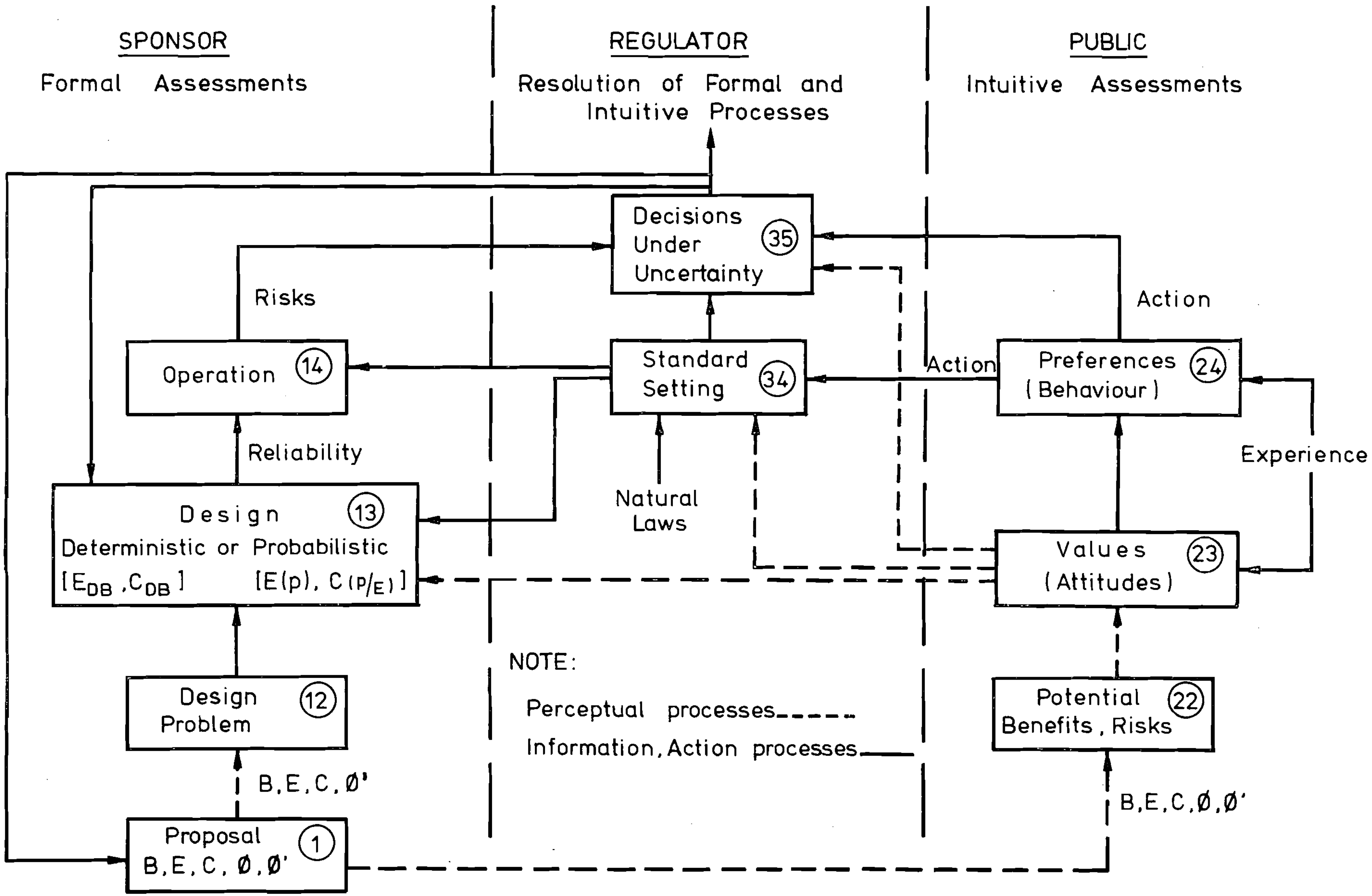

Figure 3. The process of risk assessment: technological systems.

energy needs met by the construction of a power plant. The sponsor may perceive the proposal (Box 1) as a design problem (Box 12). In his design he must ensure that the required benefit is provided and that any potential side effects meet regulatory standards. These side effects are characterized by events, E (such as accidents), and their consequences, C, which must be considered in the design.

Figure 3 also introduces the concept of an unknown set, Ø, of potential events or characteristics which could actually occur but cannot be included in design considerations because their existence has not yet been discovered. An additional "inverse" unknown set, Ø, has also been postulated to represent those events and consequences which have been imagined by the designer but could, in fact, be proved impossible if natural laws were perfectly known. Regulatory agencies may require situations to be considered in design which are unrealistic; this is done in order to provide safety margins. These also form part of the inverse unknown set.

The design of the sponsor (Box 13) may proceed in the traditional, deterministic manner in which design base limits are assumed for E and C. Safety systems are engineered which will allow adherence to regulatory standards should the design basis situation occur. An alternative design method is the probabilistic approach which does not employ artificial design limits. There are no limits to the events and consequences considered; however, they are weighted by their probabilities and risks are kept to acceptable levels through reliability design. Whichever design method is chosen the reliability of systems is fixed, either directly or indirectly. Reliability combined with operational philosophy (Box 14) determines the risks to which the public is exposed. The designer's perceptions of the relevant social values are also considered in the design process. Häfele [13] discusses these design processes in detail.

The Public

The public perceives the proposal (Box 1) as a potential source of societal benefit and risk (Box 22). Their intuitive estimates of risk can include allowances for the unknown set, Ø, of things possible but not considered in design. These allowances are not based upon superior technical knowlege but may be expressed simply as a lack of confidence in the designers, operators or regulatory authorities. An inverse unknown set, Ø, of things that cannot happen based upon natural laws may also be considered. An example of this is the fear of some that nuclear power plants may explode as atomic bombs. As unrealistic as such concerns might be they still influence the perception of risk. The public and the designer consider different inverse unknown sets; this reflects different conceptual frameworks.

The experience of the public has determined their values or attitudes (Box 23) towards risks. The perceived risks are intuitively incorporated into this system of values which can be measured by means of the ranking scales referred to earlier. Preferences related to risk acceptance (Box 24) exist only when revealed by behaviour. Thus lines of action are shown in Figure 3 leading from Box 24 into the regulatory sector.

The Regulator

Regulatory functions occur on several levels. One is the agency responsible for setting standards (Box 34) to regulate specific environmental effects which may arise from, for example, radioactive, thermal, or chemical releases. Standard setting takes into account the effects of environmental insults as predicted by natural laws and the perception of the relevant social values (Box 23). If standards are incompatible with social values then societal preferences may be expressed by active demands that standards be changed (the action line from Box 24 to Box 34).

Another level of the regulatory process is one where a decision must be taken, under conditions of uncertainty, regarding approval of the proposal (Box 35). This decision might require changes in the proposal, design or operation and could be appealed by societal action (Box 24). The final regulatory step which, depending upon the political process might include the judiciary, is the resolution of the formal risk assessment of the sponsor and the intuitive risk assessment of the public. For simplicity, these regulatory functions have been shown as one step in Box 35.

Summary

Reports such as the "US Reactor Safety Study" [32] serve a valuable function in formalizing the estimating of risks to which the public is exposed. Such work would also allow the determination of the system reliabilities necessary to satisfy standards based upon risk consideration. The emphasis here is upon formal risk estimates which correspond to Boxes 13 and 14 of Figure 3.

The work of the Joint Project is directed towards gaining a better understanding of the perceptual processes shown in Figure 3. This would allow information on societal attitudes (Box 23) to be integrated into design and standard setting. The uncertainties in the general decision making process (Box 35) would also be reduced.

III. Research Programme and Preliminary Results

The research activities of the Joint Project may be divided into five subtasks, related to the process illustrated in Figure 3, which will be described in this section. Preliminary results will be briefly summarized, readers are referred to the referenced publications for details.

Advanced Methods in Risk Estimating

Owing to the relatively small statistical data base it is difficult to make risk estimates for low frequency, large consequence accidents such as those that might occur in nuclear power facilities. Mathematical techniques, such as fuzzy set theory, are being applied to making macroscopic risk estimates which may then be compared with estimates based upon microscopic techniques such as accident/fault tree analysis (see Shinohara [28]). This work represents a supplement to the methodologies used in the "US Reactor Safety Study" [32].

The Application of Risk Benefit Principles to Standard Setting

An important factor in standard setting is that of expressing disparate variables in consistent units so that comparisons may be made between risk reduction and its cost. This is especially difficult in the case of activities which involve risk to human life. The Pareto theoretical approach is being adapted to the evaluation of such risks and the possibility of using Pareto criteria for the treatment of statistically and nonstatistically distributed risks is being examined. The effects of further variations are also being considered in this theoretical work, for example the question of genetic risks that occur in the future where the benefits are short term and are taken by the present generation.

A survey has been made which concentrates upon practice (mainly in France and the USA) in evaluating public projects involving life saving (see Linnerooth [16]). Further a review of theoretical models for determining the "value" of mortality risk in decisionmaking has been completed (see Linnerooth [14]). These theoretical treatments have been applied to nuclear power plant economics (Linnerooth [15]) and the problem of quantifying environmental risks (Cohen [4]).

An application was made to the treatment of tritium and krypton 85 in nuclear facilities (Cohen [2,3]). This work indicates that, based upon the number of publications on the health and safety effects of these two isotopes, more attention has been given to the control of tritium releases. However, as seen in Figure 4, the world wide radiation dose from tritium released in the nuclear industry is not only less than that from krypton, but it is smaller than that from naturally occuring tritium and far smaller than that due to residual tritium from weapons testing. This means that adding controls to further reduce tritium releases from the nuclear industry would hardly change the total tritium dose.

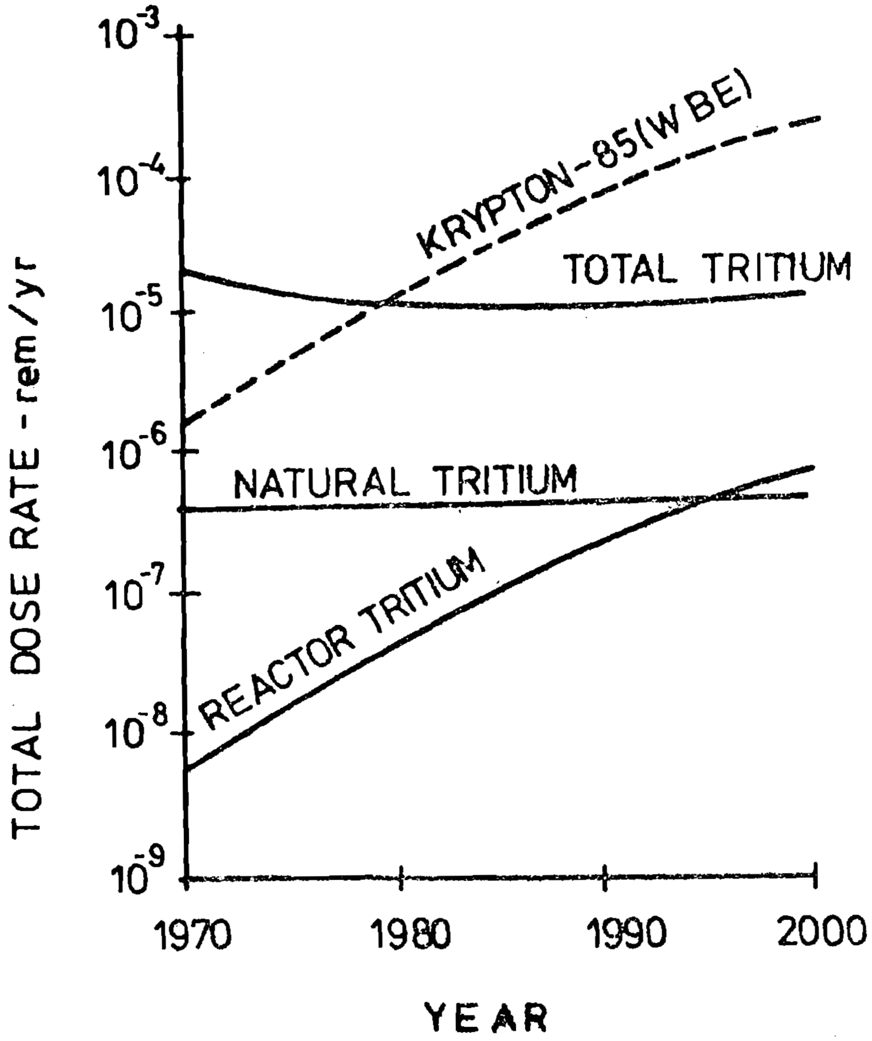

Figure 4. Whole body dose from biospheric accumulation.

Since there is essentially no krypton background level, krypton controls would have a direct effect. These dose calculations are summarized in Figure 4. An estimate of the cost of reducing tritium releases by 50%, using current technology, is about $170,000 per man-rem of radiation exposure avoided. A comparable cost for reduction in krypton releases would be about $10 per man-rem. The theoretical considerations mentioned earlier would indicate that $200 is a reasonable expenditure for the avoidance of one man-rem of whole body irradition. The conclusion here is that further consideration might be given by the nuclear industry to the relative expenditures for control of these two isotopes.

The Perception of Risks

The perception of risks is a crucial factor in determining attitudes. Obviously people respond to a threatening situation based upon what they perceive it to be rather than what it might actually be. An effort is therefore being made to develop survey techniques for determining how various types of risk are perceived. A further goal is the identification of the variables which influence risk perception and the determination of their relative importance.

A survey has been done in Austria (Otway [23]) as a replication of one previously done in Canada (Golant and Burton [9], to obtain ordinal rankings for various hazard situations. The objectives of the Austrian study were primarily to gain experience in administering this type of survey and to develop computer programmes for data analysis. A secondary objective was to make a cross cultural comparison of risk perception.

The overall cross cultural rank size correlation coefficient for the two groups was found to be $r = 0.62$. In the Canadian group the effect of the experience with specific risks was found to be most important in determining response (experienced respondents versus inexperienced, $r = 0.45$). This was not found in the Austrian sample ($r = 0.81$) where the most important determinant of risk perception was found to be the subjects self-rated ability to imagine themselves in particular risk situations ("good" imaginability versus "poor", $r = 0.59$). This latter result is conjectually interesting in the case of nuclear power plant risks where imagination must substitute for experience and difficulty in imagining a specific hazard correlates with the higher ranking of that hazard.

A further preliminary survey (Swaton [31]), designed to be less culturally dependent by using pictures of risk situations, confirmed by factor analysis that the most important determinant of risk perception is the active-passive dimension. That is, risks such as technological risks where the individual has no control over outcome or exposure tend to be ranked higher. This study is being refined to look for determinants of perception in a group of only passive risk situations. This is a collaborative effort with the University of Vienna Institute of Psychology.

Preferences Related to Risk Acceptance

Starr [30] postulated some determinants of risk behaviour based upon the analysis of national accident statistics. This work developed a philosophical basis for risk assessment and served to draw attention to the importance of such research. Based upon these analyses Starr suggested three major determinants of risk acceptance and assigned weightings to them. The major points were: "(1) The indications are that the public is willing to accept 'voluntary' risks roughly 1000 times greater than 'involuntary' risks. (2) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (3) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined)...."

The methodology used was reviewed and an attempt was made to reproduce the Starr results (Otway [20]). The results could not be reproduced using this method and it was concluded that, while the Starr hypothesis regarding the identification of these determinants (at least (1) and (3) above) was probably philosophically correct, the results could not be justified on the basis of his analysis. It was further concluded that the mathematical relationships indicating the relative importance of the determinants must be regarded as unlikely.

Further efforts in this direction will concentrate upon the combination of statistical analysis and behavioural theories employing an iterative process of empirical, multivariable analysis. This work is a collaborative effort with the Study Group for International Analyses, Vienna.

Information Transmission and Group Dynamics

The communication of scientific information plays a role in the development of societal attitudes, as shown in Figure 3. Groups serve a mediating function between the individual and the larger society, because the individual interacts with society through his membership in various groups, for example family, professional, fraternal, etc. Therefore, an understanding of group dynamics is important in learning how individual attitudes and preferences are aggregated to form attitutdes at the societal level shown in Figure 3. In the case of nuclear power plants it has been observed that until a project is made known there is no immediate concern about nuclear hazards amongst most inhabitants of the area. Once the plans are announced, people soon become acquainted with thinking about the possible threats, real or imagined; they are forced by circumstances to form relevant opinions. The project then starts being judged on a number of levels: individual, group, community, national and perhaps even international. As the responses to the proposal gradually emerge it has been noted that various interest groups start to form, develop their sources of information and, in many cases, work actively to promote or oppose the proposed facility.

As a preliminary step in understanding this problem, risk phenomena in traditional, small-scale societies have been analyzed (Linnerooth [16]) to aid in the construction of models of this process. The observation of several interest group situations has allowed the derivation of a set of typical interest group characteristics (Pahner [26]). A systems analysis application to nuclear power plant siting has been published (Gros [10]). Models of interest group dynamics in modern societies are being constructed in collaboration with the European Centre for Social Welfare Training and Research (Vienna) through an analysis of several nuclear power plant siting controversies.

IV. Concluding Remarks

The intent of this paper was to emphasize the importance of risk assessment research in providing information necessary for decisions regarding the selection, design, deployment, and operation of technological systems such as energy systems. It is not yet possible to present results which describe human behaviour in risk situations. The measurement of social values is a complex problem where little work has been done. Plans for further research and some preliminary results have been presented.

APPENDIX

The Joint IAEA/IIASA Research Project was formed in mid-1974 pursuant to an agreement between the Director General of the IAEA and the Director of IIASA. Organizationally the Joint Project comes under the IAEA Department of Technical Operations, Division of Nuclear Safety and Environmental Protection and the Energy Systems Project of IIASA.

As of July 1975 the project consisted of eight professional and two general services staff. The IAEA provides the project leader and general service staff, and IIASA provided three scientists. IAEA Member States (the Federal Republic of Germany, Japan, Sweden, the United Kingdom, and the United States of America) have indicated their interest in this work by providing seconded scientists on a cost-free basis.

Additional scientific collaboration is obtained through IAEA-sponsored research contracts with the University of Vienna Institute of Psychology, the Study Group for International Analyses and the European Centre for Social Welfare Training and Research.

The following disciplines are represented in the Joint Project: Physics, Public Health, Systems Engineering, Economics, Anthropology, Psychiatry/Medicine, Psychology, and Sociology.

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